Environmental Sustainability of Canadian Agriculture

AGRI-ENVIRONMENTAL INDICATOR REPORT SERIES

Report #3

Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

Canada

Environmental Sustainability of Canadian Agriculture

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Eilers, W., R. MacKay, L. Graham and A. Lefebvre (editors)

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Room 160
Tower 4
1341 Baseline Rd
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(613) 773-1444

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Executive Summary

In recent decades agriculture has undergone significant changes in response to evolving market demands and new production technologies. The number of farms in Canada has decreased while the average farm size has increased. More specifically, the crop area as a proportion of farmland and the number of heads of livestock have both increased over this time. This shift towards larger, more intensive operations has led to increased awareness by farmers, government and the public of the fundamental links that exist between agriculture and the environment. Canadians are placing increasing demands on farmers and processors to find the proper balance between meeting production objectives and the environmental soundness of the production methods.

Agricultural decision makers at all levels require good quality information to address these complex economic and environmental issues. In response, Agriculture and Agri-Food Canada has developed a set of science-based agri-environmental indicators that integrate information on soils, climate and topography with statistics on land use and crop and livestock management practices. The indicators provide valuable information on the overall environmental risks and conditions in agriculture and how these change over time. The indicators are also designed to be sensitive to the considerable differences in conditions and in the commodity mix across Canada, which are reflected in the significant variations in environmental performance between regions. At the same time, the systematic approach and common data sets used allow this information to be scaled up to the national level, enabling the identification of trends that may be consistent in all parts of the country.

The indicators measure the agriculture and agri-food sector's environmental performance for soil, water and air quality, farm land management and resource use efficiency in the food and beverage industries. Results from multiple agri-environmental indicators related to soil, water and air quality have been incorporated into agri-environmental performance indices to simplify the presentation of overall environmental performance. The indices are presented here to draw broad, national-level observations on the status and trends of agri-environmental sustainability of the agriculture and agri-food sector (refer to Chapter 2, Table 2-2 for a description of these indices). The regional variations are more explicitly discussed in the body of the report.

This publication can be used as a report card of agri-environmental performance for producers, consumers and the international community and can be used to highlight areas where further efforts are required. It can also provide valuable information that decision makers can draw from when developing and evaluating agricultural policy.

Overall, the results suggest that producers are responding to environmental concerns and some progress has been made towards environmental sustainability. However, further expansion and intensification of cropping and livestock production, due to an increasing demand for food and fibre or changing business conditions, could increase the environmental pressure points arising from production and practices unless appropriate actions are taken to mitigate them.

Soil Quality

When considering various aspects of soil quality together (Figure E-1), agriculture's environmental performance has a good to desired status, and generally improved over the 25-year period preceding 2006.

The overall improvement is mirrored by the individual performance indices for soil erosion, which moved into the desired status (Figure E-2), soil organic carbon change, which changed from average to good status, and soil salinization, which increased its status in the desired performance range. The performance index for contamination by trace elements was calculated only for 1981 and 2006 and was stable in the average status range. Improvements in land management practices, such as increased adoption of conservation and no-till practices, reduced use of summerfallow, particularly tillage summerfallow and increased forage and permanent cover crops were primarily responsible for the improved agri-environmental performance for soil quality.

The improved performance was driven by the western provinces where cultivated agriculture is extensive and is dominated by cereals and oilseeds. This agricultural region is most amenable to reduced-till and no-till practices. Increased soil cover resulting from these practices also improves soil moisture, in turn allowing a reduction in area of summerfallow.

Generally, higher rainfall in Ontario, Quebec and the Atlantic Provinces supports more intensive agriculture and a different mix of crops. Although soil quality agri-environmental performance in Eastern Canada improved over 25 years as it did in the rest of Canada, higher rainfall and a higher (though diminishing) reliance on conventional tillage systems both contributed to lower performance. Soil conservation practices such as reduced tillage, residue management practices and winter cover crops help maintain soil cover. These need to be continued in all agricultural areas of the country and expanded particularly in areas where crop type and tillage practices leave the soil exposed and vulnerable to erosive forces.

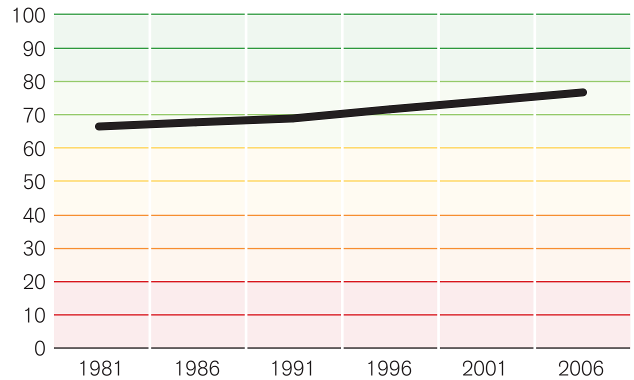

FIGURE E-1 Soil Quality Agri-Environmental Performance Index.[1]

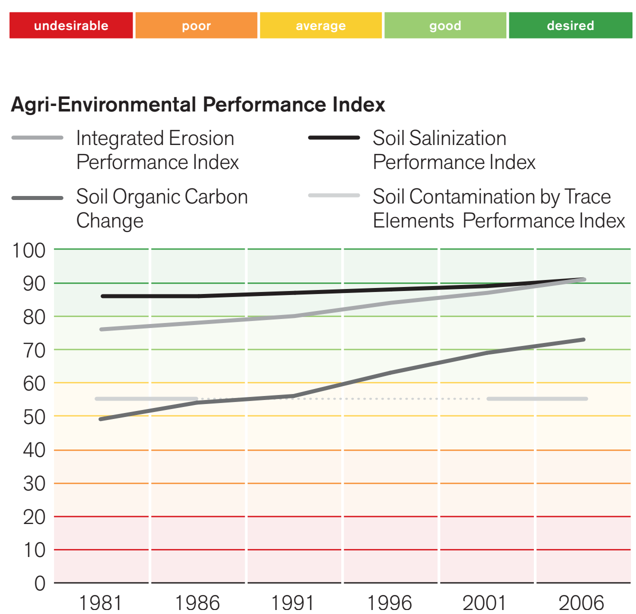

FIGURE E-2 Component Performance indices for soil quality.

1 The Soil Quality Agri-Enviornmental Performance Index combines indices for soil erosion by wind, water and tillage, soil organic carbon change, soil salinization and soil contamination by trace elements.

Water Quality

When considering various aspects of risks to water quality together (Figure E-3), agriculture's environmental performance currently has a good status. It does however represent an overall decline from a desired state in 1981. This overall declining performance is mirrored by the individual indicator performance indices, which generally moved from desired status in 1981 to good status in 2006 (Figure E-4). Increased application of nutrients (N and P) as fertilizer and manure was the main driver for the declining trend in the performance index for water quality throughout Canada.

The overall declining agri-environmental performance was observed in all regions of the country, however a significant difference between the prairies and the rest of Canada was found for the risk of water contamination by N. Eastern Canada and British Columbia have significantly higher residual nitrogen (more input from legume crops, fertilizer and manure than required by crops) and moister climates that result in more runoff and infiltration than in the drier Prairies. The generally lower rates of N application in the Prairies, combined with the drier climate and less infiltration and leaching, results in an overall N agri-environmental performance status of desired in the Prairies as opposed to a poor overall status in the rest of Canada.

In the case of phosphorus, the east vs west differences are not as significant. Performance has declined in the prairies from a desired status in 1981 to a good status in 2006, as significant increases in the ratio of crop land to farmland, continuous cropping and diversification in production, as well as significant increases in cattle and hog production resulted in increased P inputs from fertilizer and manure. In eastern Canada the status declined from 1981 to 1996 and then improved to a desired status in 2001 and 2006. The improved agri-environmental performance is related to implementation of nutrient management plans, regulations, conservation practices and beneficial management practices that decreased the P surplus particularly in Ontario and Quebec.

The shift of animal numbers from Eastern Canada to the Prairies has resulted in declining agri-environmental performance for risk of contamination of water by coliforms, whereas in the rest of Canada, particularly Eastern Canada, overall declining animal numbers have resulted in a relatively stable agri-environmental performance for coliforms.

Increased efforts are required throughout Canada to minimize the risk of nutrient, pesticide and coliform movement to surface water bodies and leaching beyond the rooting depth of vegetation. This is particularly so in higher rainfall areas of the country. This risk can be further reduced through practices such as regular soil testing and adoption of precision agriculture (better matching agricultural inputs application to localized field conditions), that increase the efficiency of nutrient use. Practices that mitigate surface runoff, such as establishing riparian buffer strips, winter cover crops, maintenance of surface residue, etc. will also contribute to reduced risk to water quality.

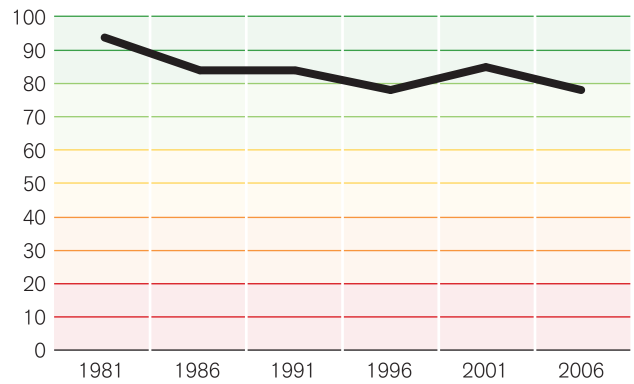

FIGURE E-3 Water Quality Agri-Environmental Performance Index for Canada.[2]

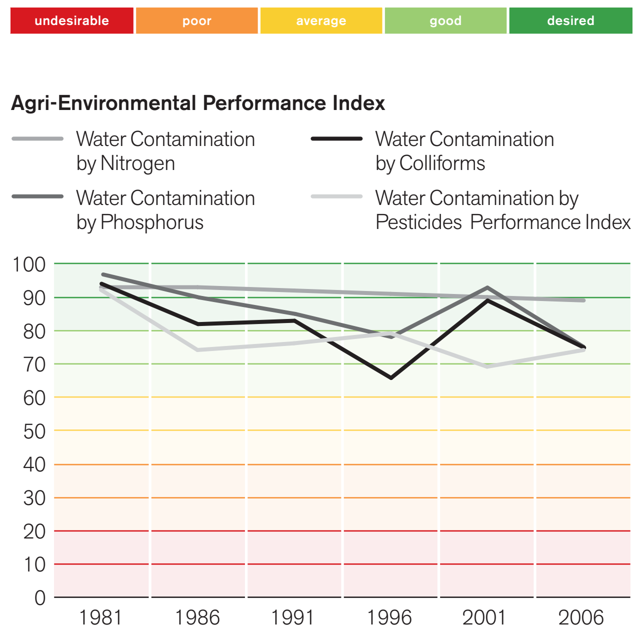

FIGURE E-4 Component indices for risk of water contamination

2 The Water Quality Agri-Environmental Performance Index combines indices for water contamination by nitrogen (N), phosphorus (P), coliforms and pesticides.

Air Quality

When considering various agricultural atmospheric emissions together (Figure E-5), agriculture's environmental performance in air quality is good, having shown gradual improvement over the 25-year period to 2006. The gradual improvement is mirrored by the individual performance indices for GHG, which fluctuated but generally improved its good status over this time, as well as for particulate matter, which improved its status from 1981 to 2006. The ammonia emissions indicator could be calculated only for the last two reporting years but showed a slightly deteriorating performance from 2001 to 2006 (Figure E-6).

Improvements in land management practices such as increased adoption of conservation and no-till practices, reduced use of summerfallow, (particularly tillage summerfallow) and increased forage and permanent cover crops were primarily responsible for the improved agri-environmental performance for air quality. Adoption of these management practices, particularly in the Prairies, led to soils becoming a net sink for atmospheric carbon, which means more carbon is being sequestered in soil than is being emitted. The same practices have led to improvements in PM emissions over the period of study. Increased numbers of livestock across the country between 2001 and 2006 is the primary reason for the small decrease in the ammonia emissions performance index.

Land management practices that favour sequestration of organic carbon in the soil, such as reduced tillage and residue management practices to maintain soil cover, need to be continued and expanded in order to maintain and increase the amount of carbon dioxide removed from the atmosphere and stored in the soil. Similar practices that reduce the number of field operations and protect the soil surface from wind erosion are effective in minimizing PM emissions. Improved animal feeding strategies and more efficient use of N in agriculture are examples of beneficial management practices that can be used to mitigate emissions of methane, ammonia and nitrous oxide.

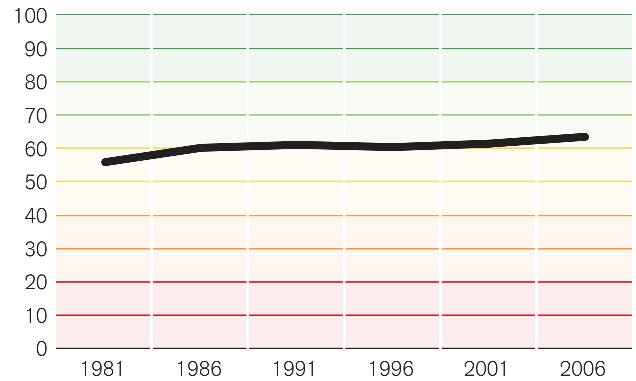

FIGURE E-5 Air Quality Agri-Environmental Performance Index.[3]

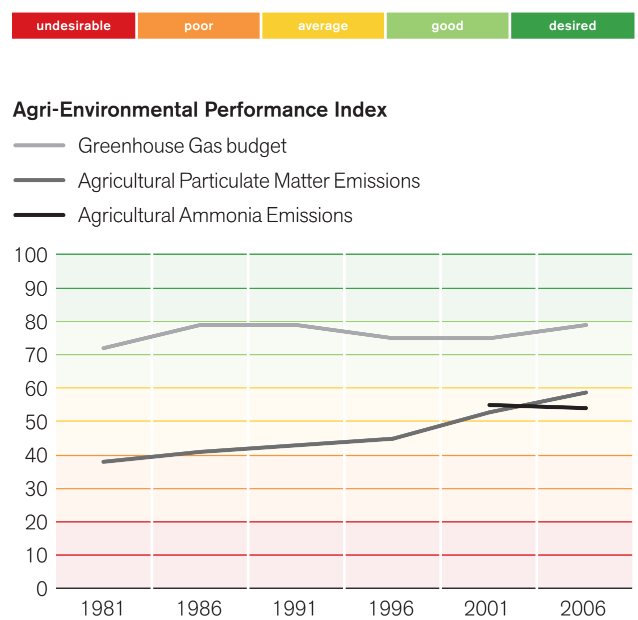

FIGURE E-6 Component indices of Air Quality

3 The Air Quality Agri-Environmental Performance Index combines indices for greenhouse gases (GHG), particulate matter (PM) and ammonia emissions from agriculture.

Farm Land Management

How farm land is used and managed is a primary determinant of agriculture's effect on the environment. Trends in land use changes and beneficial management practice adoption provide highly relevant information to help understand the results from the environmental performance indicators.

Over the 25-year period from 1981 to 2006, agricultural land use increased in intensity across Canada as both the area of cropland and the proportion of cropland to total farm land increased, mainly due to decreases in pasture and idle land in eastern Canada and decreases in summerfallow in western Canada. In response to market opportunities, cropping patterns diversified with the proportion of oilseeds, pulses and forages increasing at the expense of more traditional cereal grains. Total numbers in all major livestock categories increased over the 25-year period for the country as a whole, but there was a significant shift in cattle numbers: eastern Canada declined 26% and western Canada increased 41%, in large part due to removal of government subsidies on the transportation of feed grain.

Concurrently, producers across Canada are implementing a number of beneficial management practices (BMPs) to manage manure, fertilizers and pesticides and protect land and water resources. Results indicate strong adoption of nutrient management practices such as soil nutrient testing, optimizing the timing, application and incorporation of solid and liquid manure and fertilizer, and increased manure storage capacity. Results also indicate that improvements could be made in other areas such as solid and liquid manure storage practices, livestock access to surface water and pesticide application. Soil conservation tillage and no-till practices generally increased across Canada, together affecting 72% of cropland in 2006, contributing to the overall improvement in soil health across Canada.

Canada's agricultural landscape is a mosaic of cultivated, natural and semi-natural land that is used by close to 600 species of birds, mammals, reptiles and amphibians. Agricultural landscapes are dynamic, with economic drivers sparking land cover change that can be either beneficial (summerfallow to pasture) or detrimental (wetland to cropland) to wildlife habitat. The loss of natural and semi-natural land cover and the intensification of agricultural operations resulted in a decline in average national habitat capacity on farmland from 1986 to 2006. The significance of this national trend can vary from one region to another depending on whether or not there is a high proportion of natural and semi-natural land covers in the broader landscape. Beneficial management practices such as conserving riparian areas, adopting conservation tillage, managing woodlands and implementing rotational grazing should be encouraged, particularly in agricultural regions that have limited wildlife habitat capacity and in areas where there has been a significant decline in habitat capacity.

Food and Beverage Industry

Eco-efficiency indicators for the food and beverage industry have been developed to assess resource use intensity on the basis of dollar of manufactured goods produced. The indicators have been developed for benchmark years, which means no national trend analysis is available at this time. Structural and product differences in the industry throughout Canada lead to differences in resource use intensity. For instance, the grain & oilseeds milling and the sugar & confectionery products manufacturing sectors are much higher energy users than seafood, meat and dairy products manufacturing. Also, types of energy used vary by region within a given sector and influence the energy use and GHG emissions intensity within the industry. Similar structural and product differences affect the performance for the use of packaging materials, water intake and discharge intensity. Future updates of these indicators will allow for trend analysis.

Introduction

01 Introduction

AUTHOR
R. MacKay and A. Lefebvre

The Canadian agriculture industry has evolved significantly over the past 25 years. Across Canada the number of farms has decreased while the average size of farms, crop area and number of heads of livestock have all increased. Advances in technology and farming practices have allowed farmers to manage much larger operations with the same or less labour, making this structural adjustment towards intensification possible and contributing to sought after economies of scale given the decreasing profit margins.

Throughout, producers have had to increase their efficiency and yields from a finite amount of land, and have had to do so while operating in a highly competitive world market of unstable commodity prices. Meanwhile, they have faced a number of natural, economic and social challenges, including droughts, floods, high energy prices, urban development and increasing regulation.

