Linking Water Science to Policy: Effects of Agricultural Activities on Water Quality

A CCME sponsored workshop

Science de l'eau et politiques: Effets des activités agricoles sur la qualité de l'eau

Un atelier parrainé par le CCME

January 31 and February 01, 2002 — Québec City

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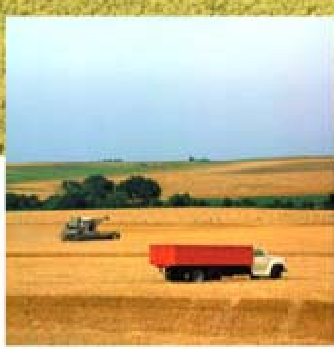

CCME Linking Water Science to Policy Workshop Series

Effects of Agricultural Activities on Water Quality

A workshop sponsored by the Canadian Council of Ministers of the Environment

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The report, *Linking Water Science to Policy: Effects of Agricultural Activities on Water Quality*, synthesizes presentations and discussions that took place during a two-day workshop held in Québec City on January 31 and February 1, 2002. The workshop was attended by about 70 science and policy experts from provincial and federal environment and agriculture departments, other federal departments, universities, and private agencies. The workshop was organized by a working group that set the scope of the workshop and established the program. Members of the workshop organizing committee were:

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Sincerely,

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Workshop Context and Overview

The Canadian Council of Ministers of the Environment (CCME) provides a forum for federal, provincial and territorial governments to cooperate on priority environmental issues. Because of concerns about water quality and the value placed on water by Canadians, CCME has made water quality one of its top priorities.

One active CCME initiative is directed at ensuring that CCME members, and policy and decision makers in particular, are up-to-date on the latest science with respect to various water quality issues. CCME also wanted to provide an opportunity for its members to give input to the scientific community on water quality-related research priorities.

CCME identified an initial list of three priority areas for information exchange:

1. water quality impacts of agricultural practices;
2. groundwater quality; and
3. water quality issues related to water reuse and recycling.

It was agreed that Environment Canada's National Water Research Institute (NWRI), on behalf of CCME, would organize a series of workshops where leading scientists would be invited to present the latest science related to the above issues. The targeted audience would include CCME members' representatives, and other federal, provincial and territorial departments, as well as stakeholders. The meetings would be designed to maximize the exchange of information and to provide CCME members and stakeholders an opportunity to comment on future research directions and priorities.

This is the report from the first of the workshops, held January 31 and February 1, 2002, and co-chaired by NWRI and the Province of Québec. The workshop was attended by about 70 science and policy experts from provincial and federal environment and agriculture departments, other federal departments, universities, and private agencies. A tremendous success, this workshop has set the standard as a ground-breaking enterprise in building a substantive, much-needed and ongoing dialogue between the scientific and policy-making communities.

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Executive Summary

The Canadian Council of Ministers of the Environment (CCME) is the major inter-governmental forum in Canada for discussion and joint action on environmental issues of national and international concern. In fall 2001, in response to concerns about water quality in Canada, CCME initiated a workshop series, *Linking Water Science to Policy*, on priority water quality issues. Organized by Environment Canada's National Water Research Institute with provincial co-chairs, the series will communicate results of new research and management practices to senior decision makers and policy makers, and provide a mechanism for scientists and water managers to contribute expert input to Canadian water programs.

The first workshop, held January 30 to February 1, 2002, in Québec City, focused on the effects of agricultural activities on water quality. It was attended by about 70 science and policy experts from provincial and federal environment and agriculture departments, other federal departments, universities, stakeholders and private agencies. This report synthesizes the workshop's presentations, panel discussions and town-hall debates on impacts of agricultural practices on water quality, the role of new technologies for minimizing agriculture's impacts on water, and the usefulness of new and proposed regulations for protecting environmental quality from agricultural pollution.

Risks to Water Quality from Agriculture in Canada

Intensification of agricultural operations over the last 40 years has increased the risk of contamination of surface and ground waters by pollutants such as eroded soil, nutrients and pesticides. Today, elevated concentrations of nutrients and pesticides are frequently detected in surface waters draining cropland.

Recently, both the water science community and the public have become concerned about pathogenic organisms, endocrine-disrupting compounds, and veterinary pharmaceuticals persisting in agricultural soils fertilized with manure, potentially to be transported to surface and ground waters.

At present in Canada, there are not enough data to evaluate risks to humans and aquatic biota from agricultural sources of these materials. What is to be done to improve our understanding of these and other risks to Canadian water quality from agricultural activities? Workshop participants identified several areas where scientific knowledge is lacking and research efforts should be strengthened.

- To promote accurate prediction of the impacts of changes in agricultural land management practices on water resources, a greater understanding of biogeochemical and hydrological cycles is needed, particularly in light of the variations in precipitation and discharge resulting from climate change.

- Soil erosion can play an important role in non-point pollution of receiving waters. Information is needed on the bioavailability of contaminants in soil, and the effects of agronomically acceptable rates of soil loss on aquatic ecosystems.

- Nutrients such as nitrogen and phosphorus moving off farmland can elevate levels in surface water, causing eutrophication. More work is needed to determine the pathways of nutrients from ground to water, and to develop models to predict effects on biota in different types of aquatic systems.

- Surface and ground water in certain regions of Canada are contaminated by pesticides, although concentrations seldom exceed water quality guidelines for drinking water. However, Canadian guidelines are among the least stringent in the western world and do not adequately address the issue of mixtures of pesticides. Research should evaluate the effects to humans and aquatic ecosystems from long-term exposure to low levels of chemicals and to potential synergistic effects of chemical mixtures.

- Animal and municipal waste is applied to agricultural land as fertilizer, and the question is whether pathogenic organisms in manure persist in the fertilized soil and are transported to surface and ground water. Soils and water are hostile environments for pathogenic organisms, but they have been found in groundwater and rural wells. To understand risks, more research is needed on their persistence and ecology in the environment.

- In the agricultural setting, endocrine-disrupting substances and veterinary pharmaceuticals find their way into water bodies through runoff or seepage from fields treated with manure. At present, data for Canada are very limited and more scientific information is needed on exposure and dispersal of these substances in the environment, and on the role and importance of naturally occurring hormonally active substances.

Technologies for Minimizing Risks to Water Quality from Agriculture

Many science-based solutions for reducing agricultural losses of chemical or biological contaminants to surface and ground waters are available or in the developmental stage. In recent years, considerable effort has been directed at reducing the nutrient content of hog manure through practices such as enhancing the digestibility of phosphorus in the feed, producing transgenic pigs capable of better digesting phosphorus, and reducing the quantity of crude protein in the diet.

New approaches for treating manure are also available, including composting of manure, solid-liquid separation of manure, and manure digesters. Another method to reduce the use and potential off-site transport of agrochemicals and manure is precision agriculture, a computer-guided approach for managing variability within a field by precisely tailoring inputs to crop needs.

Although some of these techniques require further testing to make them operational or to meet regulatory requirements, improvements in water quality can be expected as these and other practices aimed at reducing environmental losses of nutrients, pesticides, and other chemicals and pathogens are implemented.

Policies and Initiatives for Minimizing Agricultural Water Pollution

To promote management practices and technologies that make the agricultural production and processing industry more environmentally sustainable, both federal and provincial governments are developing and implementing new policies.

Federal and provincial ministers of agriculture are developing a National Agricultural Policy Framework that will make Canada a world leader in food safety, innovation and environmental protection. To put this new framework into practice, Agriculture and Agri-Food Canada has adopted a new business line, *Health of the Environment*, which focuses on using agri-environmental resources in a sustainable manner.

Other new agri-environmental initiatives include:

- legislation in Prince Edward Island requiring buffer zones along all watercourses;
- a regulation in Québec on application of fertilizing materials to agricultural land; and
- the Alberta Environmentally Sustainable Agriculture Program to promote adoption of environmentally sustainable practices by the agri-food sector and monitor changes in the environment affected by agricultural activities.

Linking Water Science and Policy

This workshop has served as a vigorous first step in building a substantive, much-needed, ongoing dialogue between the scientific and policy-making communities in agriculture and environment. Several issues in relating science to policy recurred:

- the need for sound science as the basis of policy decision;
- improved sharing of policy experiences among jurisdictions;
- improved sharing of technology and a concise plain language repository of current scientific information; and
- regular communication to scientists of the needs of policy developers.

There was general agreement that environmental/agricultural policy needs to keep pace with our scientific knowledge and technology development. Global market demands and economies of scale associated with larger farm size and specialization will support the adoption of science-based solutions and development of new technologies which will assist in reducing pollutants entering waterways from the agricultural land base.

It is critical that the advances in agricultural production necessary to feed an increasing global population do not outpace adoption of better management practices and other control measures aimed at environmental protection, and that the best and most advanced science be integrated systematically into practical solutions.

Maintaining the Dialogue

CCME is considering options for maintaining, and indeed expanding the dialogue initiated during the workshop.

In all likelihood, electronic media — particularly dedicated or re-vamped web sites, electronic bulletin boards, moderated chat rooms, and subject-specific, subscription-based email lists — will prove most expedient in encouraging the flow of information. The potential for follow-up workshops, or perhaps dedicated sessions at targeted conferences, for both the science and policy communities will also be explored.

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Introduction

Water is a key component of the modern Canadian economy: it is a fundamental resource for food production, plays an important role in virtually every modern industrial process and many recreational activities, and is essential for urban development. It is critical to the health and survival of plants, animals, and people. In Canada, water is generally plentiful and clean, however, it is sometimes locally or regionally polluted. Pollution enters surface and ground waters from industrial and municipal discharge, in runoff and seepage from land managed for agriculture or forestry, and from deposition of airborne pollutants. Impacts of pollution include threats to drinking water in certain areas, closures of shellfish harvesting areas on the Atlantic and Pacific coasts, loss of part of the Great Lakes fishery, reduced ecosystem diversity, and fewer recreational opportunities.

