An Assessment of the Economics of Adopting Stewardship Practices in Livestock Production in Response to Environmental and Societal Concerns

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A Report Prepared For

The Expert Committee on Manure Management
Canadian Agri-Food Research Council (CARC)

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Summary

This report is a review of current literature pertaining to measurement of the economic value of benefits and costs to Canadian society from livestock production and related activity. Included in the review is academic, public sector, institutional, trade and other publicly available documentation representative of the current state of measurement and quantification of livestock production externalities. An externality occurs whenever the welfare of one is directly affected by the activity of another. The major externalities of livestock production are its potential impact on water, air, soil, biota, and indirectly human health and well-being.

The review was conducted and is presented according to a two part conceptual framework. The first and overarching framework considers livestock production activity according to six major categories of potential public impact or externality including economic activity and environmental components of soil, water, air, biota, and human health impacts. The second part categorizes livestock production and related activity into four groupings of manure handling including field application; manure storage; livestock feeding including confined livestock systems; and transformation of livestock by-products.

The literature search identified 104 citations suggesting some relationship between livestock production and selected externalities. Economic assessment of externalities of livestock production in Canada or elsewhere was found to be somewhat of a rarity. While many studies make a qualitative or descriptive reference to externalities, even in various models developed for integrated assessment, quantitative and monetary impact estimation is missing.

Of the total citations reviewed for this report, 44 percent are primarily concerned with manure handling and application, 22 percent livestock feeding and confinement, and 15 percent with manure storage. About 19 percent of the available literature is general in nature or involves multiple pathways such that they are not classified according to the major categories. Manure handling has the greatest number of Canadian studies, followed by manure storage, general studies, and livestock feeding and confinement.

Estimation of damage by livestock production is problematic because of the uncertain relationship between potential pollutants applied to field and the actual transport of these pollutants to a site where an environmental damage can occur. Such uncertainties also create problems in developing proper regulations. As concerns the economic valuation or quantification of externalities, an observation made in 1996 continues to be largely true today. "At the present time there are no studies using any of the approaches that have examined the economic value of environmental damages caused by manure pollution. There are a few related studies that have determined that households would be willing to pay from $50 to $1,150 annually to lower nitrates in groundwater. However, no study has examined total impacts from manure which has a host of potential pollutants (nitrates, phosphorus, and odors) and a number of effects on the natural resource systems."

Major externalities exist for water and air quality and their effect on human health. When it comes to measurement of livestock and air externalities, quantitative description of odors is a task yet to be accomplished. At most, descriptive measures such as number of complaints or individuals signing a petition for granting a license for livestock operations has been used as a

surrogate measure of odor problems. The air quality valuation work that has been undertaken is largely in the area of smog, ozone concentration, pesticide residues, and other air-borne diseases.

Disease incidence and its economic cost is generally examined using the disease rather than a source domain. Diseases associated with livestock, particularly manure have been identified but an economic evaluation has not been conducted. Five types of diseases associated with manure include bacterial (Salmonella, Anthrax, Tuberculosis, Brucellosis, Tetanus and Lofiform mastitis); viral (Hog cholera, and Foot and mouth disease); fungal (Ringworm); protozoal (Coccidiosis, and Toxolasmosis), and parasitic (Ascarissis and Sarcocystisis). By way of an indirect example, a 1998 assessment of the economic impact of zoonotic disease considered a case of salmonella affecting 40 poultry farms was estimated to result in economic loss of $2.3 million at the farm level, and $4.5 million in terms of human health.

The literature provides a range of mixed options for feeding, manure handling, field applications, and storage. For example, various investigations including work done as background to climate change and greenhouse gas mitigation advocate covering stored manure to reduce methane emissions and odor. On the other hand, other work indicates that open lagoon and silo storage are the most cost effective while at the same time not without potential environmental benefit depending on their integration with other handling components.

Agricultural research has long been concerned with optimizing livestock rations. When applied to environmental including climate change considerations, the available evidence recommends the addition of phytase and synthetic amino acids to livestock diets; measures to incorporate optimum levels of nitrogen and essential nutrients; and multi-phase feeding and better timing of feeding to animal needs.

Intensive livestock operations have also been a subject of many studies, particularly in terms of their environmental impacts and social acceptability. Unfortunately, despite numerous impressions and opinions, none of the available literature provides systematic and quantitative evidence of their impact. Statistics Canada analysis of the geographic location and concentration of livestock using current Census data concludes that the available evidence does not support the notion that large livestock farms are solely responsible for high livestock densities.

Several current Canadian and other studies indicate that care for the environment can only be achieved at some cost to farm business profitability. Environmental regulations come with a cost to producers. For example, a 2002 study estimated the cost of complying with Ontario ammonia emission regulations at $1,700 to 2,000 per farm per annum. An assessment of the Agricultural Exemptions Act in Saskatchewan estimated compliance costs to be $32,866 per farm, some 36 percent of gross revenue. Few Canadian studies estimate on-farm costs and benefits from manure management options. From those that do, two major observations can be made. Firstly, equipment operating costs are a major portion of total costs. Secondly, and perhaps most importantly, cost estimates are highly variable from one study to another indicating that on-farm economics are very site and application specific.

The available evidence indicates potential to increase use of composted manure directly and in substitution for chemical fertilizer. Analysis of the Canadian situation suggests that from an economic perspective, compost can viably replace chemical fertilizer at least to the point where distribution costs equal the value of crop response to the compost. This viability varies geographically, with some areas requiring distribution of compost beyond immediate livestock areas. Production of biogas using anaerobic digesters has been suggested; and shelterbelts proposed as one measure to reduce odor problems associated with livestock operations.

Recommendations

Policy makers, livestock producers and the general public need to have a balanced view of livestock production in Canada and its economic and environmental impact. The economic impact on producers or contribution of livestock production to the regional economy is reasonably well understood for most regions of Canada, but such is not the case for environmental services including beneficial and damaging externalities of livestock production. In order to develop better policies and regulation serving the livestock industry in parts of Canada, the following work is suggested.

Although there have been several studies identifying impacts of livestock production on environmental goods in physical terms, their valuation has not been attempted. Therefore, a first study would entail valuation of livestock production from society's point of view. The appropriate framework to follow is a comprehensive social benefit-cost analysis, wherein various valuation and analytical techniques can be used to incorporate the value of the environment. Financial balance needs to be determined from both the perspective of the individual farm operator, and the perspective of society as a whole. Such a study would provide a solid foundation for developing effective public policy and regulation for the joint benefit of producers and the environment. This analysis can be sub-divided into the following six recommended components:

1. Development of baseline profile for the livestock industry and manure handling, storage, application and transformation options.
2. Identification of potential mitigation measures.
3. Estimation of on-farm economics.
4. Measurement of physical impact of management options on environmental goods.
5. Economic valuation of damages (benefits) of environmental goods; and
6. Benefit-cost analysis

A second recommended assessment would review public policy and regulations. Various components of this study may include:

1. Compilation of policies and regulations that directly or indirectly affect livestock production.
2. Identification of factors affecting producers' adoption of management options.
3. An evaluation of the policies (under 1 above) and regulations that act as a (dis)incentive for the adoption of better manure handling systems.
4. Development of livestock production and environment friendly policies and regulations for various regions of Canada.

Policy assessments need to be undertaken for several types of practices that have significant co-benefits for society. These may include, among others: providing crop nutrients from both organic and inorganic sources; processing of manure into more compact (such as composting) or value-added products (such as biogas); using biological measures to mitigate air quality effects of large scale livestock operations; and altering livestock rations to mitigate greenhouse gas emissions from livestock production.

A major valuation of natural resource services along with a critical assessment of public policies, including regulations is needed in Canada. Although there have been several studies identifying impacts in physical and bio-physical terms, economic valuation of environmental services has not been attempted. Such an investigation should establish the linkage between various types of livestock management and any change in social welfare. A study of this type should ideally be undertaken by an interdisciplinary team consisting of physical scientists representing expertise related to the different natural ecosystems along with social scientists (economists and sociologists).

1. Introduction

1.1 Objective

The major objective of this report is to present a review of the state-of-the-art of literature pertinent to the measurement of the economic value of benefits and costs to Canadian society from livestock production and related activities. Included in this review are studies identifying various pathways where goods and services provided by natural ecosystems can be affected by livestock production, thereby affecting welfare of society as a whole. A majority of the literature reviewed deals with the physical relationships between livestock production and the environment, which typically is the first step in the economic valuation of environmental externalities. The objectives of this study can be divided into the following.

1. To identify various livestock production activities and their pathways that from a conceptual perspective could impact society directly or indirectly.

2. To review relevant studies with respect to identified impacts on society either in physical units or in value form.

3. To assess the state of the art in the valuation of impacts identified; and,

4. Suggest and recommend areas for future work in the valuation of externalities.

1.2 Scope

This report is based on a review of current literature primarily comprised of academic and trade journal articles, and public sector, institutional, and other publicly available studies, reports, and documentation etc. The material reviewed was chosen to be fully representative if not exhaustive of the range of literature pertaining to livestock production externalities and their measurement and quantification.[1] A majority of the material reviewed is North American. A major source is 'Manurenet' (http://www.agr.gc.ca/science/initiatives/manurenet/manurenet_en.html) which contains a large number and range of studies dealing with livestock production, including economic aspects.

[1] In addition, a major portion of manure management literature is contained in proceedings of conferences on various topics. Their inclusion in this report was severely handicapped by their limited public availability.

2. Conceptual Framework

2.1 Identification of Pathways

The major ways in which agricultural livestock production and related activity can directly impact society can be considered according to four groupings or sets: (1) manure handling and application; (2) manure storage; (3) livestock feeding including confined livestock systems; and (4) activities leading to transformed products from livestock by-products.

Numerous pathways to economic and environmental externalities can be identified. In general, these externalities are related to losses (or prevention of losses) in the form of gaseous emissions, and soluble materials leached from manure and transported in runoff or air-borne particulates. The loss of nitrogen, phosphorus and potassium as plant nutrients is the most important economically. Others such as pathogens and odor producing organic compounds are not so much a loss to production as they are a potential economic and environmental burden to other parts of the ecosystem.

The dispersion of minerals in the environment depends on many variables. Livestock production generates gaseous emissions both directly from livestock and from manure. Some of the gases e.g. methane, have been linked to global climate change; others, e.g. ammonia result in the loss of value from manure (plant nutrient nitrogen). Emission of ammonia takes place from the moment the manure leaves the animal up to and including application to fields.

In the field, manure is incorporated into the soil matrix but some may also be transported by water. The crop extracts part of the minerals, while other mineral and organic components are incorporated into the soil. Nitrogen in the nitrate form is quite soluble and may move with water percolating through the soil below the rooting zone into tile drains or groundwater. Depending on moisture conditions, a portion of the nitrogen may be denitrified to gaseous forms including nitrous oxide (a greenhouse gas) and di-nitrogen. The other major nutrients contained in manure (phosphorus and potassium) are less mobile and the portion not removed by a crop tend to remain in the surface layers of the soil. They may be transported in association with soil particles lost through erosion (by water, air or tillage). Where these nutrients accumulate to high levels, they may saturate the soil capacity to retain them and a portion lost via water percolation.

Transformed products (methane and co-generation of power from anaerobic digestion, stabilized compost etc) result from the direct intervention in the normal progression of livestock by-products from excretion to field application. Through active management the normal reactions are modified to create potential benefits and to modify the potential for direct transfer to the environment of greenhouse gases, labile nutrients and viable pathogens.

2.2 Taxonomy of Impacts of Livestock Production on Society

Livestock production can affect society directly or indirectly. Some of these effects can be measured in monetary terms. Economic benefits and costs are typically expressed in monetary form, and are referred to in the literature by various names, such as private vs. public goods, externalities, and spillover and third-party effects. The following sets out some working definitions.

PRIVATE GOODS: Refers to good(s) that display rivalness in production or consumption. Here exclusion is possible, in the sense that if one party uses the good, another cannot use it. This means that one person's consumption of the good reduces the quantity available to others. Exclusion by a producer means that a producer of the good can restrict its use to those consumers who are willing to pay for it. Under these conditions, free exchange of goods is possible and markets can operate.

PUBLIC GOODS: Goods that if supplied to one person can be supplied to another with no extra cost. Exhibit non-rival consumption and non-excludability – if the good is provided, a producer is unable to prevent anyone from consuming it. This prevents private markets from functioning since a seller is unable to ensure that only those individuals that pay for the good are able to use it. Since the good is available for no payment, no one would be willing to pay for it. For this reason, private markets do not provide public goods.

EXTERNALITIES: Also known as external effects, external economies and diseconomies, spill-over or neighboring effects. An externality occurs whenever the welfare of a firm or household is directly affected by the activity of others. Thus, if the actions of a livestock producer bring some hardship to other members of society, some form of externality is created. Presence of externality may lead to economic inefficiency if the nature of the impact is adverse. Externalities can also be beneficial, if an externality-generating activity raises the production or utility of the externally-affected party.

There may exist some overlap in the classification of these goods using public/private goods, and externalities. An attempt is made to clarify this in Table 1.

Table 1. Taxonomy of Benefits by Type of Good and Economic Agents

Party Affected	**Private Goods** Commercial Economic Goods	**Public Goods** Non-Commercial Goods)	**Presence of Externality**
Livestock Producers	XX	X	No
Other members of Society	X	XX	Yes
XX: major X: minor			

Not all externalities are public goods, and not all public goods are externalities. For example, if a livestock producer pollutes a water body affecting the health of cattle on the farm, this translates into a private disbenefit for the livestock operation. However, if the same polluted water creates similar problems on other farms, or is a source of a health problem to local water utilities, this becomes an externality. Polluted water may also affect the aesthetics of the water body thereby affecting recreational and tourism potential, and would be classified as a public good, which is also an externality resulting from livestock production. Thus, in the context of livestock production, both public and private goods are encountered. Some of the impacts are received by livestock producers and therefore internalized, while others affect other parties, and are called externalities. Some externalities are associated with public goods, while others are similar to private goods.

2.3 Interrelationships between Livestock Activities and Impact on Society

Livestock production can create a number of impacts through various pathways, some borne by livestock producers and others by society. Each of the pathways is associated with by-product, namely manure and gases. Gas production may result directly from animals (methane emissions) or indirectly through manure management related activities. Similarly, negative effects of the minerals in manure can be distinguished by the three major nutrients: mineral nitrogen, phosphorus, and potassium. Nitrates typically find their way into both surface and ground water creating potential hazards to the health of humans and livestock and other economic externalities. Little information exists concerning the impact of potassium, apart from the danger of hypomagnesaemia for cattle[2]. Dispersion of phosphorous in surface water bodies is associated with eutrophication of lakes and other surface water bodies.

Depending upon the actions of producers, manure enters the system at two levels: manure handling and application, and manure storage. Depending upon the option selected by producers at each of these levels, additional pathways may be generated. These include run-off, leaching, emission of greenhouse gases, and nutrient availability. Run-off may also be related to soil erosion, which in turn has implications for nutrient availability. These impacts are shown in Figure 1. Major impacts on society are caused by a change in a natural ecosystem. Odor, for example, may affect air quality. Greenhouse gas emissions affect air quality as well as may be associated with climate change. It is predicted that climate change could have significant impacts on society globally. Some of these impacts would be through direct effects of the changing climate, such as health effects, while others might result indirectly through modification in production possibilities for various industries. Since a major part of these impacts are on society (with some limited impact on livestock producers themselves), these impacts are called externalities.

Water quality, including surface and ground water, can also be affected by livestock production. Deterioration of groundwater is a more serious problem, since once polluted, it may take decades, if not centuries, to return to its natural state. A combined effect of water and air quality impacts and climate change is to change economic development opportunities in a given region. This again affects the quality of human life directly and/or indirectly. Changes in air and water quality and climate are examples of public goods. These changes affect many economic activities that affect social welfare.

The gist of the above discussion is that livestock production can create many externalities, some of which can be considered public goods, while other impacts may be realized by private parties. Many physical science studies have identified, based on either

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[2] Based on a review of Netherlands studies reported in G. Tamminga and Wijnands, J. 1991. "Animal Waste Problems in the Netherlands", pp. 117-136, in N. Hanley. *Farming and the Countryside: An Economic Analysis of External Costs and Benefits.* Wallingford: CAB International.

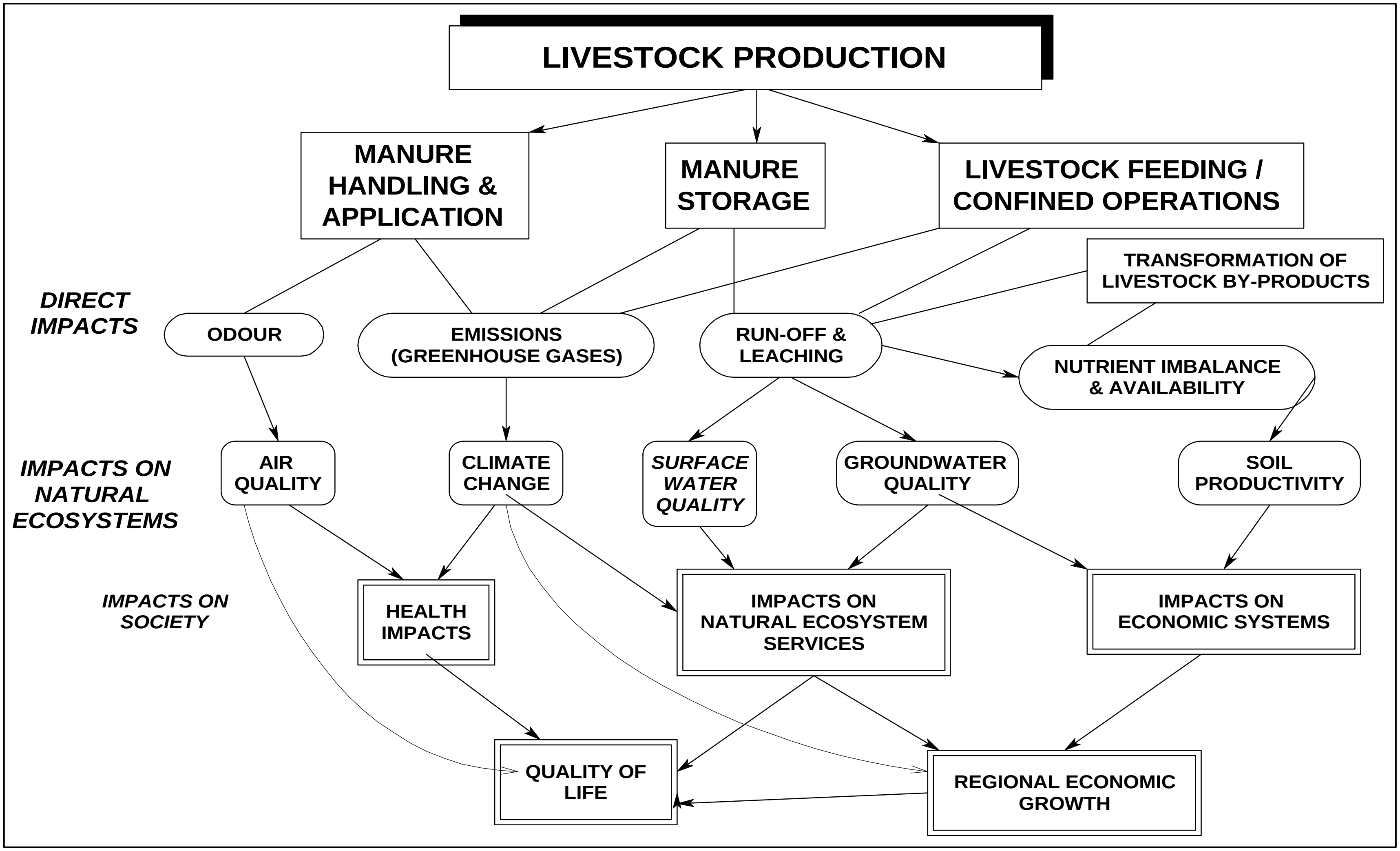

Figure 1: Inter-relationships Between Livestock Production and Human System

conceptual or experimental data, physical pathways. Many of these studies have also hinted at implications for society at large. In the next few sections, these studies are reviewed.

The presence of externalities creates a problem in resource allocation for society as a whole. If the nature of the externality is negative (damaging effect), other members of society have to pay to correct it. This leads to waste of resources. If a particular private agent creates negative externalities, thereby damaging, say the environment, there is a tendency on the part of that private party to over-produce (produce at a level higher than that desired by society). The situation is depicted in Figure 2.

In Figure 2, producers are creating a negative externality. Since they are not paying for the damage to society, their cost is shown by the curve '*Marg.Pvt.Cost*'. Society now puts the bill for the external damage, and thus moves the cost function to the left of the private cost function, as shown by the '*Marg.Soc.Cost'* curve. The difference between the two cost curves is the magnitude of the external damage created by livestock producers. The private decision maker under profit maximization would like to produce at point '$0Y_p$', but society would be better off through a production of only '$0Y_s$' units. Thus, under negative externalities, which are most frequently encountered with livestock, production is more than what society would like to see from the standpoint of sustainability. This then compels the rest of society to allocate resources that would lead to reducing these damages.

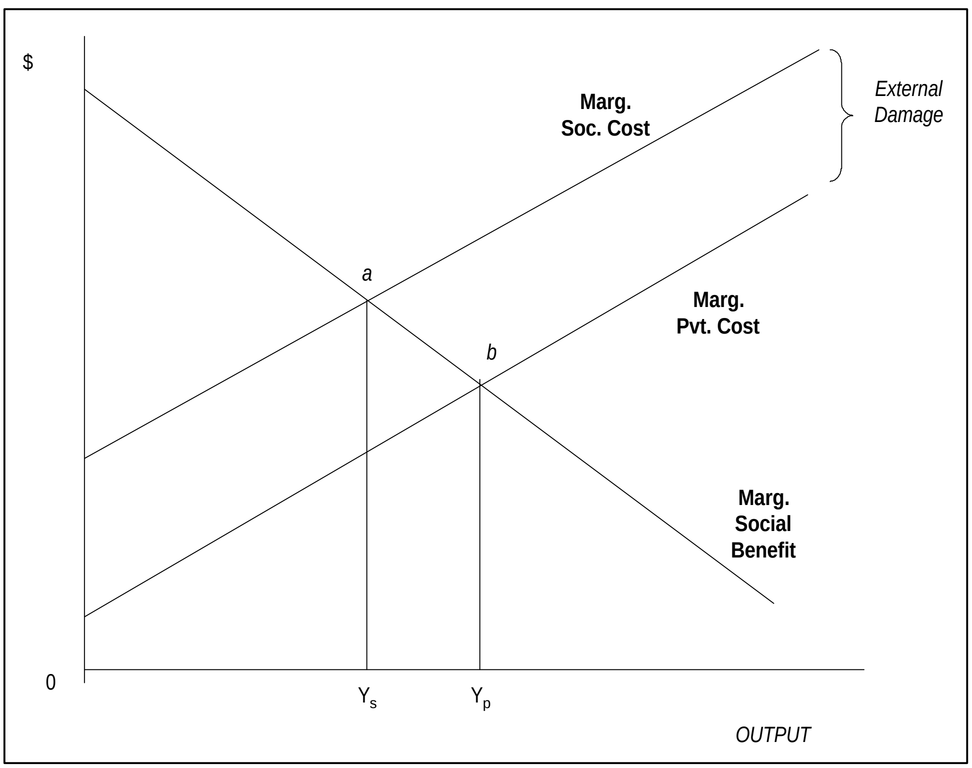

Figure 2: Private and Social Optimum Level of Output under Externalities

Although Figure 1 outlines a number of externalities, many of these, being indirect in nature, are not addressed in the literature related to livestock production. For this reason, a broad grouping of private and public goods according to the six major categories of the horizontal axis of Table 2 is used to organize the remaining discussion. These categories include economic activity, and soil, water, air, biota, and human health. Economic activity includes on-farm activities as well as social impacts.

Economic externalities can be created through two separate pathways: Direct impacts of livestock production activity, or indirect through changes in environmental amenities affected by livestock production. In Table 2, only direct economic benefits are considered, since those through improved ecosystems should logically be included with other public impacts.

Livestock production activity can create a multiple of pathways leading to some external effect as suggested by Table 2. Manure handling and application, for example, is identified with at least six pathways, whereas the number of such pathways is relatively small for manure storage and livestock feeding.

The interrelationships between various environmental attributes and livestock production poses a number of management challenges. Peters, Negrave and Collwell (undated) present a list of these, shown in Table 3. Three key risk factors were identified – contamination of water, air and soil. A number of linkages between these risk factors and management of manure can be identified. For example, a reduction in the over-supply of nutrients will reduce the risk of soil contamination, and at the same time, will reduce the risk of water contamination from surface runoff and leaching.

Table 2. Major Categories of Potential Public Impact by Livestock Activity and Pathway of Impact Identified in Literature

Livestock Production Activity and Pathway of Impact Identified in Literature	Major Categories of Potential Public Impact (Externality)					
	Economic Activity	**Soil**	**Water**	**Air**	**Biota**	**Human Health**
Manure Handling and Application						
• Odor	X			X		I
• Ammonia emissions	I	X	X	X		X
• Pollution by phosphorus	I		X		X	
• Runoff and leaching including ambient pollution[1]	I	X	X		X	I
• Nutrient imbalances including efficient use of organic and inorganic N and P	X	X	X		X	
• Greenhouse gas emissions	I			I		I
Manure Storage						
• Pollution by excess phosphorus	I	X	X	X	X	I
• Runoff and leaching	I	X	X		X	I
• Greenhouse Gas Emissions	I			X		X
• Odor	I			X		X
Feeding generally, and in localized areas. Confined systems.						
• Odor	I			X		I
• Run-off and leaching	I	X	X			I
• Greenhouse gas emissions	I	X		X	X	X
• Nitrogen and phosphorus excretion, including ammonia emissions and nutrient recycling	I	X	X			I

X = Major Impact I = Indirect Impact

[1] Pollution related to agricultural production can be classed as non-point source pollution, where no localized source of contaminant is identified, or point source pollution. Ambient pollution refers to point source pollution from livestock facilities, manure storage areas, and possible spills.

Table 3. Key Challenges from Manure Management Systems	
Risk Factor	**Management Challenge**
Water Contamination	• Preventing loss of nutrients in surface runoff • Preventing leaching of nitrates into groundwater • Reducing pollution of waterways by manure runoff or direct livestock access • Build up of nutrients and bacteria in ponds, wells and other waterways
Air Quality Contamination	• Reducing nitrogen-loss to the atmosphere • Minimize or reduce odors • Ammonia losses
Soil Contamination	• Eliminating over-supply of nutrients • Reducing or eliminating soil compaction and degradation of soil structure • Appropriate spreading of manure on forage and pasture to avoid rejection from animals

Source: Adapted from Peters, Negrave and Colwell (undated)

3. Summary of Literature Reviewed

3.1 Sources

A total of 82 studies were reviewed to examine the nature of externalities created by livestock production. These represent 104 citations that suggest some relationship between livestock production and the six selected categories of externality. Details on the studies reviewed are presented in Appendix A[3]. The major sources of the studies reviewed can be summarized as follows:

- All references provided by CARC to the project team at the outset and over the course of the project to date.

- A comprehensive bibliographic (library) search: A comprehensive search of national and international economic, science and technical literature pertaining to livestock manure and externalities using state of the art library search resources. This included electronic data search using selected keywords.

- References provided by project team members.

Some of the studies reviewed provide a general discussion of livestock production or various externalities related to it. Almost a fifth of the total were of this nature, and therefore were not classified into anyone single activity. Of the total of 104 citations, over 40 percent were related to manure handling and application. This category, as shown in Table 4, also includes the greatest number of Canadian studies. Livestock feeding including confined operations was the next largest category in terms of the number of citations. Less than a third of the studies were Canadian. There were more studies noted for manure handling and application for the Canadian context than those for other pathways.

Table 4. Summary of Canadian Studies Citations by Major Pathways to Externalities

Pathway	Citations of Canadian Studies	Total No. of Citations	Percent Canadian
Multiple Pathways or General studies	7	18	38%
Manure Handling and Application	28	45	62%
Manure Storage	8	16	50%
Livestock Feeding, Confined Feeding Systems, and Intensive Livestock Operations	6	23	26%
Total (Including processing of manure)	**50**	**104**	**48%**

3 The Appendix includes all references pertaining to livestock production and manure and their externalities. In addition to these, a number of other studies were consulted. These studies are referenced as footnotes underneath the first citation.

Although it was anticipated that this review would encounter studies covering all aspects of livestock production (production related activities, pathways, and externalities), such was not the case. As shown in Table 5, no Canadian study was found that described pollution by phosphorus and ammonia emissions from manure storage. Also for the livestock feeding pathway, studies documenting odor issues were not found. A larger number of studies were found dealing with manure handling and application related issues, followed by livestock feeding (including confined operations and intensive livestock operations).

A distribution of the citations reviewed according to the six major categories of externalities is reported in Table 6. The most commonly cited environmental good (ecosystem) was that related to water, surface and ground water. Air quality was the next most popular environmental good noted in these studies. Generally speaking, there are fewer studies that identify impact on economic activity from livestock production. Human health impacts and impact on biota are also not commonly found.

In the remainder of this report, each of the three major pathways – manure handling and application, manure storage, and livestock feeding are discussed. This discussion begins with a review of general studies. Since one objective of this report is to review those studies that have undertaken a valuation of the externalities of livestock production, a separate section is devoted to this issue. Here the emphasis is on a review of the area in general, not necessary connected to the external effects of livestock production.