Scientific research has brought advances in technology such as new cultivars and machinery, and has enabled better production practices that use inputs such as *fertilizer*[1] and pesticides more efficiently. These improvements have allowed producers to be more adaptable and innovative in their operations, and have made it possible for them to intensify production. As agricultural production has become increasingly sophisticated and intensified, environmental pressures have become more complex. This has drawn public and consumer scrutiny about how food is grown, making it an even greater challenge for producers to find the balance between achieving their economic objectives and managing their land in a sustainable manner. In other words, meeting the needs of today without compromising the needs of future generations (UNWCED, 1987).

These conditions do not mean that environmental degradation is an inevitable consequence of agriculture. Fortunately, producers generally understand well the importance of managing *ecosystem* functions and services such as *nutrient* and water cycling, *carbon sequestration* and storage and pollination, and that they must practice stewardship over critical natural resources such as water, soil and *biodiversity* to ensure long-term, successful farming.

Evaluating environmental performance: agri-environmental indicators

Agro-ecosystems are human-managed ecosystems that produce food, fibre and other products for society. The manipulations required to produce these services involves actions such as clearing, cultivating, seeding and harvesting, supplementing nutrients and natural precipitation and controlling weeds and pests, and can be undertaken in a variety of ways. Agro-ecosystems, like natural ecosystems, are dynamic, with a constant flow of energy, water and chemical elements entering and leaving the system in cycles.

Agricultural decision-makers require good information to properly understand and address complex ecological systems (Millenium Ecosystem Assessment, 2005) in addition to economic and social considerations. However, the long term and highly technical nature of ecological research means that results are not always available when required and are not always easily understandable.

In 1993, in response to a need for agri-environmental information, and to assess the impacts of agricultural policies on the environment, Agriculture and Agri-Food Canada (AAFC) began to develop a set of science-based environmental indicators specific to the agriculture and agri-food sector (McRae et al, 2000). This mandate was strengthened in 2003 when AAFC established the National Agri-Environmental Health Analysis and Reporting Program (NAHARP). Agri-environmental indicators (AEIs) aggregate a large amount of biophysical information such as soil types, climate and topography, and combine it with data on land use, crop and livestock management practices. The result is easy-to-understand measures that can inform agricultural and other decision makers on the following topics:

- The environmental performance of agriculture, i.e. management and conservation of natural resources and compatibility with the broader environment
- How the environmental performance of agriculture changes over time
- The impact of adopting environmentally *beneficial management practices*
- The development of strategies and actions to safeguard areas and resources that remain at environmental risk
- The effectiveness of agricultural policies and programs

This report, Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series—Report #3, builds on past efforts. Agri-environmental performance results and trends are now presented for the 25-year period from 1981 to 2006 for many indicators. Most indicators have been refined and updated from previous reports and now have improved calculation methodologies. Almost all indicators now present national and provincial coverage of results. Some of the newer indicators that were introduced and under development in report #2 (Lefebvre et al, 2005) are now at a stage where national results can be presented.A description of the progress made to date is provided for indicators still under development.

1 All specialized terms included in the glossary (Chapter 25) are italicized the first time they appear in the report.

Contributing to OECD work

Agriculture is linked to many global environmental issues, and agricultural products are a key element of global trade. Internationally comparable indicators are being developed to help researchers better understand the health of the global environment and assess the environmental performance of the agriculture sector within it across countries.

The Organisation for Economic Co-operation and Development (OECD) recently released the report Environmental Performance in OECD countries since 1990 (OECD, 2008), which summarizes efforts among member countries to develop a set of AEIs that are based on consistent and compatible methodologies. The OECD's indicators:

- provide information on the current state and changes in environmental conditions within agriculture,
- identify linkages between the environmental impacts of agriculture, agricultural policy reform, trade liberalization and environmental measures along with the associated causes, and guide the responses to changes in environmental conditions, and
- evaluate the effectiveness of policies addressing agri-environmental concerns and the promotion of *sustainable agriculture*.

The development of environmental indicators at the international level is especially challenging because of differences in environmental conditions, economic activity, national priorities and the availability of data across countries. Through AAFC's work on AEIs, Canada actively contributes to the OECD's efforts and benefits from co-operation and the exchange of results.

Other pressures or responses such as shifts in markets, government policies and private expenditure also influence the sector's environmental performance. Although these additional factors are not covered in this report, Chapter 3 discusses the progress that has been made on integrating AEIs with economic models. This work helps assess and predict the environmental outcomes of different economic scenarios and it can provide policy makers with more complete information on the environmental and economic risks and benefits of various policy options. Progress has also been made on determining the economic value of the ecological goods and services provided by agroecosystems.

As federal and provincial governments reiterate their commitment to helping producers improve their environmental performance under Growing Forward,[2] the information in this report's AEIs will help track producers' progress in addressing stresses on the environment arising from farm production and practices.

The indicator results presented in this report are designed to provide a snapshot of the environmental risks and conditions in agriculture at regional and national scales. The report is intended for readers who would like to learn about the environmental issues most important to the agriculture sector, and whether the agriculture sector is moving towards or away from *environmental sustainability.* This information can be used as a report card for producers, consumers and the international community as it points out areas where further efforts are required. It also provides valuable information to decision makers for developing and evaluating agricultural policy.

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2. Growing Forward is a Federal, Provincial and Territorial agreement whose objectives are: focusing on building a competitive and innovative agriculture and agri-food sector, ensuring the sector contributes to society's priorities and being proactive in managing risks.

02 Assessing the Environmental Sustainability of the Agri-Food Sector

AUTHOR
W. D. Eilers

Summary

This chapter explains how Agriculture and Agri-Food Canada uses agri-environmental indicators (AEIs) to conduct comprehensive national assessments and report on the agri-environmental performance of primary agriculture and the food and beverage processing industry. This report covers four key aspects of primary agriculture: farm land management, soil quality, water quality and air quality. For the food and beverage industry, the indicators assess resource use and emissions intensity for energy use, *greenhouse gas* emissions, water use and liquid effluents, and use of packaging materials.

Agri-environmental Indicators

AEIs can be used to assess the environmental sustainability of agriculture. They are designed to be responsive to changing land use and management practices and to lend themselves to the analysis of large areas, zeroing in on the sector's negative and positive impacts on the environment. To be considered consistent and credible, all AEIs have to meet the following set of fundamental criteria:

POLICY RELEVANT
Indicators must relate to an environmental issue that governments and other stakeholders in the agriculture and agri-food sector are seeking to address.

SCIENTIFICALLY SOUND
Indicators must rely on methodologies that are scientifically sound, reproducible, defensible and accepted, recognizing that their development may involve successive stages of improvement.

UNDERSTANDABLE
The significance of the indicator values that are reported must be readily understood by a non-scientific audience.

CAPABLE OF IDENTIFYING GEOSPATIAL AND TEMPORAL CHANGE
Indicators should allow identification of trends over time and area.

FEASIBLE
Indicators should make use of existing data as much as possible and they should be economically efficient to develop.

The indicators typically fall into one of three categories:

1. ***Risk indicators*** are an estimate of the likelihood of a potential environmental impact.

2. ***State indicators*** estimate the actual presence and degree of an impact.

3. ***Eco-efficiency indicators*** estimate resource use efficiency, typically by comparing inputs and outputs of some material.

Calculation Method

PRIMARY AGRICULTURE

AEIs that assess primary agriculture are calculated using mathematical models or formulas that integrate information on soil, climate and landscape, mainly derived from the *Soil Landscapes of Canada* (SLC) (Soil Landscapes of Canada Working Group, 2007), with information on crops, land use, land management and livestock from the *Census of Agriculture* and other custom data sets from provincial agencies, private sector, remote sensing, etc. Results are generalized to provide a snapshot of an environmental condition on the landscape at a given time. These mathematical models and formulas have been adapted or developed from solid scientific knowledge and understanding of the interactions between various aspects of agricultural practices and the environment.

Summarized results from the Census of Agriculture, special surveys such as the Farm Environmental Management Survey (Statistics Canada, 2007) or combinations of these two sources are also presented in this report (Chapters 4 and 5) to complement the information provided by AEIs. These results are not considered indicators per se, but nevertheless offer important information that can help researchers interpret the results of the indicators.

The data used to calculate AEIs are collected at various temporal and geographical scales and must be interpreted and integrated into a common geospatial framework for indicator calculation and mapping. The areas used for most of the primary agriculture indicator model calculations are *polygons* of the SLC map series.

A common set of agricultural SLC polygons has been identified through analysis of the Census of Agriculture, remote sensing, and local expert knowledge. Figure 2-1 shows a map of the agriculture SLC polygons as well as the proportion of agricultural land in the polygon area. This map identifies the extent of the agricultural area covered by AEIs in this report. In fringe areas where agricultural activities are highly dispersed, some SLC polygons are omitted from calculations due to lack of verifiable

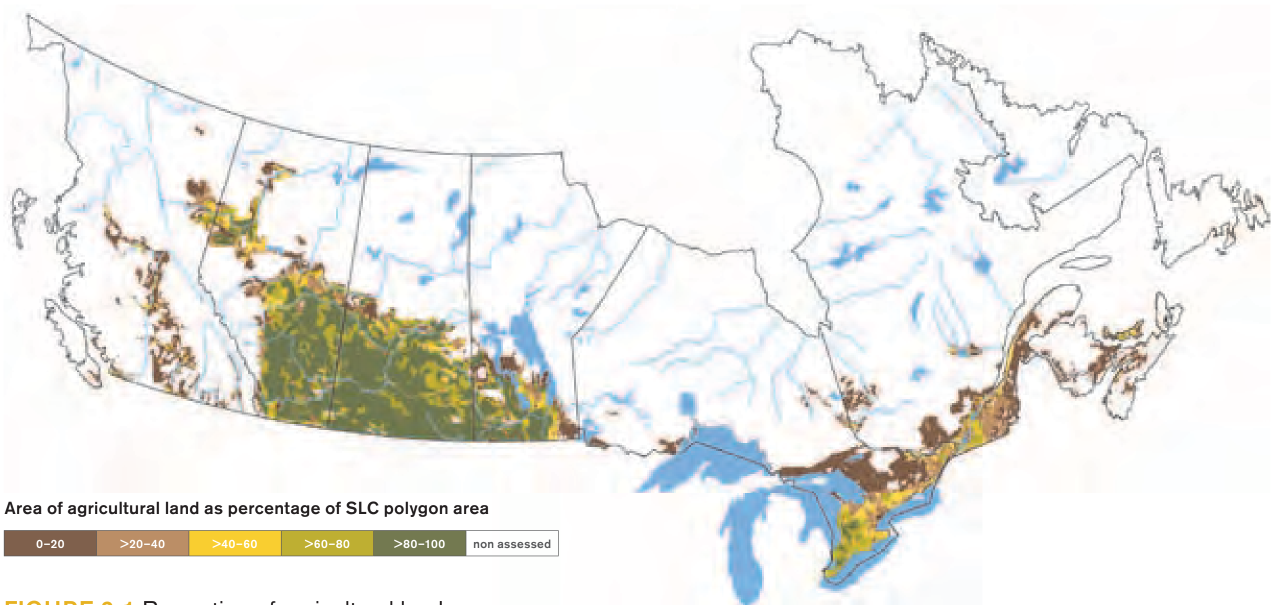

FIGURE 2-1 Proportion of agricultural land

information. Agriculture in the Yukon Territory, the Northwest Territories and Nunavut was also excluded from the study.

A second framework based on *watershed* boundaries, National Scale Frameworks Hydrology—Drainage Areas, Canada, v 5.0 (NRC, 2003), is used by two indicators that assesses risk to water quality. This framework allows integration of soil and farm management information with the surface *drainage* network within these watersheds to report risk to water quality from agricultural sources.

> Online mapping capabilities and detailed methodologies and data sources for each indicator can be accessed through AAFC's website at **www.agr.gc.ca/naharp-pnarsa**.

FOOD AND BEVERAGE PROCESSING INDUSTRY

In processing agricultural and seafood commodities into consumer products, the food and beverage industry consumes resources—energy, water and processing materials—and can release wastes—gaseous emissions, liquid *effluent* and organic materials—into the environment. Indicators for the food and beverage processing industry have been developed to assess how intensely the industry uses resources and discharges waste to the environment. The indicators are largely based on results of Statistics Canada's 2002 Annual Survey of Manufactures and Statistics Canada Industrial Water Use 2005, Survey. They are calculated as a ratio of the quantity of resources used or waste discharged per dollar of product sold.

These indicators are reported nationally, based on sub-sector, geographic location and the size of the processing plant. They provide an assessment of environmental performance trends by establishment size and by region within the same sector. Results for the indicators are relative in that individual establishments are ranked in comparison to the sector's most eco-efficient establishments.

Understanding the Results

A standard classification framework for all indicators has been developed to help researchers interpret them. This framework consists of a five-class rating system where each class has a general meaning in relation to environmental sustainability or a given implication from a policy perspective (Table 2-1).

The maps used in this report that show indicator results typically represent the most recent assessments of the conditions in question, which correspond to the status of the indicators based on 2006 Census of Agriculture data. In these maps, whole SLCs or other spatial polygons are assigned a value while the results apply only to the agricultural portion of the polygons. Also, the indicator results present aggregated values, which means that although a wide range of values may exist in any particular SLC polygon, the aggregation may obscure local realities. Because of this (as well as other limitations) the indicators cannot be interpreted as showing any specific conditions on individual farms.

The trend that an indicator shows over time is just as important as the current condition or status of an indicator. Temporal trends are generally presented in tables that show the results for Canada and individual provinces for each year that the indicator was calculated. Maps are included in each chapter to show areas where indicator classes have changed (usually from 1981 to 2006).

An Agri-Environmental Performance Index has been developed to show environmental performance status and trends over time. The index presents results for each individual indicator and

TABLE 2-1 Description of indicator classes for risk indicators

Classes	Meaning	Implication
1. Very low risk	In general, this level of risk is **negligible**. Agri-environmental health is likely to be maintained or enhanced over time.	A more detailed analysis of the situation is warranted to understand the various factors that have contributed to this rating. Some potential may exist to export policy and program approaches to areas of higher risk.
2. Low risk	In many cases this level of risk may be **acceptable**. Agri-environmental health is at low risk of being significantly degraded.	Continued adoption of beneficial management practices to better match the limitations of the biophysical resource may improve sustainability in some areas. Specific (policy or program) actions are not necessarily warranted.
3. Moderate risk	**Awareness** of the situation is important. Agri-environmental health is at moderate risk of being significantly degraded.	The trend towards or away from sustainability needs to be assessed. More attention should be directed locally to promoting the adoption of beneficial management practices. This will better match the limitations of the biophysical resource and reduce this risk.
4. High risk	Heightened **concern** is warranted. Under current conditions, agri-environmental health is at high risk of being significantly degraded.	A more thorough local assessment is probably warranted. Additional efforts and targeted actions are likely needed locally to better match management practices to the limitations of the biophysical resources.
5. Very high risk	**Immediate attention** is likely required. Under current conditions, agri-environmental health is at very high risk of being significantly degraded.	A more thorough local assessment is warranted. Concrete and targeted actions are likely needed locally to better match management practices to the limitations of the biophysical resources. It may be necessary to consider alternate land uses to reduce the risk.

Note: A similar scheme may be applied to non-risk indicators with slight variations in the class description, meaning and implications.

also can aggregate multiple indicators within an environmental theme (e.g. water quality). The calculation for this unit-less index is based on the percentage of agricultural land that falls into each of the five classes for each indicator The scale of the index ranges from 0 (all agricultural land in the most undesirable indicator class) to 100 (all land in the most desirable indicator class) (Table 2-2). This index is presented graphically at the beginning of each *agri-environmental indicator* chapter and is used to discuss overall trends in the executive summary.

The AEIs communicate information in summary form about important issues from a biophysical perspective. However, their use is not strictly limited to showing present status and trends. Individual indicators may show an obvious change in risk but the complex nature of agriculture's interactions with the environment means that positive trends in one indicator may lead to negative trends in another, and therefore the indicators should not be interpreted in isolation. As well, there are broader questions to consider for the sector, such as the overall socio-economic and environmental costs and benefits associated with adopting alternative land use or management practices. As part of its efforts to develop AEIs, AAFC is also developing tools and approaches for linking these indicators to economic and policy models. This is to provide guidance for policy and program evaluation and development. Use of the indicators in policy development is discussed in greater detail in Chapter 22.

TABLE 2-2 Agri-environmental performance index

Scale	Desired 81–100	The range for this unit-less index is from 0 to 100. The higher the value, the more agricultural land falls in the lower risk categories for the indicators captured in each index. A hypothetical value of 100 would mean that all of the agricultural land is at very low risk (or is considered environmentally sustainable). A hypothetical value of 0 would mean that all of the agricultural land is in the very high risk categories
	Good 61–80	
	Average 41–60	
	Poor 21–40	
	Undesirable 0–20	
Target	81+, Stable or improving	This is a long term target–the outcome to strive for. It is not meant to be interpreted as a short term target.

Limitations

In developing AEIs, scientists assess the environmental performance of a complex system that is not fully understood and must work within the limits of available data. Hence, the approach used for the development of the AEIs in this report is subject to the following general limitations. (Particular limitations that apply to individual indicators are described in each chapter.)

KNOWLEDGE GAPS

How we develop indicators depends on our understanding of the ecosystem processes involved. For some indicators, work on calculation methodologies has been underway for some time and is quite advanced while, for others, work on quantification is less developed. In some cases, the linkages between key issues are not fully understood, which may affect how the indicator results are interpreted. In addition, the boundaries of the five classes used for reporting results would ideally use science-based reference thresholds such as environmental quality standards. However, these are largely not available at a national scale. For most of the indicators, classes are based on expert knowledge.

SCALING-UP

In this publication, indicators are typically calculated using models that have been developed and tested at the field level, which provides a good theoretical foundation for assessment. However, the results become less reliable when the field-tested models are used at broader scales. Because of this, the national evaluations in this publication are limited to potential or relative risk assessments as opposed to determined, actual physical contributions to the environment in specific locations.

DATA ISSUES

All measured data used in calculating the indicators carries an intrinsic uncertainty. In addition, the required data may not always be available for all census years or for the whole country. This situation may occur because a particular parameter has not been consistently measured or surveyed (e.g. Census of Agriculture measurement of *no-till* and *conservation tillage* has only been conducted since 1991), or because data have been suppressed to protect producers' confidentiality (e.g. when there are only a few instances of a particular farm activity in a given area). When aggregated over an entire province or *ecozone*, considerable data may be lost and results skewed. Alternative approaches are used to overcome these limitations and estimate the missing values, which are then used in the calculations.