Because of concerns about water quality and the value placed on water by Canadians, the Canadian Council of Ministers of the Environment (CCME) recently identified water quality as a priority issue. CCME is the major inter-governmental forum in Canada for discussion and joint action on environmental issues of national and international concern. The Council is made up of environment ministers from the federal, provincial and territorial governments. CCME works to promote cooperation on and coordination of interjurisdictional issues (e.g., waste management, air pollution, water and toxic chemicals) and to provide a forum for cooperation in developing and maintaining the scientific information base required to support sound environmental decision making. In response to concerns about protection of water quality, CCME recently sponsored a workshop on the effect of agricultural activities on water quality.

> 75% of Canadians are very concerned about quality of their drinking water and 68% are very concerned about water pollution (Goldfarb 2001).
>
> The Canadian Council of Ministers of the Environment in collaboration with the National Water Research Institute has organized a series of workshops on priority water quality topics to strengthen the links between science and policy.

Agriculture is integral to Canadian society, making significant contributions to the economy, rural communities and food security. A major question facing the agricultural sector, however, is the long-term environmental sustainability of production. The last century saw great development in many agricultural technologies such as high-yielding crop varieties, chemical fertilizers, pesticides, irrigation and mechanization. These developments resulted in agricultural operations becoming increasingly specialized so that emphasis is now either on livestock rearing or intensive cropping. Considerable amounts of chemical inputs (fertilizer and pesticides) are required for crop production. In the case of intensive livestock operations, inadequate acreages of nearby cropland have resulted in manure being regarded in some locales as a waste requiring disposal, rather than as a fertilizer and soil amendment. These issues along with the cultivation of marginal land, caused in part by loss of prime agricultural land to urbanization, have raised concerns about the effect of agricultural activities on water quality.

This paper presents the results of the CCME sponsored workshop *Linking Water Science to Policy: Effects of Agricultural Activities on Water Quality* held on January 31 and February 1, 2002, in Québec City (Appendix 1). The goals of the workshop were to:

- present current research findings to policy and decision makers;

- ensure that this research is meeting the needs of this user community;
- identify future research priorities; and
- determine a process for ongoing information sharing and communication.

Approximately 70 representatives from provincial and federal environment and agriculture departments, other federal departments, universities, and private agencies attended. Presentations, panel discussions and town-hall debates took place on the impacts of agricultural practices on water quality, including issues such as the role of agriculture as a contributor of pathogens, pesticides and nutrients to surface and ground waters. Also discussed were the role of new technologies for minimizing agriculture's effects on water, and the usefulness of new and proposed regulations for protecting environmental quality from agricultural pollution. This report synthesizes the information presented during these two days of information exchange and debate on the effects of agricultural activities on water quality in Canada.

Risks to Water Quality from Agriculture in Canada

Over the past 40 years, the number of farms in Canada has declined, but those that remain have become larger and more productive. This transformation was made possible by greater mechanization, the use of mineral fertilizers and pesticides, new and better crop varieties, and innovative farming practices. Over time, some of these advances have compromised environmental health, including water quality. Agricultural impacts on water resources are caused by:

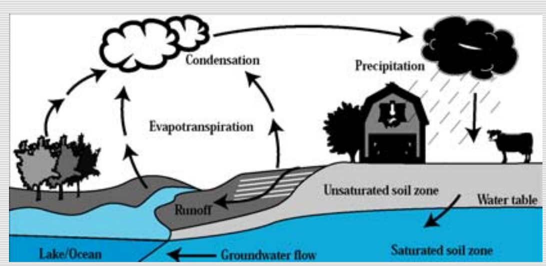
- the need for additional water (semi-arid landscapes) or to route excess water off fields (humid landscapes);
- the need for additional nutrients, organic material or both (in the form of mineral fertilizer, manure, compost, sewage sludge) to maintain soil quality and increase crop productivity;
- the use of pesticides (fungicides, herbicides and insecticides) for disease, weed and insect control;
- alterations to soil conditions caused by tillage and cropping patterns; and
- drainage of wetlands and canalization of streams to increase the area of agriculturally productive land.

In certain regions, these activities have increased the potential for soil erosion and the loss of nutrients, pesticides, pathogens and veterinary pharmaceuticals from agricultural land to surface and ground waters.

Hydrology and Agriculture

Knowledge of hydrological processes is essential for understanding agricultural impacts on water quality because most contaminants are transported in water either from the field or in the atmosphere. Agricultural impacts on water quantity may also have indirect impacts on water quality through concentration or dilution of contaminants. The components of the hydrologic cycle with the greatest relevance to agriculture and water quality are evaporation (specifically evapotranspiration of crops and evaporation from bare soil), soil storage, and partitioning between infiltration and surface runoff. Changes to one component of the cycle will have consequences for the others.

Agriculture and the hydrologic cycle. (From Agriculture and Agri-Food Canada 2000)



Intentional modifications to the hydrologic cycle by agriculture include irrigation and drainage. Under irrigation management, surface or ground water is artificially moved to become precipitation. Subsurface drainage systems take percolating water destined to recharge groundwater and transfer it to surface waters. This accelerates the natural process where some of the water percolating to groundwater may slowly return to surface water through groundwater contributions to base flow.

Many components of the hydrologic cycle are more subtly affected by agricultural management practices. For example, summer fallowing eliminates transpiration, causing an increase in soil moisture storage that could increase deep percolation and reduce subsequent infiltration. Land management can directly affect partitioning between infiltration and runoff. As an instance, introduction of brome grass in the upland area around prairie wetlands can eliminate spring runoff to the wetland within several years, due to retention of snow by this stiff-strawed grass and subsequent infiltration of meltwater into the upland soil. Similarly, the stable soil and pore structure that develops under zero-tillage can increase the infiltration capacity of the soil and thus reduce runoff compared to conventional tillage.

As climate varies across Canada, so does the regional expression of the hydrologic cycle. The greatest soil moisture deficits occur in the south-western Prairies and the interior of British Columbia while the greatest runoff is measured in coastal British Columbia and Atlantic Canada. These differences in climate and agricultural management lead to different agricultural impacts on hydrology. In coastal British Columbia, excess water is the major hydrological challenge in agriculture, and agricultural management that maximizes water use is preferable. Conversely, efficient water-use is critical for irrigated horticultural crops grown in the semi-arid climate in the interior of British Columbia, and there is a trend toward development of improved irrigation management systems to conserve moisture. On the Prairies, snowmelt is the critical event for surface water recharge and also affects groundwater recharge. Snowmelt occurs over frozen soils with low infiltration rates controlled by fall soil moisture content. Snow processes, such as blowing snow and sublimation, can be altered by stubble management and affect the accumulation and distribution of snow and, hence, the relative proportions of infiltration and runoff as the snowpack melts. Much of the agricultural land in Ontario and Québec is tile-drained. A combination of preferential flowpaths and subsurface drainage can result in almost immediate detection in tile drain effluent of amendments that are applied to the soil. These can cause concern for water quality. In Atlantic Canada, erosion control practices such as terracing and contour tillage may modify local hydrology but their impact has not been studied.

Knowledge Gaps for Hydrology

Understanding risk:
- identification of hydrologically active areas
- identification of critical transport pathways
- identification of recharge areas for groundwater
- determination of the relative amount of water moving through preferential flow
- climate change impacts on hydrology

Managing risk:
- BMPs adapted for hydrologically active areas

Since knowledge of the pathways through which water has passed and the amount of water flowing is central to the understanding of water quality, water quality models should consider hydrology. Although models have been developed that include hydrology and water quality, they can not be applied throughout Canada (particularly the Prairies) due to deficiencies in understanding of cold region hydrology. Research is currently underway to characterize prairie hydrology for water quality modelling. Another objective in water quality modelling is the identification of hydrologically active areas that contribute water to streams, wetlands, lakes and groundwater. Best management practices can then be targeted to these areas to minimize impacts on water quality.

Soil Erosion

Soil erosion moves topsoil and deposits it elsewhere. Although a natural process, soil erosion may be greatly accelerated by cultivation of soils or implementation of aggressive agricultural practices, a condition referred to as accelerated or anthropogenic erosion. Many factors combine to define the vulnerability of agricultural landscapes to erosion including erosivity of precipitation, soil erodibility, slope length and gradient, and crops and cropping practices, resulting in considerable variation in risk of soil erosion across Canada. Worldwide, water erosion accounts for 56% of all forms of soil degradation.

Percentage of Canadian cropland at risk of water erosion under prevailing management practices, by province (1996 data). From: Shelton et al. 2000

	% of Cropland in Various Risk Classes				
	Tolerable (less than 6t/ha/yr)	Low (6 to 11 t/ha/yr)	Moderate (11 to 22 t/ha/yr)	High (22 to 33 t/ha/yr)	Severe (greater than 33t/ha/yr)
BC	56	19	19	5	1
AB	83	11	6	1	<1
SK	90	5	5	1	<1
MB	89	4	4	1	2
ON	58	27	6	10	<1
QC	88	9	3	0	0
NB	48	30	14	5	3
NS	72	15	10	<1	2
PEI	59	23	19	0	0

Agricultural soils can tolerate a certain amount of erosion without adverse effects on soil quality or crop productivity because new soil is constantly being formed. In Canada, the tolerable limit for soil erosion is about 5 tonnes soil/ha on well-developed agricultural soils and less on shallow or already degraded soils. However, accelerated soil erosion results in a general decline in soil quality due to loss of soil organic matter and nutrients, degradation of soil structure, soil compaction, and less water infiltration and more runoff in spring and after storms, leading to the formation of rills or gullies in fields. Ultimately, these changes in soil physical, chemical and biological properties can result in reduced crop quality and yield and water pollution. On-farm impacts of soil erosion have been estimated to millions of dollars annually and are particularly significant in provinces (Québec, British Columbia, Maritimes) where availability of prime quality soils is limited.