Table 5. Summary of Frequency of Reference to Selected Issues Related to Pathways and Externalities of Livestock Production				
Pathways	**Canadian Studies**	**Other Jurisdictions**	**Total Studies**	**Sub-Total**
General Studies				**18**
Multiple Pathways/Integrated Assessments	6	2	8	
No Identified Pathways	2	8	10	
Production of Biogas	1	1	2	**2**
Manure Handling and Application				**45**
Odor	5	2	7	
Ammonia Emissions	3	2	5	
Phosphorus	1	3	4	
Run-off and Leaching	6	5	11	
Nutrient Balance and Recycling	5	2	7	
Efficient Use of Organic/Inorganic N & P	4	0	4	
Ambient Pollution	1	0	1	
Greenhouse Gas Emissions	5	1	6	
Manure Storage				**16**
Ambient Pollution[1]	1	2	3	
Pollution by Phosphorus	0	1	1	
Ammonia Emissions	0	1	1	
Run-ofs and Leaching	4	3	7	
Greenhouse Gas Emissions	2	1	3	
Odor	1	0	1	
Livestock Feeding, Confined Livestock, and Intensive Livestock Operations				**23**
General	0	2	2	
Odor	0	3	3	
Pollution by Phosphorus	1	1	2	
Run-off and Leaching	1	4	5	
Greenhouse Gas Emissions	1	2	3	
N and P in Excretion	1	3	4	
Ammonia Emissions	1	0	1	
Nutrient Recycling	2	1	3	

[1] A general definition of ambient pollution was not found. In the context of this report it represents point source pollution from livestock facilities, manure storage areas, and possibly from spills.

Table 6. Summary of Frequency of Citations[1] to Selected Externalities Associated with Livestock Production						
Pathway	**Economic Activity**	**Soil**	**Water**	**Air**	**Biota**	**Human Health**
General Studies						
No Identified Pathways	1					
Production of Biogas			2	1		
Subtotal	***1***	***0***	***2***	***1***	***0***	***0***
Manure Handling and Application						
Odor			2	7		2
Ammonia Emissions				3		1
Phosphorus			2			
Run-off and Leaching			9		2	
Nutrient Balance and Recycling		2	1			
Efficient Use of Organic/Inorganic N and P		3	1			1
Ambient Pollution			1	1		
Greenhouse Gas Emissions						
Subtotal	***0***	***5***	***16***	***11***	***2***	***4***
Manure Storage						
Ambient Pollution			1	1		
Pollution by Phosphorus	1					
Ammonia Emissions				2		1
Run-off and Leaching		1	5			
Greenhouse Gas Emissions						
Odor				2		
Subtotal	***1***	***1***	***6***	***5***	***0***	***1***
Livestock Feeding, Confined Livestock, and Intensive Livestock Operations						
Odor	2	1			1	
Pollution by Phosphorus			1			
Run-off and Leaching			2			1
Greenhouse Gas Emissions						
N and P in Excretion			1	1		
Ammonia Emissions						
Nutrient Recycling						
Subtotal	***2***	***1***	***4***	***1***	***1***	***1***
Total	**4**	**7**	**28**	**17**	**3**	**6**

[1] These numbers differ from the total number of studies in each pathway since a study may report more than one mitigation measure. Also it should be noted that a study may concentrate on a specific mitigation measure and may not explicitly note a particular externality.

3.2 General Studies

'General Studies' include those that do not identify a single specific pathway to externality from livestock production. Three types of studies are included: (1) reviews of other studies in the literature; (2) Decision Support Systems (DSS) or expert models developed as a guide to livestock production planning or management decisions; and (3) general descriptions of livestock production related issues. Details are provided in table A.1 (Appendix A).

In the first sub-category, three studies are noteworthy. One by Feng, Kurkalova and Seechi (2002) reviewed various studies in the U.S., and concentrated on the examination of externalities from agricultural production with the following major conclusions:

- In the empirical literature, the concept of transactions costs are acknowledged but are rarely estimated.

- Most studies cite only one particular aspect of multifuncionality of agriculture, and not all aspects of impacts of agriculture on environment.

- Some impacts of agriculture on the environment could be seen as a positive externality in some areas and negative externality in others.

- Baseline data are missing for a variety of issues, particularly the water quality issue.

Goss et al. (1993) provided a review of Canadian studies in the area of manure management. All three pathways were included. However, the focus of this study was to identify research priorities in these areas in Canada. The future research areas identified were a combination of natural and physical aspects of manure management and utilization as well as economic considerations. The following are noteworthy in the context of economic evaluation:

- Establish a research programme involving engineers, animal scientists, agronomists, soil scientists and economists to develop a comprehensive framework by which alternative manure management systems can be compared.

- Develop practical cost-effective methods for managing manure odors from farm systems. This should include seeking means by which the hazard to human or animal health from toxic gases, such as hydrogen sulphide, can be relieved in different manure systems, and developing better engineered and economic manure management systems that minimize gaseous losses from manure.

- Assess on-farm economics of different manure management systems in direct association with storage, application and utilization of manure.

- There is a need to assess off-farm costs due to environmental impacts, but this should not be developed solely with respect to manure management. However, the information on environmental degradation associated with alternative manure management systems must be qualified to allow the costs to be determined.

As one would note the recommendations include both economic assessment of farm level impacts, as well as those on society through externalities.

The third study was by Nugent (1997) who reviewed food production occurring within the confines of cities. Case studies included various countries. The various externalities identified include health risks (through drinking water contamination); ecological degradation including soil depletion; potential groundwater contamination, and social conflicts from mixed use of land.

The second sub-category of studies involves DSS or similar models. A Canadian model -- MCLONE4 – Manure Costs, Labor, Odors, Nutrients and Environment, Version 4 was developed for swine operations in Ontario, and has since been applied to other livestock enterprises. It is a comprehensive model and includes various aspects and pathways of manure handling, application and storage. It is also a good integration of economic, physical and biophysical, and ecological impacts and considerations in manure management. This model was initially developed by the Manure Systems Research Group (1999), and has been described in Stonehouse and Goss (1999), and Stonehouse and Giraldez (1996).

Two other models were reviewed. One by Michie and Petkau (1999) is software developed as a tool for manure management, and the other a model for Netherlands by Dijk, Leneman and van der Veen (1996). The former is a micro-simulation model to estimate the cost of various activities. The latter is a nutrient flow model and combines physical with economic activity. However, details as reported in the study, are inadequate to assess the quality of economic valuation of externalities.

General studies dealing with livestock production and/or externalities resulting from livestock production do not suggest any particular pathways to environmental or economic impacts. Only two studies in this sub-category apply to Canada. One is a CSALE (1996) examination of constraints to expansion of livestock production in Saskatchewan. The other by Rempel (1999) observed that poor manure management is a result of several factors including (1) focus of producers on gallons per acre; (2) heavy application of manure to crops; (3) ignorance and culture; and (4) knowledge and perception.

Observations from other "General Studies" reviewed include:

- Government policies and regulations affect producer decisions; yet no empirical analysis of cost of compliance with environmental regulations was found (Lazurus, 2001).

- Agriculture creates many positive and negative externalities, according to Legg and Potier (1998). Positive externalities include maintenance of rural landscape, preservation of wildlife, biological diversity, and providing a sink that traps carbon that would otherwise pollute the atmosphere as carbon dioxide.

- Negative externalities in the form of air and water quality impacts are also present. Alignment of agricultural and environmental policies to remove conflicting goals is suggested as one avenue that would assist the long-term pursuit of sustainable development (Legg and Potier, 1998).

- Estimation of damage by livestock production is problematic because of the uncertain relationship between potential pollutants applied to field and the actual transport of these pollutants to a site where an environmental damage can occur. Such uncertainties create problems in developing proper regulations.

- Environmental policies affect many aspects of livestock production, including regional distribution of such production systems.

- Most of the “General Studies”, as shown in Table A.2 (Appendix A), did not report any specific links to environmental or social and health related externalities.

Although the General Studies provide a good introduction to livestock production and aspects related to externalities, and to modeling advances in related areas, the economic aspect of externalities of livestock production is not a very common focus.

3.3 Studies Related to Manure Handling and Application

The review of manure handling and application studies identified eight pathways. Two of these relate to gases (odor and greenhouse gas emissions), and the remaining six pathways deal with minerals (ammonia emissions, pollution by phosphorus, run-off and leaching of minerals, nutrient imbalance and recycling, efficient use of organic/inorganic nitrogen and phosphorus, and ambient pollution).

Studies identifying odor issues were primarily concerned with hog production, and were qualitative in nature. Details are presented in Table A.3 of Appendix A. In many of these studies, odor was identified as a social problem and shown to be a constraint to acceptability of major expansion of hog production in various parts of North America. When it comes to precise measurement of the problem, according to Tessier (2001), quantitative description of odors is a task yet to be accomplished. In most cases, a descriptive measure such as the number of complaints or individuals signing a petition for granting a license for such operations is used as a surrogate measure of odor problems. Lague (2000) has suggested that producers, through proper management, can reduce odors that should have a positive effect on the health of farm workers.

Much of the greenhouse gas (GHG) emission work from livestock production has been based on the efforts made under Climate Change initiatives. The Intergovernmental Panel on Climate Change (IPCC) has been the major instigator of national development of greenhouse gas emission inventories. To make this happen, a list of GHG emission coefficients have been supplied. Strategies for minimizing GHG emissions have been tested using such coefficients. Much of the work reported by (The) Thomsen Corporation for Ontario (2000) and that by AAFC (2000) for various regions of Canada are examples of such efforts. Although use of IPCC coefficients is a common practice, Tessier and Maquis (1998) have questioned their use for Canada. These authors however, do not report any Canadian GHG emissions coefficients. Although a number of studies were funded under the auspices of the Green Plan in Canada, there still exists some uncertainty in developing a Canadian-based GHG emission coefficient[4].

Based on AAFC study, livestock production generates GHG directly (emissions of methane) and through manure handling and application. In addition, manure nitrogen is also a major source of nitrous oxide emissions from agriculture.

Studies related to minerals from livestock production span six pathways. Most of these pathways are either related to air quality (through emissions) and in part to climate change, or to water quality. Sommer and Hutchings (2001) have reported that in Europe livestock production is a major source of atmospheric ammonia (Table A.4, Appendix A). Lague (2000) also points to the production of phosphorus by these enterprises. Much of the nitrogen (N) and phosphorus (P) finds its way either through the atmosphere or in the soil. However, a good part could also be involved in run-off where it results in water quality impairment. In associating manure content with water quality, Letson and Gollehon (1998) have warned of the process – "… we need to know more about manure application methods, soil mobility, crops grown, rainfall events, proximity to surface water, depth of water table, water uses, and the contributions of

[4] Details of these studies can be found in Agriculture and Agri-Food Canada. 1997. *Workshop on Greenhouse Gas Research in Agriculture.* Sainte-Foy, Match 12-14. Ottawa

other sources of minerals". Thus, they note that additional spending on manure management does not guarantee water quality benefits, since it is only one of several linkages, and is very site and cultural practice specific.

Many of the studies reviewed indicate the direction of change for various externalities. Sharpley and Moyer (2000), for example, point to reduced freshwater pollution from phosphorus under certain mitigation measures. Brouwer et al. (1999) suggest that nitrogen pollution is a major threat to the quality of the European aquatic environment (ground, surface, and marine waters). These reports do not provide any estimate of the magnitude of the externalities either in physical or value terms.

3.4 Studies Related To Manure Storage

Essentially, studies dealing with manure storage have very similar pathways as those for manure handling and application, and reporting is not duplicated here. Details on manure storage studies are shown in Tables A.5 and A.6, Appendix A.

In many of these studies, it is noted that odor and minerals through gas emissions or run-off and leaching threaten air and water quality (surface and ground water). Several studies identify damages from run-off and leaching, as well as pointing out the contribution livestock production makes to GHG emissions. A number of studies in this category point to a need for proper manure storage systems, and better public policy.

In the context of GHG emissions, the use of a geotextile cover for stored manure is suggested by Barrington and Cap (1991). This is also supported by the AAFC (2000) observation that covering liquid storage tanks reduces methane emissions. Covered storage systems also reduce odor (Larson, 1991) and help public perception of air quality as affected by livestock production. Work by Haan and Blackburn (1996) also indicates systems that collect feces for solid bulk storage may lead to better health via improved air quality. This would also lead to reduced influence of climate change. Covering storage tanks and keeping manure under solid barn floors would have the same effect.

Bolland, Preckel and Foster (1998) suggest that lagoon storage and irrigation application of manure is the least cost method of management. Holmes and Klemme[5] (1987) estimated the economics of daily haul and long term storage systems for dairy farms in Wisconsin including capital investment and annual operating costs for a solid and liquid daily haul system, and for a long-term concrete storage system. Switching from a daily haul to a concrete tank storage system was estimated to cost $250 (U.S.) per cow for a 40-cow herd. In a subsequent study (Holms and Klemme, 1989) shown that the type of manure storage can have a large influence on the cost structure and debt load. Annual producer net income changes for the various manure handling systems examined were as follows:

Daily Haul	+$44 per cow in U.S. dollars
Concrete Tank	-$46 per cow in U.S. dollars
Stacking Slab	+$12 per cow in U.S. dollars
Earthen Basin	+$45 per cow in U.S. dollars

The study suggested that concrete tanks provide environmentally friendly manure storage. An open concrete tank with a storage capacity of six months or more, along with application of manure by top loading tank spreader, would improve soil quality, result in reduced nutrient run-off, and eventually result in improved groundwater quality but at the cost of a net income loss to producers.

5 Holmes, B. and Klemme, R. 1987. *Dairy facility costs: changing technologies and herd sizes*. A Report Presented to the Wisconsin Dairy Task Force.

3.5 Studies Related To Livestock Feeding And Confined Livestock Operations

Several studies address issues related to feeding of livestock and externalities resulting from it. Details on these are summarized in Tables A.8 and A.9 of Appendix A.

Boland, Preckel and Foster (1998) studied feeding in the context of surface water pollution. Their suggestion to decrease surface water pollution is to add phytase and synthetic amino acids to livestock diets. Steinfeld, de Haan and Blackburn (1996) discuss ways to decrease emissions due to feeding. They suggest improving nutrient formulation by incorporating optimum levels of nitrogen into feed and adding enzymes to improve the utilization rate of plant phosphorus. They also suggest multi-phase feeding that closely times feeding to animal needs, and balancing feeds with essential nutrients. Adding phytase to feed was also suggested for decreasing emissions.

Sharpley and Moyer (2000) looked at the externality of animal feeding. The types of impacts examined include freshwater pollution as well as the accumulation of P. Mitigation of P accumulation is provided by the presence of soil that will affect the adsorption of P released from manures or composts.

Intensive livestock operations have also been a subject of many studies, particularly in terms of their environmental impacts and social acceptability. Ikerd (1999) suggests large-scale, corporate-owned factory-type livestock operations are not socially responsible, not ecologically sound nor economically viable. Large hog operations have also been reported by Abeles-Allison (1990) in Michigan to diminish local amenities. In addition, they generate odor and flies, and thus impart significant externalities on society.

Statistics Canada (Beaulieu 2001) analysis of the geographic location and concentration of livestock using current Census data concluded that the available evidence does not support the notion that large livestock farms are solely responsible for high livestock densities. High livestock concentration is not always related to large livestock farms. For example, in Alberta high-density areas, most of the livestock are on very large intensive farms while, in Quebec and Ontario, they are on relatively smaller, less intensive farms. The cumulative impact of several non-intensive small farms may be comparable to the impact of a few large intensive farms. Additional research is required to determine whether livestock concentration in certain regions of Canada has reached limits where it could pose an ecological threat. This requires establishing regional nutrient budgets based on manure produced, farmland available for manure disposal, soil characteristics, crop requirements, and use of chemical fertilizer and municipal sewage sludge to identify areas where the environment might be at risk from a lack of sufficient land to recycle animal waste.

3.6 Farm Level Economic Valuation

The economics of livestock production is a subject of various databases. Several Canadian provincial departments of agriculture maintain (on their websites) cost of production data for various types of livestock enterprises. However, when it comes to manure management, and within that development of new strategies for minimizing adverse effect on environmental goods, studies are not common. Details of on-farm benefits reported in the studies reviewed are provided in Tables A.9 to A.11, Appendix A.

3.6.1 On-Farm Level Data Related to Economics

Apart from the data collected by various provincial studies, very few Canadian studies estimate on-farm costs and benefits from manure management options. Some are incorporated in various DSS models, such as those described below by Stonehouse, de Vos and Weersink (2002). Stonehouse and Giraldez (1996) report costs which included (1) capital costs of manure handling systems, and (2) operating costs that include equipment maintenance, fuel, repairs and other costs. According to these, equipment operating costs are a major portion of total costs.

In addition to models, some estimates of farm costs are reported. Lazenby (1995) reported the cost of an alley flush system to vary from $130 to $224 per cow, whereas earthen lagoon system costs can be as low as $2 per cow. Fulhage (1994) using data for Missouri, U.S. estimated lagoon system costs to vary from $36 to $64, compared to slurry system costs in the range of $58 to $156 per annum. These and other variable cost estimates support the observation that on-farm economics are very site and application specific.

3.6.2 Economics of Alternative On-Farm Manure Management Systems

A number of studies have addressed the on-farm cost of alternative manure management systems. Much of this has been on various livestock operations in Ontario. Narayanan and Stonehouse[6] (1981) examined manure handling and utilization systems for a representative Ontario beef feedlot operator. The optimal system was found to be a liquid system with slatted floor, mechanical collection, solid separation, above ground storage, and tanker injection. Increased energy prices changed the optimal method to gravity collection of liquid manure and under-the-slat storage. This model was extended to four livestock types (dairy, beef, swine, and poultry) by Kelland and Stonehouse[7] (1984). Alternatives of manure digestion, composting and off-farm sales were also added. Using the criterion of cost minimization, no specific manure-

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6 Narayanan, A.V.S. and Stonehouse, D. 1981. A Programming Model for Analyzing Alternative Systems of Handling and Utilization of Livestock Manure for Crop Production – An Application to a Hypothetical Beef Feedlot Operation. School of Agricultural Economics and Extension Education. Guelph: University of Guelph.

7 Kelland, D. and Stonehouse, D. 1984. *A mixed integer programming model for analyzing manure-handling system alternatives.* School of Agricultural Economics and Extension Education. Guelph: University of Guelph.

handling system was found to meet the criterion. However, Landeerville[8] (1987) extended the model further to examine cost reducing modifications to existing manure-handling systems on a farrow-to-finish hog operation. This study recommended increased manure application to field during spring and summer, thereby reducing fall and winter applications.

The cost of spreading liquid manure was estimated for three systems by Flemming and Stoner[9] (1982). These systems included: tanker broadcast, tanker injection, and hard-hose traveler irrigation. Cost per 1,000 gallons of manure was estimated at \$7.70, \$11.30, and \$13.70 respectively. Irrigation systems were observed to require large amounts of manure and therefore not suitable for small sized operations. One major limitation of this study is that collection, transfer, and storage of manure were not considered. This limitation was improved by Lazenby (1995) for a dairy operation.

Stonehouse, de Vos and Weersink (2002) focused on hog finishing enterprises in Ontario. Four enterprise sizes were modeled including (1) small 200 sow; (2) medium 500 sow; (3) large 1,000 sow; and (4) extra large 5,000 sow operations. The study integrates manure management with crop production and livestock management in a whole-farm setting, thereby showing how manure management decisions and crop and livestock production decisions influence and support one another. Two models were used. The first was an economic model where there were no constraints placed on ammonia emissions, and excess N and P. The objective of the model is to maximize net returns. The second is an environmental model whose objective is to minimize manurial ammonia, and excess N and P. Three alternative ways of collecting manure, three storage methods, and three types of field application were combined with three different feed rations with two variants of a corn-soybean meal ration used as alternatives. One ration includes synthetic lysine, one of the essential amino acids in a hog's diet; and the other conjoins exogenous phytase in a corn-soybean meal ration.

The results of the model show that under the economic criterion of farm net returns maximization, a ration comprised of corn-soybean meal and synthetic lysine decreased N and P emissions in the manure and improved hog-feed conversion ratios. The economic criterion also called for a manure handling system based on solid floor collection, earthen pit storage, and travelling irrigation gun for field application across small, medium and large farm size categories.

Under the environmental criterion, the objective was to minimize ammonia emissions from manure operations, or to minimize excess N or P in manure applied to cropland, regardless of economic impact. The model shows that an operator of a small hog enterprise would have foregone over \$2,000 of farm net returns to comply with minimum NH_4 loss restrictions, and nearly \$1,700 of farm net returns in order to minimize excess N applications. Other mitigation

8 Landeerville, D., 1987. An Economic Evaluation of Manure-Handling Systems for Hog Farrow-to-finish Operations. M.Sc. thesis. Guelph: University of Guelph.

9 Flemming, R. and N. Stoner, 1982. Comparison of 3 Systems of Spreading Liquid Manure. Unpublished report. Guelph: Ontario Ministry of Agriculture and Food and Rural Affairs.

strategies to minimize NH_4 emissions include a corn, soybean meal, and synthetic lysine ration, combined with fully-slatted floor collection, covered concrete storage, and tanker-injector for field application across all four hog enterprise sizes. Thus, in summary, this work indicates the best way to minimize applying excess N to cropland is through a combination of feed ration with lysine, solid floor collection, covered concrete tank storage, and irrigation for field application. The model shows that regardless of collection, storage and field application system components, manurial P content remains the same.

Stonehouse, de Vos and Weersink (2002) conclude that care for the environment can only be achieved at some cost to farm business profitability. Since there is some cost to hog producers for protecting the environment that benefits society at large, there should be some consideration given to public financial assistance for farmers' environmental protection efforts.

3.6.3 Economics of On-Farm Application of Manure

Using the situation in Colorado, U.S., Wang and Sparling (1995) reported economics of feedlot manure application to irrigated crops. The substitution of raw and composted manure for chemical fertilizers was examined with the observation that about 12 percent of chemical fertilizer could be viably replaced by raw or composted manure, with compost exhibiting slightly higher estimated net returns than raw manure. Each feedlot animal is assumed to excrete one ton of manure with 40 percent moisture, 1.1 percent N, 0.6 percent P and 1.2 percent K. When applied as raw manure, 50 percent of N and 80 percent of P and K were assumed to be eventually available to crops. Composting was assumed to result in no loss of P or K.

A similar study involving substitution of manure for fertilizer is reported for Canada by Janzen et al. (1999). (The Canada-Ontario Green plan also had studies involving the substitution of manure for fertilizer; however, the focus of these studies was on crop production rather than externalities). The study focuses on all types of livestock and confined systems, and is based on a model that equates ecological and economic considerations applied in a case study of an Alberta farm. Results suggest that the value of the crop response and the cost of transportation are more significant economic considerations than is the cost of processing manure into compost. The study shows that manure management can be ecologically and economically sustainable if the land area required to recycle manure macronutrients effectively is equal to or smaller than the land area for which the cost of manure distribution is offset by crop response. In fact, the break-even value of manure is the value that equals the cost of transporting to an area of land with the capacity to recycle macronutrients effectively. A major implication of the study is that manure products may need to be transported outside the boundary of the livestock operation in order to be ecologically sustainable. The authors predict that crop response to manure macronutrients will increase with the number of years of application. This will depend on the nature of the soil because if applied to poor soil, improvement will be greater than that for soil in good condition. Manure use can be made more effective by processing to increase nutrient retention, reducing transport costs, and using application technologies to increase crop response.

Another potential benefit of manure application to land is the restoration of desurfaced soils. Larney and Janzen (1996) looked at how various amendments of manure affect the productivity and restoration of soil. Seedbed conditions improve with manure application, and translate into better seed germination and seedling establishment. Major benefits of composted manure include lower moisture content and volume, reduced odor, and reduced potential for leaching of NO_3^- into ground water. Manure is more beneficial in restoring soil productivity than inorganic fertilizer. Manure P has the advantage of positional availability because it moves vertically with water through the root zone and remains in a form subject to continued mineralization and cycling as inorganic P cannot. The best amendment identified was hog manure, followed by poultry manure and alfalfa hay. This study confirms that there is an economic benefit from manure application in terms of restoration of productivity to eroded soils.

3.6.4 Economics of Manure Hauling

A number of studies have addressed the economic distance which manure can be moved. Unterschultz and Jefferey (2001) estimate manure can be economically transported up to 300 km in the absence of commercial fertilizer i.e. assuming cost competitiveness of commercial fertilizer is not considered; in other words, in the absence of commercial fertilizer. Nagy et al. (1999) estimate this distance to be more moderate. Swine manure has an economic hauling distance of 6.3 to 13.6 km depending upon the crop response to applied nutrients, while cattle manure can be hauled economically for a distance of 8 km.

Younie et al. (1996) suggest that the costs associated with transport and handling of manure is high and this makes the export value low. Because of this, the most economical option for producers is to dispose of manure at rates of application in excess of that required by crops. However, this then creates potential for nitrate accumulation in the soil and contamination of surface water and groundwater.

3.6.5 Adoption of Manure Management Practices

The magnitude of improvements in water or air quality is determined by farm operators' attitudes and adoption of beneficial practices. One study by Camboni and Napier[10] (1994) addressed the following factors that may inhibit producers from adopting better management practices. These factors can be instrumental in the adoption of management practices and technologies regardless of regulations or economic subsidies.

- Significant initial investment costs of adoption;
- Direct costs associated with the practice, including investment in other needed farm equipment;
- Resistance to change, due to fear of failure;
- Risk aversity;
- Lack of sufficient information;
- Economic viability of farm enterprise;
- Lack of economic subsidies; and
- Profit maximization orientation of producers.

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10 Camboni, S. and Napier, T. 1994. *Adopting Conservation on Farm.* Soil and Water Conservation Society.

3.7 Economic Valuation of Externalities

References for this section have to do with valuation methodology rather than livestock production and externalities. In order to distinguish these from other references in this report, they are included as footnotes.

3.7.1 Conceptual Framework

The environment provides a variety of services to society. Many of these services are irreplaceable, although for some there may be alternatives. Table 7 provides a list of various services provided by the environment that can be affected by livestock production. Many of these services are provided free and therefore taken for granted until such time they are damaged and are not available to society.

Table 7. Functions, Goods and Services Supplied / Provided by the Natural Ecosystems

Function	Details on the Function	Goods and Services Provided
1. Gas regulation	Bio-geochemical cycles	Air quality, prevention of diseases
2. Climate regulation	Influence of land use on climate	Maintenance of favorable climate for humans, plants and animals
3. Water regulation	Regulating river run-off and discharge	Drainage, irrigation and transportation services
4. Water supply	Storage of freshwater in aquifers	Water for consumptive uses
5. Soil retention and formation	Soil biota and accumulation of organic matter	Maintenance of arable land, prevention of damage from erosion
6. Nutrient regulation	Recycling of nutrients	Maintenance of healthy soils and productive ecosystems
7. Food	Conversion of solar energy into edible plants and animals	Buildings, manufacturing, and other economic development activities
8. Genetic and medicinal resources	Provision of biological and chemical substances for medicinal and other natural uses	Health care drugs and pharmaceuticals
9. Aesthetics	Attractive landscape features	Enjoyment of scenery

Source: Adapted from R. S. de Groot, M. A. Wilson and R. Boumans. 2002 “A typology for the classification, description and valuation of ecosystem functions, goods and services”. *Ecological Economics.* 41: 393-408.

An externality is created when the natural provision of services is disrupted. Water pollution from dumping raw manure into a nearby stream, and air pollution from gases emanating from livestock operations are some examples. Although the environment provides these services free, society does value them. They are valued because there are uses for them, either as necessities or enrichments of life.

Valuation of environmental goods is generally undertaken using a “Total Economic Value (TEV)” framework. The framework is shown in Figure 3. Two types of values are identified: use-related and non-use related values. Use related values are a sum of four values: (1) Direct commercial values; (2) Social and educational values; (3) Ecological functions values; and (4) Options value. Option value is the value that people place on having the option of enjoying goods and services in the future, although they may not use them currently. The second major category is non-use related values. These values are a sum of bequest and existence value. Bequest value is the value people place on knowing that future generations will have the option to enjoy the goods and services from the environment (or natural resources). Existence value is simply the enjoyment society gets from the knowledge that some natural ecosystems are in place and exist (although they may not be using them currently).