Indicators are often calculated using data that was not collected on the same spatial framework used to report the indicators, and reallocation of the data had to be performed. A prime example of this approach is the re-assignment of Statistics Canada Census of Agriculture data, which is aligned to political boundaries and cannot easily be linked to biophysical information such as that in the Soil Landscapes of Canada framework. A method based on the proportion of SLC polygon areas to Census framework area was devised to calculate and reassign the Census data to the SLC polygons (AAFC, 2004). However, where agriculture is present in only a small proportion of SLC polygon area (Figure 2-1), unknown errors can be introduced.

Representative information on the soils and landscapes in the SLC polygons are key components for many indicators. However, data on specific soil properties or landscape characteristics are often based on limited or historic information, which increases uncertainty.

RELIABILITY

Efforts have been made to validate the results of the indicators (e.g. see inbox Chapter 12.1), however, there is often very little independent experimental data with which to calibrate or validate the indicator model results. In this report we were unable to use statistical methods to determine the actual uncertainty associated with the indicator results. Work is planned to improve this aspect of indicator analysis.

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03 Driving Forces

UPDATED BY
J. Jensen and H. Morand

Summary

The driving forces affecting agriculture are continuously evolving. Globalization, technological innovations, decreasing profit margins and an effort to keep pace with domestic and worldwide demand for agricultural products all spur Canadian agriculture to increase its productivity and output. In response, the sector has undergone structural changes in the last century, some of which have environmental implications. At the same time, the social preferences of Canadians are evolving and concerns are being raised about the environmental costs of food production. Canadians have supported a widening array of domestic and international agreements and regulations designed to protect the environment.

The agriculture sector has responded to these driving forces by looking for ways to integrate environmental considerations into decision-making processes on the farm and in policy development. The sector is adopting new technologies and carrying out voluntary initiatives to improve environmental outcomes, coupled with some provinces establishing regulations. This chapter reviews some of the driving forces that have likely influenced the agriculture sector's environmental performance as measured by the agri-environmental indicators presented in this report.

Introduction

Agriculture is inextricably connected to the broader policy, economic and social trends of the world. Globalization, trade agreements, changing domestic and world demand, changing market structure and technological innovations all influence the decisions agricultural producers make. Producers consider these forces and select production strategies that will enable them to achieve their desired outcomes most efficiently. Producers can also influence the level of environmental risks and benefits of agricultural production, which can vary significantly depending on the methods of production they select and the local ecosystems where those methods are applied.

During the past century, the forces driving the agriculture sector have evolved, becoming more complex—and changing even more quickly in recent years. New issues have emerged as the agriculture sector continues to broaden its environmental approach to address the effects of agricultural operations on the larger ecosystem. Driving forces will continue to evolve, and risks to the environment will remain a concern as output expands. Policy, technology and other means will be required to respond to these driving forces so that economic, environmental and social objectives can all be achieved.

Market Demand

The expanding world population, higher disposable incomes and increased life expectancies have boosted global demand for food. With rising incomes in both developed and developing countries, consumer preferences are changing and diets are becoming more varied to include higher valued livestock products and fresh fruits and vegetables along with more traditional cereals. Industrial demand for non-food agricultural products (e.g. *biofuels*, *bioplastics*, building materials, *nutraceuticals*) is also growing. This rising global demand for food and other agricultural products has been accompanied by the globalization of markets and trade liberalization.

Canada, with its large land base, limited population, ample water supplies and competitive industry, has been able to respond to this opportunity (Figure 3-1). Conversely, agriculture and agri-food production and trade can also be negatively affected by climate conditions and market forces. For example, drought, border closure due to animal diseases (such as the discovery of *Bovine Spongiform Encephalopathy*) and the appreciating Canadian dollar (30% gain relative to the US dollar) are all factors that affected trade between 2002 and 2006 (Bank of Canada, 2006).

The need for Canada to increase its competitiveness and productivity in the global economy has spawned research initiatives, changes in government policies (such as income support programs) and marketing efforts. As market signals change, Canada's agriculture sector seeks to adapt, which has led to structural changes that may have positive or negative environmental implications for air, soil and water quality, and farm land management, including:

- the ongoing development and adoption of production methods aimed at enhancing competitiveness (improved management systems such as conservation tillage, precision farming);
- changes in the mix of commodities produced, such as a significant increase in the production of lentils, peas, canola, soybeans;
- greater farm size, specialization and production intensity to capture economies of scale (e.g. 36% increase in the number of hogs between 1996 and 2006 concurrent with a 45% decrease in the number of farms reporting hogs); and
- changes in land use and management practices (e.g. increasing use of inputs such as *nitrogen* fertilizer to increase production).

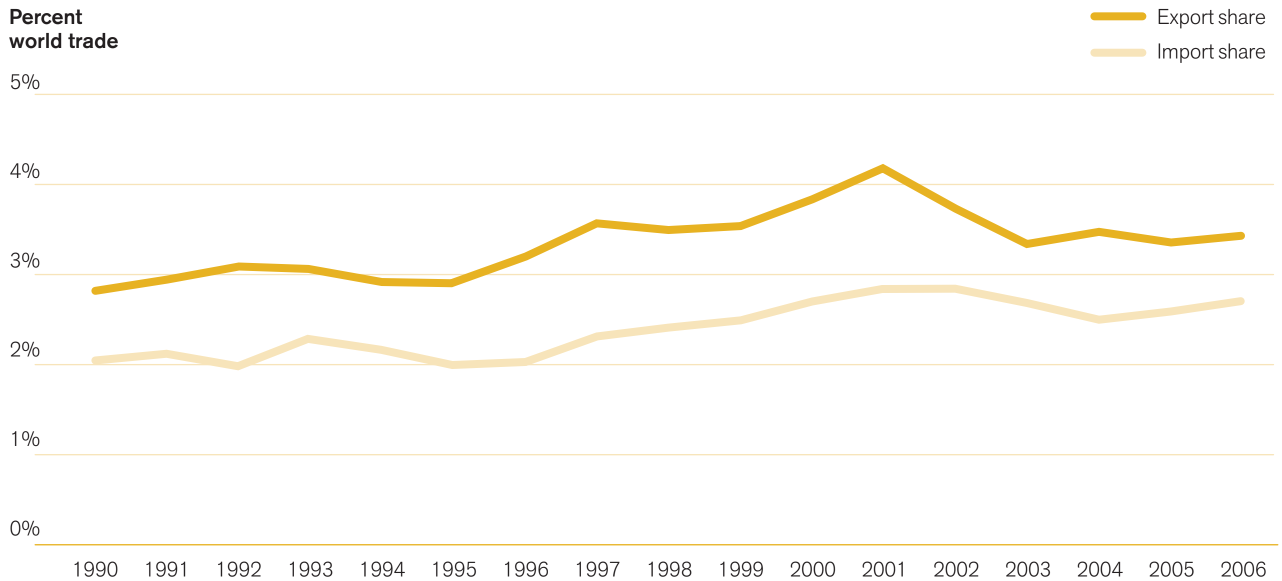

FIGURE 3-1 Canada's share of World Agriculture and Agri-Food Trade, 1990–2006.

Social Preferences

The preferences and expectations of the general population can have an important influence on the agriculture and agri-food sector, and this has been reflected by the sector's response to mounting consumer demands for a safe and reliable food supply. Consumers at home and abroad are increasingly aware of the economic and ecological value of natural resources as well as the environmental risks associated with agricultural production. Canadians also support rural development and employment and the contributions that agriculture makes to national income and trade.

Consumer choices also influence farm production practices that affect the environment. For example, the growing market for organic foods (crops produced without chemical fertilizers or synthetic pesticides and not derived from genetic engineering) could lead to a reduced risk of chemical and *pesticide* contamination of water in some areas, however could increase the risk of *pathogen* contamination of water given the greater use of organic fertilizers and manure.

Changing public expectations for the environment and food products have direct ramifications for the agriculture sector. Canadians are generally supportive of initiatives for environmental preservation and protection and governments have responded to Canadians' preferences by adopting a number of strategies that have influenced agricultural production and food processing, such as supporting technological research and innovation that affect agricultural production and output, implementing policies and voluntary programs to promote environmentally sustainable agriculture and passing regulations to protect the environment.

There is growing public recognition of the environmental benefits that agricultural ecosystems can provide, such as habitat for *wildlife*, pleasant landscapes, recycling of effluents and solid waste, reduction of greenhouse gas emissions (GHGs) through *carbon sinks* and innovations such as *anaerobic digesters* that capture *biogas* for energy. Producers may be able to benefit from this recognition via public programs or market-based instruments such as environmental certification, GHG *offset payments*, and auctions for *ecosystem services*.

Government Policy

Government policies operate at local, regional, provincial, national and international levels and have a strong influence on the use of agricultural resources. Since the early 20th century, the primary objective of Canadian agricultural policy has been to increase output and promote income stability in a sector that has to grapple with variable weather conditions, volatile commodity prices and strong international competition. Over the past few decades, government support has shifted to include funding for agricultural research, long-term capital to finance growth and the adoption of technology, income stabilization programs, removal of trade restrictions and supply management (dairy and poultry).

Government support peaked during the 1970s and 1980s when the total amount of direct and indirect subsidies (the Producer Support Estimate, or PSE) reached about 30% of the value of production. Realizing that much of this support simply offset what other countries were doing, most developed countries agreed under the auspices of the World Trade Organization and the Agreement on Agriculture (ratified in 1995) to reduce measures that distort trade. Canada has been a strong proponent of measures to reduce trade-distorting agricultural subsidies, as Canadian producers are considered to be highly competitive in most commodities. From 2001 to 2006, the PSE for Canada stood at a lower level, about 25%, than in previous decades as a result of various reforms, such as the elimination of grain transportation subsidies, and the decoupling of farm income safety nets from specific commodity production (so producers could respond to prevailing market signals). The PSE for Canada is now comparable to the average of member countries of the Organization for Economic Cooperation and Development (OECD).

Not all government policies are geared to expanding production. Although producers have long been stewards of Canada's land and water resources, growing concern that the increase in agricultural output was causing environmental damage prompted governments to focus to a greater extent on improving the environmental performance of Canadian farms and harnessing the resulting benefits. Concurrently, global pressures related to environmental issues such as climate change, *ozone* depletion, organic pollutants, *wildlife habitat* and biological diversity have given rise to a number of international initiatives that Canada has become part of. A wide range of policies and initiatives have been adopted both nationally and internationally with important implications for Canadian agricultural production and the environment (Tables 3-1 and 3-2).

Federal, provincial and territorial Ministers of Agriculture agreed in 2008 to Growing Forward, an agricultural policy framework for the period 2008 to 2013, which included a $1.3 billion investment in the sector. The funding represents $330 million more than Canada's previous *Agricultural Policy Framework* and is cost-shared on a 60:40 basis between the Government of Canada and the provincial and territorial governments. Growing Forward emphasizes building a profitable agriculture sector through the development of three strategic outcomes: a competitive and innovative sector, a sector that contributes to society's priorities, and a sector proactive in managing risks. It is the cornerstone of agri-environmental policy in Canada and includes environmental objectives such as the voluntary implementation of on-farm environmental risk assessments, where environmental risks are identified and remedial action is encouraged through incentives for producers to adopt beneficial management practices (BMPs). Incentives are cost-shared so producers make a substantial investment.

With respect to regulation, producers face a number of site-specific requirements for environmental protection—for example, for pesticide storage, or situation and construction of manure tanks. Increasingly, producers are facing more regulation at the provincial and municipal levels such as land zoning restrictions and requirements for nutrient management plans.

Agriculture and Agri-Food Canada's role centers on providing research, funding agri-environmental programs, providing market information, identifying and promoting environmental BMPs, reforming trade policy and fulfilling Canada's international agricultural commitments. To provide producers with an incentive to meet environmental goals and standards, some countries have made eligibility for farm program support contingent on environmental compliance—a practice known as cross-compliance. Canada's main thrust to date has consisted of voluntary measures and incentives.

Technological Change

At the farm level, the technological developments of the past 200 years have significantly altered the way in which producers

TABLE 3-1 Examples of international environmental initiatives

International Initiative	Implications for Agriculture
United Nations Framework Convention on Climate Change (including the Kyoto Protocol on GHG emissions and post-Kyoto agreement)	Post-Kyoto agreement currently in negotiation, which will likely define the nature and extent of the role of agricultural GHG mitigation and adaptation.
Global Research Alliance on Agricultural Greenhouse Gases Mitigation	The Alliance is a global network that will better coordinate and increase research on agricultural greenhouse gas mitigation. This will help provide farmers with new practices that will improve efficiency, reduce the cost of production and help farmers to participate in carbon trading.
United Nations Convention on Biological Diversity (including the Cartegena Protocol on Biosafety)	Canadian biodiversity strategy developed promoting conservation of crop and livestock biodiversity, habitats and species.
Montreal Protocol on Substances that Deplete the Ozone Layer	Elimination of the use of methyl bromide (an agricultural fumigant) by 2005.
North American Agreement on Environmental Cooperation (NAAEC)	A commitment under the NAAEC prohibits the export of a pesticide or toxic substance whose use is prohibited within one of the signatories. As well, when a country adopts a measure prohibiting or severely restricting the use of a pesticide or toxic substance within its own borders, it must notify the other countries of the measure, either directly or through an appropriate international organization.
North American Waterfowl Management Plan	May impact the use of wetlands within agricultural boundaries.
UN Economic Commission for Europe (includes Canada and US)	
Protocol to Abate Acidification, Eutrophication and Ground Level Ozone	Canada reports on ammonia and nitrous oxide emissions, of which agriculture is a significant source, but has not ratified the protocol.
UNECE Protocols on Persistent Organic Pollutants (POPs) and Heavy Metals	Canada ensures adherence through its domestic regulations on chemicals, which include chemicals used in agriculture.

TABLE 3-2 Examples of Canadian environmental regulations

Federal Regulations	Implications for Agriculture
Canadian Environmental Protection Act (CEPA)	CEPA provides the regulatory framework for: establishing an offsets trading system under which agriculture could provide emissions trading credits, ethanol use targets, and vehicle fuel efficiency including diesel.
Canadian Environmental Assessment Act	Requires consideration of environmental impacts of projects prior to implementation. Could affect agriculture on federal lands or in cases where federal funds or regulations support or approve projects on private land.
Fisheries Act	Conserves and protects fish and fish habitat and can affect management of agricultural watercourses including irrigation and drainage canals, as well as control the release of deleterious substances into waterways.
Pest Control Products Act	Ensures safe use of pesticides based on environmental, human health and other factors.
Species at Risk Act	Possible limitations on the use of agricultural land that provides habitat for species at risk.
Provincial and Municipal Regulations	
Numerous provincial acts and regulations and municipal bylaws and provisions	Controls imposed on a wide range of agricultural activities (e.g. separation distance to wells, conversion of agricultural land, spreading of manure, manure storage capacity, location of large hog barns). Regulations vary by province and by municipality.

use resources. This is particularly true of the technology explosion that marked the latter part of the 20th century. Noteworthy technological advances include new farm implements, major improvements in information technology and genetic engineering and the advent of precision farming. Between 1991 and 2006, the use of no-till methods more than quadrupled (from 7% to 46%), producing many positive environmental effects: improved soil quality, reduced erosion, enhanced water quality, reduced net GHG emissions through increased *carbon sequestration* in the soil, and enhanced biodiversity. The proportion of farms using a computer to help manage the farm nearly doubled every five years from 1986 to 2001 and by 2006 stood at 46.4%.

These developments are shifting the emphasis in agriculture away from physical production to activities based more on knowledge and skills. Modern agriculture is characterized by a reduction in physical labour and a move towards specialization, concentration and consolidation. Specialization has spread through entire regions where specific crops are most profitable, and where farms previously supplied a wider range of crops to local markets. Since the prices for specialized crops tend to fluctuate, producers have also adapted by adding value through processing, introducing and developing markets and production practices for new crops, and becoming more involved in crop selling online or via market agents. For most commodities, distance to market is no longer the most important factor in deciding where production should take place. Selecting the right physical and economic environment is a key factor for success in today's competitive world marketplace.

The environmental effects of technological change are the subject of considerable debate. Some technologies have had unanticipated, adverse effects on the environment, such as the *fumigant* methyl bromide that provided benefits for agriculture for a number of years, but whose use has been phased out because of negative effects on stratospheric ozone.

Many new technologies and practices reduce environmental risks, such as biological *pest* control, improved manure management, more efficient livestock diets and conservation tillage. *Biotechnology* and genetic engineering potentially offer considerable advantages to farmers for improving crop yields. Herbicide tolerance and insect resistance—the dominant traits of genetically modified (GM) crops—can help increase crop productivity and reduce the use of pesticides. However, in Canada and elsewhere there has been considerable debate about the merits of this technology. Many countries oppose GM products due to uncertainty regarding environment and human health.

Another emerging technology relates to the use of agricultural feedstocks for a number of bioproducts, such as biofuels. Rising *fossil fuel* prices and a desire to decrease GHG emissions have sparked interest in the domestic production of biofuels. Current research is focusing on the next generation of biofuels from cellulose. The commercialization of *biomass* (e.g. manure) for heating and energy generation is also an important renewable energy opportunity from agriculture.

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Summary of agricultural statistics in Canada, 2006

Land Statistics (hectares (ha))

Total area	998.5 million ha
Total land area	909.4 million ha
Total farm area	67.6 million ha
Cultivated land	58%
Pastureland	31%
Other land	11%
Average farm area	295 ha

Farm Characteristics

Total # of farms	229,000
Total # of families	176,000
Total # of operators	327,000
Average age of operators	52

Major Agricultural Outputs

Cattle & calves	$6.4 billion
Dairy	$4.8 billion
Hogs	$3.4 billion
Canola	$2.5 billion
Poultry & eggs	$2.4 billion
Wheat	$2.2 billion
Floriculture & nursery	$1.9 billion
Vegetables	$1.7 billion
Potatoes	$0.9 billion
Corn	$0.7 billion

Livestock Population (number of animals)

Poultry	125 million
Cattle and calves	16 million
Pigs	15 million
Dairy cows	1 million

Farm Income

Total net cash income	$5.3 billion
Total cash receipts	$36.9 billion
Total operating expenses	$31.6 billion
Distribution of farms by revenue class	
Less than $10,000	22%
$10,000 to $49,000	30%
$50,000 to $100,000	14%
More than $100,000	34%

Food and Beverage Industry

Total # of establishments	3,347
Small (less than 50 employees)	70%
Medium (50 to 199 employees)	20%
Large (more than 200 employees)	10%
Total value of shipments	$77.8 billion
Food Processing	$67.7 billion
Meat products	27%
Dairy products	19%
Fruit & vegetables	9%
Grain and oilseed milling	8%
Other food	37%
Beverages	$10.0 billion

International Trade Statistics

Trade balance	$5.4 billion

Contribution to GDP

Agri-food sector	$31.3 billion
Primary agriculture	$14.1 billion
Food processing	$17.2 billion

Exports

Total agricultural exports	$27.9 billion
Bulk	26%
Intermediate	24%
Consumer-oriented	50%
Major export markets	
United States	$16.2 billion
Japan	$2.4 billion
EU 15	$1.7 billion
Mexico	$1.1 billion
China	$0.7 billion

Imports

Total agricultural imports	$22.4 billion
Bulk	11%
Intermediate	13%
Consumer-oriented	75%
Major import markets	
United States	$13.0 billion
EU 15	$3.1 billion
Mexico	$0.9 billion
Brazil	$0.6 billion
Australia	$0.5 billion

Farm Land Management

Farm Land Management

Summary

How farm land is managed is a primary determinant of agriculture's environmental performance. The Census of Agriculture and the Farm Environmental Management Survey (FEMS) are two important surveys that provide useful information for determining how agriculture is changing over time and about which activities and beneficial management practices (BMPs) are being implemented to address the environmental risks of agriculture. The surveys provide the data sources for two key summaries that, while not indicators themselves, provide highly relevant information and trends about the status of agriculture and agricultural practices.