Impacts of water erosion are not limited to soils. The quality of receiving water bodies may be impaired by problems of turbidity and sedimentation. The eroded sediments are also very effective as carriers for pollutants such as nutrients and pesticides. It is now accepted that a large proportion (>75%) of the losses of phosphorus through surface runoff are associated with eroded soil particles. The same holds for many pesticides.

Knowledge Gaps for Soil Erosion

Understanding risk:
- bioavailability of contaminants moved with eroded sediments
- effect on aquatic ecosystems of agronomically acceptable rates of soil loss
- significance of snowmelt erosion in annual erosion budgets

Monitoring risk:
- whether soil conservation practices work at a watershed scale

Managing risk:
- modelling tools for strategic management of problem areas

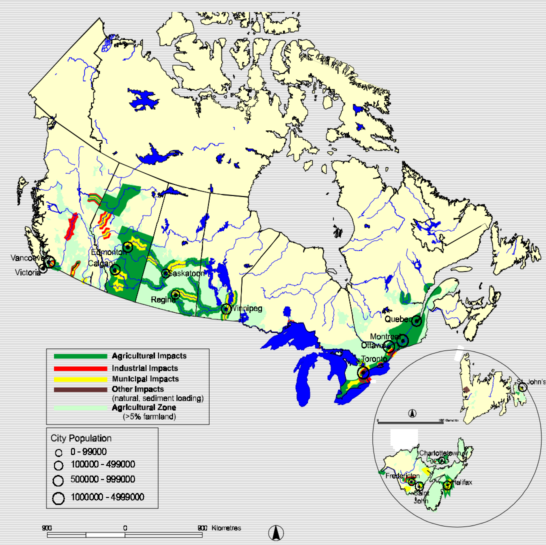
The links between soil erosion and non-point pollution call for common solutions. Soil conservation techniques also present a strong potential for controlling agricultural non-point pollution. However, for a significant and effective reduction of non-point pollution, implementation of these practices must be part of an integrated approach, at the farm and watershed scales.

Nutrients

Nutrients are chemical elements essential for nourishment and growth of all organisms. Of the 16 elements classified as nutrients, nitrogen (N) and phosphorus (P) are the ones most in demand in terrestrial and aquatic ecosystems not greatly affected by human activity. Until recently, the supply of N and P for most plants, and ultimately to animals, was limited. The most abundant N source, N gas, could only be used by plants once it was fixed by certain bacteria or algae into ammonium or nitrate compounds. Similarly, the most abundant P source, P-bearing minerals, only became available by weathering. Consequently, N or P were limiting nutrients in most ecosystems prior to human settlement and agricultural development. However, addition of N and P to ecosystems as a result of human activity has resulted in deleterious changes in water quality.

Agriculture can accelerate the movement of nutrients to surface or ground waters, particularly from overuse of fertilizers and inappropriate manure management practices. While addition of fertilizer and manure to agricultural soils is essential for soil health and optimal crop yield, application in excess of plant requirements can lead to a build-up of nutrients in the soil and their loss to the environment. Nitrogen becomes available for crop use when it is in water-soluble forms, such as nitrate. Because it is soluble, nitrate not used by the crop can be leached by water below the root zone into groundwater. Phosphorus can dissolve in water or remain in particulate form, attached to soil particles. It can, therefore, move off farmland dissolved in runoff water or attached to eroding soil.

P and N moving off farmland may elevate concentrations of these nutrients in surface waters and thus cause eutrophication, a condition characterized by excessive growth of aquatic plants that, in turn, causes loss of habitat for other aquatic organisms, changes in biodiversity and reduction in recreational potential. Increased organic matter production resulting from nutrient addition can lower oxygen concentrations in water to an extent that threatens fish survival. Elevated nutrient concentrations are one of several factors conducive to development of algal blooms that are toxic when ingested or in contact with skin.



Documented sites of eutrophication caused by agricultural nutrient sources. (From Chambers et al. 2001)

High concentrations of certain forms of N can be toxic to humans and aquatic organisms. Nitrate is naturally present in all groundwater, but agriculture can contribute to elevated levels of this substance. Approximately 8 million Canadians, 26% of the population, rely on groundwater for domestic water supply. All provinces show nitrate contamination of some groundwater (>10 mg L^{-1} N as nitrate). Although nitrate itself is relatively nontoxic, it can be converted in the digestive tracts of human infants and ruminant animals (e.g., cows and sheep) to nitrite, which is toxic. Nitrate can also be toxic to aquatic organisms. About 20% of surface water samples from the Great Lakes basin were high enough to cause developmental anomalies and 3% were high enough to kill amphibians. In addition to nitrate, un-ionized ammonia at concentrations >2-3 mg L^{-1} is toxic to aquatic organisms. In Canada, elevated concentrations of un-ionized ammonia are rare, except in mixing zones below certain municipal sewage discharges or in some waters receiving manure or fertilizer runoff.

At present, environmental problems caused by excessive nutrients are less severe in Canada than in countries with a longer history of settlement and agricultural production. This situation is due to our relatively small population compared to our land base and the protective measures implemented by both the federal and provincial/territorial governments in the last 30 years. However, it is critical that the gains achieved by improved wastewater treatment and other control measures not be reversed by relaxation of standards or by failure to keep pace with population growth.

Knowledge Gaps for Nutrients

Understanding risk:
- pathways of nutrients from agricultural land to water
- models to predict effects of nutrient loading on aquatic biota for various types of water bodies

Monitoring risk:
- predictive models and rapid screening tools to identify harmful algal blooms

Managing risk:
- development of manure treatment techniques
- new technologies for N and P recovery
- increased efficiency of nutrient use by plants and animals
- better management practices to minimize nutrient runoff and seepage

Sewage Biosolids

Sewage biosolids are the residue remaining after municipal wastewater treatment. They represent a concentration of contaminants including organic and inorganic materials, nutrients, trace metals and pathogens. Biosolids must be removed from wastewater treatment plants but options for their management are limited. They can be buried in a landfill (disposal), burned in an incinerator (disposal) or spread on land as a fertilizer/soil conditioner (beneficial reuse). Current Canadian biosolids production is estimated at 667,000 tonnes dry solids per year, of which approximately 22% is landfilled, 18% is incinerated and 49% is land applied. The remaining 11% is not accounted for or accumulates in wastewater treatment lagoons and is removed infrequently for landfilling or land application.

Increased public environmental awareness and government-sponsored recycling programs have reduced landfilling and incineration of biosolids. Consequently, there has been increasing pressure for land application of this material. But the nutrients, trace metals, pathogens and organic compounds in land-applied biosolids require careful management to avoid health and environmental problems. Provincial guidelines for material supplied free-of-charge and a federal regulation for material represented for sale have been developed to address the problems. The guidelines and regulation define both biosolids quality and recommended application rates for land application.

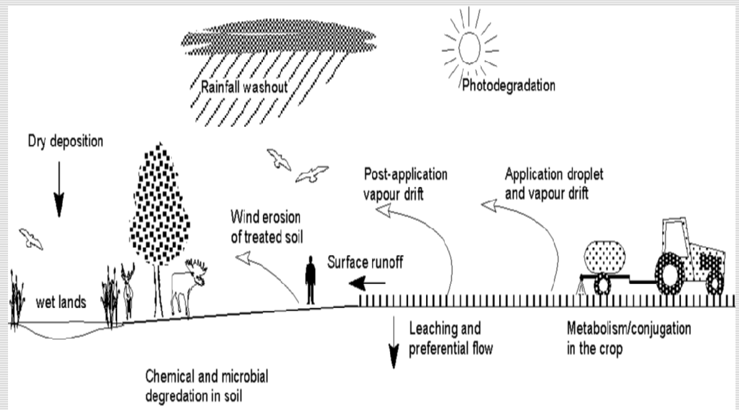
Land-applied biosolids are used in Canada and the U.S.A. primarily as a source of nitrogen for crop production. This has led to development of application rates based upon the N requirement of the crop and limits on annual or cumulative trace metal additions to soil. Studies in both countries have shown a very low risk that biosolids applied according to guidelines/regulations will cause N contamination of surface or ground water. Similarly, P, trace metals and pathogens represent minimal risk to surface and ground water because of strong adsorption to solids. However, contamination has been observed under exceptional circumstances. Surface water contamination has resulted from heavy rainfall causing runoff prior to incorporating surface-applied biosolids and tile drainage water contamination has been observed shortly after applying liquid biosolids to the surface of dry, cracked soil not tilled prior to application. Best management practices must be observed to avoid risks associated with exceptional circumstances that may occur during land application of biosolids and of other soil amendments such as animal manure, fertilizer and pesticides.

Land application of sewage biosolids in Canada is regulated more carefully than most other agricultural practices and it is likely to come under increasing scrutiny as nutrient management legislation is introduced throughout the country. It is highly unlikely that agricultural use of these materials is now, or is likely to become a significant contributor to water degradation in Canada. To minimize the potential for tile drain water contamination, land with macropores is tilled prior to liquid biosolids application.

Pesticides

In Canada, pesticides play an integral role in most crop and animal production systems. Over the last several decades, use of pesticides has become the primary approach to control weeds, insects and diseases that reduce animal and crop productivity. Herbicides constitute about 85% of pesticide sales in Canada and approximately 70% of pesticides purchased are applied in the Prairie region. The cold winters and relatively dry growing seasons typical of this region inhibit microbial and chemical degradation of pesticides that enter the atmosphere or aquatic systems. Pesticides can diffuse from the agricultural land base into the broader environment through application and post-application losses to the atmosphere; in snowmelt, rainfall and irrigation runoff into surface receiving waters; or by leaching/preferential flow to groundwater.

Pathways for pesticide loss from the agricultural landbase. (From Headley et al. 1998. Used with permission of John Wiley & Sons Inc.)