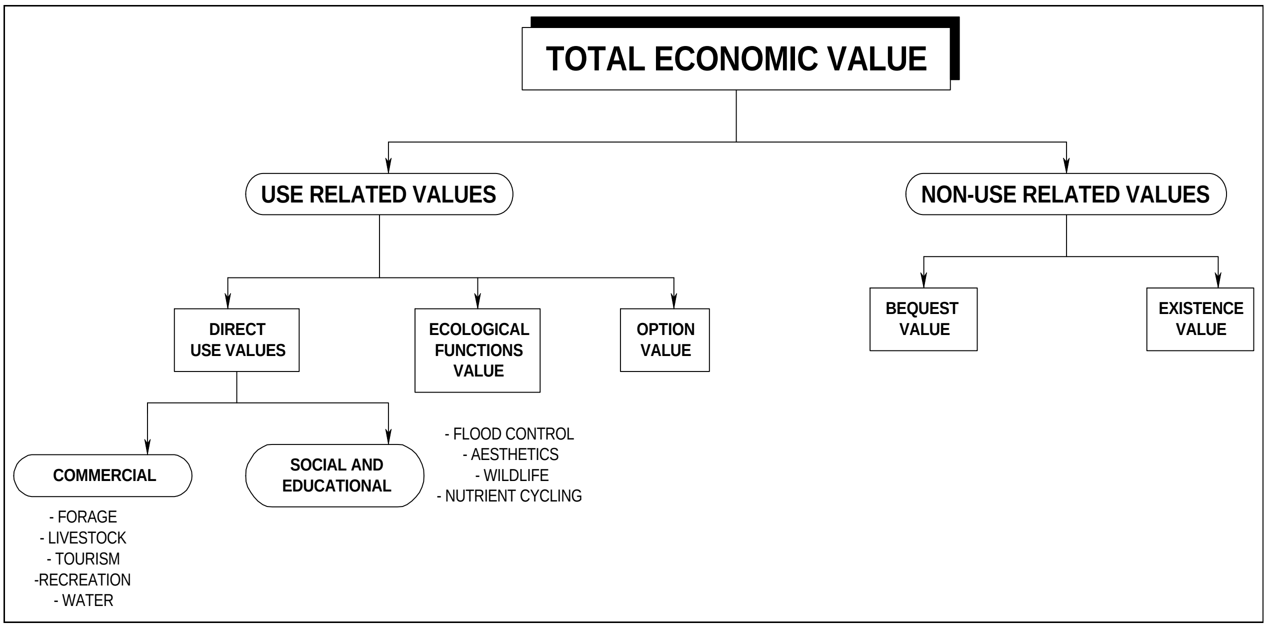

Figure 3: Total Economic Value Framework for Valuation of Environmental Goods

Valuation of environmental (natural ecosystems) based externalities has not attracted much attention in the context of livestock production, although some attempts have been made in a general context or in the context of environmental impact assessment exercises. Since many of the goods and services are not traded in the marketplace, a new set of techniques, called non-market valuation methods, have been developed. A partial list of such approaches includes:

- Productivity change approach
- Market price
- Loss of earnings
- Replacement or repair cost
- Defensive expenditures
- Travel cost
- Contingent valuation or willingness to pay
- Property value
- Hedonic pricing

In the following sections, studies of the valuation of externalities relevant to livestock production are described. Every attempt was made to find and review studies directly dealing with livestock production (and within that to manure management). However, where such studies were not found, a general discussion of the valuation of the specific natural resource or service provided by it is presented.

Pearce and Turner (1990)[11] suggested the use of willingness to pay (WTP) or to accept (WTA) as a measure of the value of an environmental good. Four possible measures are identified (1) WTP to secure a benefit; (2) WTP to prevent a loss; (3) WTA or forego a benefit; and (4) WTA or tolerate a loss. Studies have indicated a wide range in estimated WTP and WTA values.

3.7.2 Valuation of Selected Externalities

Featherstone (1998) suggests that the mere presence of animal excretions in a watershed does not imply an environmental problem. Land application of manure, when properly undertaken, recycles manure ingredients to nourish plant growth. However, improperly managed applications or accidental releases from manure storage facilities – no matter how small or infrequent – can have detrimental effects on the environment. Massey and Zerring (2001) have argued that damage values based on non-market methods or benefit transfer methods may undervalue or overvalue the benefit. This practice is faulty because a constant marginal value (price) is applied to ever increasing levels of environmental quality degradation. This is contrary to the premise that the value of environmental quality remains unaffected by its supply. A more appropriate approach is to undertake a cumulative impact assessment of damages being done in a region.

3.7.2.1 Rural Amenities

The effect of livestock production activities on rural amenities has been described by Abeles-Allison (1990) and Weida (2001). Regional effects of large-scale hog operations were examined, with the conclusion that they interfere with rural amenities. They also place constraints on regional development due to reduced employment (cost minimization requires substitution of cheaper input for more expensive ones), reduced tax revenues, and vertical integration. No Canadian studies on the subject were found.

3.7.2.2 Land and / or Property Values

Abeles-Allison (1990) estimated that in Michigan hog production decreased house values. For every additional hog within a five-mile radius, house prices decreased by $0.43 (U.S. dollars). Thus, an increase of 10,000 hogs in this region would decrease the price of a house by $4,300 (U.S.) indicating large-scale hog operations have had an adverse effect on property values in parts of Michigan. Since property values are location and culture specific, such conclusions cannot be extended to Canada. Therefore, undertaking such studies for Canada is highly desirable.

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[11] Pearce, D. W. and R. K. Turner, 1990. *Economics of Natural Resources and Environment.* Baltimore: The Johns Hopkins University Press.

3.7.2.3 Canadian Valuation Studies

Weersink (1996) reviewed livestock production related externalities, and concluded that "At the present time there are no studies using any of the approaches that have examined the economic value of environmental damages caused by manure pollution. There are a few related studies that have determined that households would be willing to pay from $50 to $1,150 annually to lower nitrates in groundwater. However, no study has examined total impacts from manure which has a host of pollutants (nitrates, phosphorus, and odors) and a number of effects on the natural resource systems" (p. 9-13).

3.7.3 Valuation of Natural Ecosystems

Although economic valuation of environmental amenities associated with or affected by livestock production through manure management has not been a very common focus, such valuations have been undertaken in other contexts. Some of these studies are reviewed in this section to provide a glimpse of the nature of the subject matter associated with valuation of natural ecosystems.

3.7.3.1 Valuation of Air Quality

Air quality aspects related to livestock production are affected primarily by the generation of odor from some livestock operations. In some instances, these may be related to health, while most situations simply involve a socially unacceptable change in air quality. Most air quality valuation work has been undertaken in the context of smog, ozone concentration, pesticide residues, and other air-borne diseases.

Freeman[12] (1993) has proposed a three-stage process of valuation of air quality. In the first stage, reductions in ambient air pollutant levels are estimated. Impact on humans is the focus of second stage where attention is paid to reduced morbidity and mortality, improved agricultural productivity, reduced soiling and materials damage, and improved visual amenities. The third stage places an economic value to the identified changes. Studies of this type are complex, as a full understanding of the relationship between air pollution and the health status of the population requires a comprehensive epidemiological analysis that controls for socioeconomic influences and other confounding variables such as diet, life style, and occupational exposures to harmful substances.

3.7.3.2 Valuation of Water Quantity

Water is a resource associated with considerable sentiment. Remarks on the value of water reflect its fundamental importance, similar to clean air, from an ecological as well as a social point of view. It is suggested water is a "priceless" element, inherently too vital to be allocated by market mechanisms. In fact, the International Conference on Water and the

12 Freeman, A. M., 1993. The Measurement of Environmental and Resource Values – Theory and Methods. Washington, D.C.: Resources for the Future.

Environment[13] issued the Dublin statement, proposing that "Water has an economic value in all its competing uses and should be recognized as an economic good."

The total value of water can be divided into two major categories of the TEV framework: use related and non-use values. The first category is formed either through direct uses, such as domestic consumption or water-based recreation, or through indirect uses in which water contributes to production of other goods such as industrial products or irrigated crops. Water not only enters production processes directly, but also serves to assimilate and remove human and industrial wastes. In addition, in some areas, watercourses are used as major navigational channels. This, at least historically, has contributed to major economic development the world over.

In addition to the direct use of natural environments, people place value on knowing that such environments exist, that they could use them and that they will be available for future generations. These lead to non-use values of water -- existence and bequest value. In addition to the valuation of water in terms of gain in economic welfare of people, its value can also be measured through its role in economic development. Here the value is equated to lost economic growth (typically measured in terms of income) to the people of a given water resource management region.

Four aspects of water resources affect economic value: quantity, location of use, time of use, and quality. The first three are associated with the relative scarcity of the resource in determining its value. Also important is the distinction between marginal, average, and total value of water resources. Although a number of U.S. studies have estimated the value of water, there is a general dearth of such studies for Canada. Since water is not traded as an economic good, its value has to be estimated using indirect methods. Muller (1985)[14] investigated the value of water for major Canadian sectors such as municipal, irrigation and industrial use, and for a number of in-stream uses such as hydroelectric generation, waste assimilation, navigation and fisheries. The total value of water in Canada in 1984 dollars was $6,968 million for municipal uses, $6,553 million for hydroelectric power generation and $6,309 million for sport fishing. In addition, in-stream uses were valued at $15,134 million, almost double withdrawal uses value at $8,590 million.

Kulshreshtha et al. (1988)[15] estimated short and long run average value of water in major uses in Saskatchewan. Domestic water use was estimated to have the highest value for both short and long run (up to $3,356 per dam^3), followed by recreation (up to $2,787 per dam^3 in short run and $790 per dam^3 in the long run). Although irrigation had a positive value in the short run, when all resources are accounted for, its value is positive only for certain crops. The study also noted a large spatial variation in the values of water for the same use. Non-use and in-situ values for certain

13 For details see International Conference on Water and the Environment. 1992. *The Dublin Statement and the Report of the Conference*. Dublin, Ireland. 26-31 January.

14 Muller, R. Andrew. 1985. The Socioeconomic Value of Water in Canada. Inquiry on Federal Water Policy, Research Paper 5, Ottawa.

15 Kulshreshtha, S. N., Brockman, J. L. and O'Grady, K. L. 1988. *The Value of Water in Alternative Uses in Saskatchewan*. Moose Jaw: Saskatchewan Water Corporation.

uses (such as environmental and fishing) were not provided by this study. A distribution of these values, by type of water use, is shown in Table 8.

Table 8. Estimated Value of Water in Alternative Uses, Saskatchewan, 1985

Water Use	**Value in \$ per dam^3**
Irrigation	51 – 104
Potash Mining	1
Food and plastics	10 – 19
Primary fabricated metals	17 – 35
Refined petroleum, coal and chemical products	17 – 130
Residential	5 – 3356
Hydroelectric	7 – 18
Recreation	1 – 2787
Source: Kulshreshtha et al. (1988)	

Very few studies have been devoted to the value of water for national and regional economic development. The role and hence value of water in hydroelectric generation is quite pronounced and the link from power generation to economic development is straightforward. There are studies that estimated this value but in a slightly different context. Kulshreshtha (1984)[16] investigated the value of groundwater in the Assiniboine Delta aquifer of Manitoba from economic efficiency and economic development perspectives. The value of water weighted over all uses in the aquifer region was estimated at \$464 per dam^3 compared to \$4,343 per dam for regional development. The relative differences in the values shows the externalities that are imparted by irrigation in regional development activities. Pearse and Tate[17] examined sustainable development as it pertains to the water resources in the Fraser River Valley. While the study did not provide an estimate of the value of water, the authors discuss quantity and quality issues related to the economic costs of water use. Included in the discussion is the current price charged to users and the cost of delivering that service. The authors conclude that policy makers need to encourage greater conservation of water resources.

Kulshreshtha and Gillies (1991)[18] document the value of water in the context of valuing the South Saskatchewan River to the residents of the City of Saskatoon. Their analysis details value in the following categories: domestic use, waste assimilation, recreation, aesthetics, business activity, and upstream use (i.e. irrigation, livestock, hydroelectric power) by three groups (residents, businesses, and municipal government). The authors calculated the economic value of the river to be \$36 M per annum.

16 Kulshreshtha, S. N. 1994. *Economic Value of Groundwater in the Assiniboine Delta Aquifer in Manitoba*. Social Science Series No. 29. Ottawa: Environment Canada.

17 Pearse, P. H. and Tate, D. 1981. "Economic Instruments for Sustainable Development of Water Resources." In A. H. J. Dorcey (ed.). *Perspectives on Sustainable Development in Water Management towards Agreement in the Fraser River Basin.* Vancouver: Westwater Research Center, University of British Columbia.

18 Kulshreshtha, S. N. and Gillies, J. A. 1991. *An Assessment of the Economic Value of the South Saskatchewan River to the City of Saskatoon*. Saskatoon: Department of Agricultural Economics, University of Saskatchewan.

The US National Research Council (1997)[19] has suggested the use of extractive values and TEV framework for the valuation of water in underground aquifers. Several case studies were undertaken. Each case study was handled through an interdisciplinary team (ecologists, economists, agrologists etc.). Of the six case studies reviewed, only two provided an estimate of the value of the ground water function. The estimates refer only to cost (i.e. cost of delivery of water to consumers/users) and not the "value" of water to consumers/users. Torell et al. (1990)[20] examined the market value of water in the Ogallala aquifer area (Kansas, Colorado, Nebraska, Oklahoma, South Dakota, Wyoming, Texas, and New Mexico). Using a Hedonic Pricing model, the study estimated the value of water through differences in the sale price of dryland and irrigated farmland. Results indicate the value of water was as much as 78 percent of the value of irrigated land in northern Colorado in 1979 to as little as 30 percent in southern Colorado in 1984 and 1985 dollars.

One of the major uses of water uses is in-situ where recreational activities and aesthetics play a major part in determining value. Recreation value has been a subject of several investigations, although in some cases these are non-water related. O'Grady, Brockman, and Kulshreshtha (1987)[21] provide an estimate of the value of water-based recreation in Saskatchewan. Using Travel Cost and Contingent Valuation methods, the weighted average annual value of water was estimated to be $6.16/dam^3 and $3.00/dam^3 for the short and long run, respectively.

3.7.3.3 Valuation of Water Quality

Quality is an implicit criterion in the valuation of water. Quality affects the range of possible uses, and treatment costs. Water quality is a strong determinant of its value, as lower quality resources command a lower price in the market place[22].

Water quality enters human systems in various ways. Poor water quality, as demonstrated by recent experiences at North Battleford, Saskatchewan, and Walkerton, Ontario, can become a major social problem, sometimes with a large legal liability. The immediate effect of water contamination is increased mortality of humans, and animals, and/or increased incidence of water-borne diseases. According to Livernois (2002)[23] the tangible costs to society

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19 National Research Council (U.S.). 1997. *Valuing Ground Water: Economic Concepts and Approaches.* Washington, DC: National Academy Press.

20 Torell, L. A., Libbin, J. D., and Miller, M. D. 1990. "The Market Value of Water in the Ogallala Aquifer." *Land Economics*. 66(2): 163-176.

21 O'Grady, K. L., Brockman, J. L., and Kulshreshtha, S. N. 1987. *The Value of Water-Based Recreation in Saskatchewan.* Water Use and Value Study Report 9, Moose Jaw: The Saskatchewan Water Corporation.

22 Saliba, B. C. and D. B. Bush, D. B. 1987. *Water Markets in Theory and Practice: Market Transfers, Water Values, and Public Policy*. Boulder, Co.: Westview Press, 1987.

23 Livernois, J. 2002. *The Economic Costs of the Walkerton Water Crisis*. The Walkerton Inquiry Commissioned Paper No. 14. Toronto.

from any future contamination in magnitude similar to Walkerton are estimated at $64.5 million. Although no economic costs for the North Battleford incident were reported, the Commission of Inquiry (see Laing, 2002[24]) did recommend a series of measures to protect water quality in the province, which may have various cost implications both for water users as well as for regulating authorities.

In light of this evidence, one way to place an economic value on water quality is to determine the cost of treatment of poor quality water. Although the quantitative value of such cost reductions have not been reported for Canada, Bolland, Preckel and Foster (1998) have reported a reduction in treatment costs for domestic and municipal water in the U.S. when quality improved.

A review of estimated cost of groundwater protection is provided by Weersink (1996). Eight studies were reviewed, as summarized in Table 9. Estimated groundwater protection values, estimated using a variety of estimation methodologies, varied from $56 to $1,154 (in 1992 U.S. dollars), which is equivalent to $101 to $2,077 (in 2002 Canadian dollars).

Benefits of good quality water are realized both by producers as well as society at large. Benefits of improved water quality have also been noted for livestock. Based on a study by the Western Beef Development Centre, Kirychuk and Braul (2001)[25] reported that aerated and coagulated water improved weight gain by steers significantly (approximately 20 percent) compared to direct-accessed water. In addition, there is a strong relationship between water consumption and weight gain of yearlings. Similarly, Russell[26] estimated the breakeven number of animals for certain remedial measures if water quality for animals is poor. For yearlings, assuming a daily weight gain of 1.4 pounds, and improvement due to better quality water of 10 percent, a solar power aeration and remote pumping system requires 256 animal months to breakeven. Similarly for a cow–calf operation, assuming a 2.8-pound daily gain and 10 percent water qualify improvement, such a system will pay for itself with 91 animal months.

Beside human health and mortality impacts, quality is also a factor in water-based recreation demand, as suggested by Parkes (1974)[27]. Users of lakes with poor water quality are willing to pay a significant amount per user-day per season over and above the additional costs that are normally incurred in the recreation experience.

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24 Laing, R.D. 2002. *Report of the Commission of Inquiry into matters relating to the safety of the public drinking water in the City of North Battleford, Saskatchewan*. Regina.

25 Kirychuk, B. and Braul, L. 2001. *Effect of Water Quality on Cattle Weight Gain*. Regina: Agriculture and Agri-Food Canada – PFRA. November.

26 Russell, K.D. 2000. *Economic Aspects of Rural Water Quality*. Agri-food Innovation Fund Report.

27 Parkes, J.G.M. 1974. “User Response to Water Quality and Water-Based Recreation in the Qu’Appelle Valley, Saskatchewan”, Chapter 6 in F. M. Leversedge (ed.). *Priorities in Water Management*. Victoria: University of Victoria.

Table 9. Summary of Contingent Valuation Studies of Groundwater Protection			
Author	**Study Location**	**Contaminants**	**WTP in 1992 USD***
Caudill (1)	Michigan	Unspecified	$56
Edwards (2)	Cape Cod	Nitrates	$1,154
Jordan and Elnagheeb (3)	Georgia	Nitrates	$139
McClelland et al. (4)	U.S.	Landfills	$118
Poe (5)	Wisconsin	Nitrates	$320
Powell (6)	Minnesota, New York, Pennsylvania	General list	$70
Shultz (7)	New Hampshire	Unspecified	$165
Sun (8)	Georgia	Nitrates, pesticides	$750
*WTP: willingness to pay			

(1) Caudill, J., 1992. The evaluation of groundwater pollution policies: the differential impacts of prevention and remediation. Unpublished Ph.D. thesis. Department of Agricultural Economics. East Lansing: Michigan State University.
(2) Edwards, S., 1988. “Option prices for groundwater protection.” *Journal of Environmental Economics and Management.* 13(1): 69-80.
(3) Jordan , J. and A. Elnagheeb, 1993. “Willingness to pay for improvements in drinking water quality.” *Water Resources Research.* 29(2): 237-245.
(4) McClelland, G. et al., 1993. *Methods for measuring non-use values: A contingent valuation study of groundwater cleanup.* Final Report Co-operative Agreement #CR-815183. Washington: Environmental Protection Agency.
(5) Poe, G.L., 1993. Information, risk perceptions and contingent values: The case of nitrate nitrates in groundwater. Unpublished Ph.D. thesis. Department of Agricultural Economics. Madison: University of Wisconsin.
(6) Powell, J.R., 1991. The value of groundwater protection: Measurement of willingness-to-pay information and its utilization by local government decision-makers. Unpublished Ph.D. thesis. Department of Agricultural Economics. Ithaca: Cornell University.
(7) Shultz, S., 1989. Willingness to pay for groundwater protection in Dover, New Hampshire: A contingent valuation approach. Unpublished M.Sc. thesis. Department of Resource Economics and Community Development. University of New Hampshire.
(8) Sun, H., 1990. An economic analysis of groundwater pollution by agricultural chemicals. Unpublished M.Sc. thesis. Department of Agricultural and Applied Economics. University of Georgia.

With respect to improvement of groundwater quality, some caution is advised since potential contamination sites could be unique, and the efficiency of alternative policies site specific. Furthermore, it also possible that benefits from preventing groundwater contamination might not always exceed its cost. However, Ducks Unlimited (see Gabor et al., 2001[28]) has argued that investment in wetland and riparian area protection and restoration is probably a cost-effective way to improve water quality.

From a societal point of view, Hauser and Van Kooten (1993) have estimated the economic value of water quality improvements[29] in a study of the Abbotsford aquifer, British

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28 Gabor, T.S., Murkin, H., Curry, P., Hill, M., Chekay, D., and Anand, M. 2001. *Beyond the Pipe – The Importance of Wetlands and Upland Conservation Practices in Watershed Management: Functions and Values for Water Quality and Quantity.* Oak Hammock Marsh, MB: Ducks Unlimited Canada, Institute for Wetland and Waterfowl Research.

29 Hauser, A. and van Kooten, G. 1993. *Review of Improving Water Quality in the Abbotsford Aquifer: An Application of Contingent Valuation Method.* Ottawa: Environment Canada.

Columbia. The estimated value had a lower bound of $70/household in terms of defensive expenditures. Willingness-to-pay was estimated between $78 - 90/household. Similar results have been shown by Athwal (1994)[30]. In a more general context, Spasic (2002)[31] undertook a survey of 300 randomly selected Saskatchewan residents and estimated their willingness-to-pay for riparian management (with implicit recognition of water quality benefits). The sample consisted of 61 percent urban households, 15 percent rural non-farm (towns) households, and 15 percent farm households. The average willingness to pay for water quality improvements was estimated at $39.92 per household, with the median value $23.60 per household.

3.7.3.4 Valuation of Climate Change

Increased concentration of greenhouse gases in the atmosphere has been predicted to alter future climatic changes. These impacts are going to be felt globally, although not all parts of the world would be equally and similarly affected. For Canada, the following major impacts of climate change have been suggested:

- Higher temperature, on average an increase by 2-5 degrees C
- Increased variability in precipitation and temperatures, along with changing seasonal patterns
- Increased frequency of droughts and floods
- Rise in sea level by up to a meter in some places, leading to inundation of low lands, and intrusion of saline water into freshwater bodies.

In Canada, most of the climate change related research has been on developing mitigation strategies to reduce GHG emissions or on adaptation measures that would be justified under a changed climate. A review of various GHG mitigation measures is provided in AAFC (2000) and in (The) Thomsen Corporation (2000). At the time of writing this report, no study was found in the public arena that has estimated the cost of climate change to Canada.

3.7.3.5 Valuation of Health Impacts

Health impacts from manure management can be classified into two types: Direct impacts from manure through disease incidence and indirectly through degradation in air and water quality. An economic evaluation of these externalities has yet to be conducted, particularly in connection with livestock manure. A partial reason for this is the availability of appropriate information. The most appropriate methodology is the use of a damage function in examining the relationship between human health and exposure to various pollutants. This approach is often referred to as "macroepideminology" (Pearce and Markandya, 1989)[32]. After the

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[30] Athwal, R. K. 1994. Costs and benefits of improving water quality by composting livestock wastes: A co-ntingent valuation approach. M.Sc. thesis. University of British Columbia.

[31] Spasic, L., 2002. *Social Benefits Associated with Riparian Management Practices.* Regina: Saskatchewan Wetland Conservation Corporation.

[32] Pearce, P. and Markandya, A. 1989. *Environmental Policy Benefits: Monetary Valuation.* Paris: Organization for Economic Co-operation and Development.

relationship between the pollutant level (dose) and mortality / morbidity (response) has been estimated, the next step is to value health damages. The most common way to estimate damages is increased expenditures on health care and lost economic opportunity due to poor health and shorter life. However, according to Weersink (1996), this approach is likely to be incomplete and unsatisfactory.

Some progress has been made in the area of macroepidemiology, as Weida (2001) has identified five types of diseases associated with manure:

- Bacterial (Salmonella, Anthrax, Tuberculosis, Brucellosis, Tetanus and Lofiform mastitis)
- Viral (Hog cholera, and Foot and mouth disease)
- Fungal (Ringworm)
- Protozoal (Coccidiosis, and Toxolasmosis), and
- Parasitic (Ascarissis and Sarcocystisis)

During the course of this review no study was found, either in Canada or in U.S., which has estimated the cost of these diseases. Younie et al. (1996), in a study for Ontario, indicate human health improvements may be realized by reducing nitrous oxide concentrations. Nitrite levels also pose threats to human health. However, according to this study, there is little evidence linking the concentration of nitrous oxide in drinking water to stomach cancer.

Examination of disease incidence and the economic cost to human health is generally conducted using the disease domain, rather than a source domain. Such a study for the outbreak of *Salmonella* and *E. Coli*, both of which can be transferred by manure, has been reported by (The) Thomsen Corporation (1998)[33]. In this study *Salmonella* affecting 40 poultry farms created an economic loss of $2.3 million at the farm level, and $4.5 million in terms of human health. It should be noted that the scenarios upon which these estimates were based were not necessarily as a result of a manure issue, but that the diseases are ones for which manure is and can be a common route.

33 The Thomsen Corporation. 1998. "The Current Impact of Possible Animal and Zoonotic Disease Incursion to Canada." and "The Canadian Livestock and Meat Industries and the National Animal Health Program (NAHP) in the 1990's." Prepared for the Canadian Food Inspection Agency, Ottawa.

3.8 Mitigation Measures in the Literature

3.8.1 Overview of Nature of Mitigation Practices

As summarized in Table 10, 70 percent of the studies reviewed suggest some type of mitigation strategy. Most of these studies were limited to one aspect of manure management – manure handling, treatment, storage, and animal feeding and housing. Additionally, 15 of these studies include discussions and/or analyses of public policy measures. More details on the nature of mitigation measures suggested in the studies reviewed are reported in Tables A.13 to A.16 of Appendix A.

Table 10. Summary of Major Types of Mitigation Measures in the Literature

Type of Mitigation Measure	No. Studies, Citations	
	Number	Percent
Animal and Manure Management Technology		
Land application and handling of manure	29	21
Treatment of manure	16	12
Feed (and feeding, nutrient composition)	14	10
Animal building, facility and equipment design, sitting etc.	12	9
Storage of manure	9	7
Combinations of two or more of above	14	10
No Mitigation Measure Identified/Discussed	41	30
Total	**136**	**100**
Mitigation Involving Public Policy (primarily regulation)		
Animal building, facility and equipment design, sitting etc.	9	
Land application and handling of manure	3	
Combinations of two or more of above	3	
Subtotal	15	

3.8.2 Selected Examples of Mitigation Measures

3.8.2.1 Feeding Regimes

Steinfeld, de Haan and Blackburn (1996) suggest technologies that can improve feed conversion, and reduce production costs and the amount of by-products (manure) from animals. One technique is by more precisely determining animal nutrient needs so less manure is produced and fewer nutrients are emitted into the air. Better balancing of feed with essential nutrients can reduce feed protein content and then reduce the excretion of nitrogen and phosphorus. Adding an enzyme, e.g. phytase, can increase digestibility and catalyze the digestion of phosphorus contained in feed. Producers can use feeding systems that decrease intake by moving away from buffet style feeding. A reduction of odor and ammonia loads can be achieved through natural or forced ventilation systems or through bio-filters or bio-washers that absorb odors and ammonia from polluted air.

3.8.2.2 Replacement of Inorganic Nutrients

Taylor and Rickerl (1998) studied cattle feedlot operations. Most of the feedlots examined have other livestock as part of the total operation including slaughter hogs, brood sows, dairy, stocker cattle, sheep, slaughter lambs, broilers, and layers. 78 feedlots in South Dakota were examined. The authors discuss how nutrients affect the soil, and water and plant growth. An example of how excessive manure applications can retard plant growth is described. The following is a chain of events that can occur: build-up of salts in soil; breakdown of soil structure, and reduced soil aeration and water infiltration. Also maximum "environmentally safe" nutrient loadings on farmland depend, among many factors, on site-specific soil N and P levels, soil properties and condition, aquifer depth, distance from surface water, crop nutrient requirements, conservation practices and weather at the time of application. This study suggests that the nutrients in livestock manure can substitute for the nutrients in synthetic fertilizer, and also when managed efficiently will result in crop yields equivalent to those from similar amounts of nutrient in commercial fertilizers. Livestock manure nutrients also contain other macroelements and microelements that can meet important nutrient needs of crops.

3.8.2.3 Composting

Several studies have suggested the use of processed manure or compost, rather than raw manure to crops. Composting can minimize the impact of manure on the environment and the community (Rynk[34], 1989). However, it requires capital expense, equipment, labor, land management attention, but can pay off in improved manure handling and/or revenues from compost sales and services. Janzen et al. (1999) suggest that compost is a way to get nutrients recycled into crop growing regions. Wang and Sparling (1995) found that composting leads to higher net returns to the producer relative to raw manure.

3.8.2.4 Alternative Manure Handling, Storage and Application Systems

De Vos, Weersink and Stonehouse (2003) examined the cost-effectiveness of 81 alternative manure management systems for a swine finishing operation in reducing three pollutants in livestock waste – ammonia, nitrogen and phosphorus. There were some trade-offs between reduction in these pollutants and farmers' economic returns. Optimal strategies for a hog farm with 1,000 hogs per 100-day hog finishing cycle included the following:

- Feed: corn-soybean ration with lysine added
- Housing: solid floors
- Storage of Manure: earthen pits
- Application of manure: irrigation gun

The authors indicate that under these strategies, residues can be reduced by more than half from present levels. Further reduction will require changes in hog numbers to reduce the volume of manure and consequently residual levels.

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[34] Rynk, R., 1989. Composting as a dairy manure management technique. *Dairy Manure Management – Proceedings from the Dairy manure Management Symposium.* Syracuse, New York. February 22-24.

3.8.3 Mitigation through Production of Biogas through Anaerobic Digestion

Two studies look at converting raw manure into biogas using farm level anaerobic digestion. Details on these studies are reported in Tables A.17 to A.20, Appendix A. Such measures control odor, stabilize waste volatility, and convert methane emissions to usable energy. According to CEEDAC (1999), biogas digesters are a source of pollution-free heat and electricity, enriched fertilizer, and waste management. However, Higham (1998) found that such plants are not economically attractive based on economic criteria alone. If, at the same time, environmental benefits are included, the economics improve. Environmental benefits include reduced leaching and run-off resulting in improved water quality, reduced odor and improved air quality, and reduced methane emissions resulting in reduced impacts of climate change.

Three Ontario farms are currently participating in a government-subsidized program to try anaerobic manure digestion to produce methane gas to power an engine to generate electricity (Ontario Farmer, March 11, 2003). One digester in Cambridge is an old or existing one, and public money is going into a new trial to try to make the system work and to try different manures. These trials are part of five Agriculture and Agri-Food Canada demonstration and trial sites across Canada.