- The Agricultural Land Use Change Chapter (Chapter 4) provides a summary of changes in land use, cropping and tillage practices, and livestock populations that occurred between 1981 and 2006 in Canada. The summary is based on data from the Census of Agriculture and the information is used by the agri-environmental indicators to track practices and their effect on the environment. This is a key component for assessing agriculture's environmental performance.
- Farm Environmental Management in Canada (Chapter 5) presents a summary of key findings from the 2006 FEMS questionnaire that gathered information on management practices used by producers in 2006. Producers were asked about manure storage and spreading, grazing practices, crop and nutrient management, pesticide application, wildlife damage, land and water management, waste management, and environmental farm planning.

Farm land management influences the environment in many ways, including the efficiency of resource use and conservation, the availability of wildlife habitat, and the vulnerability of agriculture to risks posed by wildlife and invasive species. The Soil Cover Indicator and the Wildlife Habitat Capacity on Farm Land Indicator are fully developed agri-environmental indicators and are reported on in this section. Three other indicators are still under development and are summarized within the other chapters.

1. The Soil Cover Indicator (Chapter 6) summarizes the number of days in a year that agricultural soils are covered and protected from erosive forces. An increase in the number of soil cover days over time indicates an improvement in environmental sustainability since the soil is more protected from degradation and is less likely to contribute to water contamination and atmospheric emissions.

2. The Wildlife Habitat Capacity on Farmland Indicator (Chapter 7) assesses broad-scale trends in the capacity of the Canadian agricultural landscape to provide suitable habitat for populations of terrestrial vertebrates. Agricultural landscapes are dynamic, with economic drivers propelling both beneficial and detrimental land-cover change. It is the nature of these changes that ultimately determines the habitat capacity of a landscape and the structure and viability of incumbent wildlife populations. Assessing the wildlife habitat capacity of farmland is an important element in understanding the impact of agriculture on the environment.

3. Water Use Efficiency Indicators for *irrigation* (In-box, Chapter 4) are currently being developed to estimate the physical and economic productivity of water used for irrigated cropping. The indicators will estimate both the mass (for selected crops) and monetary value of all irrigated agricultural production per unit of irrigation water used.

4. An Indicator of the Risk of Wildlife Damage (In-box, Chapter 7) is under development and aims to identify areas at higher than average risk of damage by wildlife and determine how this risk is changing over time in response to land management changes. The indicator will consider driving forces for wildlife damage: area of field, climatic conditions, crop type, location of field in relation to preferred animal habitat, and wildlife numbers.

5. An Indicator of the Risk from *Invasive Alien Species* (IAS) is also in development (In box, Chapter 7) and aims to assess trends in population distribution and in numbers of IAS in agricultural habitats. Thus, it will reveal major pressures or threats to agro-ecosystem health and agricultural trade posed by existing IAS in Canada, established species with invasive attributes and IAS not currently present in Canada but with potential to invade.

Over the 25-year period from 1981 to 2006, agricultural land use increased in intensity across Canada. The area of *cropland* and the proportion of cropland to total farm land increased, and the area under *summerfallow* declined. Conservation tillage and no-till management practices generally increased across Canada, together accounting for 72% of cropland in 2006. Adoption of conservation and no-till practices were largely responsible for a 7% increase in the average level of soil cover from 1981 to 2006, however, cropping intensification caused some downward pressure on soil cover levels. Nationally, average habitat capacity on farmland declined from 1986 to 2006 due to the loss of natural and semi-natural land cover and the intensification of agricultural operations. The extent of decline was buffered by an overall improvement in the ability of cropland to provide wildlife habitat. Improvements were generally related to beneficial, yet transitory changes to large areas of crop cover (e.g. a shift in the share of farmland from summerfallow to tame hay) that favor a limited number of species.

Total numbers of all major livestock categories increased over the 25-year period for the country as a whole, but there was a significant shift in cattle numbers from eastern Canada (down 26%) to western Canada (up 41%). Producers showed a strong adoption of nutrient BMPs such as soil nutrient testing, optimizing the timing, application and incorporation of solid and liquid manure and fertilizer, and increasing manure storage capacity.

04 Agricultural Land Use

AUTHORS
T. Huffman and W. Eilers

STATUS
National Coverage 1981 to 2006

Summary

Agricultural land uses and management practices are key determinants of the current status of agri-environmental sustainability in Canada. Changes in these factors influence whether the trend is either towards or away from enhancing sustainability. Reliable information on agricultural land use and management practices is critical to assessing agriculture's environmental performance.

Over the 25-year period from 1981 to 2006, agricultural land use increased in intensity across Canada as both the area of cropland and the proportion of cropland to total farm land increased, and the area under summerfallow declined. In eastern Canada increases in cropland came from decreases in pasture and idle land, while in western Canada increases in cropland generally were due to decreases in summerfallow. In response to market opportunities, cropping patterns diversified with the proportion of oilseeds, pulses and forages increasing at the expense of more traditional cereal grains. Soil conservation tillage and no-till practices generally increased across Canada, together affecting 72% of cropland in 2006. Total numbers in all major livestock categories increased over the 25-year period for the country as a whole, but there was a significant shift in cattle numbers: eastern Canada declined 26% and western Canada increased 41%, in large part due to removal of government subsidies on the transportation of feed grain.

The Issue

Agri-environmental health and sustainability depend on the widespread use of agricultural management practices designed to consider the degree to which land, water and air are vulnerable to environmental degradation. Practices designed to reduce environmental risks to resources tend to be more sustainable while practices that do not take environmental conditions into account tend to be less sustainable. As an example, an increase in the area of row crops under *conventional tillage* or that are not being managed using measures to protect against erosion generally indicates movement toward higher erosion risk. Conversely, an increase in the use of land to grow hay, pasture or other perennial crops signals a lower risk of erosion. Similarly, changes in the number, type and location of livestock herds can have significant implications for the health of air, soil and water. The level of risk may increase or decrease according to the specific management practices employed, such as the type of tillage and manure management practices used in crop and livestock production.

Agri-environmental indicators integrate data about agricultural activity with environmental resource information to provide insights into the environmental sustainability of agricultural production. Examining the status and trends of land use and management practices over time are key actions in enabling agri-environmental indicators to track whether agriculture is becoming more or less environmentally sustainable.

Important agricultural land use and management information

This chapter presents some of the key changes in land use, cropping practices, tillage practices and livestock populations that occurred between 1981 and 2006 in Canada, based on data from the Census of Agriculture. The potential environmental implications of these trends are identified and explored in the indicator chapters of the report.

LAND USE

Different agricultural crops and land uses have different propensities for maintaining or degrading the environment. To present an overview of long-term trends in land use for the individual provinces and nationally, five census variables have been used:

1. Area of farm land
2. Area of cropland (includes hay, excludes summerfallow and pasture)
3. Area of summerfallow
4. Area of pasture (improved pasture and rangeland)
5. Area of other land (agricultural land including buildings and yards, woodlots, marshes, etc.)

CROPPING PRACTICES

In addition to land use information, it is important to know the crop types and the temporal trends in crop types that are grown in a region, because different cropping patterns typically have differing effects on the environment. Seven census variables are used:

1. Area of cereal grains (wheat, barley, oats and mixed grains)
2. Area of oilseeds (canola, mustard, flax, safflower and sunflowers)

Irrigation Water Use Efficiency Indicators

AUTHORS
L. Tollefson, G. Dyck and J. Harrington

Agriculture accounts for approximately 9% of water withdrawals in Canada. Of the water withdrawn for agriculture, 74% is consumed (not returned for downstream use), and most is consumed for irrigation. This makes the agriculture sector one of the largest consumers of freshwater (Statistics Canada, 2003). Increasing demand for supplies of fresh water and the possible implications of reduced supply due to climate change increases the need for efficient water use on agricultural land.

Efforts are being made to manage water more efficiently. For example, some jurisdictions have noted improvements in the efficiency of their irrigation systems as producers have moved away from flood irrigation methods to highly efficient drip nozzle centre pivot systems. Irrigation water use efficiency indicators will provide a means of measuring this performance.

A pilot study was launched in south-central Saskatchewan that calculated first-generation indicators to estimate two measures of water use efficiency:

1. Water use technical efficiency (WUTE) estimates the mass of agricultural production per unit volume of irrigation water used on selected crops.

2. Water use economic efficiency (WUEE) estimates the monetary value of agricultural production per unit volume of irrigation water used, for all irrigated crops.

The pilot study investigated variations in WUTE and WUEE across three growing seasons, tested methodological issues such as the appropriate scale for measuring efficiencies and identified crops suitable for regional and national comparison.

The study showed that at the irrigation district scale, WUTE and WUEE indicators were calculable, responsive and understandable. Initial findings indicate that the WUTE can reflect changes in irrigation management practices, including changes in crop choice and in irrigation methods. Increased WUEE reflected the selection of high-value crops and the seasonal irrigation of those crops.

The ability to calculate these indicators at a national scale is limited, however, by a lack of accurate and comprehensive irrigation data, including the number of irrigated acres, crop yields and water volumes. Despite these challenges, work will continue to develop a regionally sensitive national indicator of Irrigation Water Use Efficiency that adequately reflects changes in crop selection, irrigation technology and management practices.

3. Area of corn (grain corn and silage corn)

4. Area of potatoes

5. Area of *pulse crops* (beans, lentils and peas)

6. Area of *forage* crops (alfalfa, tame hay and forage seed)

7. Area of other crops (all other crops such as sugarbeets, vegetables, fruit, grapes and berries etc.)

TILLAGE PRACTICES

Management practices employed by farmers need to be considered in interpreting land use trends. Tillage practices have been evaluated in the Census of Agriculture since 1991 using six variables:

1. Area of cropland prepared for seeding using conventional tillage practices (tillage that turns over the top 15 to 20 cm of soil, burying plant residues and exposing the soil, followed by secondary tillage to break up soil aggregates and produce a smooth, even seedbed)

2. Area of land prepared for seeding using conservation tillage (tillage practices that break up the soil and kill weeds but do not turn the soil over, thus maintaining most of the *crop residue* on the surface)

3. Area of land prepared for seeding using no-till (management practice in which there is no tillage between harvesting one crop and seeding the next and thus all plant residues are maintained on the surface)

4. Area of summerfallow on which weeds are controlled by tillage only (the practice of fallowing traditionally required that tillage be carried out periodically during the growing season, thus burying crop residue)

5. Area of summerfallow on which weeds are controlled by a combination of chemical applications and tillage. (Chemical and tillage weed control reduces the amount of tillage through either reduced-frequency of tillage or spot cultivation).

6. Area of summerfallow on which weeds are controlled by chemicals only (no tillage)

The use of conservation and no-till practices on cropland more than doubled from 1991 to 2006 as awareness grew about the benefits of these practices to the soil

LIVESTOCK

Data on the number, location and type of livestock, and changes over time, are critical for assessing the relationship between agricultural production practices and the environment. The crop and livestock sectors are closely connected, as the cropping systems of many farms are determined by the feed and manure management requirements of on-farm livestock, while efficient local production of some crop types encourages the development of specific livestock production systems. This relationship between land use and livestock production has significant implications for assessing and mitigating greenhouse gas emissions, soil erosion, surface and groundwater contamination, soil carbon sequestration and air quality issues. For this report, the number of animals in each of five categories is used to identify relevant changes and trends:

1. Cattle
2. Pigs
3. Poultry
4. Sheep and goats
5. Horses

Limitations

The main limitations to the numbers reported in this chapter relate to the possibility that the census questions have been misinterpreted, and to changes in the questions over time. For example, according to Statistics Canada (2007), in 1981, the area of unimproved land was underreported in the four western provinces. This affected the area of total farmland and *all other land* categories for each of the western provinces and for Canada as a whole. A more complete description of potential errors and data quality is provided by Statistics Canada (2007).

Results and Interpretations

The total amount of farm land reported in Canada in 1981 is uncertain due to limitations on Census information. However, it remained relatively stable between 1986 and 2006 at 67.8 million hectares (ha) and 67.6 million ha, respectively. Farm land use intensified as the proportion of farm land growing crops (cropland) grew from 47% in 1981 to 53% in 2006 (Table 4-1, Figure 4-1). In western Canada this was mainly the result of a 64% decline in summerfallow area and in eastern Canada reduced cattle numbers allowed a decline in the area of pasture. Nationally the percentage of farm land in pasture remained fairly constant at 28% to 31% and the proportion in all other land grew by 3%.

The large decline in summerfallow area (Table 4-1) was accomplished through the adoption of practices that allow for *continuous cropping*, through more efficient use of available moisture, and through the use of new and affordable weed control methods. With the decline in summerfallow area, some marginal land was converted to *permanent cover* or pasture but the primary result was an increase in the area of cropped land, which expanded by 5 million ha from 1981 to 2006 (Table 4-2). Even though the amount of cropland increased, the proportion of it planted to cereals dropped by 21% from 1981 to 2006. Diversification of cropping led to more cropland in oilseeds, pulses and forages and, to a lesser extent, potatoes and other specialty crops such as vegetables, berries and grapes.

The use of conservation and no-till practices on cropland more than doubled from 1991 to 2006 (Table 4-3) as awareness grew about the benefits of these practices to the soil, suitable conservation and no-till equipment became more available and as producers increasingly recognized the cost savings of reduced machinery operation . Similarly, the proportion of summerfallow maintained by tillage declined by 27%, *reduced tillage* (tillage and chemical) decreased by 7% and no-till (chemical only) increased by 34% to represent 31%, 31% and 38% of summerfallow land, respectively.

The herd size for all livestock types increased in Canada between 1981 and 2006 (Table 4-4). Cattle numbers increased by 17%, pigs by 52%, poultry by 33%, sheep and goats by 46% and horses by 27%. The cattle industry shifted west with a 41% increase in cattle numbers in western Canada and a decrease in numbers in all provinces east of Manitoba except for Newfoundland and Labrador. All provinces except British Columbia, Nova Scotia and Newfoundland and Labrador showed an increase in the number of pigs, and all provinces showed an increase in poultry numbers.

The changes in land use, cropping practices, tillage regimes and livestock numbers illustrate the significant intensification of the Canadian agricultural production industry since 1981. The ratio of land devoted to crops as opposed to pasture, forest and unproductive land is used as a measure of change. An increase represents a growing proportion of farm land put into crop production and thus indicates an increase in the average intensity of farming in the area, while a decreasing ratio indicates a greater proportion of farm land in pasture and unproductive land and thus a decline in the intensity of production. Intensification of agriculture does not necessarily translate into increased risk for the environment as it could and often does indicate that agricultural production is being concentrated on those soils and landscapes more environmentally suited for production.

TABLE 4-1 Agricultural land use as a share (percentage) of farmland, 1981–2006

	Area of Farmland (hectares)		Share of Cropland (percentage) in Various Uses ("-" indicates less than 1%)																								
			Cropland						Summerfallow						Pasture						Other Land					
	1981	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	2,178,596	2,835,458	26	24	23	23	24	21	3	3	2	2	1	1	59	51	53	56	56	62	12	22	21	20	19	17
AB	19,108,513	21,095,393	44	44	45	45	46	46	12	10	9	7	6	4	40	38	40	41	42	43	4	7	6	7	6	7
SK	25,947,086	26,002,606	45	50	50	54	59	58	26	21	21	17	12	9	27	24	24	24	25	27	2	5	5	5	5	6
MB	7,615,926	7,718,570	58	58	62	61	62	61	8	7	4	4	3	2	29	26	27	26	26	27	5	9	7	9	9	11
ON	6,039,237	5,386,453	60	61	63	63	67	68	1	1	1	–	–	–	24	19	19	18	15	14	15	19	17	18	17	18
QC	3,779,169	3,462,936	46	48	48	51	54	56	1	1	–	–	–	–	21	17	19	15	11	9	31	34	33	34	35	35
NB	437,888	395,228	30	32	33	36	39	39	1	1	–	–	–	–	20	14	16	13	12	11	49	53	52	51	49	50
NS	466,023	403,044	24	26	27	29	32	31	1	1	–	–	–	–	20	16	17	14	14	14	55	56	56	56	55	55
PE	283,024	250,859	56	57	60	64	67	68	1	1	–	–	–	–	18	14	14	10	9	9	25	28	27	25	23	22
NL	33,454	36,195	14	13	13	17	21	26	1	1	–	–	–	–	64	34	39	21	24	35	21	52	47	62	55	39
CANADA	**65,888,916**	**67,586,741**	**47**	**49**	**49**	**51**	**54**	**53**	**15**	**13**	**12**	**9**	**7**	**5**	**31**	**28**	**30**	**29**	**30**	**31**	**7**	**10**	**9**	**10**	**9**	**10**