Pesticides losses to the atmosphere during and following application can range from <5% to >25% of the amount applied. Pesticide loss due to application drift ranges from <2 to 5% of the amount applied when current pesticide ground-delivery systems are used under recommended environmental and operational conditions. However, with older application technologies, application drift can be >15%. Post-application vapour loss depends primarily on the vapour pressure of the pesticide and whether it is incorporated into the soil, and can range from <1% for polar pesticides with low vapour pressures to >25%. Pesticide inputs to the atmosphere can also occur as a result of wind erosion of treated soil. Pesticide concentrations in precipitation can sometimes exceed water quality guidelines for the protection of aquatic life.

Pesticides transported to surface waters as a result of runoff are those present in what is referred to as the runoff-soil interaction zone (the top 0.5 to 1 cm of soil). Losses due to runoff seldom exceed 1% of amounts applied and depend on water solubility of the pesticide, soil properties, and the length of time between pesticide application and the runoff event. Surface runoff from treated agricultural land generally flows into some type of receiving water such as farm dugouts or ponds, wetlands, lakes and streams. Thus, the presence of pesticides in surface water bodies may reflect both atmospheric and surface runoff inputs.

Surface water bodies in Canada are contaminated with pesticides. In a 1996-1998 study in Saskatchewan, detection frequencies and concentrations of individual herbicides in wetlands on farms with intense (minimum till), moderate (conventional till) and no (organic farming) herbicide use were similar. Atmospheric deposition could explain both concentrations and the relatively uniform distribution of herbicides across all landscape types. In a 1994 survey in Alberta, 48% of 103 farm dugouts had detectable herbicide concentrations. Of 25 Saskatchewan dugouts studied (1987 to 1989 and 1994 to 1996), all contained detectable concentrations of at least one herbicide at some point during the growing season. In Ontario, 63% of 212 farm ponds sampled between 1971 and 1985 were contaminated with pesticides. As early as the 1970s, atrazine and its metabolite deethylatrazine were frequently detected in streams in Québec and Ontario. Several other pesticides were also detected in the Ontario streams. Later, in Ontario, similar contamination of the Grand, Saugeen and Thames rivers (1981 to 1985) and the Payne River (1991 to 1992) were reported. In Alberta, 27 streams were sampled from 1995 to 1996 and a direct correlation between pesticide levels in the streams and levels of agricultural inputs in the stream basins was noted. Herbicides were also detected in several small lakes in Alberta (1995 to 1996).

Pesticides move down through the soil profile by both leaching and preferential flow. Preferential pathways consist of cracks or fissures in the soil, insect or animal burrows, as well as cavities left by decaying plant roots. As a consequence of preferential flow, some groundwaters in Canada are contaminated with pesticides. In the Fraser Valley of British Columbia, pesticides were detected in 2% of 75 private wells and 192 community wells monitored between 1992 and 1993. In Alberta, 3% of 824 farm wells (1995-1996 data) had detectable concentrations of herbicides. Pesticides were detected in 26% of 184 farm wells in Saskatchewan (1996) situated in shallow hydraulically and physically unconfined aquifers. In Ontario, herbicides were detected in 11.5% of 1204 farm wells (1992), the majority of which were situated in areas of intense agriculture. In a 1990 study, 38% of wells monitored in Nova Scotia had detectable concentrations of herbicides. In Québec, pesticides were detected in 55-78% of samples collected from private wells monitored between 1999 and 2001 in potato-growing areas. Water quality guidelines were exceeded for about 24% of samples collected from 4 agricultural rivers (draining primarily corn fields), and drinking water guidelines were exceeded for 1.7 to 4.9% of these samples.

Knowledge Gaps for Pesticides

Understanding risk:
- toxicological significance of long-term exposure to low levels of chemicals
- potential synergistic effects of chemical mixtures
- hazards to non-target organisms of genetically expressed pesticides

Monitoring risk:
- targeted monitoring of pesticide residues in environmental media to determine trends and better assess hazards
- development of better laboratory methods to detect and measure new low-dose pesticides

Managing risk:
- models to characterize transport mechanisms and the quantity and persistence of pesticides in aquatic systems
- models to predict effects of changes in agricultural production practices on aquatic systems

Pesticide concentrations in Canadian surface and ground waters seldom exceed water quality guidelines for drinking water. However, it should be noted that guidelines have not yet been established by Health Canada for several pesticides, and that Canadian water quality guidelines for drinking water are among the least stringent in the western world. For example, the countries of the European Union have adopted a generic water quality guideline for drinking water of 0.1 µg/L for any pesticide. For some pesticides, Canadian guidelines are three orders of magnitude greater. The European Union has also adopted a drinking water quality guideline that states that the total concentration of all pesticides in drinking water cannot exceed 0.5 µg/L. Currently, Canada's water quality guidelines for drinking water do not address the presence of mixtures of pesticides. It could be argued that water quality guidelines concerning pesticides should, at the very least, reflect good management practices with respect to their use. With our current pesticide delivery systems and pest management practices, pesticide concentrations in prairie surface and ground water that occur from non-point pollution seldom exceed 5 µg/L.

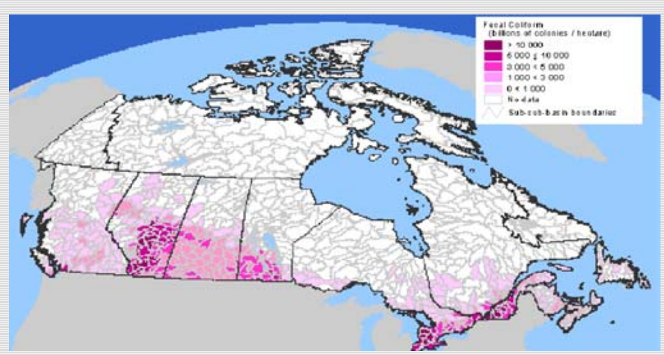
Pathogens

The risk of water contamination by pathogens from animal wastes and municipal biosolids applied to agricultural land is of significant regulatory concern. Intensification of livestock production, particularly in areas of rapid urbanization, and high-profile incidents of waterborne diseases are heightening public attention to this issue. Particular concerns with respect to human and environmental health are whether pathogenic organisms in manure persist in agricultural soils fertilized with manure and are transported to surface and ground waters. The issues of whether antibiotic-resistant bacteria are more abundant in agricultural soils receiving manures from medicated animals, and if this promotes an environmental component to development of antimicrobial resistance in human pathogens are also of considerable concern.

Pathogenic microorganisms associated with livestock and poultry manure include bacteria, protozoa and enteric viruses. The types and abundance of pathogens in agricultural waste is extremely variable and depends on a number of factors including the particular livestock or poultry being raised, the health of the animals or poultry, and waste storage practices. Bacteria, protozoa, and viruses vary widely in their biology, size, environmental persistence, and infective dose, key considerations for understanding and managing risk of contamination of adjacent water.

Fecal material is typically composed of >30% bacteria (on a dry weight basis), corresponding to a shedding rate of about 10^{11}/g fecal dry matter. Typical bacterial concentrations in stored liquid swine manure are 10^{13} bacteria/L of slurry, with the result that application of this slurry to agricultural fields at a typical rate of 2 L/m^2 will add about 2 x 10^{13} bacteria/m^2 to the soil. However, only a small fraction of these bacteria are likely to be pathogenic and even within a given bacterial species, pathogenic determinants may not be widely distributed. For example, of the more than 140 existing serotypes of *E. coli*, only about 11 cause gastrointestinal disease in humans.

Estimated fecal coliform bacteria production in livestock manure, 1996 (Adapted from Statistics Canada 2001).



Pathogenic protozoa of fecal origin are found in lower numbers than bacteria, are larger, and can have in their life cycles stages (e.g., cysts, oocysts) that are more environmentally persistent. *Cryptosporidium* and *Giardia* sp. are the most frequent parasitic protozoa found in water contaminated with sewage or animal wastes.

Viral pathogens are distinguished by their very small size, and their obligate need to be associated with a host; they are dependent upon living cells for reproduction. Enteric viruses infect the gastrointestinal tract of humans and animals and are excreted in the feces. Over 100 types of enteric viruses are known. Enteric virus strains that infect animals probably do not generally infect humans.

Agriculture relies on soils to inactivate pathogenic organisms before they reach surface or ground water. Pathogens need to remain alive to cause disease and have evolved for survival in a host, not the environment. Soils and water are, therefore, hostile environments where pathogens are subject to starvation, predation and physical conditions not conducive to survival. Their large size (compared to chemical contaminants) reduces movement through the soil matrix and consequently penetration to deeper soils or groundwater. When vertical movement occurs, it tends to be along preferential flowpaths (e.g., cracks and biopores in the soil that allow water to move rapidly to depth) or by surface flow. Despite a low potential for survival and movement in the environment, pathogenic microorganisms have been isolated from groundwaters and 10-46% of rural wells in any Canadian province exceed the Canadian water quality guideline for total coliform numbers, suggesting a high incidence of fecal pollution.

Assessing the risk to water is subject to a number of uncertainties. The types and abundance of pathogens in agricultural effluents vary with the farming system. Indicator microorganisms used to detect fecal pollution are unlikely to be representative of all pathogens of concern. Identifying the source of fecal pollution with certainty can be problematic, particularly in rural areas where septic systems are common. The environmental persistence and mobility of pathogens are variable and difficult to characterize, particularly when considering viruses, bacteria, and protozoan pathogens. Risk prediction must take into account livestock type and density, location with respect to water sources, and physical characteristics of the watershed. Improved characterization and management of risk will require a better understanding of the persistence of pathogens in wastes during storage and following application to land.