3.8.4 Mitigation of Odor Through Shelterbelts

Tyndall and Colletti (2002) recommend the use of shelterbelts to reduce odor from livestock operations. The ability of the shelterbelts to reduce odor is directly related to their ability to reduce particulate matter. The majority of odor compounds (also known as volatile organic compounds or VOC’s) are easily absorbed onto and carried by particulates. Shelterbelts create turbulence at the surface and disrupt the travel of odor plumes. They also reduce wind speed over storage lagoons, which reduces the convection of odorous compounds from the surface and allow for slower release of the plume, which may facilitate dilution.

3.9 Selected Regulations In Canada

As part of this review of literature, some provincial regulations affecting the livestock industry with particular reference to manure management were examined. Many of the regulations have been developed to protect water bodies -- surface and ground water, as well as air quality. A comprehensive review of all provinces' regulations is beyond the scope of this report. Therefore, regulations for the provinces of Alberta, British Columbia, and Ontario are described in this section.

3.9.1 Alberta

Under the Agricultural Operations Practices Act of Alberta, there are regulations that affect livestock producers. These regulations as outlined in Alberta Agriculture, Food and Rural Development (2001a and b) have perhaps been developed to protect water bodies and air quality. Those pertaining to intensive livestock operations (ILO), with special reference to manure storage, include the following:

- Manure storage facilities must be designed and located to minimize odor nuisance and avoid contamination of ground water and surface water. These should not be constructed within 100 meters of any spring or water well and not within 30 meters of any open body of water.
- An operator must have storage volume available for at least nine months to store all of the manure, wash water and water spillage produced by the operation.
- An operator shall provide a run-on control system that prevents the flow of surface water into the storage.
- The operator must also ensure that the run-off from the storage site must not enter an open body of water or leave the owner's property.
- When building an ILO, the operator should avoid sites with porous soils and /or fractured bedrock that would allow contaminants direct access to ground water.
- The operator must prevent the retention of contaminated liquids on the lot surface by providing drainage within the feedlot or animal holding areas.
- The manure run-off from drainage must not enter an open body of water or leave the owner's property.

In addition, to the above, additional regulations include:

- The owner or operator of a CFO (cattle feedlot operation) or manure storage facility must construct a surface water control system for their operation or facility. The system must comply with the following.
  - The system must limit the amount of surface water, run-on and run-off flowing through and from the operation or facility.
  - The system must not considerably alter the volume, quality or rate of water flowing to each location where water naturally discharges from the area where the facility exists.
  - The system also must not alter or affect any non-flowing water body.

There is another section under the above Act that deals with manure application. These regulations include:

- That an operator must not apply manure to land other than arable land, and there must be access to a sufficient amount of land for the application of manure.
- A person must not spread manure on land if the manure cannot be incorporated within 48 hours unless the manure is spread on forage or direct seeded crops and the land is frozen or snow covered.
- An operator is not to apply manure within 10 meters of a common body of water when using subsurface injection.
- An operator is not to apply manure within 30 meters of a water well or common body when applying manure to the surface and incorporating it within 48 hours
- A person who applies liquid manure or catch basin contents has the responsibility to ensure that it does not create a risk to the environment by leaving the land to which it is applied, by entering a common body of water, or by becoming return flow.
- A person must also not apply manure to a crop that is grown for human consumption and intended to be eaten uncooked.

3.9.2 British Columbia

The British Columbia Ministry of Agriculture, Fisheries and Food (1998) has developed the following somewhat similar regulations for manure management. In substance, these regulations, although somewhat more advisory, are very similar to those for the Alberta.

- Maximum benefit is derived from manure when it is spread on the land in spring.
- Beef cattle manure should not be spread within 5 meters of a bank or a slope leading to any watercourse, or within 30 meters of streams flowing into shellfish growing areas or any wells for a domestic water supply.
- Apply manure on a cool day when odor production is lower.

3.9.3 Ontario

The Nutrient Management Act received Royal Assent on June 27, 2002. A series of consultations began in August 2002 to collect input from a variety of stakeholders on draft regulations under the act. Thirty-four information sessions and public consultation meetings were held across the province over the fall and winter. They were conducted in two stages, covering two sets of draft regulations. Hundreds of stakeholders attended and/or participated in the proceedings and Ministers Johns and Stockwell hosted many of them. The ministers also discussed the draft regulations at many other meetings with farm organizations, commodity groups and stakeholder organizations. More than 500 written submissions were received, including those under the Environmental Bill of Rights Registry. As a result of this input, several changes are being proposed to the government's approach to nutrient management in the province. The changes would provide farmers with greater flexibility to comply with standards and maintain the government's key water and environmental protection objectives

The government is proposing to make the following changes regarding the implementation of the regulations under the Nutrient Management Act:

- Making July 1, 2003 the implementation date of the proposed regulations for all new livestock farms and those expanding into and within the large category (more than 300 Nutrient Units). A nutrient unit is the amount of manure that gives the fertilizer replacement value of the lower of 43 kg (95 pounds) of nitrogen or 55 kg (121 pounds) of phosphorus.

- Making 2005 the implementation date for existing large livestock farms (more than 300 Nutrient Units).

- Setting up a provincial advisory committee. It would provide recommendations to the government regarding nutrient management issues. The committee would include farmers, environmental scientists, municipal representatives and others.

- Some of the issues that would be referred to this committee for further examination and recommendations are:
  - When the proposed regulations would apply to all types of farms except new livestock farms, large livestock farms and those expanding into the large livestock category
  - Restrictions regarding the sitting and construction of nutrient storage, as well as manure handling and application near municipal wells
  - Seasonal outdoor feeding area standards
  - Manure storage issues for existing operations
  - Decommissioning of manure storages
  - Nutrient application on tile-drained land
  - Nutrient application on shallow soils
  - Related-related setbacks and standards
  - Winter spreading restrictions for nutrients from the pulp and paper sector
  - Tying the implementation dates of any future regulations, other than for new and expanding livestock farms, to the availability of cost-shared funding.
  - A protocol would be established whereby the Ministry of the Environment would have the ultimate authority to ensure compliance with the regulations through investigations and enforcement.
  - The Ministry of Agriculture and Food would be the first point of contact for on-farm nutrient management issues, including monitoring.

3.9.4 Instruments for Regulations and their Impacts

Many instruments are available to policy makers to protect environmental goods, and thus, reduce the adverse impact of livestock production on externalities. Korevaar (1995) reviewed European polices and experience of intensive livestock operations (livestock and poultry). According to this study, new regulations concerning the handling, application, and storage of manure have been put into effect in many countries. Beside the targets for reducing mineral losses, environmental legislation also include targets for the emission of acidifying substances such as ammonia.

One of the major impacts of regulations on industry is to change its economics. If regulations are not uniform (or standardized) across space (various regions of production), rational producers will move to areas where the cost of doing business is lower, provided that there are no barriers to entry or exit. Izik (2003)[35] has shown that in the U.S., the higher the environmental stringency, the lower is the total number of dairy cows and intensity of dairy production in a county.

Environmental regulations come with a cost to producers. Stonehouse, de Vos and Weersink (2002) have estimated the cost of compliance for ammonia emissions regulations for Ontario farm is $1,700 to 2,000 per annum. Vukina and Woosink (1998) in a Netherlands study found that differing requirements of environmental regulations alter land values. A study of the Agricultural Exemptions Act in Saskatchewan by Knopf (2002)[36] estimated the cost of compliance to be $32,866 per farm, some 36 percent of gross revenue.

3.9.5 Needed Improvements in Regulatory Policies

Improvements and changes in regulation and/or environmental policies have been suggested by various studies. Ikerd (1999) suggests that it does not make sense to apply the same environmental rules to small, diversified family farms as to large, specialized livestock factories, since the environmental risks are not comparable.

Innes (2000) looked at waste storage and the impact of ambient pollution. He suggests taxing producers for external costs created by entry and increases in animal numbers. Implications of this study are that marginal environmental damages rise with the volume of spilled/leaked material because potential health hazards and pollution costs increase as the volume of spilled and leaked waste grows, which causes the capacity of the local environment to absorb a spill to lessen as its volume increases. Increased animal production, even with proper waste-handling, raises environmental costs by increasing the size of potential waste storage spills, raising the level of excess manure application and increasing pollution generally. The author suggests various mitigation strategies that could be implemented to reduce the amount of emissions into the air.

- Tax producers for external costs created by both entry into production and to increases in animal numbers.
- Regulations that limit facility size using direct and unit area specifications. Direct regulation would specify a minimum or maximum facility size. Unit area regulations would limit producers to a certain number of animals depending on the amount of land available for manure spreading.

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35 Izik, M. 2003. Environmental Regulation and the Spatial Structure of the U.S. Dairy Sector. Unpublished paper. Center for Agricultural and Rural Development, Iowa State University, Ames, IA.

36 Knopf, E., 2002. "Public benefit and cost analysis of alterations to intensive livestock operations: Agricu-ltural Operations Act, Saskatchewan case study. Regina.

- Fertilizer tax. "By raising chemical fertilizer prices, a fertilizer tax raises the opportunity cost of excess manure applications, those applications for which fertilizer substitution benefits are low. The tax thereby prompts the facility to lower the extent of excess application close to the facility, where applications are greatest and substitution benefits are smallest, by shifting manure to more distant farmland where applications are smallest and substitution benefits are greatest."

Letson and Gollehon (1998) suggest that a threshold policy targets regions with large numbers of animals rather than specialized animal producers. Technological change likely alters in-region variability in facility scale and slope. The authors conclude that additional spending on manure management does not guarantee that water sources will benefit from it.

Steinfeld, de Haan, and Blackburn (1996) describe the environmental effects of livestock production and who receives the benefit and who incurs the cost, which ties into public goods. The authors state that those who reap the benefits from over-exploitation or from degradation do not pay the full costs, and those who preserve natural resources or who pay the costs of conservation gain few of the benefits. This is what causes a market failure. They suggest that mechanisms to address the underlying causes of environmental degradation are likely to be more effective than those that just address the symptoms. They also suggest that instruments, mechanisms and policies need to be coordinated in order to maximize effectiveness and they must be adjusted over time according to circumstances.

The report suggests several measures including incentives and penalties to those in mixed farming and industrial systems according to nutrient surpluses. A first measure is removal of subsidies on or taxation of imported concentrated feed to reduce significant nutrient transfer. If subsidies are removed then this will encourage producers to use resources more efficiently. A second is incentives to achieve a more balanced distribution of crop and livestock activities. A third is a levy on waste discharge that will encourage producers to adopt low polluting management practices. Another incentive that could be used would be removal of import restrictions on materials and equipment that improve feed efficiency that in turn could lead to less waste.

The authors suggest that zoning is important now and will be in the future for both animal manure and product processing. There are two different approaches that can be taken: intensive production units can be distributed over a wide geographical area to bring the production of waste products in line with the absorptive capacities of the land, or production can be concentrated to benefit from economies of scale in waste treatments.

4. The Canadian Livestock Industry

4.1 Size and Distribution

The following profile of the size and distribution including density of the Canadian livestock population was obtained from Statistics Canada, notably the 1991 and 2001 Census[37], and Beaulieu et al. (2003).

A Note on Methodology and Reporting Format

This methodological description of the animal reporting format used herein has been condensed from Beaulieu et al. (2003). In order to provide a reporting standard and determine livestock density, Beaulieu et al.[38] (2003) used the concept of 'animal units' to create equivalence among different types of livestock. This concept is often used in regulations, codes of practice and municipal by-laws related to livestock production. This concept, originally developed in the United States in the 1960s, is based on the number of animals that are required to produce 73 kilograms of nitrogen to fertilize one acre of corn for one year. The number of animals of a given kind—such as broiler chickens or beef steers—in one animal unit is expressed as a coefficient. One beef cow, for example, equals approximately one animal unit, while four sows or 125 broiler chickens are required for one unit.

Individual totals are calculated at the enumeration area level for total livestock, cattle (beef and dairy), pigs, poultry and other livestock (such as elk, deer, bison and wild boars). Poultry includes birds such as broilers, pullets and pullet chicks, laying hens and turkeys. Less common poultry (such as geese, ducks) and less common birds (such as ostriches, game birds and emus) are included in the 'other' category. In the case of turkeys, inventories are reported without distinction by age or type of production. Turkey animal unit coefficients are adjusted at the provincial level to compensate for the predominance of one type of bird, such as broilers versus heavy-weight broilers.

Livestock density refers to the number of animal units per km^2 (100 hectares) of farmland. Farmland includes all cropland, summerfallow, and improved and unimproved pasture. To calculate the livestock density within each Census Consolidated Subdivision (CCS) in the Prairie Provinces or each Census Division (CD) in the other provinces, the number of animal units was divided by the total farmland area in each CD or CCS.

Regions are typed into 10 classes of livestock densities based on the statistical distribution of the number of animals reported. The 10 were in turn aggregated into 3 classes of low, medium and high density. The lowest density class was defined as less than 25 animal units per square kilometer. Densities of between 25 and 70 animal units per square kilometer were classified as medium density. Areas with a livestock density of more than 70 animal units per square kilometer were designated as high density.

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37 For details see, Statistics Canada, *Census of Agriculture* 1976, 1981, 1986, 1991, 1996, 2001

Statistics Canada, *Food Statistics* 1998, 2001, 2002, Catalogue no. 21-020-XIE

Statistics Canada, *A Geographical Profile of Manure Production in Canada*" Statistics Canada, Catalogue No. 16F0025XIB.

38 Beaulieu, Martin S. 2001. *Intensive Livestock Farming: Does Farm Size Matter?* Agriculture and Rural Working Paper Series Working Paper No. 48, Statistics Canada, Agriculture Division, Ottawa, Ontario

Geographical references assigned to census farms are the addresses of the headquarters. Exact locations of land for pasture, manure disposal, or barn(s) in which the animals are housed do not necessarily match the location of the headquarters. Census Consolidated Subdivisions CCS are used as the geographical scale in the Prairie Provinces. The Census Division (CD) unit is used for the other provinces. The 1991 Census was rebased to 2001 as necessary.

Livestock inventories are as reported by farmers to the Census of Agriculture, and do not represent the number of animals that were on the farm during the whole year. No adjustment was made to estimate average herd size, total livestock production during the year, or number of livestock in confinement (in pens, for example) for the whole year or part of the year.

The Canadian livestock industry is the largest it has been. The Census population of major food livestock is reported in number of animals in Table 11a, and in animal units in Table 11b. Between 1991 and 2001, the total number of animal units in Canada increased 17 percent. The number of cattle increased 20 percent to a record 15.6 million head, mostly due to an expansion in beef cattle. The Census counted 13.9 million hogs in 2001, up 37 percent from 1991; and 126.2 million hens and chickens, up 33 percent from 94.9 million in 1991.

The livestock industry has been undergoing a modest shift from east to west as it grows. Table 12 reports that between 1991 and 2001 the proportion of the Canadian beef herd in Alberta increased from 44 to 48 percent, while it declined an offsetting amount in the eastern provinces and BC. The hog industry expanded, led by Manitoba, such that as of 2001 Manitoba accounted for 19 percent of the hog population up from 13 percent in 1991; while the proportion of hogs in Ontario and Alberta declined from 29 to 26, and 17 to 15 percent respectively, and the proportion in Quebec was steady to up from 28-29 percent. Distribution of the dairy and poultry industries was relatively steady, with a small shift from BC to eastern provinces. “Other” non-major food animals also shifted from east to west, notably from Ontario to Alberta and Saskatchewan.

Table 13 reports the following broad changes between 1991 and 2001 in the distribution of the major food animal population within each province. Broadly over the period 1991 to 2001, Atlantic and BC production shifted from dairy to poultry; Ontario and Quebec shifted from dairy to all other; Manitoba moved away from dairy to pork; Saskatchewan and Alberta experienced a relative increase in “other” livestock; while beef population grew in relative size in Alberta.

4.2 Density

Table 14 reports the distribution of livestock (farms) by density according to the methods used by Beaulieu and Bedard (2003) [39] and Statistics Canada. Nationally, a majority of livestock are located in low and medium density areas, however the proportion of livestock in high density areas has increased. Between 1991 and 2001, the proportion of livestock in higher density areas increased from 13 to 16 percent, while the proportion in lower and medium density areas

[39] Beaulieu, Martin S., and Bédard, Frédéric. 2003 “A Geographic Profile of Canadian Livestock, 1991-2001,” Agriculture and Rural Working Paper Series Working Paper No. 62, Statistics Canada, Agriculture Division Ottawa, Ontario

declined from 45 to 43, and 43 to 41 percent respectively. This trend was marked in Quebec, Manitoba and Alberta. In Quebec, the proportion of livestock in high density areas increased from 33 to 38 percent, while the proportion in medium density areas declined from 64 to 57 percent. Manitoba and Alberta underwent an increase in density from essentially no livestock in high density areas in 1991 to 8 and 12 percent respectively by 2001. Manitoba saw a decline in low-density concentrations, while Alberta medium density area also increased from 41 to 48 percent of all livestock. The Atlantic, Ontario and B.C. differed from the national trend. The Atlantic and B.C. saw a decline in the concentration of livestock in high density areas from 12 to 3, and 37 to 32 percent respectively, as the low density proportion increased from 16 to 27, and 33 to 52 percent. The (distribution) density of Ontario's livestock population remained relatively steady.

Table 11a. Canadian Livestock Population. Number of Animals, Major Types, 1991 and 2001 Census (000 head, birds)									
Livestock	**Year**	**ATL**	**QU**	**ON**	**MB**	**SK**	**AL**	**BC**	**CAN**
Beef Cows	1991	64	187	390	411	898	1,636	243	3,829
	2001	61	208	376	563	1,215	2,099	280	4,802
	% Change	*-4*	*11*	*-4*	*37*	*35*	*28*	*15*	*25*
Dairy Cows	1991	75	515	443	56	45	106	75	1,315
	2001	62	407	364	42	30	84	71	1,061
	% Change	*-17*	*-21*	*-18*	*-24*	*-34*	*-21*	*-5*	*-19*
Heifers & Steers	1991	105	347	847	220	453	1,360	166	3,498
	2001	88	317	782	270	458	2,151	159	4,224
	% Change	*-16*	*-9*	*-8*	*23*	*1*	*58*	*-4*	*21*
Hogs	1991	332	2,909	2,925	1,287	809	1,730	224	10,216
	2001	391	4,267	3,457	2,540	1,110	2,028	166	13,959
	% Change	*18*	*47*	*18*	*97*	*37*	*17*	*-26*	*37*
Hens & Chickens	1991	7,764	23,035	34,059	6,409	3,618	8,702	11,285	94,873
	2001	9,658	29,212	43,625	7,986	4,683	12,175	18,820	126,160
	% Change	*24*	*27*	*28*	*25*	*29*	*40*	*67*	*33*
Turkeys	1991	384	1,713	3,289	792	285	813	801	8,077
	2001	297	1,747	3,403	694	279	864	820	8,116
	% Change	*-23*	*2*	*3*	*-12*	*-2*	*6*	*2*	*0*

Table 11b. Canadian Livestock Population. Animal Units 1991-2001 Census (000)									
Livestock	**Year**	**ATL**	**QU**	**ON**	**MB**	**SK**	**AL**	**BC**	**CAN**
Beef	1991	129	325	926	658	1,452	3,035	402	6,928
	2001	117	375	903	886	1,856	4,249	445	8,831
	% Change	*-9*	*15*	*-2*	*35*	*28*	*40*	*11*	*27*
Dairy	1991	150	989	922	111	89	215	148	2,624
	2001	123	779	767	85	59	171	142	2,126
	% Change	*-18*	*-21*	*-17*	*-23*	*-34*	*-20*	*-4*	*-19*
Hog	1991	34	301	307	134	85	183	24	1,068
	2001	31	332	294	221	81	165	14	1,139
	% Change	*-9*	*10*	*-4*	*65*	*-5*	*-10*	*-42*	*7*
Poultry	1991	47	143	230	48	24	59	74	623
	2001	55	175	282	57	30	78	113	790
	% Change	*17*	*22*	*23*	*19*	*25*	*32*	*53*	*27*
Other	1991	24	63	157	70	89	199	74	676
	2001	25	91	198	114	173	363	105	1,068
	% Change	*4*	*44*	*26*	*63*	*94*	*82*	*42*	*58*
Total	1991	384	1,822	2,541	1,021	1,740	3,691	721	11,920
	2001	352	1,752	2,443	1,363	2,200	5,026	819	13,954
	% Change	*-8*	*-4*	*-4*	*33*	*26*	*36*	*14*	*17*

% Change: Percent change from 1991 to 2001.

Table 12. Distribution of Livestock by Province 1991-2001. Percent Distribution of Animal Units, Major Animal Type

	Beef		Dairy		Hogs		Poultry		Other		Total	
	1991	2001	1991	2001	1991	2001	1991	2001	1991	2001	1991	2001
ATL	2	1	6	6	3	3	8	7	4	2	3	3
QU	5	4	38	37	28	29	23	22	9	9	15	13
ON	13	10	35	36	29	26	37	36	23	19	21	18
MB	10	10	4	4	13	19	8	7	10	11	9	10
SK	21	21	3	3	8	7	4	4	13	16	15	16
AL	44	48	8	8	17	15	10	10	29	34	31	36
BC	6	5	6	7	2	1	12	14	11	10	6	6
CAN	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 13. Distribution of Provincial Livestock Population by Type 1991-2001. Percent Distribution of Animal Units, Major Animal Type

Region	Year	Beef	Dairy	Hog	Poultry	Other	Total
CAN	1991	58	22	9	5	6	100
	2001	63	15	8	6	8	100
ATL	1991	34	39	9	12	6	100
	2001	33	35	9	16	7	100
QU	1991	18	54	17	8	4	100
	2001	21	44	19	10	5	100
ON	1991	36	36	12	9	6	100
	2001	37	31	12	12	8	100
MB	1991	65	11	13	5	7	100
	2001	65	6	16	4	8	100
SK	1991	84	5	5	1	5	100
	2001	84	3	4	1	8	100
AL	1991	82	6	5	2	5	100
	2001	85	3	3	2	7	100
BC	1991	56	21	3	10	10	100
	2001	54	17	2	14	13	100

Table 14. Distribution of Livestock, by Livestock Density, 1991 and 2001						
Region	Year	Livestock Density			Total	
		Low	Medium	High	Percent	000 Animal Units
CAN	1991	45	43	13	100	11,920
	2001	43	41	16	100	13,954
ATL	1991	16	73	12	100	384
	2001	27	71	3	100	352
QU	1991	3	64	33	100	1,822
	2001	5	57	38	100	1,752
ON	1991	4	72	24	100	2,541
	2001	5	71	24	100	2,443
MB	1991	92	8	0	100	1,021
	2001	82	9	8	100	1,363
SK	1991	100	0	0	100	1,740
	2001	99	1	0	100	2,200
AL	1991	59	41	0	100	3,691
	2001	40	48	12	100	5,026
BC	1991	33	30	37	100	721
	2001	52	16	32	100	819

Table 15 highlights changes in the distribution of the livestock population according to the major types of food animals. As reported, a majority of livestock are located in low and medium density areas although the proportion of livestock in high density areas has increased. This increase has been led by beef followed closely by hogs and dairy. Between 1991 and 2001 the proportion of beef animals in high density areas increased from 3 to 9 percent as low density concentration declined from 61 to 55 percent. High-density hog areas increased to include 37 percent of animals in 2001 up from 33 percent in 1991; while high-density dairy concentration increased from 24 to 28 percent. Medium and high density poultry areas increased modestly.

Table 16 reports 30 regions of the country with the greatest livestock density as of the 2001 Census ranked according to density measured in Animal Units per km^2. Table 17 reports 30 regions of the country with the largest livestock population (irrespective of density). Notable is that only seven of these regions are also amongst the mostly densely concentrated or populated areas. This, combined with related data, prompted Beaulieu et al. (2003) to observe “livestock concentration is not necessarily due solely to larger livestock populations. Some high-density areas appear to be the result of limited numbers of livestock located on a small farmland base. Livestock concentrations are declining in some high-density areas. Of the 30 regions in Canada with the highest livestock densities, 18 were in Quebec. Ten of those in Quebec reported declines in livestock densities over the past 10 years. Concentrations in any given area are related partially to the capacity of the resource base in that area, both the land and water, to sustain more livestock.”

Table 15. Distribution of Livestock, by Type and Livestock Density, 1991 and 2001						
Livestock Type	**Census Year**	**Livestock Density**			**Total**	
		Low	**Medium**	**High**	**Percent**	**000 Animal Units**
All types	1991	45	43	13	100	11,920
	2001	43	41	16	100	13,954
Beef	1991	61	35	3	100	6,928
	2001	55	36	9	100	8,831
Dairy	1991	13	64	24	100	2,624
	2001	11	61	28	100	2,126
Hogs	1991	30	36	33	100	1,068
	2001	27	36	37	100	1,139
Poultry	1991	17	43	40	100	623
	2001	14	45	41	100	790
Other	1991	47	43	11	100	676
	2001	48	42	10	100	1,068

4.3 Productivity

Alongside growth and changes in the geographical and structural distribution, productivity of the livestock industry has also been increasing. Table 18 reports some basic, aggregate productivity indicators for selected livestock. Perhaps most notable is the increase in dairy productivity. For example, from 1976 to 2001 dairy productivity measured in milk produced per cow increased a total of 105 percent, or at an average annual compound rate of 2.9 percent. Hog productivity measured in terms of pork produced per sow improved at an average annual compound rate of 0.9 percent for a total of 26 percent. Beef productivity measured in terms of beef per beef cow improved at an average annual rate of .2 percent or a total of 4.2 percent. When beef productivity is measured relative to the entire cow herd (beef and dairy cows), productivity is observed to have improved at an annual rate of 0.8 percent or a total of 23 percent between 1976 and 2001. In addition to generally positive implications for the overall performance and competitiveness of the industry, these productivity improvements also translate into greater output/manure efficiency. More precisely, for a fixed amount of manure per animal, the amount of final food product produced per unit of manure generated has also been increasing.