TABLE 4-2 Share of cropland in various uses, 1981–2006

	Area of Cropland (hectares)		Share of Cropland (percentage) in Various Uses ("-" indicates less than 1%)																							
			Cereal Grains						Oilseeds						Corn						Potatoes					
	1981	2006	81	86	91	96	01	06	81	86	91	96	01	06	81	86	91	96	01	06	81	86	91	96	01	06
BC	568,241	589,803	30	22	22	22	17	15	4	8	7	5	4	4	2	2	2	2	2	2	1	1	1	1	1	1
AB	8,441,242	9,622,121	71	65	65	63	57	52	8	13	14	14	11	18	–	–	–	–	–	–	–	–	–	–	–	–
SK	11,740,864	14,960,355	85	80	78	71	58	52	6	11	12	15	17	21	–	–	–	–	–	–	–	–	–	–	–	–
MB	4,420,369	4,701,355	67	64	62	60	52	45	15	17	18	19	21	25	2	1	1	1	1	2	–	–	–	1	1	1
ON	3,632,727	3,667,333	24	25	19	18	15	20	–	–	1	1	–	–	31	27	26	25	26	21	–	–	–	–	–	–
QC	1,756,038	1,941,166	20	20	20	16	17	16	–	–	–	–	–	–	14	17	20	21	26	24	1	1	1	1	1	1
NB	130,526	154,209	20	21	21	22	21	17	–	–	–	–	–	–	1	1	1	1	2	3	17	15	17	16	16	16
NS	112,782	125,742	16	13	12	10	9	7	–	–	–	–	–	–	4	4	3	4	5	6	1	1	2	2	2	1
PE	158,280	171,494	46	–	41	37	36	32	–	–	–	–	–	–	2	1	1	1	1	2	16	17	20	26	25	23
NL	4,744	9,298	1	–	3	2	3	1	–	–	–	–	–	–	1	–	–	–	2	7	8	5	4	5	3	4
CANADA	**30,965,812**	**35,942,878**	**66**	**63**	**62**	**58**	**49**	**45**	**7**	**8**	**11**	**13**	**13**	**17**	**5**	**4**	**4**	**4**	**4**	**4**	**–**	**–**	**–**	**–**	**–**	**–**

	Pulse Crops						Forages						Other Crops					
	81	86	91	96	01	06	81	86	91	96	01	06	81	86	91	96	01	06
BC	–	–	–	1	1	–	58	62	63	64	70	71	5	5	5	7	6	6
AB	–	–	1	1	3	3	20	21	20	21	27	26	–	–	–	–	–	–
SK	–	1	2	4	14	11	8	7	7	8	10	14	–	1	1	2	–	1
MB	1	2	3	2	4	6	13	14	15	16	20	21	1	3	1	1	1	1
ON	10	13	19	23	25	26	30	30	31	29	28	28	5	5	4	4	6	4
QC	–	–	2	6	8	9	61	59	53	50	42	44	4	3	4	5	5	5
NB	–	–	–	–	–	1	56	56	53	50	52	54	6	7	8	10	9	9
NS	–	–	–	–	1	1	65	64	64	58	58	60	13	17	19	27	26	26
PE	–	1	2	1	2	3	33	34	33	32	33	37	3	47	2	3	3	3
NL	–	–	–	–	–	–	74	80	78	70	75	69	16	15	14	23	16	19
CANADA	**2**	**2**	**3**	**5**	**10**	**9**	**19**	**18**	**18**	**18**	**21**	**23**	**1**	**4**	**1**	**2**	**1**	**2**

TABLE 4-3 Proportion of cropland area under various tillage and summerfallow practices, 1981–2006

	Percentage of cropland area in various tillage practices												Percentage of summerfallow area in various practices											
	Conventional				Conservation				No-till				Tillage only				Tillage & chemical				Chemical only			
	1991	1996	2001	2006	1991	1996	2001	2006	1991	1996	2001	2006	1991	1996	2001	2006	1991	1996	2001	2006	1991	1996	2001	2006
BC	83	65	65	55	12	24	21	26	5	10	14	19	66	65	65	62	31	29	30	23	3	5	6	15
AB	73	57	37	25	24	33	35	28	3	10	27	48	58	51	39	27	37	38	38	28	5	11	24	45
SK	64	45	32	18	26	33	29	22	10	22	39	60	57	55	48	31	39	37	36	31	4	9	16	38
MB	66	63	54	43	29	28	33	35	5	9	13	21	73	61	50	46	24	34	38	40	3	6	12	13
ON	78	59	52	44	18	22	22	25	4	18	27	31	66	53	65	68	26	38	24	23	8	9	11	9
QC	85	80	77	62	12	16	19	28	3	4	5	10	48	43	56	71	28	25	18	11	24	32	26	17
NB	85	80	82	78	12	18	15	17	2	2	3	5	79	72	71	76	14	8	17	18	8	20	12	6
NS	88	77	71	66	8	20	20	20	4	3	8	14	72	62	69	78	19	26	19	17	9	13	12	4
PE	91	82	76	78	8	16	22	19	1	2	2	3	35	55	44	49	23	32	17	38	42	13	39	14
NL	84	88	76	88	8	8	13	6	8	4	11	6	49	74	62	62	38	19	7	38	13	7	30	0
CANADA	**69**	**53**	**41**	**28**	**24**	**31**	**30**	**26**	**7**	**16**	**30**	**46**	**58**	**54**	**46**	**31**	**38**	**37**	**36**	**31**	**4**	**9**	**18**	**38**

TABLE 4-4 Change in livestock populations in Canada, 1981–2006

	Cattle			Pigs			Poultry			Sheep & Goats			Horses		
	1981	2006	percent change	1981	2006	percent change	1981	2006	percent change	1981	2006	percent change	1981	2006	percent change
BC	789,841	800,855	1	254,895	135,826	-47	10,958,442	19,702,467	80	75,783	74,124	-2	39,356	53,246	35
AB	4,192,887	6,369,116	52	1,199,397	2,052,067	71	10,358,078	12,673,071	22	211,861	251,453	19	118,708	155,533	31
SK	2,418,457	3,363,235	39	574,334	1,388,886	142	4,860,929	5,058,314	4	81,369	144,152	77	60,180	65,914	10
MB	1,175,966	1,573,097	34	874,995	2,932,548	235	7,257,002	8,654,889	19	41,047	81,255	98	31,284	46,580	49
ON	2,898,494	1,982,651	-32	3,165,837	3,950,592	25	38,727,767	50,335,141	30	297,037	387,276	30	74,986	97,285	30
QC	1,665,691	1,393,434	-16	3,440,724	4,255,637	24	24,756,269	31,854,630	29	125,232	337,678	170	24,682	26,522	7
NB	110,942	89,191	-20	89,620	107,254	20	2,329,911	3,382,137	45	14,133	8,460	-40	2,972	2,973	0
NS	140,209	103,687	-26	139,344	95,131	-32	3,544,852	4,458,002	26	44,391	27,306	-38	3,297	3,705	12
PE	102,454	86,435	-16	116,843	123,192	5	234,955	451,219	92	7,967	4,130	-48	2,317	1,921	-17
NL	6,963	11,826	70	19,076	1,999	-90	936,087	1,576,936	68	7,731	4,741	-39	340	286	-16
CANADA	**906,551**	**15,773,527**	**17**	**9,875,065**	**15,043,132**	**52**	**103,964,292**	**138,146,806**	**33**	**1,320,575**	**1,320,575**	**46**	**358,122**	**453,965**	**27**

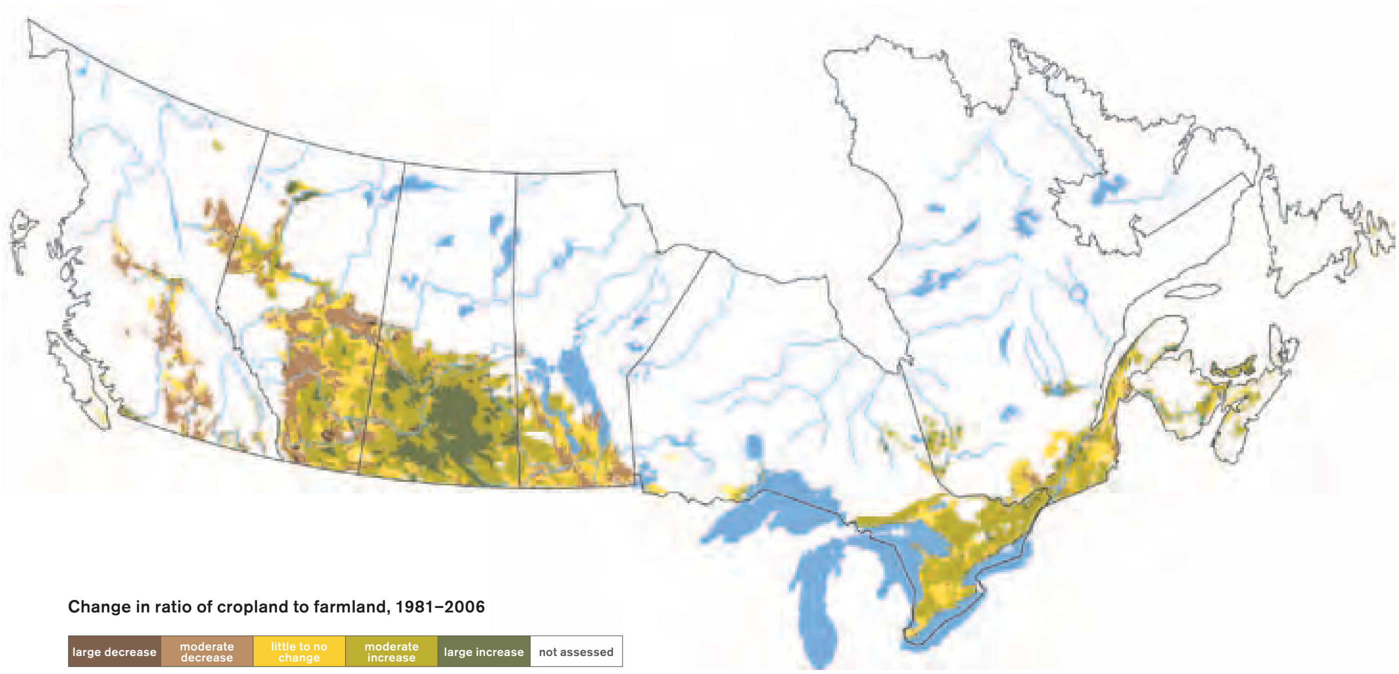


FIGURE 4-1 Change in the ratio of cropland to farm land in Canada, 1981–2006

Conclusion

Changes in land use, cropping and tillage practices and livestock numbers across Canada and in the provinces reveal a significant intensification and diversification of agricultural production activities over the past 25 years. Diversification can be seen in the shift in the area seeded from more traditional crops such as wheat, oats, barley and forages to corn, oilseeds and pulse crops.

Figure 4-1 shows that the areas where cropland has declined as a proportion of farm land (i.e where pasture, summerfallow, forest, idle and other non-productive land have become a larger portion of census farm land) are typically the transition zones between intensive farming and forest areas, such as the interior and Peace River districts of British Columbia, the edges of the Prairie Parklands, and along the edge of the Canadian Shield. Areas with small to no change in the proportion of cropland on farm land generally are areas on the farming side of the farm-to-forest transition zones described above, or areas of high-intensity farming such as the lower Fraser River Valley, southern Manitoba, southwestern Ontario and the Annapolis Valley (Figure 4-1). The fact that there has been little change in high-intensity farming areas indicates that current practices are economically sustainable and that there is little opportunity or incentive for further conversion of pasture and forest land to crops. Most of the remaining agricultural areas of the country have experienced a moderate to large increase (Figure 4-1), suggesting that intensification through conversion of pasture, summerfallow, forest and idle land to active crop production has been the dominant land use change over the past three decades.

The information presented in this chapter provides an insight into the status and trends of some major agricultural land uses and management. However, it does not provide an analysis of the resulting environmental conditions, risks and trends. It offers key information for specific environmental issue analysis performed by the agri-environmental indicators in this report.

References

Statistics Canada. (2007). About the census of agriculture. Retrieved June 12, 2009 from http://www.statcan.ca/english/agcensus2006/aboutmenu.htm

05 Farm Environmental Management

AUTHORS
R. MacKay and J. Hewitt

SURVEY NAME
Farm Environmental Management Survey (FEMS)

Summary

Farm management is an important component of environmental performance. The practices a producer chooses influence economic efficiencies and have direct effects on air, water and soil quality. Results from the 2006 Farm Environmental Management Survey (FEMS) showed that producers across Canada implemented a number of beneficial management practices (BMPs) to manage manure, fertilizers and pesticides and protect land and water resources. Results indicate strong adoption of nutrient management practices such as soil nutrient testing, optimizing the timing, application and incorporation of solid and liquid manure and fertilizer, and increased manure storage capacity. The 2006 survey showed that an unchanged percentage of producers had used a certified pesticide applicator since 2001. It also indicated that improvements could be made to solid and liquid manure storage practices, the level of access grazing livestock have to surface water and the timing of pesticide applications.

The Issue

Producers across Canada directly influence the environmental performance of the agriculture sector depending on the types of management practices they choose to implement in their operations. The management practices implemented are selected for many reasons, including cost effectiveness or what has historically been practiced on the farm.

Many BMPs can be implemented that maintain or improve productivity while mitigating or reducing risk to the environment. In many cases, BMPs provide environmental benefits such as water filtration and wildlife habitat.

This chapter examines the extent to which Canadian farmers have adopted key BMPs to manage environmental risks related to water quality, air quality and soil quality. The BMPs presented in this chapter highlight some of the practices used to manage agricultural inputs such as nutrients and pesticides. However, this chapter does not present an exhaustive list of all practices that can improve the environmental performance of the sector.

The Survey

Statistics Canada, in partnership with Agriculture and Agri-Food Canada, conducted the second FEMS to gather information on management practices used by producers in 2006. The voluntary survey was delivered to 20,000 crop and livestock producers across Canada (excluding Yukon, Nunavut and Northwest Territories) who reported more than $10,000 in gross receipts in the 2006 Census of Agriculture. Producers were asked about manure storage and spreading, grazing practices, crop and nutrient management, pesticide application, wildlife damage, land and water management, waste management, and environmental farm planning. The questionnaire was well received by producers, with a response rate of approximately 80%. The 2006 FEMS built on the success of the first FEMS conducted in 2001, and now provides information for trend analysis on the adoption rates of some BMPs over that five-year period. Some data is available from the 1995 Farm Inputs Management Survey (FIMS), which allows trend analysis over a longer timeframe. The information presented in this chapter is a summary of key findings from the 2006 FEMS questionnaire. Detailed results from the 2006 FEMS are available from Statistics Canada.

Limitations

Farm management practices and their potential environmental impacts vary regionally since agricultural production, soil and landscape characteristics, weather and other factors are not uniform across the country. This means that a management practice that may pose an environmental risk in one part of the country may be effective and acceptable in another. These biophysical differences were not considered in the results presented in this chapter and therefore the results should be interpreted with caution. This chapter provides an overview of the types and levels of adoption of practices that may improve environmental performance across Canada. However, the results are insufficient on their own to assess environmental performance. A more comprehensive assessment of the environmental performance of the sector is presented by the agri-environmental indicators found in this report.

Environmental Farm Management

Awareness of on-farm environmental issues and how to manage them is the first step to improving environmental performance. The Environmental Farm Planning (EFP) process has become a key source of information and education for producers in Canada. It includes learning about agri-environmental issues, applying this knowledge on individual farms to identify potential environmental risks and developing an action plan to mitigate those risks. Implementing BMPs to improve farm environmental performance is among the most effective methods to improve agricultural sustainability. In 2006, FEMS results showed that 28% of farms in Canada had a formal written EFP and another 10% had plans under development.

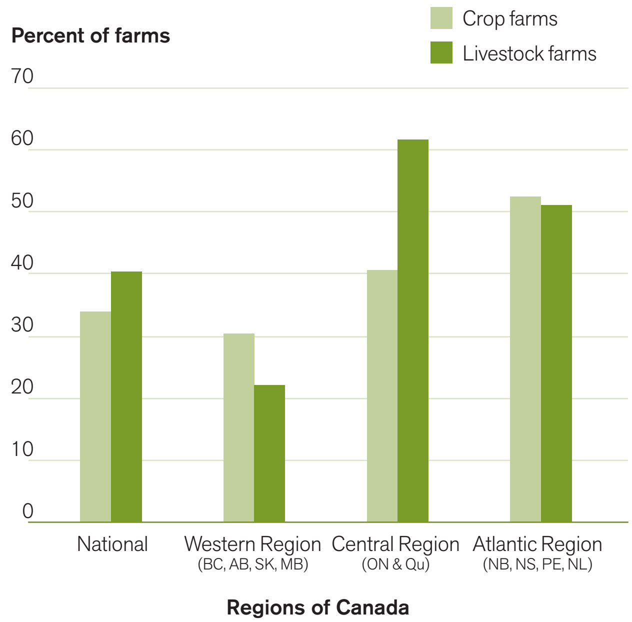
Both livestock and annual crop producers have actively participated in EFP programs (Figure 5-1). In Ontario and Quebec there is a significantly higher proportion of livestock producers participating in the EFP program than in other provinces, likely due to provincial legislation that targets nutrient and manure management issues. In 2006 participation in EFP programs was higher in eastern and central Canada than in western Canada since the program is relatively new in the west.

The following sections provide details on practices implemented on Canadian farms in 2006 for management of nutrients, pesticides, and land and water resources. The relationship between EFPs and BMP adoption is presented in an EFP Highlight box in each section.

Nutrient Management

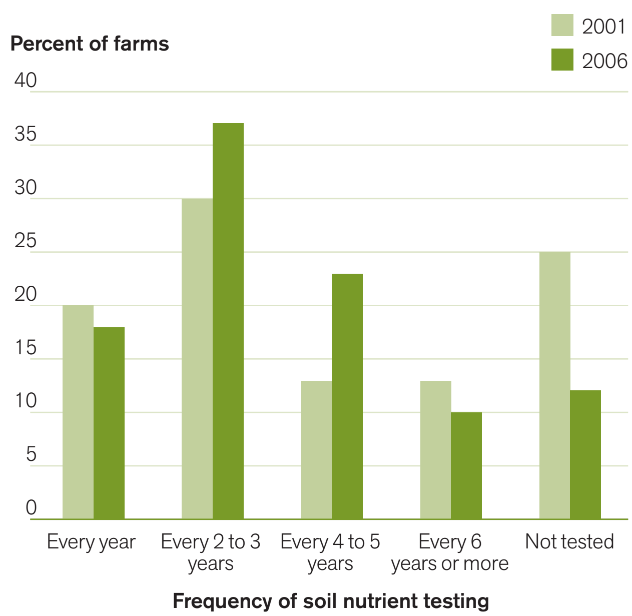
Nitrogen (N), *phosphorus* (P) and potassium (K) are nutrients essential for good plant growth. Healthy soils contain these nutrients, but not always in amounts required by crops, so supplementing with manure or fertilizers is often necessary to maximize productivity and economic returns. However, increasing the nutrient content of soils can pose environmental risks. Over-application of manure and fertilizers, or reduced nutrient uptake due to drought or crop damage can result in excess nutrients remaining in the soil that may be lost to the environment. Excess N can volatilize into the air, contributing to atmospheric greenhouse gas emissions and poor air quality, and both N and P can be transported by water out of the soil into *ground water* or streams and surface water bodies potentially causing overgrowth of algae or other plant material and resulting in *eutrophication*. Although some loss is inevitable, there are a number of BMPs that can be implemented to manage nutrients and reduce risk of loss to the environment.