Knowledge Gaps for Pathogens

Understanding risk:
- environmental persistence of pathogens
- ecology of viral pathogens in the environment
- methods for scaling-up risk indicator

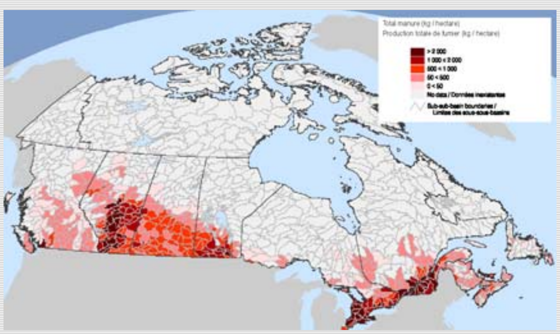
Monitoring risk:
- methodology for monitoring less tractable pathogens
- monitoring of presence and abundance of pathogens in environment

Managing risk:
- re-examination of soil application best management practices
- knowledge of manure storage methods and pathogen persistence
- methods to reduce pathogen shedding

Endocrine-Disrupting Substances and Veterinary Pharmaceuticals

Historically, endocrine-disrupting substances, pharmaceuticals and related products have not been viewed as environmental pollutants. Because these substances are present in the environment at very low concentrations, they were thought to pose little risk. However, continuous exposure even at very low doses may have significant biological effects, especially during sensitive life stages. Endocrine-disrupting substances and pharmaceuticals enter the environment through discharge of human sewage (which contains natural hormones as well as pharmaceuticals) and runoff or seepage from fields treated with manure (which contains pharmaceuticals used to enhance animal health and food production as well as natural hormones excreted by livestock). Currently, there are only limited data on the distribution of a select number of these substances in Canadian environments. Although the data are limited, this issue has been identified as a potential threat to water quality in Canada.

Estimated total livestock manure production, 1996. (Adapted from Statistics Canada 2001).



Endocrine-disrupting substances are compounds that can interact with the endocrine system and thereby adversely affect growth, reproduction and development. The endocrine system is a complex network of chemical signals and messages found in fish, invertebrates, birds, and mammals that controls many immediate and life-long responses and functions (such as growth, embryonic development, and reproduction). Endocrine disruptors can alter or disrupt endocrine systems by mimicking or partly mimicking hormones; blocking, preventing and altering hormonal binding to hormone receptors; altering production and breakdown of natural hormones; or modifying the making and function of hormone receptors. Effects on development and reproduction observed in wildlife in Canada include:

- deformities and embryo mortality in birds and fish exposed to industrial chemicals or organochlorine insecticides;
- impaired reproduction and development in fish exposed to pulp and paper mill effluents;
- abnormal development of molluscs exposed to antifouling substances applied to the hull of ships;
- depressed thyroid and immune functions in fish-eating birds in the Great Lakes; and
- feminization of fish exposed to municipal effluents.

Available data suggest a potential for these types of effects to occur in humans, although there is only circumstantial evidence that they occur in response to environmental contamination.

Known or suspected endocrine disruptors include industrial chemicals such as dioxin and PCBs, a number of now-banned pesticides such as DDT and chlordane, and certain other synthetic chemicals, including some agents in pesticide formulations and chemicals in land-applied sewage sludge. Natural hormones, such as estrogens, are excreted in animal manures and may also be disruptive should they move to surface water and reach high concentrations. Agriculture could potentially be a source of endocrine disruptors to the environment through the use of pesticides and land application of biological wastes (manure and sewage biosolids). Animal wastes may contain elevated levels of natural hormones (e.g., 17β-estradiol and estrone) and phytoestrogens (e.g., equol). Sewage biosolids may also contain a wide variety of pharmaceuticals (e.g., 17α-ethynylestradiol) and industrial chemicals such as alkyphenols. However, many of these compounds are readily biodegradable in soils under a range of temperature and moisture conditions and should rapidly dissipate in aerated agricultural soils following application of manure or municipal biosolids during a temperate growing season. Improved characterization and management of risk will require a better understanding of the persistence, transport and ecological significance of endocrine disruptors following application to land.

In addition to the direct effects of pharmaceuticals, the heavy use of antimicrobial drugs may result in the development of antibiotic-resistant microbes. Antimicrobial drugs (antibiotics and others) are often administered at low levels to livestock to enhance feed efficiency and promote growth, to fight infections not usually detectable without clinical examination, and to prevent diseases. Antibiotic resistance is created when bacteria transfer antibiotic-resistant genes to other, unrelated species of bacteria, including known pathogens. Application of manure to agricultural fields results in a very low but continuous concentration of a vast array of antibiotics in the environment. Ultimately this will favour the proliferation of antibiotic-resistant bacteria (pathogens as well as non-pathogenic bacteria) as compared to bacteria that have not had the resistant gene passed to them. Because the number of available antimicrobial drugs is limited and the same or related drugs are often used for both animals and humans, concern has arisen that pathogens resistant to microbial drugs may affect humans, livestock or other animals. The European Union has prohibited non-therapeutic use of antimicrobial products that are used in livestock production and are also used to treat human medical conditions as a precaution to avoid the potential development of antimicrobial resistance. Although studies that positively trace drug-resistant human illnesses back to a resistant livestock source are rare, related evidence, namely that:

- medicated swine have a higher proportion of antibiotic-resistant bacteria in their guts,
- poultry litter has a high proportion of antibiotic resistant bacteria,
- bacteria in groundwater proximal to swine farms may have a higher level of antibiotic resistance, and
- the presence of several antibiotics in soils and surface waters around the globe

has raised concern about the development of drug-resistant bacteria (such as *Salmonella* and *Campylobacter*) passing from livestock to humans and causing human illnesses. The most important sources of human problems from resistant bacteria, however, are still human use and overuse of antimicrobial drugs, with hospitals being one of the more common sources of serious infections by drug-resistant pathogens.

Knowledge Gaps for Endocrine-Disrupting Substances & Veterinary Pharmaceuticals

Understanding risk:

- exposure, dispersal and fate in the environment
- ecological relevance of endocrine-disruptor responses and tests
- role and importance of naturally occurring hormonally active substances
- potential for environmentally mediated transfer of antimicrobial resistance

Monitoring risk:

- adequate analytical and biological tools to monitor exposure and effects in the environment
- assessment of subtle effects on development, growth and reproduction of non-target species

Managing risk:

- best management practices for land application of animal and municipal

Technologies for Minimizing Risks to Water Quality from Agriculture

Large-scale agricultural production without some losses of chemical or biological contaminants to ground and surface waters and to the atmosphere is virtually impossible. However, the impact of agriculture on water quality has become a point of concern in Canada and elsewhere. The focus of much of this concern is intensive agricultural operations, where the geographic intensification of crop or livestock production has raised serious questions in some regions about the ability of the agricultural land base to assimilate agricultural inputs (chemical fertilizer, animal manure or pesticides) without environmentally significant losses. Many science-based solutions for reducing agricultural losses of chemical or biological contaminants to surface and ground waters are available or in the developmental stage, and improvements in environmental quality can be expected as these and other measures are implemented.

Reducing Manure Nutrient Content

Livestock incorporate only 20 to 40% of the phosphorus and nitrogen originally present in the feed; the remainder is excreted. Phosphorus in corn, barley and other cereal grains fed to pigs is the most serious problem because between 60 and 80% of the phosphorus is in a form (known as 'phytate') that is not digested. Because of its poor digestibility, supplemental phosphate must be added to the diet to meet dietary requirements for optimal growth.

There are a variety of strategies to reduce the phosphorus content of livestock manure. One currently employed with hogs is to reduce supplemental phosphate in the diet and add the enzyme phytase to the feed. This enzyme hydrolyzes a portion of the phytate in the feed, thereby releasing readily digestible inorganic phosphate. Addition of phytase to the diet can result in a 25-30% reduction in fecal phosphorus for pigs. Researchers at McGill University are also testing zeolite as a natural mineral additive to improve feed digestibility and reduce mineral content of manure by about 15%. Whereas phytase is only suitable for monogastric animals such as pigs, zeolite addition works for all types of livestock, including ruminants.

Another approach for reducing fecal phosphorus is to feed pigs cereal grains containing more bioavailable phosphorus and less phytate. This method has the potential to reduce fecal phosphorus content by about 25%, however the method is still in the developmental stages. Current strains of low phytate cereals (i.e., 50 to 66% less phytate) suffer from low germination and, in some cases, low yield. Another problem with low phytate cereals is the difficulty in separating genetically modified cereals approved for use as an animal feed from regular cereals, since cereal grains are handled as commodities for milling and export.

A third approach is to produce transgenic pigs that synthesize their own phytase. This possibility too is still in the development phase. However, researchers at the University of Guelph have developed a transgenic pig that contains a mouse parotid secretory protein promoter, which drives the production of a bacterial phytase enzyme in the salivary glands with secretion in the saliva. These pigs are able to incorporate nearly all of the phosphorus in a diet with soybean meal as the sole source of phosphorus and excrete feces with up to 75% less phosphorus than non-transgenic pigs receiving the same diet. Furthermore, computer simulations have shown that for soil with low erodability, 38% less land would be required for the spreading of manure from a 350 sow, farrowing to finishing operation of phytase pigs compared to non-transgenic pigs. For highly erodable soils, 62% less land would be needed for spreading of manure from phytase pigs.

Transgenic pigs able to synthesize their own phytase have advantages over other approaches for reducing the phosphorus concentration in manure. For example they eliminate the need for adding phytase enzyme to the diet, and bypass the challenges associated with keeping separate low phytate and regular cereal grains used for human consumption. However phytase pigs are genetically modified animals and safety testing is necessary to meet the requirements of the Novel Foods regulations of Health Canada. Furthermore, acceptance by consumers will be the final barrier to their introduction.