Table 16. Regions with Greatest Livestock Density, 2001								
Rank	Region	Animals in 2001		Farm area		Livestock Density		
		Animal Units (AU)	Share %	km^2	%	1991	2001	difference
	Canada	13,954,500	100.0	674,800	100.0	AU/km^2		
1	B.C. Fraser Valley R.D.	177,500	1.3	490	0.1	304	365	61
2	B.C. Greater Vancouver R.D.	71,500	0.5	390	0.1	179	183	4
3	Quebec La Nouvelle-Beauce	80,800	0.6	510	0.1	162	157	-5
4	N.S. Digby County	7,300	0.1	50	0.0	77	145	68
5	Alberta Lethbridge County	427,000	3.1	2,980	0.4	62	143	82
6	Manitoba La Broquerie	38,300	0.3	300	0.0	39	129	90
7	Quebec Matawinie	19,500	0.1	150	0.0	135	126	-9
8	Ontario Waterloo R.M.	113,800	0.8	910	0.1	122	125	2
9	Quebec Desjardins	14,200	0.1	120	0.0	97	118	22
10	B.C. Cowichan Valley R.D.	14,400	0.1	130	0.0	84	107	22
11	Manitoba Hanover	76,100	0.5	720	0.1	62	106	44
12	Quebec La Haute-Yamaska	34,600	0.2	370	0.1	95	94	-1
13	Quebec Acton	35,200	0.3	380	0.1	90	92	3
14	Quebec Rouville	32,900	0.2	360	0.1	91	91	0
15	Quebec La Jacques-Cartier	3,900	0.0	40	0.0	125	88	-37
16	Ontario Perth County	177,400	1.3	2,040	0.3	80	87	7
17	Quebec Bellechasse	64,800	0.5	750	0.1	98	87	-11
18	Quebec Iles-de-la-Madeleine	500	0.0	10	0.0	155	86	-69
19	Ontario Wellington County	161,000	1.2	1,910	0.3	81	84	3
20	Quebec Lotbiniere	63,200	0.5	800	0.1	80	79	-1
21	Quebec Drummond	66,900	0.5	850	0.1	72	79	7
22	Quebec Maskinonge	31,400	0.2	400	0.1	79	78	-1
23	Ontario Oxford County	139,800	1.0	1,800	0.3	72	78	6
24	Quebec Les Maskoutains	87,700	0.6	1,130	0.2	82	77	-4
25	Quebec Charlevoix-Est	7,400	0.1	100	0.0	60	77	17
26	Quebec Brome-Missisquoi	55,500	0.4	720	0.1	63	77	14
27	Quebec Robert-Cliche	28,500	0.2	370	0.1	66	77	11
28	Quebec Francheville	32,200	0.2	420	0.1	62	76	14
29	Quebec Charlevoix	8,400	0.1	110	0.0	76	73	-2
30	Alberta Ponoka County	195,500	1.4	2,700	0.4	47	72	25

Note: Due to rounding, figures may not add up to totals.
Source: Statistics Canada, derived from the 1991 and 2001 Censuses of Agriculture

Table 17. Regions With Greatest Number of Animal Units, 2001								
Rank	**Region**	**Animals in 2001**		**Farm area**		**Livestock Density**		
		Animal Units (AU)	**Share %**	**km²**	**%**	**1991**	**2001**	**difference**
	Canada	13,954,500	100	674,800	100	**AU/km²**		
1	Alberta Lethbridge County	427,000	3.1	2,980	0.4	62	143	82
2	Ontario Huron County	204,100	1.5	2,910	0.4	57	70	13
3	Alberta Newell County No. 4	196,200	1.4	5,900	0.9	20	33	13
4	Alberta Ponoka County	195,500	1.4	2,700	0.4	47	72	25
5	Alberta Red Deer County	188,300	1.3	3,980	0.6	34	47	13
6	B.C. Fraser Valley R.D.	177,500	1.3	490	0.1	304	365	61
7	Ontario Perth County	177,400	1.3	2,040	0.3	80	87	7
8	Alberta Foothills No. 31	163,400	1.2	3,730	0.6	24	44	20
9	Ontario Wellington County	161,000	1.2	1,910	0.3	81	84	3
10	Alberta Wheatland County	156,900	1.1	4,520	0.7	23	35	11
11	Ontario Bruce County	155,600	1.1	2,470	0.4	63	63	0
12	Alberta Willow Creek No. 26	139,800	1.0	4,470	0.7	22	31	9
13	Ontario Oxford County	139,800	1.0	1,800	0.3	72	78	6
14	Alberta Mountain View County	137,400	1.0	3,880	0.6	32	35	4
15	Alberta Rocky View No. 44	126,800	0.9	4,340	0.6	26	29	4
16	Ontario Grey County	125,900	0.9	2,400	0.4	54	52	-1
17	Alberta Vermilion River C. No.24	125,800	0.9	5,690	0.8	17	22	5
18	Alberta Lacombe County	125,700	0.9	2,780	0.4	38	45	8
19	Alberta Special Area No. 2	120,700	0.9	8,320	1.2	9	15	5
20	B.C. Peace River R.D.	115,100	0.8	8,630	1.3	10	13	3
21	Ontario Waterloo R.M.	113,800	0.8	910	0.1	122	125	2
22	Alberta Taber	112,800	0.8	4,060	0.6	14	28	13
23	Ontario Middlesex County	112,600	0.8	2,510	0.4	48	45	-3
24	Alberta Cypress County	103,000	0.7	10,080	1.5	9	10	2
25	B.C. Cariboo Regional District	99,700	0.7	4,000	0.6	26	25	-1
26	Alberta Stettler County No. 6	99,400	0.7	3,890	0.6	20	26	6
27	Alberta Wetaskiwin County No. 10	99,300	0.7	2,780	0.4	35	36	1
28	Alberta Clearwater County	96,200	0.7	3,230	0.5	33	30	-3
29	B.C. Thompson-Nicola R.D.	92,800	0.7	3,810	0.6	21	24	3
30	Ontario Stormont, Dundas and Glengarry United Counties	92,000	0.7	2,010	0.3	55	46	-9

Note: Due to rounding, figures may not add up to totals.
Source: Statistics Canada, derived from the 1991 and 2001 Censuses of Agriculture

Table 18. Aggregate Livestock Productivity Indicators, Selected Livestock 1976-2002

Year	Aggregate Productivity Indicator				Production			Livestock Population[3]		
	Beef Prod. / Beef Cow	Beef Prod./(Beef & Dairy Cow)	Milk Sales / Dairy Cow	Pork Prod. / Sow	Beef Prod.[1]	Pork Prod[1]	Milk Sold off Farm[2]	Dairy Cows	Beef Cows	Sows & Gilts[4]
	kg/cow		litres/cow	kg /sow	000 tonnes		million litres	000 head		
1970	250.90	146.26			804.8	745.7		2,295.0	3,207.7	
1971	244.43	149.44		1,031.4	844.1	813.2		2,195.0	3,453.5	788.4
1972	235.23	149.61		1,091.3	885.8	787.1		2,155.0	3,765.7	721.2
1973	#N/A	#N/A		1,112.1	874.6	763.4		#N/A	#N/A	686.4
1974	221.20	147.65		1,296.4	918.4	767.2		2,068.0	4,152.0	591.8
1975	230.37	158.37		1,135.2	1,034.8	654.7		2,042.0	4,491.7	576.7
1976	252.63	173.08	3,379	959.7	1,111.9	596.2	6,835.5	2,023.0	4,401.3	621.2
1977	280.69	186.20	3,538	892.0	1,092.1	626.0	6,984.8	1,974.4	3,890.8	701.8
1978	280.52	184.26	3,602	817.3	1,024.0	721.9	6,868.0	1,906.9	3,650.3	883.3
1979	265.02	173.55	3,780	817.3	917.9	880.8	6,899.4	1,825.4	3,463.3	1,077.7
1980	271.17	179.34	4,055	958.6	938.8	1,023.8	7,187.4	1,772.6	3,462.0	1,068.0
1981	282.16	186.99	4,153	944.3	978.2	1,015.2	7,328.2	1,764.4	3,466.7	1,075.1
1982	282.00	186.91	4,259	975.8	986.5	1,005.9	7,580.4	1,779.8	3,498.2	1,030.9
1983	289.40	192.14	4,166	958.0	992.8	1,029.6	7,233.8	1,736.4	3,430.4	1,074.7
1984	280.97	187.64	4,447	968.6	948.4	1,043.8	7,467.0	1,679.0	3,375.5	1,077.6
1985	300.23	201.07	4,488	1,073.5	985.3	1,088.4	7,263.5	1,618.4	3,281.7	1,013.9
1986	309.81	208.40	4,721	1,091.7	985.2	1,093.9	7,305.2	1,547.4	3,179.9	1,002.0
1987	290.94	199.74	5,150	1,044.5	913.0	1,121.8	7,377.9	1,432.7	3,138.0	1,074.0
1988	278.50	194.42	5,403	1,076.5	906.9	1,181.6	7,607.8	1,408.1	3,256.3	1,097.7
1989	270.39	191.10	5,285	1,136.8	908.4	1,177.2	7,366.9	1,394.0	3,359.6	1,035.5
1990	246.59	176.81	5,350	1,113.1	857.9	1,123.9	7,345.5	1,373.1	3,479.2	1,009.7
1991	227.51	166.40	5,473	1,039.1	822.8	1,096.2	7,268.7	1,328.1	3,616.5	1,055.0
1992	226.01	168.87	5,383	1,110.6	856.7	1,207.7	6,903.4	1,282.5	3,790.3	1,087.4
1993	210.20	160.15	5,553	1,108.3	822.3	1,194.3	6,789.0	1,222.5	3,912.0	1,077.6
1994	216.42	165.55	5,751	1,102.5	861.9	1,229.4	7,036.3	1,223.5	3,982.4	1,115.1
1995	208.84	161.54	5,781	1,136.5	887.9	1,275.8	7,197.1	1,244.9	4,251.6	1,122.5
1996	222.79	173.73	5,797	1,077.4	976.1	1,227.8	7,172.2	1,237.2	4,381.3	1,139.6
1997	238.72	186.41	6,028	1,061.0	1,047.3	1,256.7	7,421.4	1,231.1	4,387.4	1,184.4
1998	261.53	205.69	6,352	1,100.1	1,140.6	1,393.6	7,521.0	1,184.0	4,361.3	1,266.8
1999	278.75	220.58	6,561	1,222.9	1,222.7	1,563.9	7,589.5	1,156.7	4,386.4	1,278.8
2000	274.77	220.19	6,796	1,228.6	1,223.3	1,640.0	7,498.6	1,103.4	4,452.1	1,334.8
2001	263.22	212.78	6,930	1,206.6	1,211.4	1,731.3	7,560.5	1,091.0	4,602.2	1,434.8
2002			6,809	1,243.7		1,854.1	7,379.9	1,083.9	4,636.0	1,490.8
Percent Change 1976-2001 (%)										
	4.2	22.9	105.1	25.7	9.0	190.4	10.6	-46.1	4.6	131.0
Average Annual Compound Percent Change (%)										
71-81	1.4	2.3		-0.9	1.5	2.2		-2.2	0.0	3.2
76-81	2.2	1.6	4.2	-0.3	-2.5	11.2	1.4	-2.7	-4.7	11.6
81-91	-2.1	-1.2	2.8	1.0	-1.7	0.8	-0.1	-2.8	0.4	-0.2
91-01	1.5	2.5	2.4	1.5	3.9	4.7	0.4	-1.9	2.4	3.1
76-01	0.2	0.8	2.9	0.9	1.2	2.6		-2.3	1.0	2.0

Sources: [1] Food Consumption in Canada, Supply and Disposition of Meats, Statistics Canada. [2] Dairy production statistics, Statistics Canada; Dairy Market Review. [3] Respective livestock inventory and/or survey, Statistics Canada. [4] Sows and gilts 6 months and older on July 1.

4.4 Estimated Manure Production

Livestock manure has both environmental benefits and drawbacks. Manure can be a valuable fertilizer for crop production. Incorporation of organic matter from animal waste can substantially reduce soil erosion and improve soil water holding capacity. Livestock manure also contains a variety of substances that can negatively affect the environment.

The major components of livestock manure include nitrogen, phosphorus, potassium, calcium, sodium, sulphur, lead, chloride, carbon and various types of bacteria. Using data from the 1996 Census, Statistics Canada estimated manure production from livestock including some of these major components and on a geographic basis ("A Geographical Profile of Manure Production in Canada, Statistics Canada – Catalogue No. 16F0025XIB."). Table 19 presents a summary of the estimated quantity of manure, major components and livestock sources.

Table 19. Estimated Manure Production From Livestock, Major Components and Livestock Source. 1996

Manure and Component	Unit	Beef Cattle	Dairy Cows	Hogs	Calves	Poultry	Horses	Sheep	Total
	thousand tonnes/year	**Percent Distribution**							
Manure	132,000	52	19	16	7	3	3	<1	100%
Nitrogen	783	51	16	16	5	7	3	<1	100%
Phosphorus	214	51	13	21	5	8	2	<1	100%
	Quintillion Colonies/day	**Percent Distribution**							
Total coliform bacteria	12	17	70	2	2	1	8	<1	100%
Fecal coliform bacteria	1.3	71	10	10	7	1	<1	1	100%

Detailed geographic estimation of manure production by Statistics Canada identified five major clusters where manure production was greatest or concentrated at over 2,000 kilograms of manure per hectare of total land. These clusters are located in central and southern Alberta, southern Manitoba, southern Ontario, southeastern Quebec and Prince Edward Island. Sub-sub-basins with notable and high manure concentration include the west Fraser River area in southern British Columbia; a sub-sub-basin near Wolfville and Kentville, Nova Scotia; Maitland sub-sub-basin, east of Lake Huron; Upper Thames, Ontario; Yamaska (Quebec) and Grand, Ontario.

Methodology and Data Sources for Manure Estimation

Statistics Canada estimated manure production by multiplying the 1996 Census of Agriculture livestock populations by enumeration area daily manure quantity coefficients derived from the 1997 American Society of Agricultural Engineers (ASAE) Manure Production and Characteristics Standard. Data were aggregated to the sub-sub-basin level, normalized by sub-sub-basin area, and then mapped.

The geographic unit used to present this analysis is the sub-sub drainage basin from Environment Canada's 1986 hydrometric map series. For estimation purposes, total manure was considered to consist of feces and urine. Bedding and other types of material such as feathers, unused feed, etc. were not included in the calculations. Nitrogen is Total Kjeldahl Nitrogen (TKN), which consists of total organic and total ammonia nitrogen. Phosphorus calculations are based on coefficients representing "total phosphorus." Annual estimates were derived by projecting the 1996 Census livestock population over the year, and therefore may be inaccurate to the extent that actual livestock populations fluctuated over the course of the year.

5. Summary and Conclusions

As of 2001, the Census of Agriculture reports the livestock industry in Canada is the largest it has been. Between 1991 and 2001, the total number of animal units increased by 17% with the largest increase (37%) in the number of hogs. The industry is present in all provinces, and is undergoing a modest shift from east to west. For example, the proportion of the national beef herd has increased in Alberta, and decreased in Ontario and Quebec. Similarly, the proportion of hogs in Manitoba has increased relative to Ontario over the most recent decade.

Livestock production is coming into more public scrutiny because of its possible effects on the environment. Non-point source pollution from manure in fields, and from intensive livestock operations have been identified as major sources of contamination in surface and ground water. Some health issues are also related to indoor and ambient air quality, which could be negatively affected by odors from swine production. With climate change in public debate, the emission of greenhouse gases (such as methane and nitrous oxide) has also become a matter of concern. Thus, evaluation of agricultural management practices has become a key component of strategies for achieving sustainable agricultural development and mitigating harmful environmental impacts.

In order to develop a better understanding of environmental impacts, information is needed on benefits and costs of undertaking mitigation measures to reduce harmful environmental impacts. Since producers understand the cost to their farm business, what is missing is the cost to society – a concept called economic value of externalities. This study was undertaken to provide a review of the available literature concerning externalities associated with livestock production including, where available, estimates of their economic value.

5.1 Approach to Literature Review

The literature concerning externality measurement was categorized according to four major subject areas. These include manure handling and application; manure storage; livestock feeding including confined livestock systems; and transformation of livestock by-products. Of the total citations reviewed for this report, 42 percent are primarily concerned with manure handling and application, 23 percent livestock feeding and confinement, and 16 percent with manure storage. A fifth or about 20 percent of the available literature is either general in nature or involves multiple pathways such that they were not classified according to the major categories. Manure handling has the greatest number of Canadian studies, followed by manure storage, general studies, and livestock feeding and confinement.

5.2 Summary of Literature Search

A literature search was conducted to review the current state of measurement of externalities associated with Canadian livestock production and related activity. A total of 104 citations (based on 82 studies) were found that suggest some relationship between livestock production and selected externalities. However, economic assessment of externalities of livestock production in Canada (or to a major extent, elsewhere in the world) was found to be somewhat of a rarity. While many studies do make a qualitative or descriptive reference to livestock externalities, even in various models developed for integrated assessment, quantitative and monetary estimation of these impacts is either weak or missing. Of the studies reviewed, only one attempts to develop a comprehensive set of values of these impacts. Two U.S. studies also attempt to estimate the effect of livestock production (hogs) on land and other property values. Economic costs due to air quality or water quality are not common; neither are studies of impact on human health. Diseases associated with livestock manure are identified, but their frequency and incidence remains to be ascertained.

Agriculture in general and livestock agriculture in particular is multifunctional, interacting with the natural and economic environment in a variety of ways. However, current literature tends to address only one aspect of this multifunctionality and its environmental implications at a time.

Estimation of damage by livestock production is problematic because of the uncertain relationship between potential pollutants applied to field and the actual transport of these pollutants to a site where an environmental damage can occur. Such uncertainties also create problems in developing proper regulations.

The cost of ignoring externalities of livestock production can also be high. For example, experiences similar to that of poor water quality at Walkerton, Ontario, can become a major social problem, sometimes with a large legal liability. The immediate effect of water contamination is increased mortality of humans, and animals, and/or increased incidence of water-borne diseases. Tangible costs to society from any future water contamination similar in magnitude to that experienced at Walkerton are estimated at $64.5 million.

However, as concerns livestock, manure and water, an earlier assessment observed that additional spending on manure management does not guarantee water quality benefits, since it is only one of several linkages, and is very site and cultural practice specific "… we need to know more about manure application methods, soil mobility, crops grown, rainfall events, proximity to surface water, depth of water table, water uses, and the contributions of other sources of minerals."

As concerns the economic valuation or quantification of externalities, an observation made in 1996 continues to be largely true today. Weersink (1996) reviewed livestock production related externalities, and concluded, "At the present time there are no studies using any of the approaches that have examined the economic value of environmental damages caused by manure pollution. There are a few related studies that have determined that households would be willing to pay from $50 to $1,150 annually to lower nitrates in groundwater. However, no study has examined total impacts from manure which has a host of pollutants (nitrates, phosphorus, and odors) and a number of effects on the natural resource systems." Even before this, Goss et al. (1993), while reviewing the state of the art in livestock production and future research needs, identified need for more economic research.

When it comes to measurement of livestock and air externalities, the quantitative description of odors is a task yet to be accomplished. At most, descriptive measures such as the number of complaints or individuals signing a petition for granting a license for such operations has been used as a surrogate measure of odor problems. The air quality valuation work that has been undertaken has been largely in the context of smog, ozone concentration, pesticide residues, and other air-borne diseases.

Examination of disease incidence and the economic cost to human health is generally conducted using the disease rather than a source domain. Diseases associated with livestock, particularly livestock manure have been identified but an economic evaluation has not been conducted. Five types of diseases associated with manure include bacterial (Salmonella, Anthrax, Tuberculosis, Brucellosis, Tetanus and Lofiform mastitis); viral (Hog cholera, and Foot and mouth disease); fungal (Ringworm); protozoal (Coccidiosis, and Toxolasmosis), and parasitic (Ascarissis and Sarcocystisis). By way of an indirect example, a 1998 assessment of the economic impact of zoonotic diseases considered a case of salmonella affecting 40 poultry farms and was estimated to result in economic loss of $2.3 million at the farm level, and $4.5 million in terms of human health.

5.3 Observations on Pathways to Environmental Impacts

The literature provides a range of mixed options for manure storage. For example, various investigations including work done as background to climate change and greenhouse gas mitigation advocate covering stored manure to reduce methane emissions and odor. On the other hand, other work indicates that open storage including lagoon and open silo storage are the most cost effective while at the same time not without potential environmental benefit depending on their integration with other handling components.

Agricultural research has long been concerned with optimizing livestock rations. When applied to environmental including climate change considerations, the available evidence recommends the addition of phytase and synthetic amino acids to livestock diets; measures to incorporate optimum levels of nitrogen and essential nutrients; and multi-phase feeding and more closely timing feeding to animal needs.

Intensive livestock operations have also been a subject of many studies, particularly in terms of their environmental impacts and social acceptability. Unfortunately, despite numerous impressions and opinions, none of the available literature provides systematic and quantitative evidence of their negative impact. Statistics Canada analysis of the geographic location and concentration of livestock using current Census data concluded that the available evidence does not support the notion that large livestock farms are solely responsible for high livestock densities. High livestock concentration is not always related to large livestock farms. For example, in Alberta high-density areas, most of the livestock are on very large intensive farms while, in Quebec and Ontario, they are on relatively smaller less intensive farms. The cumulative impact of several non-intensive small farms may be comparable to the impact of a few large intensive farms. Additional research is required to determine whether livestock concentration in certain regions of Canada has reached limits where it could pose an ecological threat. This requires establishing regional nutrient budgets based on manure produced, farmland available for manure disposal, soil characteristics, crop requirements, and use of chemical fertilizer and municipal sewage sludge to identify areas where the environment might be at risk from a lack of sufficient land to recycle animal waste.

Several current Canadian and other studies indicate that care for the environment can only be achieved at some cost to farm business profitability. Environmental regulations come with a cost to producers. For example, a 2002 estimate of the cost of compliance for ammonia emissions regulations for Ontario farm at $1,700 to 2,000 per annum. A study of compliance cost of the Agricultural Exemptions Act in Saskatchewan was estimated to be $32,866 per farm, some 36 percent of gross revenue. A 1998 Netherlands study found that differing requirements of environmental regulations alter land values.

Few Canadian studies estimate on-farm costs and benefits from manure management options. Based on the available studies, two major observations can be made. Firstly, equipment operating costs are a major portion of total costs. Secondly, and perhaps most importantly, cost estimates are highly variable from one study to another indicating that on-farm economics are very site and application specific.

The available evidence indicates some potential to increase the use of composted manure directly and/or in substitution for chemical fertilizer. Analysis of the Canadian situation suggests that from an economic perspective, compost can viably replace chemical fertilizer at least to the point where compost distribution costs equal the value of crop response to the compost. This viability varies geographically, with some areas requiring distribution of compost beyond immediate livestock areas. However, federal and provincial (including local governments) regulation may pose potential barriers[40] to this alternative if they require the compost to be treated as a fertilizer product, thereby leading to its processing and distribution to be treated as an enterprise separate from the farm enterprise.

The review uncovered two studies that look at converting raw manure into biogas using farm level anaerobic digestion. This active management of the normal progression of livestock by-products from excretion to field application provides transformed products in the form of methane for co-generation of power and nutrients in a form where they may compete more directly with conventional fertilizer materials. While such measures offer potential to control odor, stabilize waste volatility, and convert methane emissions to usable energy, the available evidence is that such installations are not economically attractive to the individual farm operator based on economic criteria alone. If the cost of potential negative externalities without active management and livestock by-product transformation and the value of environmental benefits from such proactive management are included, the economics improve.

5.4 Conclusions and Recommendations

Policy makers, livestock producers and the general public need to have a balanced view of livestock production in Canada and its economic and environmental impact. The economic impact or contribution of livestock production is reasonably well understood for most regions of Canada, but such is not the case for environmental services including beneficial and damaging externalities of livestock production. Based on the review of the literature, there is need for two parallel studies for various regions of Canada, which would assist development of a proper policy framework for livestock production in Canada. The first study needs to be focused on

[40] This statement needs to be treated as a hypothesis. Further work is needed to investigate various regulations in Canada (federal, provincial and municipal) where such processing of manure may be hampered.

valuation of externalities along with impacts on producers, while the second study needs to review existing policies and regulations that impede the process of adoption of beneficial management practices. Both of these studies are described below.

5.4.1 Comprehensive Valuation of Impacts of Livestock Production

A major study of valuation of livestock production impacts from a societal point of view is warranted. The appropriate framework to follow is a comprehensive social benefit-cost analysis. Completion of this analysis requires four types of information:

1. An assessment of management options (Combination of manure handling, storage and application, and transformation) including base (or status quo);
2. An examination of environmental risks under each option;
3. Estimation of potential economic benefits (costs) to producers and society; and
4. Estimation of potential environmental benefits from adoption of the option or damage under status quo.

Although there have been several studies identifying impacts of livestock production on environmental goods in physical terms, their valuation has not been attempted. Benefit-cost analysis must recognize the value of the environment. Financial balance needs to be determined from both the perspective of the individual farm operator, and the perspective of society as a whole.

During the course of this study, one needs to establish the linkages between various types of livestock management activity and the resulting change in social welfare function. Such a study should ideally be undertaken by a team of interdisciplinary scientists, including physical scientists representing expertise related to the different natural ecosystems along with social scientists (economists and sociologists). These studies need to focus on a detailed examination of three potential mitigation measures: composting; generation of biogas; and the use of shelterbelts and other plants in and around livestock operations.

The recommended analysis can be sub-divided into the following components:

Component One: Development of baseline profile for the livestock industry and manure handling, storage and application options

This component will contain a number of activities. These may include the following at a minimum:

(1) At the outset, further analysis of Statistics Canada data on trends and concentration of livestock production in Canada needs to be undertaken. This analysis should lead to two types of information:

- Identification of appropriate regions of analysis for the study;
- Areas of concentration, making them candidates for further analysis of environmental damage.

(2) Links between livestock production and water quality needs to be followed using a water (river) basin level of analysis. Furthermore, in some regions, even a sub-sub-river basin approach may be more suitable. The use of basins is recommended for analysis as they enable incorporation of fixed physical and land features rather than political or administrative boundaries. The sub-sub-basin[41] framework is important as it provides localized information and the relationship between manure and water quality issues.

(3) Whereas the basin approach is recommended particularly for water issues, additional work should determine its appropriateness for air quality issues. Air patterns can differ from water patterns such that an alternative geographic framework overlaid the basin framework may be recommended.

(4) Analysis of the Farm Environmental Management Survey FEMS (2002)[42] and similar data for the adoption of various options. This analysis will be helpful in selecting potential manure management options for the study.

(5) Review of management options not only in Canada and U.S., but also in Europe, as a guide to this investigation.

Component Two: Identification of potential mitigation measures

Selection of appropriate mitigation options should be both comprehensive and current. This suggests the need for continual updating, particularly as new options emerge. This component could concentrate on "active mitigation measures" including composting, anaerobic digestion and associated biogas production; in contrast to more passive measures such as manure storage and crop nutrient management.

Component Three: Estimation of on-farm economics

Although considerable work has been done in the area of on-farm manure handling costs, such cost estimates need to be continually updated as new systems emerge. Surveys of practicing farmers should be conducted to reveal the type of manure handling systems in use, problems faced with their use, their effectiveness on various types and sizes of farms, and farm information needs. There is a need for a comparable (in terms of estimation methodology) set of costs for various regions in Canada.

Development of information on manure handling can be done using benchmark models for selected livestock operations. Ideally such models should be built for representative ecoregions (and / or river basins) and types of operation. Sensitivity of the ecology of the region should be a prime requirement for defining the boundaries of such a region.

41 A sub-sub-basin is a smaller region served by a tributary of the river that makes the river basin.

42 For details see, A*griculture and Agri-Food Canada and Statistics Canada. 2002.* Farm Environmental Management Survey (FEMS). *Ottawa,*

A study of on-farm economic benefits of manure application would require an interdisciplinary team of scientists involving economists, agronomists, soil scientists, and biologists, among others. Focus of these studies to be on providing improved data on plant nutrient retention / loss rates and availability, as well as alternative ways for plants to handle manure.

Studies on economic hauling distance and form for manure in various parts of Canada needs further investigation. So far these studies have been made for Alberta, and in a limited sense, for Saskatchewan. Comparable studies (in terms of method of estimation) are required for all regions of Canada.

Component Four: Measurement of the physical impact of manure management options on environmental goods

There is a need for more intensive, longer term research into alternative manure handling systems that could establish more accurate data on nutrient and organic matter retention rates, surface and groundwater leaching rates, and other impacts on off-farm economics for the various regions of Canada.

Component Five: Economic valuation of damages (benefits) of environmental goods

Valuation of resource services particularly as applied to the livestock industry should build on existing livestock density and geographical identification work such as that done by Statistics Canada. This could entail establishing regional nutrient budgets based on manure produced, farmland available for manure utilization, soil characteristics, crop requirements, and use of chemical fertilizer and municipal sewage sludge overlaid against other factors, such as soil type, climate, precipitation, topography and manure management practices to identify areas where the environment might be at risk from a lack of sufficient land to recycle animal waste.

Component Six: Benefit-cost analysis

As outlined, estimation and analysis of the economic and environmental costs and benefits of livestock production remains to be done on a comprehensive and systematic basis for Canada. Such an exercise is strongly recommended to allow public policy decisions to be made on the fullest information possible. This work should incorporate the following major steps and components:

- Impact analysis (and public debate) should be organized according to natural geographic patterns such as those inherent in the basin (or sub-basin) approach incorporating a similarly best basis for air quality considerations.

- Analysis should be holistic simultaneously incorporating economic and environmental (including human health) considerations and clearly establishing relationships and trade-offs between the two.

- Analysis should begin with whole farm, expand to regional assessments where the regions are defined according to geographic (water and air) patterns, and ultimately national analysis.

5.4.2 Review of Public Policy and Regulations

The second study will complement the above study by investigating the policy and regulation of Canada under various jurisdictions (federal, provincial, municipal and territorial governments). This would entail the following activities:

(1) Compilation of various policies and regulations that directly or indirectly affect livestock production.

(2) Identification of factors affecting producers' adoption of management options. For Canada, such studies are rare and should be encouraged. This type of information provides useful feedback to policy makers on the effectiveness of measures. It also indicates impediments to adoption that could be modified either through additional or alternative measures.

(3) An evaluation of the policies (under 1 above) and regulations that act as a (dis)incentive for the adoption of better manure handling systems. For example, regulations that selectively define manure nutrients as pollutants discourage development of their use and thus markets. Producers will steer away from using manure when commercial fertilizers are not defined as pollutants.

(4) Development of more livestock production and environment friendly policies and regulations for various regions of Canada. Included in this group may be (among others) activities that recycle nutrients. Such measures would create a 'real market value' to livestock manure and its products by creating a demand for them.

Public policy requires a comprehensive assessment taking into consideration traditionally disjoint components including all relevant federal, provincial and municipal policies, programs and regulations to ensure their consistency. This should include a comprehensive assessment of the costs and benefits of farm and enterprise compliance with public policy to ensure measures are realizable and consistent.

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7. Appendix A. Details of Studies Reviewed

This appendix presents details on the studies reviewed to this report. It is a brief summary of selected highlights of these studies, where the selection bias is largely driven by the fact that this review was conducted from the point of view of mitigation measures and valuation of externalities of livestock operations. The studies were examined for the following four characteristics:

One, Location and salient features of the study.

Two, Nature of the externalities identified and / or values.

Three, Economic Impacts of status quo situation, and

Four, Impacts on externalities under selected mitigation measures.