Soil nutrient testing provides valuable information that producers can use to match crop nutrient requirements with nutrient levels in soil and nutrients applied in manure and commercial fertilizers. This can help to maximize productivity and make the most efficient use of resources while reducing risk of losses to the environment. The more frequently soil tests are conducted, the more confident a producer can be about applying the optimal amount of nutrients for crop growth. Figure 5-2 shows that slightly fewer farms are soil testing annually in 2006 than in 2001, representing approximately a quarter of the total Canadian acreage. More farms are soil testing every two to three years than in 2001, which accounts for approximately 36% of the total acreage. The number of farms that are not soil testing at all has been cut almost in half since 2001 and represents only 12% of farms, which indicates an improvement in nutrient management in Canada.



Source: Agriculture and Agri-Food derived from Statistics Canada, 2006 Farm Environmental Management Survey

FIGURE 5-1 Participation in EFP programs by farm type.



Source: Agriculture and Agri-Food derived from Statistics Canada, 2006 Farm Environmental Management Survey

FIGURE 5-2 Frequency of soil nutrient testing on Canadian farms.

MANURE

Manure storage and application is one of the most significant environmental challenges for livestock producers. Spreading manure provides a source of crop nutrients and a use for this inevitable byproduct of livestock production. However, sub-optimal storage and application of manure can lead to increased environmental risks.

Manure can be solid or liquid/semi-solid, depending on the type of livestock. Typically, beef and poultry operations store solid manure, while hog and dairy operations store liquid or semi-solid manure. The different manure types require different storage methods and each presents unique challenges. A primary goal for manure storage is to retain as many nutrients as possible to be available to spread on crops. Nutrient loss during storage may occur through *volatilization* into the air, through runoff when water is added or through *leaching* into the soil. The optimal storage method for solid manure is on a covered, impermeable pad with a runoff containment system. Optimal storage for liquid/semi-solid manure is a covered tank.

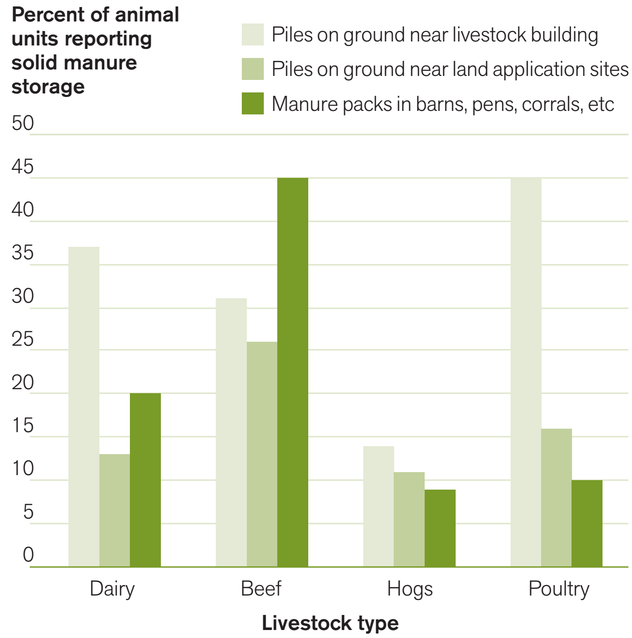


FIGURE 5-3 Solid manure storage by livestock type

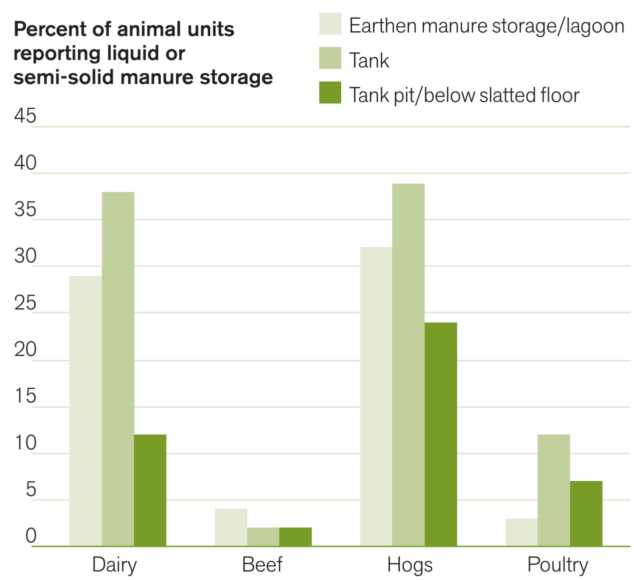


FIGURE 5-4 Liquid or semi-solid manure storage by livestock

FEMS 2006 identified three common storage locations for solid manure (Figure 5-3); on any given farm more than one location may be used. Manure piles may be located near livestock buildings or near land application sites, and manure packs may be located in barns, pens or corrals. Environmental risk associated with solid manure storage depends more on how the stored manure is managed than on where it is stored. The key to reducing nutrient loss and transport is to use storage systems with covers, impermeable bases and/or runoff containment.

In 2006, 39% of farms with manure piles near livestock buildings stored manure on an impermeable pad, but only 14% of farms with piles near land application sites and 28% of farms with manure packs in corrals used impermeable pads, indicating improvements are possible.

Common storage options for liquid or semi-solid manure include earthen lagoons and tanks outside or below a slatted barn floor. Each of these storage systems has limitations that need to be managed in order to be environmentally responsible. Earthen lagoons provide a large storage capacity but must be constructed properly to avoid leakage and are difficult to cover. Tanks are more easily covered but are costly to construct and generally have smaller storage capacity. Below-floor level storage tanks may require additional ventilation to prevent manure-generated gases from entering the barn. Figure 5-4 illustrates the frequency of use of different types of storage by different livestock farm types.

FEMS results indicated that 22% of all liquid and semi-solid manure storages are covered. Of these, 18% are covered by a lid, 4% are covered by a tarp, 3% have a crust cover and 3% are covered by straw. Seventy-two percent of covers were reported in FEMS as ‘other’ and likely consist of a permanent and non-removable material such as concrete, wood and other material. The low percentage (22%) of covers used on liquid and semi-liquid manure storages suggest future improvements are possible.

The rate, method, and timing of manure application and incorporation can influence the total nutrients lost in *run-off* or through volatilization. There are several factors producers consider before determining the amount of manure to apply to crops; the most common are listed in Tables 5-1 and 5-2, below. Ideally, the amount of manure applied will be based on the nutrient levels in the soil and the manure, and the nutrient demands of the crop.

EFP Highlight:

- Farms with an EFP are more likely than farms without an EFP to have runoff containment and impermeable pads to store solid manure (Figure 5-5).
- FEMS 2006 results show there is no difference between farms with an EFP and without an EFP for the storage and use of covers on liquid/semi-solid manure.

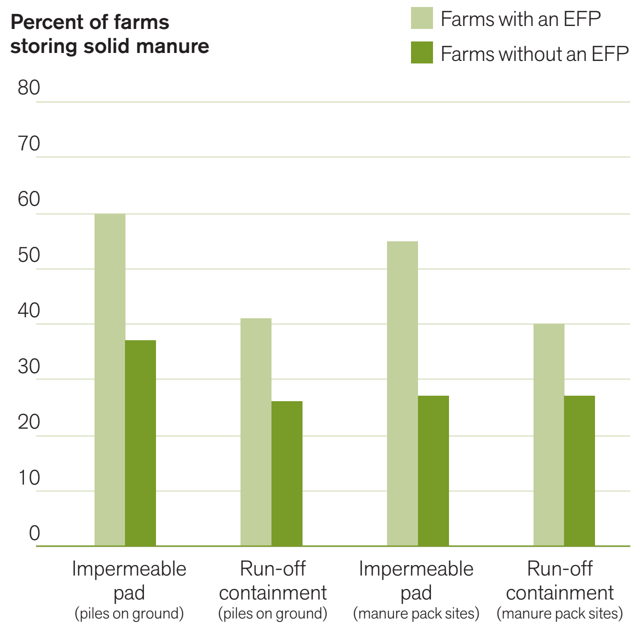


FIGURE 5-5 Solid manure storage types

TABLE 5-1 Top five decision factors for the amount of solid manure to apply

Decision factor	Percentage of crop area with solid manure applied	Percentage of farms that apply solid manure
Amount historically used	29	31
Amount of land available to receive manure	35	30
Nutrient requirement of crop	32	27
Soil nutrient testing	36	24
Distance from manure storage area to application site	28	23

TABLE 5-2 Top five decision factors for the amount of liquid manure to apply

Decision factor	Percentage of crop area with liquid manure applied	Percentage of farms that apply liquid manure
Soil nutrient testing	63	48
Nutrient requirement of crop	53	45
Amount of land available to receive manure	32	32
Nutrient content of manure	38	31
Amount historically used	29	31

Soil nutrient testing is among the most common decision factors used by producers when applying both solid and liquid manure, which indicates that producers are actively managing their nutrient inputs. However, such testing is used less commonly by producers that spread solid manure than by those that spread liquid/semi-solid manure. In addition, measuring the manure nutrient content of solid manure is not a common consideration by producers despite it being an important practice. This suggests there is room for improvement when deciding on how much manure to apply.

The method used to apply manure also influences the risk of nutrient loss to the environment. The most beneficial practice for solid manure application is to spread and immediately incorporate into the soil, and for liquid/semi-solid manure it is to inject the manure directly into the soil, apply through a low dribble bar (below crop canopies), or broadcast and immediately incorporate it. These management practices reduce the risk of surface runoff and nutrient loss to the air, reduce odours and place nutrients in immediate proximity to the roots for crop uptake. The least beneficial practice for solid manure is to spread and leave it on the surface of the soil, leaving the manure vulnerable to nutrient loss. For liquid/semi-solid manure, the least beneficial practices are to use an irrigation system for application (e.g. retracting gun) or to spread and leave it on the surface of the soil, which exposes nutrients to the air and results in significant nutrient loss and odour, and increases potential for runoff into waterways.

In 2006, 58% of farms used the optimal practice of incorporating solid manure after it was spread (Figure 5-6). However, almost 40% of solid manure producers did not incorporate

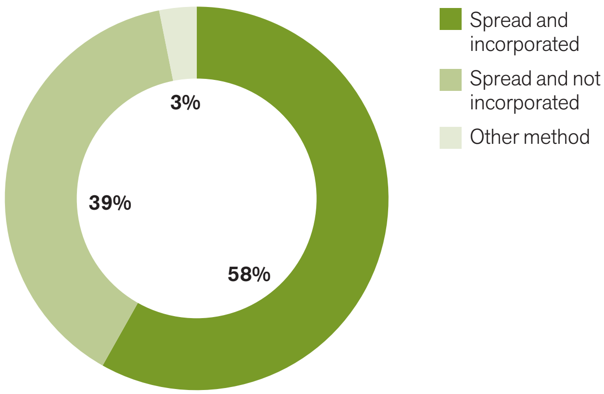


FIGURE 5-6 Method of solid manure application in Canada in 2006 (percentage of farms)

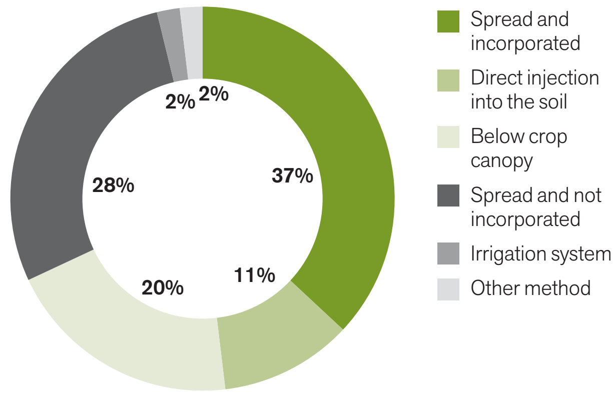


FIGURE 5-7 Method of liquid and semi solid manure application in Canada in 2006 (percentage of farms)

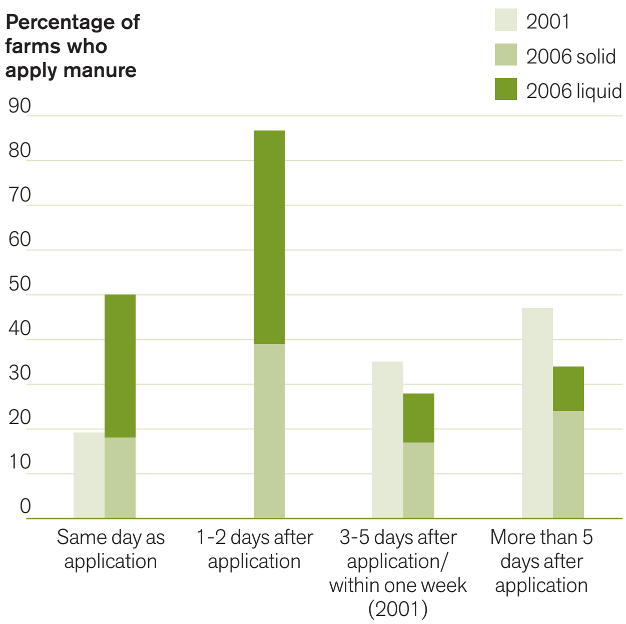


FIGURE 5-8 Time between manure application and incorporation, 2001 and 2006

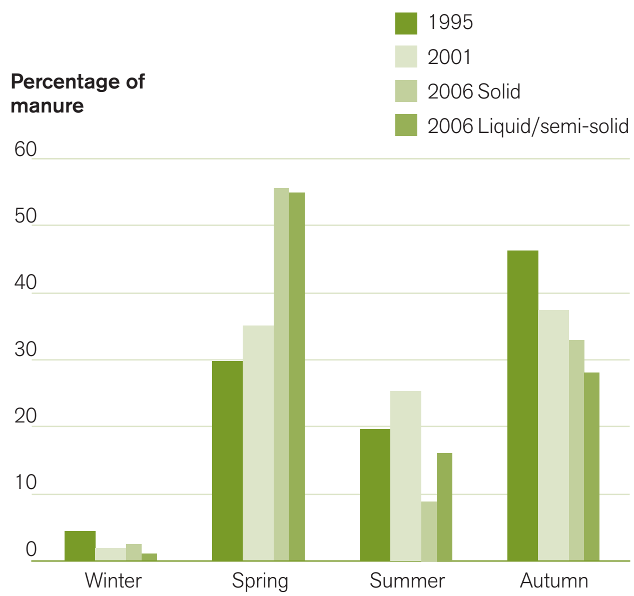


FIGURE 5-9 Trend since 1995 of proportion of manure spread at different times of the year

manure into the soil. Nearly half of producers spreading liquid manure incorporated or injected it into the soil, and another 20% applied it below the crop canopy (Figure 5-7). Yet almost a third (30%) of liquid manure producers did not incorporate the manure into the soil, or they applied the manure through irrigation. These results indicate there is room for improvement in the adoption of BMPs for both solid and liquid manure application methods.

The time between manure application and incorporation is also very important. The longer the time between manure application and incorporation, the greater the risk of nutrient loss through volatilization or runoff by precipitation. Manure incorporation also helps manage odour nuisance, so immediate or same-day incorporation is the optimal practice. Since 2001 producers have reduced the time between manure application and incorporation, improving nutrient retention and reducing environmental risk (Figure 5-8).

The time of year or crop-growth stage when manure is applied to the soil influences nutrient loss and ultimately environmental performance, as the ability of the crop to use the nutrients varies throughout the growing season. Ideally, nutrients are added to the soil when crops need them most and nutrient uptake is the highest—therefore, just before crop growth. Spreading manure on frozen ground is a poor practice that is regulated against in many provinces today. Winter spreading is often a result of manure production exceeding storage capacity during winter. This practice poses a very large risk of odour nuisance and runoff and can cause water contamination, therefore every effort should be made to avoid it.

EFP Highlight:

Farms with an EFP are more likely than farms without an EFP to:

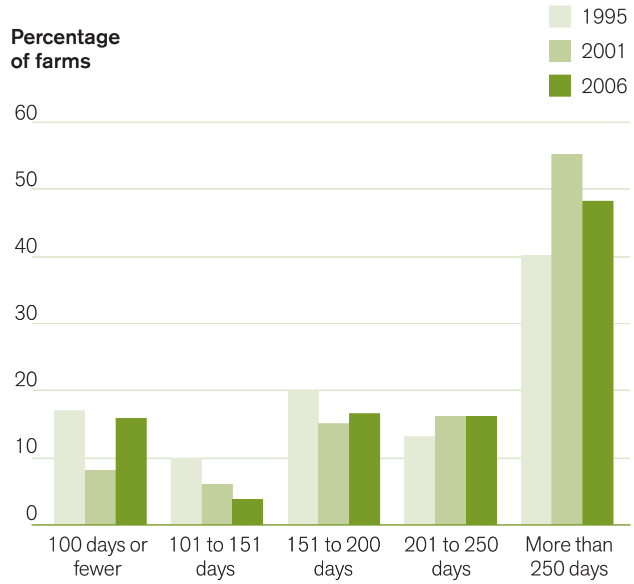
- use soil testing, manure testing and crop nutrient requirements as factors to determine application rates of manure (Table 5-3), and
- incorporate solid manure after application (65% vs. 55%).

There was no difference in the application methods for liquid/semi-solid manure between farms with and without an EFP.

TABLE 5-3 Factors used to determine application rates of manure on agricultural lands in Canada, 2006

Factors to determine application rates	Solid Manure		Liquid/ Semi-solid Manure	
	EFP	No EFP	EFP	No EFP
	Percentage of farms applying manure			
Soil testing	44	14	59	30
Manure testing	25	9	49	36
Soil and manure testing	19	3	30	11
At least one of: i) Soil testing ii) Nutrient carry over in soil iii) Crop nutrient requirement iv) Manure testing	63	34	75	56

Source: Agriculture and Agri-Food Canada, derived from Statistics Canada, 2006 Farm Environmental Management Survey



*2006 results include both liquid and semi-solid manure, while in 1995 and 2001 results are for liquid manure only.

FIGURE 5-10 Trend in liquid manure storage capacity since 1995

Since 1995 the percentage of manure spread in the fall has declined, and the percentage of manure spread in the spring has increased, which is a positive trend. Winter spreading of solid manure, while minor, has remained relatively stable since 1995 and shows there is still room for improvement (Figure 5-9).