Fewer methods are available for reducing the nitrogen content of fecal material. One approach is to reduce the quantity of crude protein in the diet and replace this with synthetic amino acids. Studies have shown that use of supplementary amino acids combined with reduced levels of protein in the food can reduce nitrogen content of fecal material by 20-25%. Reduction of crude protein in the diet not only decreases fecal nitrogen content but also reduces concentrations of a majority of odorants in the slurry. Reduction of protein in the diet, therefore, has three desirable effects: it reduces

- nitrogen content in the manure and thus potential for water quality problems following field application,
- the quantity of ammonia and thus the release of the greenhouse gas nitrous oxide, and
- odorants in the pig operation and in the manure.

Manure Treatment

With the livestock and poultry industries becoming more intensive and larger, significant amounts of manure are generated that must be collected, stored, and utilized efficiently. There are several methods that are relatively new or still in the developmental stages for treating manure, including solid-liquid separation of manure, composting of manure, manure digesters, and constructed wetlands.

Solid-liquid separation is a treatment process for animal manure that separates the solid portion from the liquid. Once concentrated, the solids can be used for soil fertilization and are much cheaper to transport over long distances. Physical treatment to separate solids from liquids usually involves screening, centrifuges or filtration/press systems. Ideally, a mechanical solid-liquid separator will remove a large portion of the solids from the liquid fraction and produce a solids fraction with a low moisture content (<75%). Because much of the nitrogen and phosphorus in manure is associated with fine solids (<0.25 mm), it is critical that these fine particles be captured in the solid phase. Another approach from separating the solid and liquid fractions of manure is chemical precipitation. Researchers at McGill University are experimenting with adding limestone to hog manure. The calcium in the limestone binds with phosphate to form an insoluble precipitate that is transferred to the solid phase. Compared with mechanical separation methods (that typically cost about $2 per grower hog for operations producing >5000 hogs per year), precipitation appears to offer a cost-effective method for concentrating nutrients in the solids phase (about $0.50 per grower hog). The advantages of solid-liquid separation include odour reduction, concentration of nutrients into an easily managed form, and less loading on lagoons or other treatment systems. The producer will, however, be dealing with two "waste streams" after solid-liquid separation. Therefore storage, handling and spreading techniques for both liquid and solid manure are required. Cost has, to date, precluded the use of more advanced separation technology in North America. However, inadequate land resources have advanced the use of this method in Asia and Europe.

Composting is the aerobic decomposition of organic materials in the thermophilic temperature range (104-149°F). The composted material is odourless, fine-textured, with low moisture; thus, it is economical for transport over longer distances and amenable for commercial sale. There are many methods of composting organic material, including active windrow (with turning), aerated windrow (supplying forced air or allowing diffusion of air through perforated pipes embedded in the windrow), and composting piles. Windrow composting is the most common method used for beef cattle feedlot manure. Manure collected from feedlots is typically composted as is or with high carbon material (e.g., straw, sawdust) to increase the carbon:nitrogen ratio and reduce nitrogen loss. In the case of hog operations, composting entails either separating the liquid fraction from the solid fraction (with the former being used, for example, in irrigation and the latter composted) or going to a solid manure system. In the latter instance straw or sawdust is placed on the floor of the barn and then the mixture is composted. The quality of compost will determine whether it is suitable for agricultural land application, horticulture, etc. All compost sold in Canada must comply with the *Fertilizers Act and Regulations*. In addition, each province regulates the disposal and use of animal waste, and the compost produced. Composting is a desirable manure management method in that it improves the handling characteristics of manure by reducing its volume and weight, and can kill pathogens, fly larva and weed seeds if proper temperatures are maintained for the appropriate length of time. However, manure has a high nitrogen content and composting can result in loss of nitrogen to the atmosphere. Composting can also be expensive to start up if an existing operation is retro-fitted and is most likely to be financially viable only if the compost is sold through retail sales. Use of manure compost as a nutrient resource needs to take into consideration that the nitrogen:phosphorus ratio in manure is less than the 10:1 ratio required for crop production. Application of compost to meet the crop's nitrogen requirement will result in over-application of phosphorus and potential water quality problems; application to meet the crop's phosphorus requirement will require addition of nitrogen fertilizer.

Anaerobic digestion is a biological process whereby organic material (such as livestock manure, food processing waste, etc.) is converted to a gas principally composed of methane (CH_4) and carbon dioxide (CO_2). Although anaerobic digestion can occur naturally, anaerobic digesters reduce the time needed to stabilize organic material (by maintaining high temperatures, typically 70 to 140°F, and ensuring even mixing of the material), control odours, and capture the gas produced. The anaerobic digestion process occurs in two stages: first, a group of bacteria called acid formers break down the volatile solids in manure to fatty acids and, second, methane-forming bacteria convert the acids to methane gas and carbon dioxide. The gas can be burned for heat (for example, to heat the digester) or used to fuel an electric generator. The digester effluent, which contains all of the nitrogen, phosphorus, potassium, and micronutrients in the original manure, can be further processed or land-applied. Anaerobic digesters used for management of livestock manure have several advantages:

- odour levels are reduced;
- pathogen levels are greatly reduced;
- at least 90% of nutrients entering digesters are conserved;
- greenhouse gas (nitrous oxides and methane) and ammonia emissions associated with manure storage and handling are reduced; and
- methane produced as a result of anaerobic digestion can be used to supply energy (heat, electricity) for the operation or, if done properly, sold to the local power grid.

However, anaerobic digesters also have limitations: they require daily attention, digester gas is explosive and must be handled with care, and setup of an anaerobic digestion system is capital-intensive. The adoption of manure anaerobic digesters is much more advanced in Europe than in North America, and especially more so than in Canada. The trend in Europe appears to be to pool resources among a variety of industries that generate non-toxic organic waste (e.g., livestock operations, other agricultural industries such as vegetable or fruit processing, slaughterhouses, and commercial industries such as distillers).

Precision Agriculture

One method to reduce the use and potential off-site transport of agrochemicals and manure is to manage better the spatial variability and specificity of agricultural soils, an approach referred to as “precision agriculture.” Traditional agriculture considers a field as a homogeneous unit. However, fields are inherently variable and this variability has increased as a result of mechanization and the ability to work larger fields. Technological developments such as global positioning systems (GPS), automated machine guidance, remote sensing, real-time sensors (e.g., for yield), geographic information systems (GIS) and mobile computing now make it possible to manage crop variability within a field by precisely tailoring inputs to crop needs. Precision agriculture relies on three sets of tools:

- in-field and remote monitoring tools (i.e., sensors that detect, for example, crop and soil moisture levels, crop yield, disease or weed infestations and that record position);
- machine controls that guide field equipment and can vary the rate, mix, and location of water, seeds, nutrients, or chemical sprays; and
- computerized GIS maps and databases that process the data produced by the first category of tools and generate the information to set the machine controls.

Precision agriculture leads to:

- a better knowledge of the characteristics of a field (cartography);
- better understanding of the processes controlling crop yield (spatial analysis); and
- where possible, greater control of variability of soils and yields in a field through interventions (e.g., drainage, leveling, chiseling, etc.) or variable application of inputs (e.g., lime, mineral or organic fertilizer, pesticides) at the appropriate frequency and timing.

Applied effectively, precision agriculture not only increases profitability by increasing yields or reducing inputs, but should also benefit the environment by enabling more efficient input use. Although the agronomic impacts of precision agriculture have been extensively documented, few research results are available to assess the true environmental impacts of this new agricultural production system. Much research remains to be done in this area.

Policies and Initiatives for Minimizing Agricultural Water Pollution

Global demand for agricultural products continues to grow. Structural changes in Canadian agriculture over the years, such as larger farm size, increased specialization and more intensive use of land and other resource inputs, have increased the potential environmental risks from agriculture. Fortunately, agricultural policy in Canada, which was once driven almost exclusively by economic and production objectives, is now increasingly adapting to ensure that environmental considerations are central to any new policy directions.

Federally, the current approach on environmental agricultural policy focuses largely on voluntary measures in the areas of capacity building and promoting stewardship. Main tools include the CARD (Canadian Adaptation and Rural Development) program, research, provision of information, use of some regulations (e.g., CEPA) and funding programs. Provincially, an array of tools is used including regulations, environmental farm plans, limited payments for environmental management improvement (e.g., Québec), information and extension, and some research and development. The approaches and level of effort vary considerably across the provinces.

Four recent initiatives were highlighted at the workshop: National Agricultural Policy Framework; buffer zone legislation in Prince Edward Island; fertilization application standards in Québec; environmentally sustainable agriculture in Alberta; and *A Freshwater Strategy for British Columbia*.

National Agricultural Policy Framework

In June 2001, federal, provincial and territorial agriculture ministers, agreed in principle on a national action plan — "The Whitehorse Agreement" — designed to make Canada the world leader in food safety, innovation and environmental protection. This action plan, known as the Agricultural Policy Framework (APF) aims to improve the existing risk management framework for agriculture; strengthen on-farm food safety; enhance environmental performance; create economic opportunity through innovation; and provide for sector renewal.

Under the environmental component of the APF, water quality is a high priority. The Whitehorse Agreement states that the Ministers "agree to work towards a comprehensive plan for accelerated environmental action, fully covering all Canadian farms, that will help achieve measurable and meaningful environmental goals in the areas of water, air and soil quality, and biodiversity. Ministers will seek agreement on indicators, targets, timetables and approaches." On the water element specifically, the intent is to reduce agricultural risks to the health of water resources in the priority areas of nutrients, pathogens and pesticides. The Agreement also calls for accelerated action on common farm management goals such as comprehensive environmental planning, nutrient and pest management, and land and water management.

Discussions are now underway among federal and provincial/territorial officials to develop details for implementation. Tentatively, four program areas have been identified under the environmental component: research and technology; information, monitoring and measurement; farm-level planning; and infrastructure support. While implementation of this Agreement will present significant challenges to governments and the agriculture and agri-food sector, it is expected that existing and emerging initiatives at both the federal and provincial/territorial levels, and among agricultural organizations, should help facilitate the process.