Each of these characteristics were examined by dividing the studies into four major categories:

One, General Studies

Two, Manure Handling and Application

Three, Manure Storage

Four, Feeding and confined Systems, including Intensive Livestock Operations

Five, Transformation of manure into other products

A guide to the summary tables here is shown below:

Study Category	Location and Impact	Environmental Externalities	Economic Impacts	Mitigation Measures
General Studies	Table A1	Table A2	Table A9	Table A13
Manure Hauling & Application	Table A3	Table A4	Table A10	Table A14
Manure Storage	Table A5	Table A6	Table A11	Table A15
Feeding & Confined Systems	Table A7	Table A8	Table A12	Table A16
Transformation of Manure	Table A17		Table A18	Table A19

List of Appendix Tables

Table A.1: General Studies Pertaining to Livestock Production		
Author	**Geographic Location**	**Particulars, Indicative Impact (No Mitigation) & Major Findings**
		Multiple Pathways or Integrated Studies
Goss et al. (1993)	Canada	General review of 1990's state-of the art in manure management. Identifies different pathways and priorities for research. Panel suggestions included developing extension packages to assist farmers in making more efficient use of nutrients in manure; establish the relation between environmentally safe and profitable rates of manure application to cropland.
Manure Systems Research Group (1999)	Canada	MCLONE4: Decision Support System for Manure Management on Hog Farms. Contains relationships for various aspects and pathways of manure and nutrient management. MCLONE4 is able to determine losses of nitrogen from leaching as well as potential movement of bacteria into ground water; and can provide user a rating of environmental risk that would be incurred by an existing or proposed system.
Stonehouse and Goss (1999)	Ontario	Paper describing MCLONE4. The model evaluates on-farm (ownership and operating) costs and opportunity cost benefits, together with environmental pollution-related externalities, associated with alternative manure-handling systems for dairy, swine, beef and poultry enterprises. Technologies with the most promise to cost-effectively control odors are: better storage covers, solid/liquid separation, anaerobic treatment (especially at low temperature) and injection during land application.
Michie and Petkau (1999)		A software package as tool for manure management. This program can calculate the economics for up to five different manure application systems at once for purchased equipment and custom manure application.
Stonehouse and Giraldez (1996)	Ontario	Examines on-farm socio-economics of manure management (Part of the Decision Support System). Authors set out two factors that affect long-run costs: 1) farmers face a learning curve in adopting new technology; 2) there is an ongoing shift to other commodities or industry. Information should be given to farmers that focus on manure handling system alternatives. Information could be given to the farmers by surveying practicing farmers, simple budgeting to develop profiles of plant nutrient retention rates, organic matter fates and economic benefits and costs attached to different manure handling systems.
B.C. Ministry of Agriculture, Fisheries and Food	British Columbia	Identifies various pollutants from beef cattle production. Impact on air: from burning, global warming gases, nitrogen oxide, odors, and pesticides. Impact on soil: from C:N ratio, metals, nutrients, pesticides, petroleum, plants diseases, salt, woodwaste by-products. Impact on water: ammonia, metals, nitrates, nutrients, oxygen demand, pathogens, pesticides, petroleum, solids, & woodwaste
Dijk, Leneman, & van der Veen (1996)	Netherlands	Nutrient Flow Model (NFM) is a micro-simulation model, describing economic activities and corresponding nutrient flows at farm level. The NFM is a suitable instrument for evaluation of environmental policy. NFM focuses on the regional, sectoral and national levels. This paper looked at the effects of obligatory injection of manure and the authors assume that farmers would respond to this by restricting their use of fertilizer. The average losses of nitrogen would be reduced by 13%, caused by a reduction of ammonia volatilization of 48% and an increase in nitrate leaching and denitrification of 7 and 3%.
Feng, Kurkalova and Seechi (2002)	Review of U.S. studies	Review of Externalities in U.S. studies. Conclusions: 1) Although in empirical studies transaction costs are acknowledged, they are rarely estimated. 2) Most studies cite only one and not all aspects of multifunctionality of agriculture and impacts of agriculture on environment. 3) Some impacts of agriculture on the environment can be seen as a positive externality in some areas, and negative externality in others. 4) Baseline data are missing for a variety of issues, particularly water quality. There is a need to use farm production models that allow for a better understanding of time constraints and risk attitudes.

Table A.1: General Studies Pertaining to Livestock Production

Author	Geographic Location	Particulars, Indicative Impact (No Mitigation) & Major Findings
		General Studies, No Specific Pathways Identified
Rempel (1999)	Manitoba	Several poor manure management regimes were identified. Included here are: (1) Focus on gallons per acre; (2) Heavy application; (3) Ignorance and culture; (4) Knowledge and perception. Application of hog manure had the greatest effect on increasing soil inorganic N levels in the spring and lesser effect on available concentrations of other soil macronutrients. Cattle manure additions had less impact than hog manure on available soil nutrient levels in the first year of application
Bontems, Dubois and Vukina. (2002)	US	A study pertaining to regulation of contracts. Optimal outcome from regulation is attainable with subsidies for one party and taxes for the other. The optimal total tax revenue that must be imposed on the contractual organization depends itself on the preferences of both parties, on their reservation utilities and the parameters of the cost and production functions.
CSALE (1996)	Saskatche-wan	Investigates the environmental and legal constraints to expanding intensive livestock operations. There are many indicators that should be used to determine which locations in Saskatchewan would be best for an ILO. These indicators include wheat stubble yield, soil texture, manure application rates, topography for drainage and human population and attitude.
Lazurus (2001)	Minnesota	- Literature review of Industry structure and competitiveness, profitability, and economic viability - Major question asked: How do government policies, regulations and programs affect the profitability and viability of livestock farms and firms in Minnesota? How do governmental policies in other states and countries differ from those in Minnesota with respect to their impacts on farm/firm profitability and viability in those places, and what can be learn from their experiences? Because of negative externalities from livestock production, too much (higher than socially-optimal) production will tend to take place in the absence of regulation. -The relationship between environmental policy and livestock industry location is a two-way one -- environmental policy developments may be a result of past livestock industry growth as well as driving future growth. -Very few studies on the empirical analysis of cost of compliance with environmental regulations.
Legg and Potier (1998)	Europe	-Examines issues related to environment and ensuring sustainable use of resources in agriculture. Agriculture affects the environment by maintaining rural landscapes, preserve wildlife habitat, and biological diversity, and provide a carbon sink by trapping carbon, which would otherwise pollute the atmosphere as carbon dioxide. -Closer attention to effective application, provision and dissemination of knowledge, including establishment of codes of good agricultural practice to help farmers adopt sustainable methods and account for effect on environment in their decisions. -Align agricultural and environmental policies to remove conflicting goals will assist the long-term sustainable development. -More attention should be paid to exploring the potential of markets and innovative market-based policy approaches to address environmental issues and to putting a value on the environmental externalities involved in agriculture.
Massey and Zering (2001)	U.S.	Discusses the application of cost-benefit analysis in issues related to animal production / manure management systems. Non-point source pollution agency costs will be higher than point source pollution agency costs per unit of pollution abated. Benefit estimation for non-point source pollution from livestock farms is problematic due to uncertain relationship between potential pollutants applied to a farm field and the actual transport of pollutants to a site where environmental damage can occur.

Table A.1: General Studies Pertaining to Livestock Production		
Author	**Geographic Location**	**Particulars, Indicative Impact (No Mitigation) & Major Findings**
Nugent (1997)	Not specific (cases from different countries)	Examines the food production occurring in the confines of the cities. Costs of urban agriculture include: health risks (drinking water contamination); ecological degradation (soil depletion, potential groundwater contamination); and social conflicts from mixed-use of land. In peri-urban areas care must be taken not to add nutrients in excess of the vegetative absorption capacity or problems such as volatilization, leaching, surface runoff and epidemiological contamination may result.
Vukina and Woosink (1998)	Netherlands	Examines the effect of environmental policies on land values. Environmental compliance legislation in the early stages serves as a barrier to entry into the swine industry in the manure surplus regions. In the latter phase, an upward shift in environmental costs acts as a stimulant for producers in the surplus region to move to the deficit region. Introduction of phosphorus quota system in 1987 increase the gap in agricultural land prices between regions. Hog farmers in The Netherlands search for less limiting environmental policies, hog farmers relocated to the manure deficit region. Over time this trend will lead to the equalization of the production costs across regions, elimination of rents and the convergence of land prices.
Vukina (2003)	U.S.	Examines the relationship between contracting and livestock waste pollution. Potential linkages between contracting and animal waste depend on scale, specialization and concentration of animal units, as well as on division of inputs and contract settlement rules. Because of significant economies of scale, in waste management , intensive livestock production units could be environmentally friendlier than small family farms because they can make technologically advanced waste management systems economically feasible. The use of manure can be expected to worsen nutrient runoff and leaching from croplands regardless of whether the livestock producer is a contract operator or an independent farmer because they save on transportation costs by applying manure on closer fields.
Zilberman, Templeton and Khanna (1999)	U.S.	Examines the linkage between agriculture and environment with implications for nutrition. Agricultural production has harmed environmental quality primarily because of inadequately designed policies and natural resource projects. Policies that recognize the profit maximizing behavior of the producers, can induce farmers to modify their behavior in ways that will improve environmental quality. Taxes if pollution, subsidies for environmental-enhancing activities, and marketable pollution permits are included as appropriate measures. Institutional innovations that better specify and restrict rights to natural resources are an important way to improve agricultural productivity while simultaneously sustaining or improving environmental quality. Public sector support for agricultural research and extension is critical if institutional and technological innovations that reduce environmental impacts of agriculture are to continue.

Table A.2: Environmental Externalities Identified for Livestock Production Systems

Author	Geographic Location	Nature of Mitigation Measures	Externalities							
			Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
Multiple Pathways or Integrated Studies										
Goss et al. (1994)	Canada	Evaluation of current state of the art re manure and nutrient management in Canada, no specific mitigative measures were addressed.	Various externalities were implicitly assumed to exist. No specific mention was made.							
Manure Systems Research Group (1999)	Canada	No mitigative measure suggested				Environmental risk assessment undertaken		Odor production estimated	Gaseous N losses from slurry estimated	
Stonehouse and Goss (1999)	Ontario	Environmental impacts in the model not based on off-site damage costs, but on the basis of social acceptability aspects. Assumed here is that social acceptability is inversely related to odor emissions, and indirectly, to gaseous emissions and to water body pollutants in the form of nitrates, phosphorus, and bacteria, as proxies for environmental damage.								
Michie and Petkau (1999)	Canada	Model emphasis on-farm decisions-making and economics. Did not specify any externalities from livestock production.								
Stonehouse and Giraldez (1996)	Ontario	Made a case for developing "knowledge-creating farmers" through the use of models and expert systems. Environmental degradation was treated in the background.								
Dijk, Leneman, Van der Veen (1996)	Netherlands	No mitigation strategies were identified. No accounting for environmental externalities.								
Feng, Kurkalova and Seechi (2002)	Review of U.S. studies	No mitigation strategies were identified.								

Table A.2: Environmental Externalities Identified for Livestock Production Systems

Author	**Geographic Location**	**Nature of Mitigation Measures**	**Externalities**							
			Social		**Environmental**					
			Health	**Other Social**	**Soil**	**Water**		**Air Quality**	**Climate Change**	**Biota**
						Surface	**Ground**			
B.C. Ministry of Agriculture, Fisheries and Food	British Columbia	Maximum benefit is derived from manure when it is spread on the land in spring. Beef cattle manure should not be spread within 5 m of a bank or a slope leading to any watercourse, or within 30 m of streams flowing into shellfish growing areas or any well for a domestic water supply. Apply manure on a cool day when odor production is lower.								
General Studies with No Specific Pathways										
Zilberman, Templeton and Khanna (1999)	U.S.	Taxes of pollution or polluting activities, subsidies for environmentally-enhancing activities and marketable pollution permits								
Rempel (1999)	Manitoba	No mitigation strategies were identified.								
Bontems et al. (2002)	US									
CSALE (1996)	Saskatchewan									
Lazurus (2001)	Minnesota									
Legg and Potier (1998)	Europe									
Massey and Zering (2001)	U.S.									
Nugent (1997)	Various									
Vukina and Woosink (1998)	Netherlands									
Vukina (2003)	U.S.									

Table A.3: Studies Dealing with Manure Handling and Application		
Author	**Geographic Location**	**Particulars, Indicative Impact (No Mitigation) & Major Findings**
		Odor
Lague (2000)	Canada	Descriptive study outlining issues related to livestock manure management. Estimates 51.7 million tonnes of swine manure, containing 143 million kg of N and 46 million kg of P. Rapid removal of animal excretions from production buildings can have positive effects on air quality in barns and therefore on the health of barn workers and animals.
Klein et. al. (1995)	Canada	Study of hog marketing systems in Canada. Does not deal explicitly with manure management, but does point out issues facing the industry
Danesh et al. (1999)	Canada	Environmental issues related to hog production operations
Flemming, Babcock and Wang. (1998)	Iowa	
Larson (1991)	Saskatchewan	Develops environmental principals of manure management. Location and management of storage facilities on the site, management of storage levels and timing and location of application events will minimize odor conflicts.
Tessier (2001)	Manitoba	Discusses manure handling strategies for minimizing environmental impacts. Quantitative description of odors is a task yet to be accomplished. A crude measure is number of complaints. Odor control is closely linked to nitrogen conservation from feeding hogs to time of plant uptake. To date, there are few manure management technology packages and operation scenarios that surely will bring both a profit into sound manure management and effectively cut odor nuisance to very low levels.
Tyndall and Colletti (2001)	U.S., general	The main thesis of this study is that shelterbelts (living tree/shrub barriers) can be cost effective biological buffers that are part of management strategies that could be used by producers and accepted by consumers to satisfactorily reduce odor and sustain rural communities and the livestock industry.
		Ammonia Emissions
De Vos, Weersink and Stonehouse (2003)	Ontario	A study of swine farms in Ontario was the focus of this study. Four different enterprise sizes were included: Small (200 hogs per 100-day finishing cycle), Medium (500 hogs per 100-day finishing cycle), Large (1,000 hogs per 100-day finishing cycle), and Extra Large (5,000 hogs per 100-day finishing cycle). The study was an evaluation of tradeoffs between environmental quality in the form of manure nutrient residuals (gaseous ammonia, excess nitrogen applied to cropland, excess phosphorus applied to cropland) emitted into the environment and net returns for the above four size hog finishing operations stemming from alternative manure management systems.
Lague (2000)	Canada	
Steinfeld, de Haan, and Blackburn (1996)	Generic; No specific region of study	Those responsible for degradation do not pay the full costs, and those who preserve natural resources or who pay the costs of conservation gain a few of the benefits. Recommends a different policy design.

Table A.3: Studies Dealing with Manure Handling and Application		
Author	**Geographic Location**	**Particulars, Indicative Impact (No Mitigation) & Major Findings**
Sommer and Hutchings (2001)	Europe	Livestock farming is the major source of atmospheric NH_3. Reviews field-applied animal manure and the methods available for its reduction. Factors most commonly found to affect losses are the concentration of total ammoniacal N and the manure dry matter, soil infiltration rate and meteorological variables. Ammonia volatilization can be reduced by incorporation of the animal slurry and farmyard manure.
Stonehouse, de Vos, and Weersink (2002)	Ontario	Application of mixed integer programming models to generate whole farm plans for specialized hog operations in Ontario. The authors found that there are considerable differences between the best way to feed livestock/handle manure economically and the best combination environmentally, as measured by farm net returns vs. levels of manurial NH_4 gaseous emissions, and excess manurial N and P applied to cropland.
Pollution by Phosphorus		
Lague (2000)	Canada	46,000 tonnes of phosphorus
Sharpley and Moyer (2000)	Pennsylvania	The potential for P to be leached from manure and compost was most closely related to water extractable inorganic P concentration of the respective materials. The presence of soil will affect the adsorption of P released from manures or composts and thereby influence surface runoff and/or leachate P concentration.
Boland, Preckel and Foster (1998)	U.S.	Hog industry. The use of synthetic amino acids or phytase has great promise for reducing the amount of excreted phosphorus. This analysis suggests that small amounts of synthetic amino acids and phytase are optimal by reducing storage costs when producers are constrained by land.
Featherstone (1998)	Texas	Clean Water Action Plan of 1998 provided a blueprint for protecting water quality through reduced polluted runoffs containing phosphorus.
Run-off and Leaching		
Letson and Gollehon (1998)	U.S.	For manure - water quality impairment, we need to know more about manure application methods, soil mobility, crops grown, rainfall events, proximity of surface water, depth of water table, water uses, and the contributions of other sources of nutrients. Additional spending on manure management does not guarantee water quality benefits.
Innes (2000)	U.S.	No empirical results. Study develops a conceptual model of impacts of livestock production. More emphasis is on policy measures. Identifies three linked, but distinct avenues for waste to reach the environment: (1) spills from animal waste stores, (2) Nutrient runoff due to application of manure to croplands; and (3) direct ambient pollution, including odors, pests, and gases. When government cannot directly regulate producers' manure-spreading practices, producers will always choose to apply more manure to surrounding croplands that just substitute for chemical fertilizer and therefore the application of manure increases environmentally harmful nutrient runoff from croplands. The government can increase efficiency by regulating observable producer choices that affect the risk of spills and leaks from waste storage facilities.
Younie et al. (1996)	Canada	By retaining nitrogen in crop residues, conservation tillage practices may reduce leaching of nitrate over the fall to spring period following the incorporation of crop residues under conventional tillage.

Table A.3: Studies Dealing with Manure Handling and Application

Author	**Geographic Location**	**Particulars, Indicative Impact (No Mitigation) & Major Findings**
Janzen et al. (1999)	Canada	Improved effectiveness in use of manure resources may be achieved by nutrient conservation and harvesting, processing to increase nutrient retention and reduce transport costs.
King et al. (1994)	Ontario	Threats to human health and wildlife. Modified injection method under NT management significantly reduced nutrient and bacteria contamination compared to other conventional treatments.
Alberta Agriculture, Food and Rural Development (2001a)	Alberta	This document is a set of regulations to be followed by livestock producers in the province. Impacts of current management practices were in the background creating environmental impacts, thereby indicating the need for these regulations
Flemming, Babcock and Wang (1998)	Iowa	Seeking policy solutions
Larson (1991)	Saskatchewan	Impact of manure application systems. Proven management practices when properly applied, will avoid risks of water pollution from land application of manure.
Wright (2001)	Western Canada	Provides guidelines for developing environmentally sound intensive livestock operations. Interested parties must work together to ensure that risks associated with the ingestion of nitrate contaminated water are managed.
Brouwer et al. (1999)	EU	Economic and environmental benefits of reducing nitrogen pollution. Nitrogen surpluses are highest at pigs and poultry farms. Costs to dispose of the remaining excess amounts of manure can only be reduced if a large share of pig and poultry holdings take nutritional management measures, allowing for a reduction of the overall environmental bill.
Coleman et al. (1999)	Minnesota	Manure application setbacks for various water bodies.
Nutrient Imbalance and Recycling		
Janzen et al. (1999)	Alberta	Mostly based on assumed functional relationships and unit cost. Resembles simulation model. Also suggest developing combined economic and ecological analysis-leading to conservation of ecological benefits of nutrients in manure, capturing of their economic value, thereby meeting both economic and ecological goals. Improved effectiveness of manure resources may be achieved by nutrient conservation and harvesting, processing to increase nutrient retention and reduce transport costs.
Wang and Sparling 1995)	Eastern Colorado	Manure, either in raw or compost, is applied to irrigated cropland. Used a linear programming model. Compost seems to improve manure with regards to weed seeds, soil compaction, inconvenience and odor, which could be a partial solution to the feedlot waste problem.
Innes (1999)	U.S.	Discusses economics of manure management. Manure transport cost increases with distance, therefore manure is spread on fields surrounding an operation.
Nagy, Schoneau and Schoney. (1999)	Saskatchewan	Issue of large sized livestock operations and economic manure hauling costs. The positive marginal return of some of the treatments indicates that grain producers would be willing to pay to have manure hauled to gain the benefits.

Table A.3: Studies Dealing with Manure Handling and Application		
Author	**Geographic Location**	**Particulars, Indicative Impact (No Mitigation) & Major Findings**
Unterschultz and Jeffrey (2001)	Review of Canadian and U. S. studies	Review of various studies on economic valuation of manure handling. Studies have used one of four types of frameworks: 1) Opportunity cost of manure, based on nutrient content; 2) Crop Benefits approach, based on comparison of manure vs. no manure crop benefits; 3) Cost of business, where manure is by-product and cost of disposal is to be minimized; and 4) Business enterprise approach, using additional value-added through composting. Manure nutrients only have on farm value if they can be used in another enterprise, in such a way that it reduces costs or adds to profits.
Stonehouse and Narayanan (1984)	Ontario	Manure handling alternatives included in the study: liquid system; a modified liquid system with specific component alternatives, and a complete solid-handling system. Mixed livestock/cropping farmers who handle their livestock manures in a manner sufficiently judicious to maximize retention of plant nutrients are in a position to supply a pre-specified set of nutrients at a lower overall cost than farmers totally reliant on purchased chemical fertilizer.
Larson (1991)	Saskatchewan	Location of production units
Efficient Use of Organic / Inorganic N and P		
Freeze et al. (1993)	Southern Alberta	Estimated the maximum distance manure can be hauled as an amendment for restoring the productivity of artificially eroded wheat cropland. Manure can be hauled 3-5 km further than would be the case with non-eroded soils.
Larney and Janzen (1996)	Southern Alberta	Use of livestock manure for restoring the productivity of land. More efficient use of organic N and P sources produced on-farm may provide an alternative for producers with a desire to restore their eroded soils and at the same time, reduce their inputs of N and P fertilizer.
Younie et al. (1996)	Ontario	Examines large livestock operations that produce quantities of manure nitrogen in excess of that required by the associated cropped land. Disposal costs are high which result in excessive rates of manure being applied to the land. Compares two types of manure and inorganic nitrogen fertilizer.
Schoneau et al. (1996)	Saskatchewan	Field experiments to examine the effects of different rates and methods of application of swine and cattle manure in the first year of application. Found considerable spatial and temporal variability in nutrient concentrations, with the land application of hog manure having a greater effect than cattle manure.
Ambient Pollution		
Weersink (1996)	Review of all available studies	Review methods for valuing environmental damage and summarize any efforts in assessing resource costs of animal manure. At the present time there are no studies using any of the approaches that have examined the economic value of environmental damages caused by manure pollution

Table A.3: Studies Dealing with Manure Handling and Application		
Author	**Geographic Location**	**Particulars, Indicative Impact (No Mitigation) & Major Findings**
		Greenhouse Gas Emissions
Thompson, Pain and Lockyer (1990)	Canada	Winter vs. spring application of manure
(The) Thomsen Corporation (2000)	Ontario	Examined strategies for reducing greenhouse gas emissions from Ontario agriculture.
AAFC (2000)	Canada	To provide quantitative analysis of mitigation scenarios related to manure management.
Jackson, Keeney and Gilbert (2000)	North Central Iowa	70% of total N volatilized. Also recommends the establishment of a statewide zoning regulation, on a township basis, for density of animal units, and consider regulating all new construction regardless of size.
Tessier and Marquis (1998)	Canada	Compares alternative sources of greenhouse gas emission coefficients from manure. No coefficients reported, but question the use of IPCC coefficients for Canada. The authors are tempted to conclude that CH_4 emissions from stored livestock manure in Canada may not be significant. They propose that CH_4 emissions from manure handling systems and manure storage structures in Canada are not a major contributor to overall GHG emissions from livestock.
ESG International (1999)	Canada	Examines strategies for reducing emissions from manure application. A high reduction of CH_4 gas can be reduced at a reasonable cost by using tarps and floating covers on medium and large sized storage facilities. Reducing manure N can be an extremely effective method to reduce N_2O emissions below 1990 levels, but only for the swine and poultry industry.

Table A.4: Environmental Externalities Identified with Manure Handling and Application Measures

Author	Geographic Location	Nature of Mitigation Measure	Externalities							
			Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
Odor										
Lague (2000)	Canada	Modification of feeds and feeding systems	Positive effect on health of farm workers					Improved		
		Rapid removal of animal excretion from farm buildings	Improved					Improved		
		Add 3 mm layer of recycled and filtered vegetable oil on top of liquid manure within the barn collection pits								
Klein et. al. (1995)	Canada						Pressures from urban dwellers to not permit groundwater contamination	Pressure from urban dwellers to reduce smell		
Danesh, Hodgkinson and Small. (1999)	Canada	Better storage covers, solid/liquid separation, anaerobic treatment (especially at low temperatures), and injection during land application					Technologies also reduce groundwater pollution	Reduced odor	Technologies also reduce GHG emissions	
Flemming, Babcock and Wang. (1998)	Iowa	Policy that requires incorporation of swine manure into soil after spreading						Improves air quality		
Tessier (2001)	Manitoba	Suggests various strategies for livestock housing, manure storage structure, and land application of manure								
Tyndall and Colletti (2001)	U.S.	Shelterbelts planting (trees and shrubs)								
Larson (1991)	Saskatche-wan	Minimum distance between a pig unit and its neighbor (rural residence) should be 305 meters.						Improves air quality		
		Apply manure annually or semi-annually to reduce frequency of odor generation						Improves air quality		

Table A.4: Environmental Externalities Identified with Manure Handling and Application Measures

Author	Geographic Location	Nature of Mitigation Measure	Externalities							
			Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
Ammonia Emissions										
Lague (2000)	Canada	Compost swine manure with other by-products of waste materials								
		Add 3 mm layer of recycled and filtered vegetable oil on top of liquid manure within the barn collection pits (Based a study by Pahl et al. 2000)								
Steinfeld, de Haan, and Blackburn (1996)	Generic: No specific region of study	Manure collected under solid floors								
		Natural or forced ventilation systems or through biofilters / biowashers						Fresher air		
		Injection or application of manure into the sub-soil								
		Better timing of application in response to crop requirements								
Sommer and Hutchings (2001)	Europe	Use trail hoses that will apply slurry onto the soil between rows of plants								
		Cultivate before applying slurry								
		Applying manure when conditions do not favor volatilization of ammonia								
		Injection of slurry into the soil								
		Increase the application rate so that a greater proportion of the slurry is likely to infiltrate in the soil							Reduced GHG Emissions	
De Vos, Weersink and Stonehouse (2003)	Ontario	Eighty one alternative manure management systems examined for 4 sizes of swine finishing operations. Results presented in terms of trade-offs between level of three pollutants – ammonia, nitrogen and phosphorus and economic returns.	No direct reference to these externalities was made in the study, although these are in the background and the need for undertaking it.							

Table A.4: Environmental Externalities Identified with Manure Handling and Application Measures

Author	Geographic Location	Nature of Mitigation Measure	Externalities							
			Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
Stonehouse, de Vos, and Weersink (2002)	Ontario	Comply with minimum NH_4 restrictions by feeding standard ration supplemented with synthetic lysine, fully-slatted floor collection, covered concrete storage, tanker-injector for field application	Improved					Cleaner air		
		Minimize excess N application by feed ration with lysine with a floor collection, covered concrete tank storage and irrigation for field application						Cleaner air		
Pollution by Phosphorus										
Lague (2000)	Canada	Application of swine manure on different soil-crop systems								
Sharpley and Moyer (2000)	Pennsyl-vania	Differences in composting processes and materials used influence the amount and relative distribution of inorganic P forms in the composted material				Reduced freshwater pollution from eutrophica-tion				
		Attributes of soil affects adsorption of P released from manure or compost								
Boland, Preckel and Foster (1998)	U.S.	Use phytase if there is a phosphorus based application and if producers are constrained by land								
Featherstone (1998)	Texas	Limit manure application to keep soil phosphorus levels below an accepted threshold level				High quality water				
Run-off and Leaching										
Janzen et al. (1999)	Canada	Manure products could be distributed beyond livestock operational boundaries				Improved quality				
Younie et al. (1996)	Canada	Leave crop residues on the soil surface								
Flemming Babcock and Wang. (1998)	Iowa	Change in nutrient upon which manure applications are based on from N to P								

Table A.4: Environmental Externalities Identified with Manure Handling and Application Measures

Author	Geographic Location	Nature of Mitigation Measure	Externalities							
			Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
Letson and Gollehon (1998)	U.S.	Nutrient applications should match the quantity removed by harvested crops plus soil buffering capacity					Additional spending on manure management does not guarantee water quality. Is only one of several; and is very site and cultural practice specific.			
Innes (2000)	U.S.	Government sets higher chemical prices that will encourage producers to transport manure a greater distance								Increase in flies from livestock facilities
		Government sets minimum or maximum facility size or have a certain amount of land available for manure spreading for a certain number of animals								
King et al. (1994)	Ontario	No till modified injection method				Water safer for humans and for wildlife				
		Disturbance of macrospores by cultivation prior to liquid manure injection in no till fields								
Larson (1991)	Saskatche-wan	Do not apply manure on snow where the land is subject to rapid spring run-off				Improved surface water quality				
		Application of manure in excess of crop requirements results in residual nitrogen in root zone					Improved groundwater quality			

Table A.4: Environmental Externalities Identified with Manure Handling and Application Measures										
Author	**Geographic Location**	**Nature of Mitigation Measure**	**Externalities**							
			Social		**Environmental**					
			Health	**Other Social**	**Soil**	**Water**		**Air Quality**	**Climate Change**	**Biota**
						Surface	**Ground**			
Alberta Agriculture, Food and Rural Development (2001a)	Alberta	The owner / operator must construct a system that will limit the amount of surface water and run-on and runoff flowing through and from the operation or facility				Cleaner water				
		The system must be constructed so that it does not significantly alter the volume, quality or rate of water flowing to each location where water naturally discharges				Cleaner water for humans, animals, and recreation				
		The system must be built so that it does not alter or affect any non-flowing water body								
		The owner / operator must not apply manure within 10 meters of a common body of water if the person is using the sub-surface injection								
		A person who applies liquid manure or catch basin contents must ensure that the contents do not create a risk to the environment by leaving the land to which they are applied, by entering a common body of water, or by becoming a return flow								
Wright (2001)	Western Canada					Identifies risk of contamination of surface water from nitrates				
Brouwer et al. (1999)	EU					Nitrogen pollution is major threat to quality of European aquatic environment:surface, ground, , & marine water				
Coleman et al. (1999)	Minnesota					Improves water quality				

Table A.4: Environmental Externalities Identified with Manure Handling and Application Measures

Author	Geographic Location	Nature of Mitigation Measure	Externalities							
			Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
Nutrient Imbalance and Recycling										
Janzen et al. (1999)	Alberta	Add processed manure								
Wang and Sparling 1995)	Eastern Colorado	Composting								
Innes (1999)	U.S.									
Nagy, Schnoeau and Schoney (1999)	Saskatche-wan	Optimum rates of application of manure through timely removal of the manure using the highest rates to reduce costs for the grain producer								
Unterschultz and Jeffrey (2001)	Review of Canadian and U. S. Studies						Trade-offs between contamination of water and release of greenhouse gases during composting		Trade-offs between contamination of water and release of greenhouse gases during composting	
Stonehouse and Narayanan (1984)	Ontario	Timely incorporation of manures into cropland to conserve plant nutrients, especially nitrogen, more effectively			Lower soil compaction costs					
Larson (1991)	Saskatche-wan	Locate them where (1) there is sufficient land base to utilize total long term production without risk of nutrient loading; (2) has cropping practices which are amenable to manure injection or incorporation techniques			Improves soil quality through the use of manure					

Table A.4: Environmental Externalities Identified with Manure Handling and Application Measures										
			Externalities							
			Social		**Environmental**					
Author	**Geographic Location**	**Nature of Mitigation Measure**	**Health**	**Other Social**	**Soil**	**Water**		**Air Quality**	**Climate Change**	**Biota**
						Surface	**Ground**			
Efficient Use of Organic and Inorganic N and P										
Freeze et al. (1993)	Southern Alberta	Manure application on heavily eroded soils			Distance hauled approximately 20 km					
Younie et al. (1996)	Ontario	Fertilizers that contain a high percentage of ammonical or ammonical-producing forms of nitrogen (such as Urea, ammonium nitrate, anhydrous ammonia)	Improved health by reducing NO_3 concentration. Nitrite (NO_2) levels also pose threats. Little evidence linking concentration of NO_3 in drinking water and stomach cancer			Safe drinking water, through reduced eutrophication of lakes				
Larney and Janzen (1996)	Southern Alberta	Using manure to restore productivity of slighted eroded soils			Improved quality					
		More efficient use of organic N and P sources			Improves eroded soils					
Schoneau et al. (1996)	Saskatchewan									

Table A.4: Environmental Externalities Identified with Manure Handling and Application Measures

Author	Geographic Location	Nature of Mitigation Measure	Externalities							
			Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
Greenhouse Gas Emissions										
Thompson, Pain and Lockyer (1990)	Canada	Injection vs. Surface application							Less loss of ammonia by volatilization	
(The) Thomsen Corporation (2000)	Ontario	Change all incorporated manure for all systems to one day							Reduced GHG emissions	
AAFC (2000)	Canada	40% of applicable land will use no fall application of manure							Reduced GHG emissions	
Jackson, Keeney and Gilbert (2000)	North Central Iowa	Using earthen basins and soil injection of liquid manure							Reduced GHG emissions	
Tessier and Marquis (1998)	Canada								Emissions related to climate change	
ESG International (1999)	Canada	Conversion of fall application to spring application							Reduce the start of climate change	
Ambient Pollution										
Weersink (1996)	Review of all available studies						A few related studies determined households' willingness to pay from $50 to $1,150 annually to lower nitrates in groundwater.	No study of the value of reduction in odor		

Table A.5: Studies Related to Manure Storage		
Author	**Geographic Location**	**Particulars -- Industry Particulars Indicative Impact (No Mitigation) & Major Findings**
		Ambient Pollution
Westenbarger and Letson (1995)	U.S.	Estimates the cost of compliance for a new Clean Water Act. Localized rather than aggregate costs could produce significant economic dislocation and political concern.
Larson (1991)	Saskatchewan	Effective management practices at all stages will reduce the potential disruption of the aesthetic quality of the air. Location and management of storage facilities on the site, management of storage levels and timing and location of application events will minimize odor conflicts.
Innes (2000)	U.S.	Increased animal production increases the amount of ambient pollution if the size of the facility is not regulated.
		Pollution by Phosphorus
Bolland, Preckel and Foster (1998)	U.S.	Hog industry; Optimization model The use of synthetic amino acids or phytase has great promise for reducing the amount of excreted phosphorus.
		Ammonia Emissions
Stenfeld, de Haan and Blackburn (1996)	Generic	Study seeks policies for correcting negative environmental effects of livestock production that are not reflected in product and input prices.
		Run-off and Leaching
Barrington and Cap (1991)	Quebec	Development of an economically solid manure storage system. Authors offer the solution of covering a solid manure platform with a coated and woven geotextile. This could be economical and practical if enough bedding can be used to curtail all seepage from the waste during its storage.
Alberta Agriculture, Food, and Rural Development (2001b)	Alberta	Standards
Ritter and Churnside (1990)	U.S.	Clay-lined storage lagoons. If located on sandy loam or loamy sand soils with shallow water tables affect water quality.
Holms and Klemme (1989)	Wisconsin	Examined economic costs and benefits of alternative manure handling and storage systems.
Fulhage (1994)	Missouri	Examined the cost of two manure handling and storage systems: a lagoon/flush system and a slurry manure system.
Lazenby (1995)	Ontario	Evaluated alternative liquid manure handling systems on dairy farms
Peters et al. (Undated)	Canada	Best management practice for manure management Effective BMP management will result in minimal risk of water quality contamination.