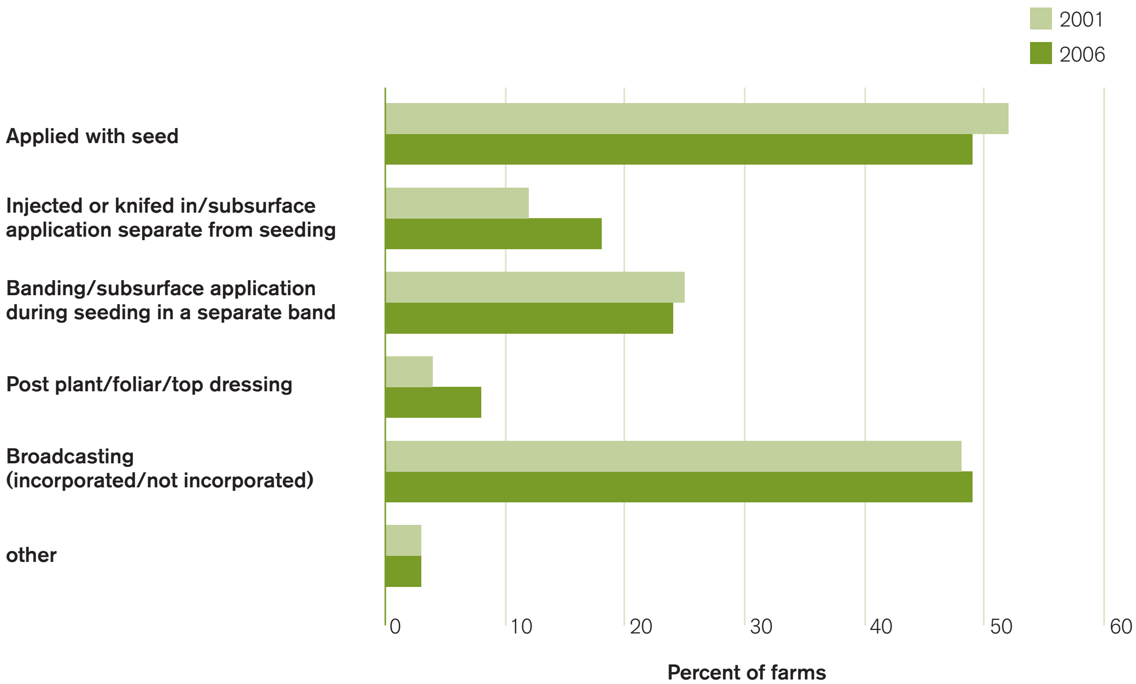
As manure storage capacity increases to meet the demand of increased manure production, so does the producer's flexibility to spread manure at the optimal time. Therefore, increasing storage capacity to accommodate increased manure production is desired. Liquid manure storage capacity has been increasing since 1995 (Figure 5-10).

FERTILIZER

Mineral fertilizers are the primary sources of nutrient input on Canadian farms. In 2006, 72% of producers growing crops applied mineral fertilizer, accounting for 91% of Canada's crop area. This is only slightly less than the 75% of farms that applied mineral fertilizer in 2001. Fertilizers represent a significant economic investment by producers, so careful attention should be paid to ensure efficient application that will gain the maximum return on their investment. Good nutrient management practices ensure efficient fertilizer application to produce high-quality crops with optimal yields and without nutrient loss to the environment. As with nutrients from manure, excess nutrients from fertilizer can be lost from farmland through leaching, runoff or volatilization, potentially contributing to contamination of surface and groundwater (see RSN, IROWC-N, chapter 12.1, 12.2 and IROWC-P, chapter 13) and emissions of *ammonia* (a precursor of air-borne *particulate matter*) (see ammonia chapter 17) and *nitrous oxide* (a greenhouse gas) (see GHG chapter 16).

The method by which fertilizers are applied affects the risk of nutrient loss. FEMS 2006 showed there is little change between 2001 and 2006 results (Figure 5-11). Sub-surface application with seed (e.g. using granular fertilizers with air seeders), or *banding liquid fertilizer* during the seeding operation lowers the risk of runoff and volatilization and reduces the number of equipment passes over fields. This also helps to reduce GHG emissions (less fuel is used) and represents an increase in time efficiency for producers. In addition, post-plant top-up applications—usually associated with applying liquid fertilizer to crops with large nutrient demands and a higher value of return—shows a slight increase from 2001 to 2006. This is also a positive trend as it shows that, increasingly, nutrients are being added to crops during periods when crops are growing rapidly. In 2006 most producers identified that broadcasted fertilizer was incorporated.

Most producers use more than one fertilizer application method for a variety of reasons. For example, the preferred method may



Note: figures may add up to more than 100% because producers were asked to 'check all that apply.'

FIGURE 5-11 Fertilizer application methods on Canadian crop farms in 2001 and 2006

TABLE 5-4 Top five most common decision factors used to decide how much fertilizer to apply

Decision factor	Percentage of crop area with fertilizer application	Percentage of farms that apply fertilizer
Soil nutrient testing	66	58
Amount historically used/ based on experience	61	52
Cost of fertilizer/crop prices	50	37
Nutrient requirement of crop	39	31
Advice from consultant/ dealer/crop advisor	38	39

be to apply with seed for most of the cropland, but broadcasting may be used on certain lands that are too wet for heavy equipment at seeding time.

Producers consider many other factors when determining the amount of fertilizer to apply. The most common decision factors for both percentage of farms and crop area is soil nutrient testing (Table 5-4).

Farms that spread manure typically require less fertilizer than those that do not, as the manure can be a rich source of nutrients. Those that do not reduce the amount of fertilizer to offset the manure applied may increase their risk of nutrient loss to the environment as well as incur higher economic costs. In 2006, 89% of producers reduced their fertilizer to offset the nutrients added to the soil from manure. This was an increase from 43% in 2001.

Pesticides

Agriculture is just one land use in the greater landscape and is therefore vulnerable to opportunistic pests that feed on or compete for the same resources as crops. There are three primary types of pests: insects, weeds and fungi. To protect their investment and ensure these pests do not destroy crop yields, producers may choose to apply pesticides, which include herbicides, insecticides and fungicides.

Pesticides have evolved in recent years to be less toxic to non-targeted organisms. However, they do continue to pose potential risks to the environment. Application under certain conditions can create drift to non-targeted areas, reduce effectiveness to targeted areas and affect air quality. Pesticides may also be transported to and contaminate waterways and soil, potentially affecting non-targeted and, sometimes, beneficial organisms.

In 2006, 76% of producers reported using pesticides on their operation, which was unchanged since 2001. In 2006, 74% of crop producers applied herbicides, accounting for 91% of the crop area. Insecticides were applied by 17% of producers, accounting for 21% of the crop area, and 16% of crop farmers applied fungicide, accounting for nearly one quarter of the total crop area in Canada. These proportions vary significantly from one region to another given the diverse nature of the sector.

EFP Highlight:

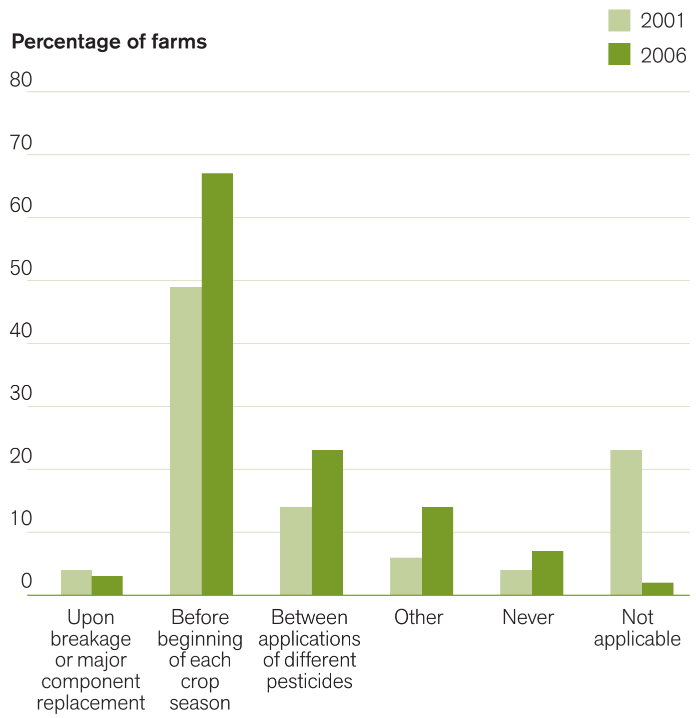
Farms with an EFP are statistically more likely than farms without an EFP to:

- use soil testing to determine the rate of fertilizer application (Table 5-5), and
- use soil testing, nutrient requirements of crops, or nutrient carry-over to determine fertilization rates.

TABLE 5-5 Factors used to determine application rates of fertilizer on agricultural lands in Canada, 2006

Factors to determine application rates	Commercial fertilizers	
	EFP	No EFP
	Percentage of farms	
Soil testing	61	32
At least one of: i) Soil testing ii) Nutrient carry over in soil iii) Crop nutrient requirement	68	42

Source: Agriculture and Agri-Food Canada, derived from Statistics Canada, 2006 Farm Environmental Management Survey



Note: 2006 values may add up to more than 100% since respondents were asked to 'check all that apply.'

FIGURE 5-12 Pesticide sprayer calibration frequency trend since 2001

TABLE 5-6 Most common alternative methods used for pest control and reduction of pesticides in 2006

Methods of pest control	Percentage of farms
Rotate crops	73
Use a tracking system to minimize overlaps and misses	67
Apply less pesticide than recommended by label	32
Use tillage implements	31
Plant *pest-resistant* crops	31

Producers consider many factors when deciding whether to apply pesticides and when determining the timing of application. Ideally, pesticides are applied only when necessary, such as when field-scouting results indicate that the economic injury threshold is approaching. The most common decision factors that determined when to apply pesticides in 2006 were producer experience, regularly scheduled application and field scouting. Scouting is a beneficial practice, however, relying on past experience or using regularly scheduled applications may result in over or under-application since decisions are not related to direct observation of the crop or pest. The ideal practice is to apply pesticides when pests exceed acceptable levels, which was the fifth-ranked consideration for insecticides and fungicides and sixth-ranked consideration for herbicides in 2006—despite it being ranked first for insecticides and fungicides 2001.

A formally certified pesticide applicator is knowledgeable about optimal application methods and timing, application equipment and the environmental risks associated with pesticides. Some provinces require that a certified applicator apply all pesticides. In 2006, 53% of farms used a certified person for all pesticide applications, which accounts for 35% of all cropland. Another 10% of farms (approximately 35% of cropland) used a certified person for some pesticide applications. This is approximately the same as in 2001, when 61% of farms had a certified person apply some or all of the pesticides.

Calibrating the pesticide sprayer is also an important practice that ensures pesticides are applied at the intended rate. It is ideal for sprayers to be calibrated throughout the crop season—for example, prior to spraying different types of pesticides. Figure 5-12 shows that in 2006 more producers were calibrating between applications of different pesticides than in 2001, which has likely resulted in a more efficient use of pesticides and potentially a reduced risk of loss to the environment.

In efforts to reduce the use of pesticides, many producers are implementing *integrated pest management*, a decision-making process that uses multiple practices to suppress pests effectively, economically and in an environmentally sound manner. In 2006, 73% of producers used crop rotations to control pests (Table 5-6), and the second most popular alternative to applying pesticides was tillage. These results are encouraging, as it suggests that producers are actively managing their operations to reduce their use of pesticides.

Land and Water Management

In addition to managing agricultural inputs such as manure, fertilizer and pesticides, Canadian producers manage their land and water resources to ensure they remain healthy and continue to contribute to the productivity of their operation. Healthy soil and clean water are critical to farm operations for healthy crops, livestock and wildlife.

Some key benefits of implementing sustainable land and water management practices include reducing erosion and, as a result, minimizing the loss of productive soil, as well as maintaining clean water, which is a vital resource for a farm. The FEMS 2006 results indicate that producers are managing their operations to reduce erosion. For instance, 34% of producers reported planting permanent perennial forages on erodible land. Thirty one percent have farmstead *shelterbelts* and 20% have field shelterbelts. Cover or companion crops were seeded by 23% of producers to reduce erosion, and 11% plant winter cover crops or green manure after harvest. All of these practices help maintain or improve soil health.

Most farms in Canada have some form of surface water for at least part of the year, including permanent or seasonal wetlands, streams, dugouts or ponds. The quality of this surface water may be compromised as a result of agricultural activities that lead to soil erosion, nutrient and pesticide runoff, or from contamination by livestock. Direct access to surface water by grazing livestock can result in the erosion of stream banks, which reduces bank stability and can contaminate the surface water with sedimentation—and also introduce nutrients and *pathogens* from manure. Controlling livestock access to surface water prevents stream bank degradation and protects water quality. In many cases this can be accomplished through limited access (especially when combined with appropriate rotational grazing strategies), but in some sensitive regions elimination of access may be required or desirable. Only 14% of farms allow no access to surface water, while an additional 19% allow limited access, and close to 47% allow unlimited access during the grazing season (Figure 5-14). This is a key area where producers have the opportunity to significantly improve their environmental performance.

Management practices such as maintaining setback distances around surface water, stabilizing shorelines and planting *riparian* buffer areas can reduce the risk of water contamination as the vegetation captures excess soil, nutrients and pesticides before they enter into the stream, and provides stability to

EFP Highlight

Farms with an EFP are more likely than farms without an EFP to:

- use BMPs that reduce pesticide drift, such as spraying when wind speed is below recommended thresholds, using boom shrouds, low drift nozzles, anti-drift agents and leaving an untreated buffer (Figure 5-13), and
- use BMPs to reduce the amount of pesticide used (67% vs. 53%).

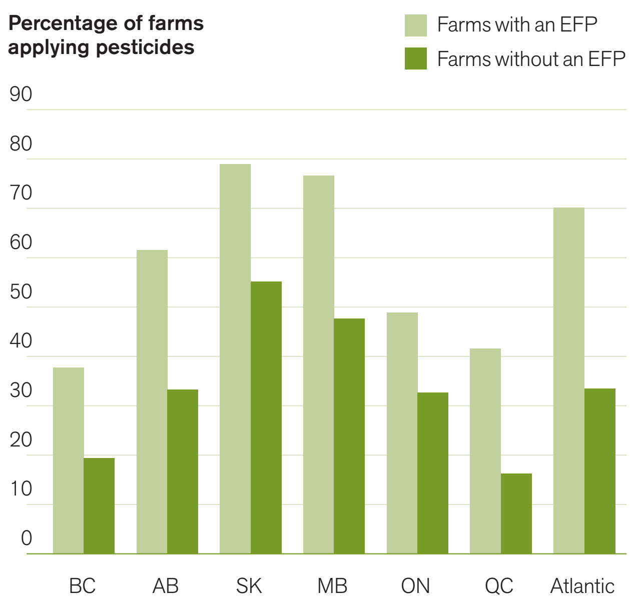


FIGURE 5-13 Comparison of producers with EFP vs. no EFP on adoption of 2 or more BMPs for pesticide drift

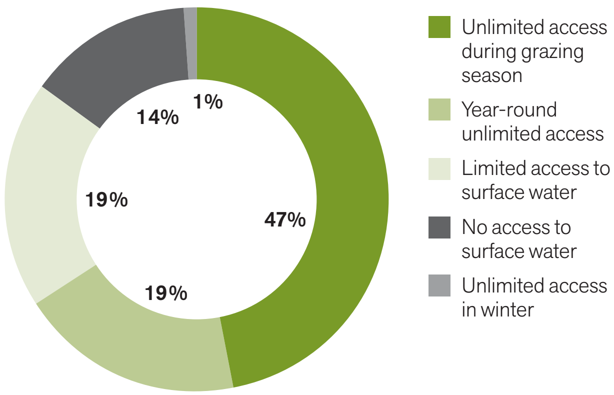


FIGURE 5-14 Grazing livestock access to surface water in 2006 (percentage of farms reporting)

Beneficial Management Practices (BMP) Adoption Index

The environmental performance of agriculture is ultimately influenced by the practices implemented on farms. All levels of government and non-governmental organizations promote different practices to enhance benefits or reduce risks from agriculture, often targeted at a specific region or issue. The overall picture of BMP adoption across Canada however, is unknown. A BMP Adoption Index is being developed to fill this information gap. This tool will provide an objective BMP adoption score to regions, provinces or commodities across Canada that reflects the practices being implemented on farms. It will be used to communicate information to decision-makers that they can then use for policy and program development. It will also be consistent with the indicator models presented in this report so that important on-farm activities can be incorporated into the indicator models and accurately reflect environmental performance.

EFP Highlight

Farms with an EFP are more likely than farms without an EFP to:

- provide ‘limited access’ or ‘no access’ for controlling grazing livestock near surface waters (Figure 5-15), and
- maintain riparian buffer areas around seasonal/permanent wetlands and waterways (Figure 5-16).

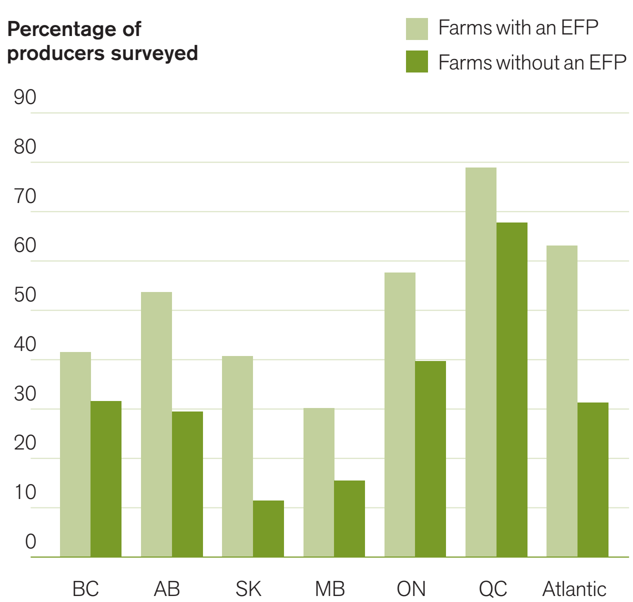


FIGURE 5-15 Comparison of farms with EFP vs. no EFP on grazing practices—allowing livestock limited or no access to surface waters.