Agriculture and Agri-Food Canada — New Business Plan and Programs

In addition to the above, Agriculture and Agri-Food Canada (AAFC) has developed a new business line and is initiating new programs to help implement the new Agricultural Policy Framework. The new departmental business line, "Health of the Environment," has the objective of making Canada the world leader in using agri-environmental resources in a sustainable manner. This is expected to help focus AAFC's activities toward improved environmental awareness and promotion of environmental stewardship.

Also, two new departmental programs have recently been initiated. The National Agri-Environmental Health and Reporting Program (NAHARP) focuses on indicators, integrated economic and environmental modelling and economic forecasting, all aimed toward producing the information and analytical tools necessary to facilitate decision making. The National Land and Water Information Service (NLWIS) is intended to provide the best available information, analysis and interpretation of land and water resources. Key aspects include land and water information integration and decision-making application tools, with national coverage.

Buffer Zone Legislation — Prince Edward Island

PEI freshwater streams and coastal estuaries have been seriously damaged over the years due to siltation from a variety of sources, including agricultural fields, forest harvesting practices, clay roads and highway ditches, as well as urban development. New *Environmental Protection Act* (EPA) legislation requiring the establishment of buffer zones along all watercourses in the province of PEI was designed to reduce the extent and impact of soil erosion and landwash on aquatic ecosystems. The new legislation represents a proactive approach designed to protect the integrity of the Province's water and wetland resources. It requires a 10-m wide buffer on all watercourses bordered by agricultural land or by residential, commercial, industrial, institutional and recreational development, and a 20- or 30-m buffer (determined by slope) along all forested areas bordering on watercourses and wetlands. Research has shown that vegetated buffer strips can be extremely effective in reducing the level of contaminants reaching a watercourse. PEI is the first province in the country to pass legislation requiring the establishment of buffer zones adjacent to watercourses and wetlands. The new legislation was supported by all major farm organizations in the province.

Fertilization Application Standards — Québec

Québec has recently adopted new standards governing the maximum fertilizer loads on cultivated land as part of the modernization of the *Regulation Respecting the Reduction of Pollution from Agricultural Sources* (RRPOA). This modernization is intended to ensure sound management of manure and other fertilizing materials; improve the quality of surface and ground water; simplify the text of regulation and administrative processes; and improve regulatory control (i.e., increase the number of inspections).

Environmental standards now cover three areas: production of manure, application of fertilizing materials, and treatment or disposal of manure. With respect to the application of fertilizing materials, the main principle is that application of materials must be based on the receiving capacity of soils and requires development of an agri-environmental fertilization plan. The new standard addresses spreading distances (prohibited in buffer strips), spreading dates (encouraged during periods of plant growth), spreading methods (promotes the use of low boom for liquid manure), and spreading rates (which introduces the use of maximum load charts). Maximum load charts are based on phosphorus levels of the soil (absolute values and percent of phosphorus saturation), crop type and crop yield. The intent of this new regulation is to keep soil saturation levels under 10% while preventing soil depletion. If the phosphorus application load exceeds soil capacity, the producer is required to find additional land for manure spreading, treat the manure to reduce its phosphorus content or, as a last resort, reduce the herd size.

In addition to the *Regulation Respecting the Reduction of Pollution from Agricultural Sources* and other provincial regulations aimed at reducing agricultural non-point pollution, the Ministère de l'Environnement du Québec continues to conduct a comprehensive sampling program to determine the effect of these measures on water quality in agricultural watersheds. This program was started in 1974 and presently includes monthly monitoring at 162 temporal stations in 50 watersheds in southern Québec. Summer data are also available for another 220 sites. Québec is the first province in Canada to conduct such a broad, long-term overview of the status and trends in water quality of its rivers. Concentrations of many parameters (e.g., ammonia, total phosphorus, turbidity and fecal coliform bacteria) appear to be decreasing, indicating that the pollution control measures are having the desired effect. However, water quality is still poor at certain sites and it is inevitable that problems that have taken more than a decade to develop will require many years to disappear.

Environmentally Sustainable Agriculture — Alberta

The Alberta Environmentally Sustainable Agriculture (AESA) program is an ongoing $5 million per year initiative launched in 1997 based on results of stakeholder consultations. The objective of the program is to facilitate continued development and adoption of management practices and technologies that make the agricultural production and processing industry more environmentally sustainable. The program has four components:

- the Farm Based Component promotes better management practices by farmers and ranchers to reduce environmental impacts of primary production.
- the Processing Based Component promotes the development and adoption of practices and procedures by processors to ensure a more environmentally sustainable industry.
- the Resource Monitoring Component monitors change in the quality of soil and water resources as affected by the agricultural sector.
- the Research Component supports applied research to develop better management practices and technologies for the cropping, livestock and agricultural processing sectors.

Within the Resource Monitoring Component of AESA, the water quality monitoring program tracks water quality in 23 streams in agricultural areas across Alberta. The 23 watersheds include a range of agricultural densities, provincial ecoregions, and runoff characteristics. Monitoring is flow-based and samples are collected for analysis of nutrients, fecal coliforms, and about 40 pesticides. Annual reports are produced for both technical and non-technical audiences, and the first 5-year trend analysis (to include both land cover and agricultural census indicators, in addition to water quality) is expected later this year. Results from this program provide a good measure of the long-term effects of human activity on the environment, as well as some comparison of differing farming practices. The integration of these results into a strategy for sustainability is part of the AESA mandate.

Freshwater Strategy — British Columbia

British Columbia has some of the cleanest and most abundant water supplies in the world. However, with a growing human population and increasing development, B.C.'s water resource – both its quality and quantity – is under stress. In November 1999, the Government of British Columbia released *A Freshwater Strategy for British Columbia*, which provided an overview of the direction of water management in B.C. The primary challenges addressed by the Freshwater Strategy include sustaining the integrity of the province's diverse ecosystems while providing for the needs of society; coordinating the actions of a variety of governmental and non-governmental agencies; changing engrained beliefs, perceptions and practices of the public and instilling a conservation ethic; responding to increasing international competitive pressures; and preparing for the uncertain impacts of global climate change. The

Freshwater Strategy addresses these challenges by setting three long-term goals:

- Healthy Aquatic Ecosystems,
- Assured Human Health And Safety, and
- Sustainable Social, Economic And Recreational Benefits Of Water.

As part of the Strategy, a non-point source (NPS) pollution action plan was developed that identifies the Province's role in addressing NPS pollution and the priority initiatives. Significant progress has been made towards the achievement of the goals in this plan. A compendium of NPS Best Management Practices was published. Pilot projects are underway throughout the province addressing NPS assessment, education, stewardship support and local government support. Status and trend assessment reports on water quality in the province are also produced regularly. In the Fraser River valley, where agriculture is a very important activity and has been the cause of environmental problems (e.g., high nitrate concentrations in the Abbotsford Aquifer, degradation of some habitat for commercial fisheries), work is underway with the agricultural sector to develop an action plan to reduce NPS pollution. Programs to transport poultry manure out of sensitive areas of the valley, improve manure storage on the farm, and conduct best agricultural waste management plans have been implemented. While efforts continue to address major industrial sources of water pollution, the focus of attention is now turning towards addressing the less tangible challenges, namely reducing non-point source pollution, efficient and effective water management, harmonization of efforts across the different levels of government, groundwater management, and conservation.

Linking Water Science and Policy

This workshop has served as a vigorous first step by the CCME in building a substantive, much-needed, ongoing dialogue between the scientific and policy-making communities in both agriculture and environment disciplines. The approach taken to linking water science and policy, related to effects of agricultural activities and water quality, is consistent with elements of the *Federal Framework for Science and Technology Advice*. This document identified key principles for ensuring that current science be optimally considered and/or applied. They included:

- early identification of issues,
- inclusiveness,
- transparency and openness, and
- sound science and science advice.

The workshops were designed to ensure that issues of key importance to CCME were considered in a timely fashion, that leading-edge science was presented to, and discussed by, a variety of interested parties, and that a process be developed for continuing information sharing and communication.

Throughout the workshop, several recurring issues arose in relating science outcomes to policy decisions, reinforcing the need for continued dialogue between the research community and policy/program managers. These recurring issues were:

- *Where to set the numbers?* Whether the issue was fertilizer application or composting guidelines, there was an interest in how the limits for a given guideline, standard or regulation were derived. There was a genuine interest in the science behind the numbers. The issue of what data are required to set a given standard was also raised.

- *The need for sustained monitoring and reporting.* Environmental monitoring and surveillance programs are in decline throughout much of Canada. However, the information that is collected from these programs provides the fundamental data for understanding how agricultural activities impact water quality, and our environment in general. In turn, interpretation of these data provides essential information for implementing sound management decisions. Workshop delegates were insistent on the need to protect and maintain our monitoring capability and report the findings.

- *Technology transfer*. The experience (successes and failures) with various technologies, whether developed in academia, the private sector or through government research and development programs, should be better communicated to decision makers. Public policy typically happens at a rapid pace and the need for quickly attainable, up-to-date technological know-how can not be overstated.

- *Share the policy experience*. There was a keen interest in what other jurisdictions were doing with respect to policy. This was the case whether the issue was buffer setbacks, the need to compensate farmers for such setbacks, biosolid compost regulations, fertilizer/pesticide application rates, experience with farmer receptivity to new policies (e.g., farm plans), or costs and benefits of various programs. There is a need for a concise, regularly updated index of policy and program initiatives across the country for quick reference.

- *Science and Policy Connection*. There was general agreement that the environment/agricultural policy response needs to keep pace with the technological know-how. Although there has been progress, the social and economic realities of maintaining a farmer's competitiveness are key factors in widespread adoption of environmental stewardship practices. More complete information on costs and benefits may be of benefit. There is also considerable need to inform both the science and the policy communities of each others' strengths and capacities, especially in terms of the timelines required by each to respond to the other.