Table A.5: Studies Related to Manure Storage		
Author	**Geographic Location**	**Particulars -- Industry Particulars Indicative Impact (No Mitigation) & Major Findings**
		Greenhouse Gas Emissions
AAFC (2000)	Canada	Strategies to reduce emissions from storage of manure
ESG International (1999)	Canada	Studied strategies for reducing GHG emissions from manure storage. High reduction of CH_4 gas can be reduced at a reasonable cost by using tarps and floating covers on medium and large-sized storage facilities. Reducing manure N can be an extremely effective method to reduce N_2O emissions below 1990 levels, but only for the swine and poultry industry.
Kirchman and Witter (1992)	U.S.	Losses of C as carbon dioxide or methane during storage.
		Odor
Larson (1991)	Saskatchewan	Type of manure storage. Location and management of storage facilities on the site management of storage levels and timing and location of application events will minimize odor conflicts.
		Locate earthen storage out of site of the public view.

Table A.6: Environmental Externalities Identified with Manure Storage

Author	Geographic Location	Nature of Mitigation Measures	Social		Environmental					
			Health	Other Social	Soil	Water: Surface	Water: Ground	Air Quality	Climate Change	Biota
Ambient Pollution										
Westbarger & Letson (1995)	U.S.									
Larson (1991)	Saskatche-wan	Storage tank made of reinforced concrete or steel					In areas of high water table, re-duces chance of contamination			
Innes (2000)	U.S.	Tax producers for external costs created by entry and increases in animal numbers						Cleaner air		
Pollution by Phosphorus										
Bolland, Preckel and Foster (1998)	U.S.	As animal numbers increase above amount required for market inventory, combination of lagoon storage and irrigation application becomes least cost method to manage manure				Reduced algae blooms				
Ammonia Emissions										
Stenfeld, de Haan, and Blackburn (1996)	Generic; No specific region of study	Covering storage tanks								
		Solid storage systems that collect feces only for storage in bulk	Improved					Improved	Reduced incidence of climate change	
		Covered tanks and manure kept under solid floors in stables								

Table A.6: Environmental Externalities Identified with Manure Storage

Author	Geographic Location	Nature of Mitigation Measures	Social		Environmental					
			Health	Other Social	Soil	Water: Surface	Water: Ground	Air Quality	Climate Change	Biota
Run-off and Leaching										
Alberta Agriculture, Food, and Rural Development (2001b)	Alberta	Manure storage facilities shall not be constructed within 100 meters of any spring or water well and within 30 meters of any open body of water				Improved quality	Improved quality			
		A run-on control system should be built to prevent the flow of surface water into storage								
		The system should be built so that run-off from the storage site must not enter an open body of water or leave the owner's property								
		The owner / operator should avoid sites with porous soil and / or fractured bedrock that would allow contaminants direct access to groundwater					Safer and cleaner water			
		Drainage must be provided within the feedlot or animal holding areas to prevent the retention of contaminated liquids on the lot surface. Manure runoff from drainage must not enter an open body of water or leave the owner's property.								

Table A.6: Environmental Externalities Identified with Manure Storage										
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Social**		**Environmental**					
			Health	**Other Social**	**Soil**	**Water**		**Air Quality**	**Climate Change**	**Biota**
						Surface	**Ground**			
Barrington & Cap (1991)	Quebec	Use of geotextile cover								
Ritter and Churnside (1990)	U.S.						Deterioration of water quality			
Holms and Klemme (1989)	Wisconsin						Concrete tanks more environmentally friendly			
Fulhage 1994	Missouri									
Lazenby 1995	Ontario									
Peters et al. (Undated)	Canada	Open concrete tank with storage capacity greater than standard 6 months; application by top loading tank spreader.			Improved soil quality	Reduced nutrients in run-off	Improved			
Greenhouse Gas Emissions										
AAFC (2000)	Canada	Cover liquid storage tanks to reduce methane emissions							Lower emissions lead to improvement in terms of climate change	
ESG International (1999)	Canada	Use of floating straw covers on large swine lagoons							Reduce the on-set of climate change	
Kirchman and Witter (1992)	U.S.	Aeration of manure							Important factor in determining gases	
Odor										
Larson (1991)	Saskatchewan	Covered storage						Improves air quality & ublic perception		

Table A.7: Feeding and Confined Systems including Intensive Livestock Operations

Author	Geographic Location	Particulars, Indicative Impact (No Mitigation) & Major Findings
		General Studies
Ikerd (1999)	U.S.	• Examines the real economics of large-scale, corporate-owned, factory-type livestock operations. Large-scale corporate livestock operations are not socially responsible, they are not ecologically sound, and thus, they are not economically viable. • It does not make sense to apply the same environmental rules to small, diversified family farms as to large, specialized livestock factories -- the environmental risks are in no way comparable. • Any system of production that is not socially responsible and ecologically sound cannot be sustained over time, and thus, is not economically viable.
Korevaar (1995)	Europe	• Review of European policies and experience of intensive livestock and poultry farms on the environment. New regulations concerning the handling, application, and storage of manure have been put into effect in many European countries. • Besides the targets for reducing mineral losses, environmental legislations also include targets for the emission of acidifying substances such as ammonia. • Reducing odors by covering manure storage and better manure application techniques will also reduce N-losses by ammonia volatilization to the atmosphere. Composting of animal manure will result in a better fertilizer and reduced transportation costs.
		Odor
Eghball and Power (1994)	U.S.	Aimed at a review of current practices and knowledge about beef feedlot manure production and utilization.
Coleman et al. (1999)	Minnesota	On account of odor and other nuisances, effect of property values has been hypothesized.
Abeles-Allison (1990)	Michigan	Large hog operations diminish local amenities. Generate flies, odor, and externalities.
		Pollution by Phosphorous
Lague (2000)	Canada	
Bolland, Preckel and Foster (1998)	U.S.	Hog industry; Optimization model The use of synthetic amino acids or phytase has great promise for reducing the amount of excreted phosphorus.
		Run-off and Leaching
Taylor and Rickerl (1998)	South Dakota	17,000 billion lbs. of manure. One billion pounds of nitrogen, and 0.33 billion pounds of phosphorus. Most feedlots applied plant-available N and P in livestock manure at rates that exceed crop and grass fertility requirements. Also manure nutrient

Table A.7: Feeding and Confined Systems including Intensive Livestock Operations		
Author	**Geographic Location**	**Particulars, Indicative Impact (No Mitigation) & Major Findings**
		loadings on croplands are strongly and positively related to feedlot size. The study findings show a risk of nonpoint-source pollution problems from larger feedlots in areas with vulnerable surface and groundwater.
Larney, Chang and Blackshaw (1999)	Southern Alberta	Application of fresh manure in the vicinity of feedlots increases N and P levels in the vicinity, and has long-run environmental impacts on groundwater, surface water, and soil quality. If fresh manure were hauled to the field immediately after it was removed from the feedlot pens, about 70% of the energy expended would bring water rather than nutrients to the field. This number dropped to 34% with composting.
Egbbal and Power (1994)	U.S.	Study updating earlier studies ion current practices and knowledge about beef cattle manure production and utilization. Factors that affect soil properties and microbial activity also affect the potential losses of nutrients from the soil by leaching, runoff, volatilization, or denitrification.
Weida (2001)	U.S.	Examines the regional economic effects of large hog confined feeding operations. CFOs interfere with rural amenities; constraints regional development due to employment (cost minimization), taxes, and vertical integration; groundwater contamination; health risks.
Weinberg and Newbold (2002)	U.S. studies	Examines externalities using the environmental economics literature A policy suggestion is to require all CFO to install lagoons for storing animal wastes. These storage systems volatilize nitrogen, thereby reducing the concentration of nitrogen in the lagoon effluent and reducing potential impairments to water quality.
		Greenhouse Gas Emissions
Steinfeld, de Haan, and Blackburn (1996)	Europe	
de Haan, Steinfeld, and Blackburn (1996)	Europe	Policy oriented study to encourage farmers to retain a mixed farming system instead of specializing in the production of one or two crops. Suggests internalizing environmental costs from negative environmental impacts.
Larney et al. (2001)	Southern Alberta	Application of fresh manure vs. composting. Nitrogen loss was between 25 and 38% depending on bedding type and the method of calculation.
		Nitrogen and Phosphorus in Excretions
de Haan, Steinfeld, and Blackburn (1996)	Europe	Improving the accuracy of determining nitrogen and phosphorus requirements, followed by better balancing of feeds with these essential nutrients.

Table A.7: Feeding and Confined Systems including Intensive Livestock Operations

Author	Geographic Location	Particulars, Indicative Impact (No Mitigation) & Major Findings
Wang and Sparling (1995)	Eastern Colorado	If most N in manure could be stabilized in organic matter through composting, less would mineralize and become available in the first year after application than if manure were applied raw.
Freeze et al. (1999)	Southern Alberta	Areas where intensive livestock operations are concentrated.
Boland, Foster and Preckel (1999)	Purdue, Indiana	Investigate the effect of excess nutrition on profits and excretion. Excess protein is excreted as nitrogen in manure in the nutrient intake that maximizes economic returns.
		Ammonia Emissions
De Vos, Weersink and Stonehouse (1998)	Review of Canadian, and European studies	Using more phases in feeding regimes enables the protein needs of the animals to be met more efficiently. Ammonia emission in barns can be reduced by at least 50% by adopting an alley scraper system or a flush system but will increase N leaching by approximately 7% due to the higher N content in the manure.
		Nutrient Recycling and Balance
Freeze and Sommerfeldt (1985)	Southern Alberta	Beef feedlot manure management and hauling distance. Results from the study indicate that manure, valued for its N and P_2O_5 content can economically substitute for commercial fertilizer in the production of agricultural crops at distances for up to approximately 15 km from feedlot sources.
Hoyt and Rice (1977)	Peace River , Alberta and British Columbia	Compared fertilizer, and fertilizer + manure application of N-P-K. Barnyard manure was used to raise the OM content but it is not known if the manure improved the tilth of the soil since it was not measured.
		Nutrition management
Brouwer et al. (1999)	EU	Least cost feed formula does not automatically correspond to the most environmentally friendly feeds. Providing feed more closely allied to the animal's requirements without affecting its performance, resulting in a reduced nitrogen excretion by animals, can reduce protein level in feeds. Preventive nutritional output at farm level is economically competitive compared to downstream processing of excess manure.

Table A.8: Environmental Externalities Identified in Studies Related to Feeding and Confined Systems Including Intensive Operations

Author	Geographic Location	Nature of Mitigation Measures	Social: Health	Social: Other Social	Environmental: Soil	Environmental: Water – Surface	Environmental: Water – Ground	Environmental: Air Quality	Environmental: Climate Change	Environmental: Biota
General										
Ikerd (1999)	U.S.									
Korevaar (1995)	Europe									
Odor										
Eghball and Power (1994)	U.S.	Composting			Manure application improves soil physical properties such as in-filtration, aggregation, and bulk density	Reduced run-off, thus improving water quality				Reduced fly breeding potential
Coleman et al.	Minnesota									
Abeles-Allison (1990)	Michigan									
Pollution by Phosphorous										
Lague (2000)	Canada	Improve feed and water management in hog operations								
Bolland, Preckel and Foster (1998)	U.S.	Add phytase to diet				Improves	Improves			
		Synthetic amino acids (replacement for soybean meal): synthetic lysine, synthetic methonine								

Table A.8: Environmental Externalities Identified in Studies Related to Feeding and Confined Systems Including Intensive Operations

Author	Geographic Location	Nature of Mitigation Measures	Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
Run-off and Leaching										
Taylor and Rickerl (1998)	South Dakota	Adjust feedlot size.								
Larney, Chang and Blackshaw (1999)	Southern Alberta	Composting					Improve-ments re-sulting from lower concentra-tion of N and P (since it is now dis-tributed over a larger area)			
Egbbal and Power (1994)	U.S.					Runoff may pollute surface waters with chemicals, microorganisms, organic materials, and soil sediments				
Weinberg and Newbold (2002)	U.S. studies	All confined animal feeding operations are required to install lagoons for storing animal wastes				Both surface and groundwater quality should improve				

Table A.8: Environmental Externalities Identified in Studies Related to Feeding and Confined Systems Including Intensive Operations

Author	Geographic Location	Nature of Mitigation Measures	Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
Weida (2001)	U.S.		Disease associated with manure: bacterial (Salmonella, Anthrax, Tuberculosis, Brucellosis, Tetanus, Coliform mastitis), Viral (Hog cholera, foot and mouth), Fungal (ringworm), Protozoal (Coccidiosis, Toxolasmosis) and Parasitic (Ascarissis, Sarcocystisis)							
Greenhouse Gas Emissions										
de Haan, Steinfeld, and Blackburn (1996)	Europe	Improve nutrient formulation in terms of incorporating optimum levels of nitrogen into feed and adding enzymes to improve the utilization rate of plant phosphorus								

Table A.8: Environmental Externalities Identified in Studies Related to Feeding and Confined Systems Including Intensive Operations

Author	Geographic Location	Nature of Mitigation Measures	Social: Health	Social: Other Social	Environmental: Soil	Water: Surface	Water: Ground	Air Quality	Climate Change	Biota
Steinfeld, de Haan and Blackburn (1996)	Europe	Multi-phase feeding where feed composition is much better suited to the needs of the animal							Through reduced GHG Emissions	
		Better balancing of feeds with essential nutrients								
		Add enzyme called phytase to animal's feed								
Larney et al. (2001)	Southern Alberta	Straw-bedded vs. chip-bedded composts were compared							Wood chip-bedded compost has better ammonia trapping ability (less N in gaseous form)	
Nitrogen and Phosphorus in Excretion										
Boland, Foster and Preckel (1999)	Purdue, Indiana	Switch rations to addressopportunity cost of replacement and joint optimization of feed ration composition for phase feeding.				Less excess protein most likely result in less N being excreted				

Table A.8: Environmental Externalities Identified in Studies Related to Feeding and Confined Systems Including Intensive Operations

Author	Geographic Location	Nature of Mitigation Measures	Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
de Haan, Steinfeld, and Blackburn (1996)	Europe	Improve accuracy of determining nitrogen and phosphorus requirements and better balancing of feeds and essential nutrients								
		Increase diet digestibility by adding phytase to the feed								
		Introduction of multi-phase feeding in order to match feed composition to the needs of the individual animal class						Improved through decreased odor		
Freeze et al. (1999)	Southern Alberta	Composting is an alternative to conventional manure management practices								
Wang and Sparling (1995)	Eastern Colorado	Composting for feedlots								

Table A.8: Environmental Externalities Identified in Studies Related to Feeding and Confined Systems Including Intensive Operations

Author	Geographic Location	Nature of Mitigation Measures	Social		Environmental						
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
Ammonia Emissions											
De Vos, Weersink and Stonehouse (1998)	Canadian, and European	Ration Adjustments									
Nutrient Recycling and Balance											
Freeze and Sommerfeldt (1985)	Southern Alberta										
Hoyt and Rice (1977)	Peace River, Alberta and British Columbia										
Brouwer et al. (1999)	EU	Protein levels in feeds can be reduced by providing feed more closely allied to animal requirements without affecting performance									
		Reduction of cereal intervention price									

Table A.9: Economic Impacts of Mitigation Measures , Farm and Society						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities**	
					Economic	
			Costs	**Benefits**	**Public Goods**	**Other Economic Impacts**
Multiple Pathways or Integrated Studies						
Goss et al.(1993)	Canada					
Manure Systems Research Group (1999)	Canada					
Stonehouse and Goss (1999)	Ontario	Environmental impacts in the model are not based on off-site damage costs, but on the basis of social acceptability aspects. Assumed here is that social acceptability is inversely related to odor emissions, and indirectly, to gaseous emissions and to water body pollutants in the form of nitrates, phosphorus, and bacteria, as proxies for environmental damage.				
Michie and Petkau (1999)			Output of the program includes: Economic value of the nutrients applied; Total cost (purchased equipment and custom operator each at both application rates); Net cost; and Storage cost.			
Stonehouse and Giraldez (1996)	Ontario		On-farm costs include: 1) capital costs of manure handling systems; 2) Operating costs: equipment maintenance, fuel, repairs, and others. Equipment operating rates is a major determinant of costs.	Inherent value of macro nutrients (N, P, K) and micro nutrients (Mn, Zn, Cu, B.).		

Table A.9: Economic Impacts of Mitigation Measures , Farm and Society						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities**	
					Economic	
			Costs	**Benefits**	**Public Goods**	**Other Economic Impacts**
Dijk, Leneman and van der Veen (1996)	Netherlands	No mitigation strategies were identified. No accounting for environmental externalities.				
Feng, Kurkalova and Seechi (2002)	Review of U.S. studies	No mitigation strategies were identified				
B.C. Ministry of Agriculture, Fisheries and Food	British Columbia	Maximum benefit is derived from manure when it is spread on the land in spring. Beef cattle manure should not be spread within 5 m of a bank or a slope leading to any watercourse, or within 30 m of streams flowing into shellfish growing areas or any well for a domestic water supply Apply manure on a cool day when odor production is lower				
General Studies with No Specific Pathways						
Rempel (1999)	Manitoba		Good manure management is cost-effective			
Bontems et al. (2002)	US	No mitigation strategies were identified.				
CSALE (1996)	Saskatche-wan	Manure from ILOs can be used as valuable fertilizer.				
Lazurus (2001)	Minnesota					
Legg and Potier (1998)	Europe	Establishment of codes of good agricultural practices				
Massey and Zering (2001)	U.S.					

Table A.9: Economic Impacts of Mitigation Measures , Farm and Society						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities**	
					Economic	
			Costs	**Benefits**	**Public Goods**	**Other Economic Impacts**
Nugent (1997)	Not specific (cases from different countries)					
Vukina and Woosink (1998)	Netherlands	Dutch legislation allows a total manure production from all animal sources of up to 125 kg of P_2O_5 per hectare of land				Distribution of land value changes under environmental policy imple-mentation
Vukina (2003)	U.S.					
Zilberman, Templeton and Khanna (1999)	U.S.	Policies to induce farmers to modify their behavior in ways that will improve environmental quality.	Taxes of pollution	Subsidies for environmentally enhancing activities		

Table A.10: Economic Impacts of Selected Mitigation Measures Related to Manure Handling and Application						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities (Economic)**	
			Costs	**Benefits**	**Public Goods**	**Other Economic**
Odor						
Lague (2000)	Canada	Modification of feeds and feeding systems		Improves animal health		
		Rapid removal of animal excretion from farm buildings				
		Add 3 mm layer of recycled and filtered vegetable oil on top of liquid manure within the barn collection pits				
Klein et. al. (1995)	Canada					
Danesh et al. (1999)	Canada	Better storage covers, solid/liquid separation, anaerobic treatment (especially at low temperatures), and injection during land application				
Flemming, Babcock, and Wang. (1998)	Iowa	Policy that requires incorporation of swine manure in soil after spreading		Dependent on distance hauled and nutrient content of manure.		
Larson (1991)	Saskatche-wan	Minimum distance between a pig unit and its neighbor (rural residence) should be 305 meters				
		Apply manure annually or semi-annually to reduce frequency of odor generation				
Tessier (2001)	Manitoba	Suggests various strategies for livestock housing, manure storage structure, and land application of manure				
Tyndall and Colletti (2001)	U.S.	No economics details were shown in the study				

Table A.10: Economic Impacts of Selected Mitigation Measures Related to Manure Handling and Application						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities (Economic)**	
			Costs	**Benefits**	**Public Goods**	**Other Economic**
Ammonia Emissions						
Lague (2000)	Canada	Compost swine manure with other by-products of waste materials				
		Add 3 mm layer of recycled and filtered vegetable oil on top of liquid manure within the barn collection pits (Pahl et al. 2000)				
Steinfeld, de Haan and Blackburn (1996)	Generic; No specific region of study	Manure collected under solid floors				
		Natural or forced ventilation systems or through biofilters / biowashers				
		Injection or application of manure into sub-soil		Significant		
		Better timing of application in response to crop requirements				
Sommer and Hutchings (2001)	Europe	Use trail hoses that will apply slurry onto the soil between rows of plants		Captures 40% of emitted NH_3		
		Cultivate before applying slurry		Reduce NH_3 losses to about 50% of those from uncultivated soils		
		Applying manure when conditions do not favor volatilization of ammonia				
		Injection of slurry into the soil				
		Increase application rate so a greater proportion of slurry is likely to infiltrate soil				
De Vos, Weersink and Stonehouse (2003)	Ontario	81 manure management systems derived from combination of 3 collection methods (gravity through slatted floors, partially slatted floors, and scraping of solid manure); 3 storage systems (earthen pit, open-topped concrete tank, and covered concrete tank); field application by irrigation gun, a tanker broadcast or a tanker injector.	No estimate of costs and benefits were provided in the study. Net returns were shown. These varied for a large farm from $115,620 to $123,600 per annum.			

Table A.10: Economic Impacts of Selected Mitigation Measures Related to Manure Handling and Application

Author	Geographic Location	Nature of Mitigation Measures	Private Economics of Mitigation		Externalities (Economic)	
			Costs	Benefits	Public Goods	Other Economic
Stonehouse, de Vos and Weersink (2002)	Ontario	Comply with minimum NH_4 restrictions by feeding a standard ration with supplemental synthetic lysine with fully-slatted floor collection covered concrete storage and tanker-injector for field application	Forego over $2,000 farm net income			
		Minimize excess N application by feed ration with lysine, floor collection, covered concrete tank storage and irrigation for field application	Forego over $1,700 farm net income			
Pollution by Phosphorus						
Lague (2000)	Canada	Application of swine manure on different soil-crop systems				
Sharpley and Moyer (2000)	Pennsylva-nia	Differences in composting processes and materials used influence the amount and relative distribution of inorganic P forms in the composted material				
		Attributes of soil affects adsorption of P released from manure or compost			Cleaner surface water	
Boland, Preckel and Foster (1998)	U.S.					
Featherstone (1998)	Texas	Limit manure application to keep soil phosphorus levels below accepted threshold		Reduced net benefits to producers		
Run-off and Leaching						
Flemming et al. (1998)	Iowa	Change in nutrient upon which manure applications are based on from N to P	Increase cost of delivering hog manure since rate of application decreases	Profit-maximizing number of hogs and profit levels under a phosphorus standard are greater		
Janzen et al. (1999)	Canada	Manure products could be distributed beyond livestock operational boundaries				

Table A.10: Economic Impacts of Selected Mitigation Measures Related to Manure Handling and Application						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities (Economic)**	
			Costs	**Benefits**	**Public Goods**	**Other Economic**
Letson and Gollehon (1998)	U.S.	Nutrient applications should match the quantity removed by harvested crops plus soil buffering capacity				
Innes (2000)	U.S.	Government sets higher chemical prices that will encourage producers to transport manure a greater distance		Reduced cost from decreased excess application		
		Government sets a minimum or maximum facility size or have a certain amount of land available for manure spreading for a certain number of animals				
Alberta Agriculture, Food and Rural Development (2001a)	Alberta	The owner / operator must construct a system that will limit the amount of surface water and run-on and run-off flowing through and from the operation or facility				
		The system must be constructed so that it does not significantly alter the volume, quality or rate of water flowing to each location where water naturally discharges				
		The system must be built so that it does not alter or affect any non-flowing water body				
		The owner / operator must not apply manure within 10 meters of a common body of water if the person is using the sub-surface injection				
		A person who applies liquid manure or catch basin contents must ensure that the contents do not create a risk to the environment by leaving the land to which they are applied, by entering a common body of water, or by becoming a return flow				

Table A.10: Economic Impacts of Selected Mitigation Measures Related to Manure Handling and Application						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities (Economic)**	
			Costs	**Benefits**	**Public Goods**	**Other Economic**
Larson (1991)	Saskatche-wan	Do not apply manure on snow where the land is subject to rapid spring run-off				
		Application of manure in excess of crop requirements results in residual nitrogen in root zone				
Coleman et al. (1999)	Minnesota					
Younie et al. (1996)	Canada	Leave crop residues on the soil surface				
King et al. (1994)	Ontario	No till modified injection method		Significant		
		Disturbance of macrospores by cultivation prior to liquid manure injection in no till fields		Reduced fuel consumption making the method more economically viable.		
Wright (2001)	Western Canada					
Brouwer et al. (1999)	EU					
Nutrient Imbalance and Recycling						
Janzen et al. (1999)	Alberta	Add processed manure		Crop response increases as number of years go by		
Wang and Sparling 1995)	Eastern Colorado	Composting	Fertilizer cost under manure was $51.2 million which was higher than that under composting at $49.7 million	Net returns increased from $190.2 million for raw manure to $191.6 million for composting		

Table A.10: Economic Impacts of Selected Mitigation Measures Related to Manure Handling and Application						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities (Economic)**	
			Costs	**Benefits**	**Public Goods**	**Other Economic**
Innes (1999)	U.S.		Results in on-farm cost minimization, but conflicts with off-farm environmental impacts			
Nagy, Schoneau and Schoney (1999)	Saskatche-wan	Optimum rates of manure application through timely removal of the manure using the highest rates to reduce costs for the grain producer		Maximizing profits is possible depending upon distance hauled		
Unterschultz and Jeffrey (2001)	Canadian and U.S.		If substitution with commercial fertilizer is ignored, manure can be transported up to 300 km			
Stonehouse and Narayanan (1984)	Ontario	Timely incorporation of manures into cropland to conserve plant nutrients, especially nitrogen, more effectively	Lower cost			
Larson (1991)	Saskatche-wan	Locate them where (1) there is sufficient land base to utilize total long term production without risk of nutrient loading; (2) has cropping practices which are amenable to manure injection or incorporation techniques.				
Efficient Use of Organic and Inorganic N and P						
Freeze et al. (1993)	Southern Alberta					
Larney and Janzen (1996)	Southern Alberta	Using manure to restore productivity of slighted eroded soils		Larger benefits than those from inorganic fertilizer		
		More efficient use of organic N and P sources		Saves money on fertilizer		
Younie et al. (1996)	Ontario	Fertilizers with high percentage of ammonical or ammonical-producing forms of nitrogen: urea, ammonium nitrate, anhydrous ammonia				
Schoneau et al. (1996)	Saskatche-wan					

Table A.10: Economic Impacts of Selected Mitigation Measures Related to Manure Handling and Application						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities (Economic)**	
			Costs	**Benefits**	**Public Goods**	**Other Economic**
Ambient Pollution						
Weersink (1996)	Review of all available studies					
Greenhouse Gas Emissions						
Thompson, Pain and Lockyer (1990)	Canada	Injection vs. Surface application	More nutrients available reducing fertilizer cost			
(The) Thomsen Corporation (2000)	Ontario	Change all incorporated manure for all systems to one day	Reduced producers margins from $14.1 million under the baseline to $9.6 million under the scenario -- a reduction of 32%			
AAFC (2000)	Canada	40% of applicable land will use no fall application of manure		Producer surplus reduced by 0.05% of baseline level		
Jackson, Keeney and Gilbert (2000)	North Central Iowa	Using earthen basins and soil injection of liquid manure				
Tessier and Marquis (1998)	Canada					
ESG International (1999)	Canada	Conversion of fall application to spring application				

Table A.11: Economic Impacts of Mitigation Measures Associated with Manure Storage						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities (Economic)**	
			Costs	**Benefits**	**Public Goods**	**Other Economic**
Ambient Pollution						
Westbarger and Letson (1995)	U.S.		Estimated cost of compliance differs regionally and by type of livestock. Higher costs in Delta region dairy farms. In general, dairy and swine farms had higher costs than poultry and beef farms.			
Larson (1991)	Saskatche-wan	Storage tank made of reinforced concrete or steel				
Innes (2000)	U.S.	Tax producers for external costs created by entry and increases in animal numbers	Tax for producers			
Pollution by Phosphorus						
Bolland, Preckel and Foster (1998)	U.S.	As animal numbers increase beyond market inventory requirements, combo of lagoon storage and irrigation application becomes the least cost method to manage manure.				Reduced cost of treating water for domestic and municipal use
Ammonia Emissions						
Stenfeld, de Haan and Blackburn (1996)	Generic; No specific region of study	Covering storage tanks				
		Solid storage systems that collect the feces only for storage in bulk				
		Covered tanks and manure kept under solid floors in stables				
Run-off and Leaching						
Barrington and Cap (1991)	Quebec	Use of geotextile cover	Covering of a solid manure platform with a coated and woven geotextile offers an economical alternative to conventional handling systems			

Table A.11: Economic Impacts of Mitigation Measures Associated with Manure Storage						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities (Economic)**	
			Costs	**Benefits**	**Public Goods**	**Other Economic**
Alberta Agriculture, Food, and Rural Development (2001b)	Alberta	Manure storage facilities shall not be constructed within 100 meters of any spring or water well and within 30 meters of any open body of water				
		A run-on control system should be built to prevent the flow of surface water into the storage				
		The system should be built so that run-off from the storage site must not enter an open body of water or leave the owner's property				
		The owner / operator should avoid sites with porous soil and / or fractured bedrock that would allow contaminants direct access to groundwater				
		Drainage must be provided within the feedlot or animal holding areas to prevent the retention of contaminated liquids on the lot surface. Manure run-off from drainage must not enter an open body of water or leave the owner's property.				
Ritter and Churnside (1990)	U.S.					
Holms and Klemme (1989)	Wisconsin			Annual net income was lowest for concrete tanks, followed by stacking slabs, daily haul, and earthen basis		

Table A.11: Economic Impacts of Mitigation Measures Associated with Manure Storage

Author	Geographic Location	Nature of Mitigation Measures	Private Economics of Mitigation		Externalities (Economic)	
			Costs	Benefits	Public Goods	Other Economic
Fulhage (1994)	Missouri		Net annual cost per cow ranged from $64 to $36 for the lagoon system, and from $156 to $58 for the slurry manure systems. No environmental costs were identified or estimated			
Lazenby (1995)	Ontario		The alley flush system costs were from $130 to $224 per cow, whereas the earthen lagoon system costs were as low as $2 per cow, while the concrete lagoon system costs were ten times higher			
Peters, Negrave and Colwell (Undated)	Canada	Open concrete tank, with a storage capacity that exceeds the standard 6 months. Application by top loading tank spreader.	BMP costs are high as net farm income declines	Improved hog health. Efficiency gains in management.		
Greenhouse Gas Emissions						
AAFC (2000)	Canada	Cover liquid storage tanks to reduce methane emissions		Reduced producer surplus by 0.02% of 2010 baseline level		
ESG International (1999)	Canada	Use of floating straw covers on large swine lagoons				
Kirchman and Witter (1992)	U.S.	Aeration of manure				
Odor						
Larson (1991)	Saskatche-wan	Covered storage	High cost of storage			
			Lower cost			

Table A.12: Economic Impacts of Mitigation Measures Related to Feeding and Confined Systems, Including Intensive Livestock Operations						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities (Economic)**	
			Costs	**Benefits**	**Public Goods**	**Other Economic**
General						
Ikerd (1999)	U.S.					
Korevaar (1995)	Europe					
Odor						
Eghball and Power (1994)	U.S.	Composting				
Coleman, Negrave and Colwell (Undated).	Minnesota					Mixed evidence on effect of location of feedlot on property values
Abeles-Allison (1990)	Michigan					Decrease land values. House values decreased $0.43 for each additional hog within 5 mile radius
Pollution by Phosphorous						
Lague (2000)	Canada	Improve feed and water management in hog operations				
Bolland, Preckel and Foster (1998)	U.S.	Add phytase to the diet	$.195/lb di-calcium replaced			
		Synthetic amino acids replacement for soybean meal: lysine & methionine	$1.65/lb lysine, $1.23/lb methionine	Reduces storage costs		
Run-off and Leaching						
Taylor and Rickerl (1998)	South Dakota	Adjust feedlot size.		Reduces storage costs		
Larney, Chang and Blackshaw (1999)	Southern Alberta	Composting	Reduction in hauling cost of 75-85% for compost instead of fresh manure	Composting renders weed seeds inviable, reducing herbicide inputs		
Weida (2001)	U.S.					

Table A.12: Economic Impacts of Mitigation Measures Related to Feeding and Confined Systems, Including Intensive Livestock Operations

Author	Geographic Location	Nature of Mitigation Measures	Private Economics of Mitigation		Externalities (Economic)	
			Costs	Benefits	Public Goods	Other Economic
Egbbal and Power (1994)	U.S.					
Weinberg and Newbold (2002)	U.S. studies	All confined animal feeding operations required to install lagoon storage				
Greenhouse Gas Emissions						
Steinfeld, de Haan and Blackburn (1996)	Europe	Multi-phase feeding where feed composition is targeted to animal needs		Less nitrogen and phosphorus		
		Better balancing of feeds with essential nutrients				
		Add enzyme-phytase to feed				
de Haan, Steinfeld, and Blackburn (1996)	Europe	Improve nutrient formulation: incorporate optimum levels of nitrogen in feed, and addenzymes to improve utilization rate of plant phosphorus				
Larney et al. (2001)	Southern Alberta	Straw-bedded vs. chip-bedded composts were compared				
Nitrogen and Phosphorus in Excretion						
de Haan, Steinfeld, and Blackburn (1996)	Europe	Improve accuracy of determining nitrogen and phosphorus requirements and better balancing of feeds and essential nutrients				
		Increase diet digestibility by adding phytase to the feed				
		Introduction of multi-phase feeding in order to match feed composition to the needs of the individual animal class		Less waste produced		
Freeze et al. (1999)	Southern Alberta	Composting is an alternative to conventional manure management practices	Reduced transportation cost of manure			

Table A.12: Economic Impacts of Mitigation Measures Related to Feeding and Confined Systems, Including Intensive Livestock Operations						
Author	**Geographic Location**	**Nature of Mitigation Measures**	**Private Economics of Mitigation**		**Externalities (Economic)**	
			Costs	**Benefits**	**Public Goods**	**Other Economic**
Boland et al. (1999)	Purdue, Indiana	Switching rations in order to handle opportunity cost of replacement and joint optimization of feed ration composition for phase feeding		For barrows and gils, feeding rather three than two rations increases returns by 22 and 8%, respectively.		
Wang and Sparling (1995)	Eastern Colorado	Composting for feedlots				
Ammonia Emissions						
De Vos, Weersink and Stonehouse (1998)	Canadian and European	Ration Adjustments	Cost-effective	Cheaper than reducing nitrogen excess through improved manure handling and storage systems		
Nutrient Recycling and Balance						
Freeze and Sommerfeldt (1985)	Southern Alberta			Based on nutrient contents of manure, is an economical substitute for commercial fertilizer when hauled up to 15 km		
Hoyt and Rice (1977)	Peace River Region of Alberta and British Columbia			Manure + fertilizer treatment gave little or no further increase in yield over the fertilizer treatment for barley		
Brouwer et al. (1999)	EU	Reduce protein levels in feed by providing feed more closely allied to animal requirements without affecting performance				
		Reduction of cereal intervention price				

Table A.13: Mitigation Measures Indicated in Studies, General Studies			
Author	**Geographic Location**	**Mitigation Measure**	
		Nature	**Impact**
Multiple Pathways or Integrated Studies			
Goss et al. (1993)	Canada	Suggestions given by this panel included developing extension packages to assist farmers in making more efficient use of nutrients in manure. The panel wanted to establish the relation between environmentally safe and most profitable rates of manure application to cropland.	
Manure Systems Research Group (1999)	Canada	No mitigation strategies identified	
Stonehouse and Goss (1999)	Ontario	Environmental impacts in the model are not based on off-site damage costs, but on the basis of social acceptability aspects. Assumed here is that social acceptability is inversely related to odor emissions, and indirectly, to gaseous emissions and to water body pollutants in the form of nitrates, phosphorus, and bacteria, as proxies for environmental damage.	
Michie and Petkau (1999)		No mitigation strategies identified	
Stonehouse and Giraldez (1996)	Ontario	No mitigation strategies identified	
B.C. Ministry of Agriculture, Fisheries and Food	British Columbia	Maximum benefit is derived from manure when it is spread on the land in spring. Beef cattle manure should not be spread within 5 m of a bank or a slope leading to any watercourse, or within 30 m of streams flowing into shellfish growing areas or any well for a domestic water supply Apply manure on a cool day when odor production is lower	
Dijk, Leneman and van der Veen (1996)	Netherlands	No mitigation strategies were identified. No accounting for environmental externalities.	
Feng, Kurkalova and Seechi (2002)	Review of U.S. studies	No mitigation strategies identified	

Table A.13: Mitigation Measures Indicated in Studies, General Studies			
Author	**Geographic Location**	**Mitigation Measure**	
		Nature	**Impact**
General Studies with No Specific Pathways			
Rempel (1999)	Manitoba	No mitigation strategies identified	
Bontems, Dubois and Vukina. (2002)	US	No mitigation strategies identified	
CSALE (1996)	Saskatchewan	Manure from ILOs can be used as valuable fertilizer but because such large amounts are accumulated, a large land base is needed for application.	
Lazurus (2001)	Minnesota	No mitigation strategies identified	
Legg and Potier (1998)	Europe	No mitigation strategies identified	
Massey and Zering (2001)	U.S.	No mitigation strategies identified	
Nugent (1997)	Not specific (cases from different countries)	No mitigation strategies identified	
Vukina and Woosink (1998)	Netherlands	In the very long run, the combined impact of the series of environmental policies aimed at regulating animal agriculture may end up having a neutral effect on land values.	
Vukina (2003)	U.S.	No mitigation strategies identified	
Zilberman, Templeton and Khanna (1999)	U.S.	No mitigation strategies identified	

Table A.14: Mitigation Measures Identified in Connection with Manure Handling and Application			
Author	**Geographic Location**	**Mitigation Measure**	
		Nature	**Impact**
Odor			
Lague (2000)	Canada	Modification of feeds and feeding systems	Reduced nutrient excretion
		Rapid removal of animal excretion from farm buildings	
		Add 3 mm layer of recycled and filtered vegetable oil on top of liquid manure within the barn collection pits	Reduce odor by 60%
Klein et. al. (1995)	Canada		
Danesh, Hodgkinson and Small (1999)	Canada	Better storage covers, solid/liquid separation, anaerobic treatment (especially at low temperatures), and injection during land application	
Flemming, Babcock and Wang (1998)	Iowa	Policy that requires incorporation of swine manure into the soil after spreading	Depends on crop rotation
Larson (1991)	Saskatchewan	Minimum distance between a pig unit and its neighbor (rural residence) should be 305 meters.	
		Apply manure annually or semi-annually to reduce the frequency of odor generation	
Tessier (2001)	Manitoba	Suggests various strategies at the livestock housing level, manure storage structure, and for land application of manure	
Tyndall and Colletti (2001)	U.S.	Planting of shelterbelts	Stipulates that shelterbelts are cost-effective way of reducing odors near livestock operations
Ammonia Emissions			
Lague (2000)	Canada	Compost swine manure with other by-products of waste materials	
		Add 3 mm layer of recycled and filtered vegetable oil on top of liquid manure within the barn collection pits (Based a study by Pahl et al. 2000)	Reduce ammonia emissions by 50%
DeVos, Weersink and Stonehouse (2003)	Ontario	Optimal method for a large farm: corn-soy base ration with lysine added, solid flood housing, earthen pit, and irrigation gun application method. This method produced highest net revenue to the producer. The same scenario except for the substitution of earthen pit by covered concrete tank provided the least amount of excess nitrogen applied.	

Table A.14: Mitigation Measures Identified in Connection with Manure Handling and Application			
Author	**Geographic Location**	**Mitigation Measure**	
		Nature	**Impact**
Steinfeld, de Haan and Blackburn (1996)	Generic; No specific region of study	Manure collected under solid floors	
		Natural or forced ventilation systems or through biofilters / biowashers	
		Injection or application of manure into the sub-soil	Reduce nutrient looses
		Better timing of application in response to crop requirements	Avoid further losses and enhance nutritive value of manure
Stonehouse, de Vos and Weersink (2002)	Ontario	Comply with minimum NH_4 restrictions by feeding a standard ration with supplemental synthetic lysine with fully-slatted floor collection covered concrete storage and tanker-injector for field application	NH_4 emissions decrease
		Minimize excess N application by feed ration with lysine with a floor collection, covered concrete tank storage and irrigation for field application	N emissions decrease
Sommer and Hutchings (2001)	Europe	Use trail hoses that will apply slurry onto the soil between rows of plants	Reduces canopy interception and a higher atmospheric NH_3 concentration above the slurry surface
		Cultivate before applying slurry	Reduce NH_3 losses to about 50% of those from an uncultivated soil
		Applying manure when conditions do not favor volatilization of ammonia	Could reduce total emissions of ammonia from applied slurry by 50%
		Injection of slurry into the soil	Effectiveness increases with depth of injection
		Increase the application rate so that a greater proportion of the slurry is likely to infiltrate in the soil	Emissions decrease with an increasing application rate
Pollution by Phosphorus			
Lague (2000)	Canada	Application of swine manure on different soil-crop systems	
Sharpley and Moyer (2000)	Pennsylvania	Differences in composting processes and materials used influence the amount and relative distribution of inorganic P forms in the composted material	
		Attributes of soil affects adsorption of P released from manure or compost	Less surface water runoff and / or leaching of P concentrate
Boland, Preckel and Foster (1998)	U.S.	Using phytase when feeding	The amount of phosphorus declined.

Table A.14: Mitigation Measures Identified in Connection with Manure Handling and Application			
Author	**Geographic Location**	**Mitigation Measure**	
		Nature	**Impact**
Featherstone (1998)	Texas	Limit manure application to keep soil phosphorus levels below an accepted threshold level	Enforcement of threshold levels may result in reduced number of animals, or closure of animal feeding facility
Run-off and Leaching			
Letson and Gollehon (1998)	U.S.	Nutrient applications should match the quantity removed by harvested crops plus soil buffering capacity	
Innes (2000)	U.S.	Government sets higher chemical prices that will encourage producers to transport manure a greater distance	Lower run-off because of decrease in excess application
		Government sets a minimum or maximum facility size or have a certain amount of land available for manure spreading for a certain number of animals	
Younie et al. (1996)	Canada	Leave crop residues on the soil surface	Decreases nitrate leaching by not disturbing soil macrospores
Janzen et al. (1999)	Canada	Manure products could be distributed beyond livestock operational boundaries	Decreases pollution into surface water
King et al. (1994)	Ontario	No till modified injection method	Reduced nutrient and bacteria contamination
		Disturbance of macrospores by cultivation prior to liquid manure injection in no till fields	Reduce contamination levels in surface water run-off and tile drain water
Flemming, Babcock and Wang (1998)	Iowa	Change in nutrient upon which manure applications are based from N to P	Applied nutrients better match crop requirements
Larson (1991)	Saskatchewan	Do not apply manure on snow where the land is subject to rapid spring run-off	
		Application of manure in excess of crop requirements results in residual nitrogen in root zone	Where precipitation rates exceed evapotranspiration, leaching can carry nitrates into underlying aquifers.
Wright (2001)	Western Canada		
Brouwer et al. (1999)	EU		
Coleman et al. (1999)	Minnesota		

Table A.14: Mitigation Measures Identified in Connection with Manure Handling and Application			
Author	**Geographic Location**	**Mitigation Measure**	
		Nature	**Impact**
Alberta Agriculture, Food and Rural Development (2001a)	Alberta	The owner / operator must construct a system that will limit the amount of surface water and run-on and run-off flowing through and from the operation or facility	
		The system must be constructed so that it does not significantly alter the volume, quality or rate of water flowing to each location where water naturally discharges	
		The system must be built so that it does not alter or affect any non-flowing water body	
		The owner / operator must not apply manure within 10 meters of a common body of water if the person is using the sub-surface injection	
		A person who applies liquid manure or catch basin contents must ensure that the contents do not create a risk to the environment by leaving the land to which they are applied, by entering a common body of water, or by becoming a return flow	
Nutrient Imbalance and Recycling			
Janzen et al. (1999)	Alberta	Add processed manure	Nutrients recycled back into crop growing regions
Wang and Sparling (1995)	Eastern Colorado	Composting	Improves net returns of the farmer
Innes (1999)	U.S.		
Nagy, Schoneau and Schoney (1999)	Saskatchewan	Optimum rates of application of manure through timely removal of the manure using the highest rates to reduce costs for the grain producer	Swine manure has an economic hauling distance of 6.3 to 13.6 km depending on crop response to applied nutrients. Cattle manure can be hauled economically for 8 km.
Unterschultz and Jeffrey (2001)	Canadian and U. S.		
Stonehouse and Narayanan (1984)	Ontario	Timely incorporation of manures into cropland to conserve plant nutrients, especially nitrogen, more effectively	
Larson (1991)	Saskatchewan	Locate them where (1) there is sufficient land base to utilize total long term production without risk of nutrient loading; (2) has cropping practices which are amenable to manure injection or incorporation techniques	

Table A.14: Mitigation Measures Identified in Connection with Manure Handling and Application			
Author	**Geographic Location**	**Mitigation Measure**	
		Nature	**Impact**
Efficient Use of Organic and Inorganic N and P			
Freeze et al. (1993)	Southern Alberta		
Larney and Janzen (1996)	Southern Alberta	Using manure to restore productivity of slighted eroded soils	Better seed germination and seeding establishment
		More efficient use of organic N and P sources	Restore eroded soil and reduce inputs of N and P fertilizer
Younie et al. (1996)	Ontario	Using fertilizers that contain a high percentage of ammonical or ammonical-producing forms of nitrogen (such as urea, ammonium nitrate, anhydrous ammonia)	Delays formation of nitrate and reduces potential loss during period
Schoneau et al. (1996)	Saskatchewan		
Ambient Pollution			
Weersink (1996)	Review of all available studies		
Greenhouse Gas Emissions			
Thomson et al. (1987)	Canada	Injection vs. Surface application	Injection results in less gaseous losses and more N available to crops
(The) Thomsen Corporation (2000)	Ontario	Change all incorporated manure for all systems to one day	Reduction in 2010 baseline emissions level by 0.7% for IPCC accounting and increase by 0.6% for the agriculture and Agri-food sector level
AAFC (2000)	Canada	40% of applicable land will use no fall application of manure	Reduced GHG emission levels by 0.13% of the baseline in 2010
Jackson, Keeney and Gilbert (2000)	North Central Iowa	Using earthen basins and soil injection of liquid manure	34% of N transferred into atmosphere compared to 88% by anaerobic lagoon storage and spray irrigation
Tessier and Marquis (1998)	Canada		
ESG International (1999)	Canada	Conversion of fall application to spring application	Reduces 500 Gg of CO_2 equivalent GHGs

Table A.15: Mitigation Measures Suggested in Connection with Manure Storage

Author	Geographic Location	Mitigation Measure	
		Nature	Impact
Ambient Pollution			
Westenbarger and Letson (1995)	U.S.		
Larson (1991)	Saskatchewan	Storage tank made of reinforced concrete or steel	
Innes (2000)	U.S.	Tax producers for external costs created by entry and increases in animal numbers	Producers would be more conscious of their waste removal strategies
Pollution by Phosphorus			
Bolland, Preckel and Foster (1998)	U.S.	As number of animals increase beyond the amount required for the market inventory, the combination of lagoon storage and irrigation application becomes the least cost method to manage manure	
Ammonia Emissions			
Stenfeld, de Haan and Blackburn (1996)	Generic; No specific region of study	Covering storage tanks	80 - 90% reduction
		Solid storage systems that collect the feces only for storage in bulk	Have low gaseous emissions
		Covered tanks and manure kept under solid floors in stables	Reduction in emissions of 80 to 90% can be achieved
Run-off and Leaching			
Barrington and Cap (1991)	Quebec	Use of geotextile cover	Prevents contact between rain and the solid manure pile, thereby reducing run-off.
Ritter and Churnside (1990)	U.S.		
Holms and Klemme (1989)	Wisconsin		
Fulhage (1994)	Missouri		
Lazenby (1995)	Ontario		

Table A.15: Mitigation Measures Suggested in Connection with Manure Storage			
Author	**Geographic Location**	**Mitigation Measure**	
		Nature	**Impact**
Peters, Negraves and Colwell (Undated)	Canada	Open concrete tank, with a storage capacity that exceeds the standard 6 months. Application by top loading tank spreader.	
Alberta Agriculture, Food, and Rural Development (2001b)	Alberta	Manure storage facilities shall not be constructed within 100 meters of any spring or water well and within 30 meters of any open body of water	Minimize odor nuisance and avoid contamination of groundwater and surface water
		A run-on control system should be built to prevent the flow of surface water into the storage	
		The system should be built so that run-off from the storage site must not enter an open body of water or leave the owner's property	
		The owner / operator should avoid sites with porous soil and / or fractured bedrock that would allow contaminants direct access to groundwater	
		Drainage must be provided within the feedlot or animal holding areas to prevent the retention of contaminated liquids on the lot surface. Manure runoff from drainage must not enter an open body of water or leave the owner's property.	
Greenhouse Gas Emissions			
AAFC (2000)	Canada	Cover liquid storage tanks to reduce methane emissions	Reduced GHG emissions by 1.37% of 2010 baseline level
ESG International (1999)	Canada	Use of floating straw covers on large swine lagoons	Estimated 3,600 Gg of CO_2 equivalent GHG reduction
Kirchman and Witter (1992)	U.S.	Aeration of manure	
Odor			
Larson (1991)	Saskatchewan	Covered storage	

Table A.16: Mitigation Measures Identified in Connection with Feeding and Confined Systems, Including Intensive Livestock Operations

Author	Geographic Location	Mitigation Measure	
		Nature	**Impact**
General			
Ikerd (1999)	U.S.		
Korevaar (1995)	Europe		
Odor			
Eghball and Power (1994)	U.S.	Composting	Provides a stabilized product that can be stored or spread with little odor
Coleman et al. (1999)	Minnesota		
Abeles-Allison (1990)	Michigan		
Pollution by Phosphorous			
Lague (2000)	Canada	Improve feed and water management in hog operations	Reduced manure production
Bolland, Preckel and Foster (1998)	U.S.	Add phytase to the diet	Reduction in land requirements for application
		Synthetic amino acids (replacement for soybean meal): synthetic lysine, synthetic methionine	Less inorganic phosphorus being fed as an ingredient
Run-off and Leaching			
Taylor and Rickerl (1998)	South Dakota	Adjust feedlot size	Smaller feedlots reduce risk of non-point pollution, whereas the large feedlots increase risk
Larney, Chang and Blackshaw (1999)	Southern Alberta	Composting	Volume reduction in the magnitude of 80%. Increase in the hauling distance.
Egbbal and Power (1994)	U.S.		
Weida (2001)	U.S.		
Weinberg and Newbold (2002)	U.S. studies	All confined animal feeding operations are required to install lagoons for storing animal wastes	These storage systems volatilize nitrogen, thereby reducing the concentration of nitrogen in the lagoon effluent and reducing potential impairments to water quality

Table A.16: Mitigation Measures Identified in Connection with Feeding and Confined Systems, Including Intensive Livestock Operations

Author	Geographic Location	Mitigation Measure	
		Nature	**Impact**
		Greenhouse Gas Emissions	
Steinfeld, de Haan and Blackburn (1996)	Europe	Multi-phase feeding where deed composition is much better suited to the needs of the animal	Less waste is produced
		Better balancing of feeds with essential nutrients	Reduction of nitrogen and phosphorus excretions by 20 - 40%
		Add enzyme called phytase to animal's feed	Catalyses the digestion of phosphorus contained in feed
de Haan, Steinfeld, and Blackburn (1996)	Europe	Improve nutrient formulation in terms of incorporating optimum levels of nitrogen into feed and adding enzymes to improve the utilization rate of plant phosphorus	Reduced loading environment with these goods
Larney et al. (2001)	Southern Alberta	Straw-bedded vs. chip-bedded composts were compared	Straw-bedded compost provided twice as much total N as wet straw-bedded manure. Wood chip-bedded compost only provided slightly less than twice as much.
		Nitrogen and Phosphorus in Excretion	
de Haan, Steinfeld, and Blackburn (1996)	Europe	Improve accuracy of determining nitrogen and phosphorus requirements and better balancing of feeds and essential nutrients	Reduce nitrogen by 20 to 40%
		Increase diet digestibility by adding phytase to the feed	Catalyzing the digesting of phosphorus in feed
		Introduction of multi-phase feeding in order to match feed composition to the needs of the individual animal class	Less waste produced
Wang and Sparling (1995)	Eastern Colorado	Composting for feedlots	Feedlot manure is an economically efficient substitute for chemical fertilizer
Freeze et al. (1999)	Southern Alberta	Composting is an alternative to conventional manure management practices	Straw-based compost had the lowest cost
Boland, Foster and Preckel (1999)	Purdue, Indiana	Switching rations in order to handle opportunity cost of replacement and joint optimization of feed ration composition for phase feeding	Substantial economic incentives for producers to feed more than one ration

Table A.16: Mitigation Measures Identified in Connection with Feeding and Confined Systems, Including Intensive Livestock Operations			
Author	**Geographic Location**	**Mitigation Measure**	
		Nature	**Impact**
Ammonia Emissions			
De Vos, Weersink and Stonehouse (1998)	Canadian and European	Ration Adjustments	Reduces excess nitrogen
Nutrient Recycling and Balance			
Freeze and Sommerfeldt (1985)	Southern Alberta	Manure valued for its N and P_2O_5 content can economically substitute for commercial fertilizer in production of agricultural crops at distances of up to 15 km from feedlot sources	Dependent on the crop
Hoyt and Rice (1977)	Peace River Region of Alberta and British Columbia		
Brouwer et al. (1999)	EU	Protein levels in feeds can be reduced by providing feed more closely allied to the animals requirements without affecting its performance	Reduces nitrogen pollution at source
		Reduction of cereal intervention price	Brings substitution between grain and protein-based feedstuff (soybean meal)

Table A.17: Studies Related to Transformation of Manure to Other Products

Author	Geographic Location	Particulars, Indicative Impact (No Mitigation) & Major Findings
CAEEDAC (1999)	Saskatchewan	Development of renewable energy as biogas. Biogas digesters may reduce methane emissions up to 70% with longer reductions possible at longer retention times.
Higham (1998)	European	Economic feasibility of farm level anaerobic digestion of agricultural wastes. The analysis done showed that the plants were not economically attractive.

Table A.18: Economic Impacts of Production of Biogas through Anaerobic Digestion

Author	Geographic Location	Nature	Private Economics of Mitigation		Externalities (Economic)	
			Costs	Benefits	Public Goods	Other Economic Impacts
CAEEDAC (1999)	Saskatchewan	Biogas digesters are a source of pollution-free heat and electricity, enriched fertilizer, and waste-management		Provision of farm inputs		
Higham (1998)	European					

Table A.19: Environmental Externalities Associated with Production of Biogas through Anaerobic Digestion

Author	Geographic Location	Nature of Mitigation Measure	Social		Environmental					
			Health	Other Social	Soil	Water		Air Quality	Climate Change	Biota
						Surface	Ground			
CAEEDAC (1999)	Saskatchewan	Biogas digesters are a source of pollution-free heat and electricity, enriched fertilizer, and waste-management				Reduced leaching and run-off resulting in improved quality of water		Reduced odor	Reduced methane emissions	
Higham (1998)	European									