- *What research do policy makers need?* Although there was some articulation of knowledge gaps that limit the development of sound policy, better communication of policy needs with respect to research is required. The research community is sufficiently flexible to accommodate new priorities, but these need to be more clearly and regularly communicated to scientists. That said, given the realities of the policy development process, in which it can be difficult to anticipate science requirements precisely, fulfilling the science community's desire to be kept informed about what is required will likely always lag behind the policy community's articulation of what is needed.

- *The need for the science — simple and fast.* Researchers and policy developers are typically on different time tracks. There is a need for concise, plain-language repositories of scientific intelligence in the area of agricultural impacts on water quality. This should be continually updated so that it is readily available for program/policy development. This information can also serve to better educate citizens on typical threats to the environment, and help in the early identification of environmental problems.

Over the course of the workshop, it was clear that although further knowledge is needed on certain topics to manage risk adequately, science-based solutions are available that can assist in reducing the loss of pollutants from the agricultural land base and improving environmental quality. New technologies are emerging that can minimize loss of chemical and biological agents to the environment. Agri-environmental research and monitoring are essential to ensure decision making is based upon sound science. It is critical that the advances in agricultural production necessary to feed an increasing global population do not outpace adoption of better management practices and other control measures aimed at environmental protection, and that the best and most advanced science be integrated into practical solutions.

Maintaining the Dialogue

As this report is being produced, the CCME is considering options for maintaining and, indeed, expanding on the dialogue initiated during the workshop. It is evident from the section above that there is a need for continued information exchange and dialogue. Various electronic media – in particular dedicated or re-vamped web sites, electronic bulletin boards, moderated chat rooms, and subject-specific, subscription-based email lists – are being considered as means of ensuring the flow of information. The potential for follow-up workshops, or perhaps dedicated sessions at selected conferences, for both the science and policy communities will also be explored.

Ultimately, the logic for bringing researchers and policy managers together is to make better public policy decisions. Bringing the latest scientific knowledge to decision makers is critical in helping to target programs, and develop and implement more refined policies to minimize any negative effect of agricultural activities on water quality. The dialogue at the workshop, and reflected in these proceedings, serves as a starting point for this improved resource decision making.

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APPENDIX 1 - Workshop Programme

DAY 1 — JAN 31st, 2002

8:30-9:00	Coffee and croissants
9:00-9:15	Welcome from M. Charles Larochelle, Sous-Ministre Adjoint, Ministère de l'Environnement du Québec, Direction générale des évaluations environnementales et de la coordination Welcome from the workshop Co-chairs: Goals/logistical items/introductions (Dr. Patricia Chambers, Environment Canada, NWRI, Burlington, ON, and M. Jacques Dupont, Ministère de l'Environnement du Québec)
9:15-9:30	Welcome from CCME (Jennifer Moore, Environment Canada, Hull, QC)
9:30-10:00	Challenges of Change in Canadian agriculture (Michele Brenning, Agriculture and Agri-Food Canada, Ottawa, ON)
10:00-10:30	Break

Risks to Water Quality from Agricultural Activities (1)

10:30-11:00	Hydrology and Agriculture - tracking the flow of water (Dr. Jane Elliott, Environment Canada, Saskatoon, SK, and Dr. Bernie Zebarth, Agriculture and Agri-Food Canada, Fredericton, NB)
11:00-11:30	Soil erosion and soil non-point pollution, two interrelated issues (Dr. Claude Bernard, Institut de recherche et de développement en agroenvironnement, Sainte-Foy, QC)
11:30-12:00	Nutrients — from farm to water (Dr. Patricia Chambers, Environment Canada, NWRI, Burlington, ON)
12:00-12:30	Questions for the Presenters / General Discussion
12:30-1:30	Lunch

Risks to Water Quality from Agricultural Activities (2)

1:30-2:00	Sewage Biosolids — Production Management and Water Quality Impacts (Dr. Mel Webber, Burlington, ON)
2:00-2:30	Pesticides — Balancing the risks (Dr. Allan Cessna, Agriculture and Agri-Food Canada / Environment Canada, Saskatoon, SK)
2:30-3:00	Break
3:00-3:30	Risk to water quality from pathogens from agricultural sources (Dr. Ed Topp, Agriculture and Agri-Food Canada, London, ON)

3:30-4:00 Exposure and Effects of Endocrine-Disrupting Substances Associated with Intensive Agricultural Practices
(Dr. Mark Servos, Environment Canada, NWRI, Burlington, ON)

4:00-4:30 Questions for the Presenters / General Discussion

Dinner (on your own)

DAY 2 — FEB 1st, 2002

8:30-9:00 Coffee and croissants

Protecting Water Quality — New Technologies & Policies

Panel 1 — Manure Management

9:00-9:30 The three Rs of Manure Management — Reduce, Reuse, Recycle
(Dr. Suzelle Barrington, Agricultural and Biosystems Engineering, McGill University, Ste. Anne de Bellevue, QC)

9:30-9:50 Reducing nutrients in hog manure
(Dr. Cecil Forsberg, Microbiology, University of Guelph, Guelph, ON)

9:50-10:10 Recycling hog manure
(Bob Notenbomer, Pure Lean Hogs Inc., Medicine Hat, Alberta)

10:10-10:30 Questions for panel

10:30-11:00 Break

Panel 2 — Crop Production

11:00-11:20 Impacts of Precision Agriculture on Water Quality
(Dr. Michel Nolin, Agriculture and Agri-Food Canada, Sainte-Foy, QC)

11:20-11:40 Setting soil nutrient guidelines
(Robert Bertrand, Ministère de l'Environnement du Québec, Sainte-Foy, QC)

11:40-12:00 Questions for Panel

12:00-12:30 Linking Water Science to Policy: Effects of Agricultural Activities on Water Quality
(Terence McRae, Agriculture and Agri-Food Canada, Ottawa, ON)

12:30-1:30 Lunch

Assessing and Restoring Agricultural Watersheds — Lessons Learned

1:30-1:50 Assessing and Restoring Agricultural Watersheds in Prince Edward Island
(Jim Young, Department of Fisheries, Aquaculture and Environment, Charlottetown, PEI)

1:50-2:10 Water Quality in Québec's Agricultural Watersheds: An Overview
(Michel Patoine, Ministère de l'Environnement du Québec, Sainte-Foy, QC)

2:10-2:30	Agricultural Water in Alberta: Programs, Projects, and Lessons Learned (Jamie Wuite, Alberta Agriculture, Food and Rural Development, Edmonton, AB)
2:30-2:50	Water Quality in British Columbia's Agricultural Watersheds: Fraser River Valley (Jack Bryden, Ministry of Water, Land and Air Protection, Victoria, BC)
2:50-3:10	Questions for the Presenters / General Discussion
3:10-3:30	Break
3:30-4:00	Lesson from Walkerton (Dr. Harry Swain, Chair, Research Advisory Panel, Walkerton Commission)
4:00-4:30	Workshop summary — information gaps, where do we go from here? (CCME delegates — John Cooper, Environment Canada; Jack Bryden, BC; Jim Young, PEI; Dave Briggins, NS)

APPENDIX 2 - List of Attendees

* indicates presenter

Jack Bryden *
British Columbia Water, Land & Air Protection

Anne-Marie Anderson
Alberta Environment

Pritam Jain
Saskatchewan Environment & Resource Management

James J. Wuite *
Alberta Agriculture, Food & Rural Development

Andy Jansen
Gloria Parisien
Saskatchewan Agriculture and Food

Curtis Cavers
Manitoba Agriculture & Food

Aaron Todd
Ontario Ministry of Environment

Susan Humphries
Peter Roberts
Ontario Ministry of Agriculture, Food and Rural Affairs

Robert Bertrand *
Pierre Delude
Jacques Dupont
Emilie Gagnon
Michel Patoine *
Marc Simoneau *
Ministère de l'Environnement du Québec

Mario Lapointe
Ministère de l'agriculture, des pêcheries et de l'alimentation du Québec

Claude Bernard *
Roch Jancas
Institut national sur la recherche et le développement en agriculture

Peter McLaughlin
New Brunswick Environment & Local Government

Kevin J. McKendy
New Brunswick Agriculture, Fisheries & Aquaculture

David Briggins, Manager
Nova Scotia Environment & Labour

Jim Young *
Prince Edward Island Fisheries, Aquaculture & Environment

Haseen Khan
Newfoundland & Labrador Environment

Ian Bell
Newfoundland & Labrador Forest Resources & Agrifoods

Rod Allan
Alex Bielak
Allan Cessna
Patricia Chambers *
Allan Crowe
Jane Elliott *
Martha Guy
Karl Schaefer
Mark Servos *
National Water Research Institute
Environment Canada

John Cooper
Pascale Groulx
National Water Issues Branch
Environment Canada

Connie Gaudet
Environmental Quality Branch
Environment Canada

Martine Bluteau
Environnement Canada - Région du Québec

Gilles Babin
Division des services météorologiques
Environnement Canada

David Donald
Environment Canada – Prairie & Northern Region

Jennifer Moore *
Water Coordinating Committee
CCME

Michelle Brenning *
Christian De Kimpe
Tim Marta
Terence McRae *
Michel C Nolin *
Ed Topp *
Agriculture and Agri-Food Canada

Gary Bank
Brook Harker
Bill Schutzman
Prairie Farm Rehabilitation Administration
Agriculture and Agri-Food Canada

Alfonso Rivera
Natural Resources Canada

Jim Bunch
Trudie Forbe
Maurice de Maurivez
Department of Fisheries and Oceans

Suzelle Barrington *
McGill University

Cecil Forsberg *
University of Guelph

Eric Aubin
Canadian Pork Council/Conseil canadien du porc

Bob Notenbomer *
Pure Lean Hogs Inc.

Harry Swain *
Sussex Circle/Walkerton Inquiry

Nicole Howe
Canadian Federation of Agriculture

Mel Webber *
Webber Environmental Consultant

Dan McCabe, V.P.
Ontario Corn Producers Association