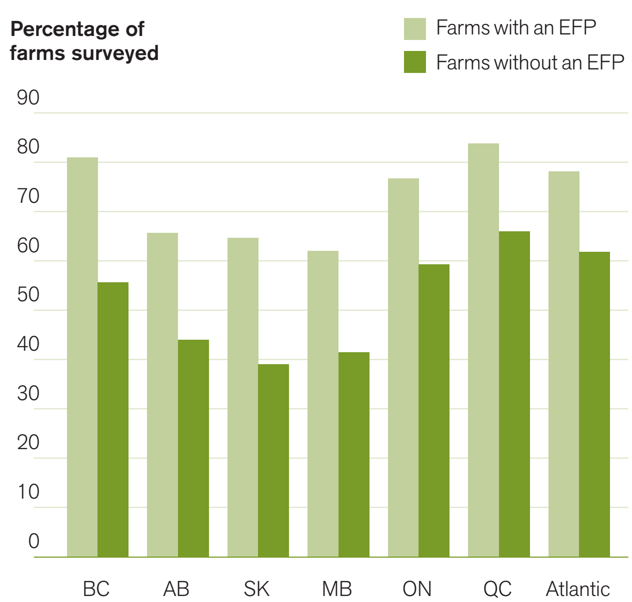


FIGURE 5-16 Comparison of land and water management practices for producers with and without EFP—producers maintaining a riparian area around surface waters, 2006

TABLE 5-7 Farms maintaining riparian buffer areas and setback distances from surface water bodies 2006

	Maintained riparian buffer strip (percentage of farms)	Maintained setback (percentage of farms)
Seasonal wetlands	45	46
Permanent wetlands	56	50
Waterways	63	60

shorelines. Approximately half of all producers with permanent or seasonal wetlands maintain a riparian buffer and setback, while over 60% maintain a buffer and setback for waterways (Table 5-7). Producers are least likely to maintain setbacks and riparian buffers around seasonal wetlands (sloughs, potholes, etc. that have water only part of the season) as these wetlands can be at least partially utilized for agricultural purposes during drier parts of the summer and during drought years. Producers in many provinces are required by regulation to maintain set-back distances from waterways which is likely reflected in the results. Despite this, these trends indicate there is continued room for improvement.

References

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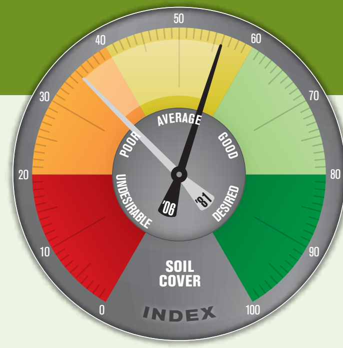
06 Soil Cover in Canada



AUTHORS
T. Huffman and D. Coote

INDICATOR NAME
Soil Cover

STATUS
National coverage, 1981 to 2006

Summary

Agricultural soils that are covered by vegetation, crop residue or snow are partially protected from the elements and are less susceptible to degradation processes such as wind and water erosion, organic matter depletion, structural degradation and loss of fertility. The amount of time soil is covered over the course of a year depends on many factors such as the type of crop and the amount of biomass it produces, the harvest practices used, the climate and the timing of field operations and tillage practices. The Soil Cover Indicator summarizes the number of days in a year that agricultural soils are covered. An increase in the number of soil cover days over time indicates an improvement in environmental sustainability since the soil is more protected from degradation and is less likely to contribute to water contamination and atmospheric emissions.

The Soil Cover Indicator is estimated for each census year between 1981 and 2006. Over that 25-year period, average levels of soil cover in Canada have increased by 7%. This improvement comes primarily as a result of widespread adoption of reduced tillage and decreased use of summerfallow in the Prairie Provinces. However, increases in soil cover associated with reduced-tillage practices were offset to a considerable degree by cropping intensification (shifts from perennial to annual crops) and by increases in the proportion of land under crops such as potatoes, canola and soybeans, which have generally shorter durations of full canopy cover and produce less crop residue than corn, cereal grains and forages.

The Issue

In agro-ecosystems, *bare soil* is more susceptible to soil degradation processes such as wind and water erosion, loss of organic matter, breakdown of *soil structure* and loss of fertility. The issue of soil degradation is of concern not only from the perspective of soil quality, but also from a broader environmental perspective. Higher levels of erosion can increase the risk of ground and surface water contamination by solids, nutrients and chemicals, while increased oxidation of *soil organic matter* under bare soil contributes to greenhouse gas emissions. Bare soil also generally serves as poor wildlife habitat and therefore could potentially impact biodiversity.

The type of crop grown determines row spacing, the growth rate of the crop and the amount of biomass created, and thus has a strong influence on the amount of soil cover produced in a given year. Perennial field crops such as hay offer good soil coverage year-round, while annual crops such as wheat or corn may leave soil exposed after planting or after fall tillage. In addition, crops such as beans, peas, canola and potatoes tend to have shorter periods of full crop canopy and leave lower levels of residue after harvest. Residue management, such as whether crop stubble is left in the field or removed by baling, grazing or burning also has significant implications for soil cover, as does the method, timing and frequency of tillage. Conventional tillage practices typically incorporate most of the crop residue into the soil to leave a clean surface for seeding, while conservation and no-till leave more crop residue on the soil surface and thus provide greater cover. Also, tillage done in the fall after harvest exposes soil for a greater length of time than tillage done only in the spring immediately before planting the next crop.

Soil productivity and climatic or weather conditions also influence soil cover by affecting the vigour of crop growth, and thus the amount of canopy and crop residue available as cover. The same crop grown under different climatic regimes will generally provide different amounts of residue as the amount of residue depends on the extent of vegetative growth. Similarly, the number of days in a year in which soil is protected by snow cover against wind and water erosion varies widely in Canada.

The primary factor that influences change in agricultural soil cover over time is land management. Adopting conservation tillage and no-till practices, reducing the amount of summerfallow and converting land from annual crops to perennial crops tends to increase soil cover, while increasing tillage, greater harvesting of crop residues and expanded production of annual crops tend to lower soil cover values.

The Indicator

The Soil Cover Indicator summarizes the number of days per year that agricultural land is covered in a typical crop production cycle. A soil cover day (SCD) can be achieved with 100% cover for one day, 50% cover for two days, 10% cover for 10 days, and so on. The indicator considers the soil cover provided by crop canopy, crop residues on the soil surface, and snow. As an example, a perennial hay crop typically has more than 300 SCDs per year since there is very little soil exposed at any time. By contrast, a soybean crop in an area of low snowfall and with no *winter cover crop* may have fewer than 150 SCDs.

The indicator is based on a calculation that estimates, under each crop and tillage practice, the number of days in a year that there would likely be soil cover. To estimate the number of SCDs, an annual calendar was developed that includes dates of typical field activities and soil cover amounts for each crop and tillage practice within each *ecoregion*. The Soil Cover Indicator takes into account the following variables:

- the day on which significant changes in soil cover occur (e.g., planting, harvesting, tillage) and the percentage of soil cover upon completion of the operation,
- canopy development and decline between planting and harvest,
- the *decomposition* of residue,
- the total number of days of snow cover greater than 2 cm,
- the removal of straw through baling and burning, and
- multiple cuts and grazing on hay and pasture.

A series of SCD calendars have been developed for all crops and ecoregions in Canada using data from field studies (Wall et al., 2002), extension bulletins (Prairie Farm Rehabilitation Administration, 2003), published literature (Steiner et al., 1999) and consultation with local agronomy experts. For crops with very limited extent, calendars were generated by extrapolating from known values for similar areas, crops and management practices.

Crop and tillage data were obtained from the Census of Agriculture for 1981, 1986, 1991, 1996, 2001 and 2006. An area-weighted average SCD value was calculated for each Soil Landscape of Canada (SLC) polygon, each province and for the whole country.

The indicator results are expressed in both the mean annual number of SCDs, as well as the proportion of cropland falling into each of five classes of soil cover for each census year between 1981 and 2006. An increase in the number of soil cover days or in the proportion of land in the high cover classes over time indicates an improvement in sustainability and a declining likelihood that soils will become degraded or contribute to the degradation of the surrounding environment.

Limitations

A number of assumptions and limitations are inherent in the methodology. The use of typical cropping practices and long-term climatic averages (for snow cover) means that local variations in cropping practices, dates and weather conditions are not accounted for. However, the greatest limitation is that the average tillage practice is used within each SLC polygon for all crops equally. Thus, differences in the conservation tillage practices used for various crops are not considered. Similarly, since conservation tillage and no-till have been used commonly only over the past 20 to 25 years and data on tillage practices has been collected only in the census since 1991, we assumed that all tillage on both crops and summerfallow was conventional in 1981 and 1986.

Results And Interpretation

Tillage practices, residue management, the frequency of crop harvest and summerfallow, snow-cover and soil-climatic growing conditions vary across agricultural regions of Canada and these differences are reflected in the differing SCD values of the regions (Figure 6-1 and Table 6-1). The adoption of reduced tillage has had a positive influence on soil cover for all crops, in all regions of Canada and in all years under study (Table 6-3). In the Prairie provinces, reduced tillage, decline in the frequency of summerfallow and increased perennial crops has contributed significantly to the increase in soil cover. A decline in perennial crops in eastern Canada and a national increase in low-cover annual crops such as canola, potatoes and soybeans have negatively influenced soil cover over this period.

Average SCD values over the study period ranged from a low of 258 in Saskatchewan in 1981 to a high of 334 in Newfoundland and Labrador in 1996 (Table 6-1). The national average increased over the 25-year period from 272 SCDs to 291 SCDs (Table 6-1). The greatest increases occurred in Saskatchewan (10%), Manitoba (9%), Newfoundland and Labrador (8%), Alberta (6%) and Ontario (6%).

Three percent of Canadian farmland was in the very high soil cover class in both 1981 and 2006, while the proportion of land in the high class rose 34% from 1981 to 2006 (Table 6-2). This increase in the high soil cover class was the result of a significant shift of land from the lower classes of soil cover, particularly the very low class. The very low soil cover class decreased by approximately 24% to represent less than 1% of Canadian farmland in 2006. In fact, the number of soil cover days increased on 94% of farmland between 1981 and 2006 with 84% showing a large increase. Approximately 3% of Canadian farmland underwent a decrease in SCDs and 3% showed little or no change between 1981 and 2006 (Figure 6-2).

Response Options

Changes in soil cover are influenced by changes in tillage practices such as the adoption of conservation tillage and no-till, and changes in the distribution of crops. Thus, although the adoption of reduced tillage may increase soil cover by 45% or more for a specific crop (e.g. cereal grains in Prince Edward Island, or summerfallow in the Prairie Provinces—Table 6-3), a shift from no-till on a high-residue crop such as corn to no-till on a lower-residue crop such as soybeans can result in a decrease in SCDs.

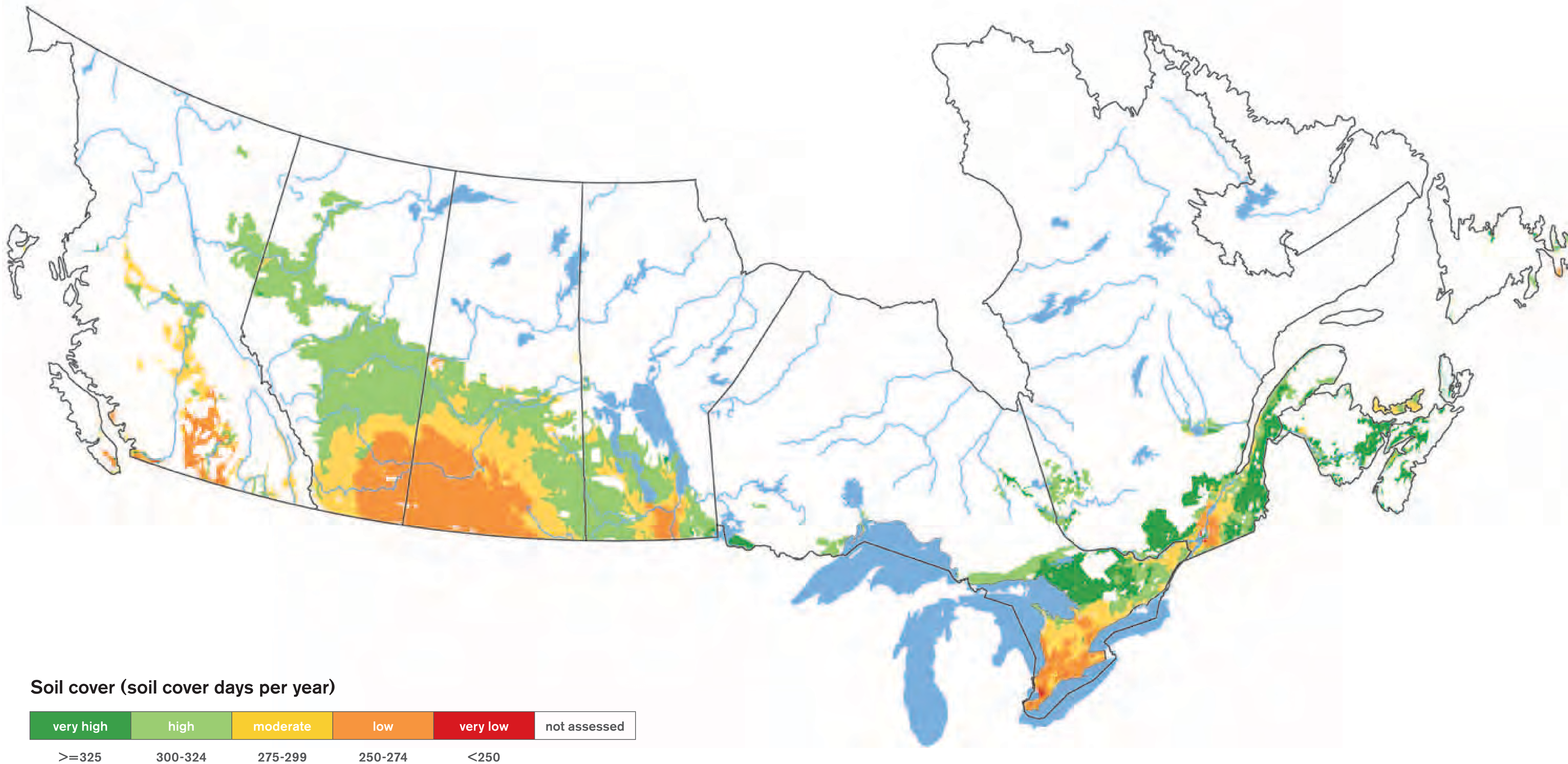


FIGURE 6-1 Soil cover in Canada, 2006

TABLE 6-1 Area-weighted mean annual Soil Cover Days (SCD) by province and Canada, 1981–2006

	Area-weighted mean annual soil cover days (SCD)					
	1981	1986	1991	1996	2001	2006
BC	284	293	294	295	295	293
AB	279	282	286	290	292	295
SK	258	263	272	278	278	284
MB	274	278	284	286	288	297
ON	268	269	273	280	281	285
QC	306	307	306	307	304	308
NB	324	328	326	327	325	327
NS	326	329	330	331	330	330
PE	286	289	290	290	291	292
NL	291	322	318	334	328	313
CANADA	**272**	**275**	**281**	**285**	**286**	**291**

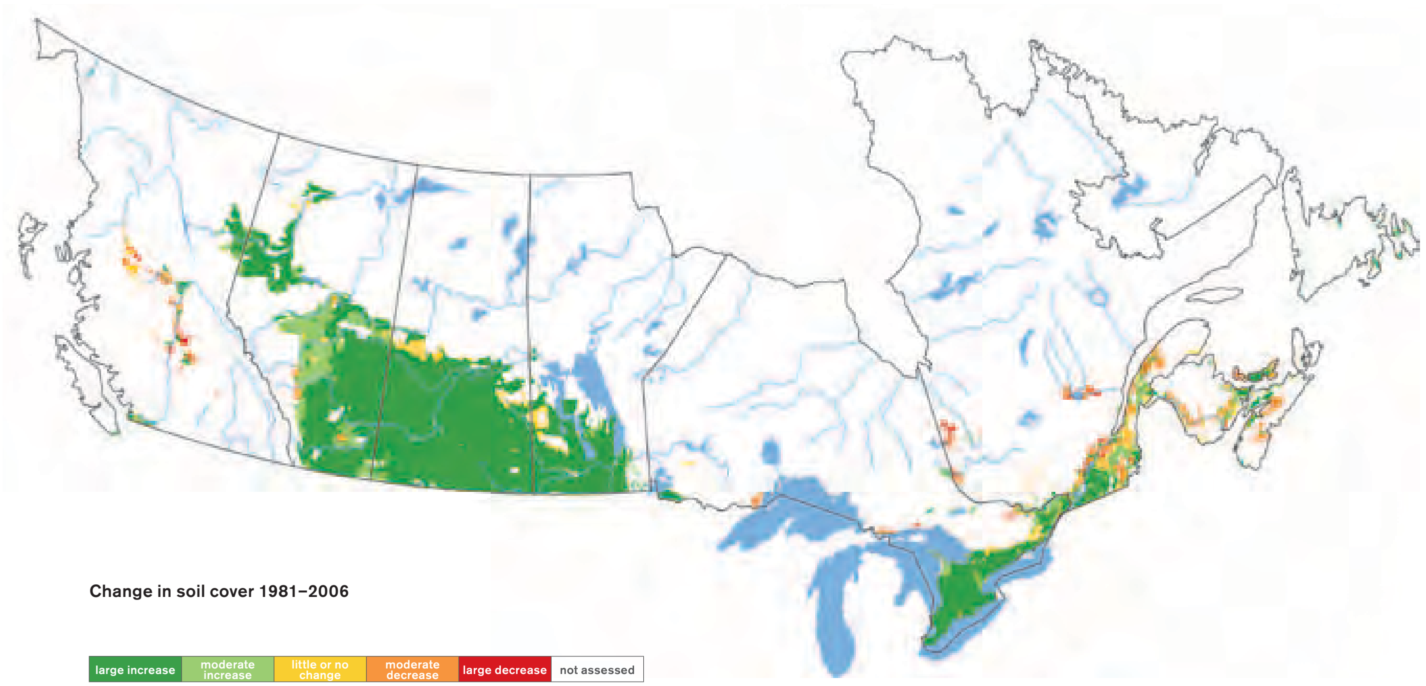


FIGURE 6-2 Change in soil cover, 1981–2006, by soil-landscape unit, Canada

TABLE 6-2 Percentage of farmland by soil cover class,1981–2006

	Very High (>=325 SCD/yr) (%)						High (300–324 SCD/yr) (%)						Moderate (275–299 SCD/yr) (%)						Low (250–274 SCD/yr) (%)						Very Low (< 250 SCD/yr) (%)					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	0	1	0	1	1	2	24	48	54	55	54	40	53	34	32	27	29	35	17	13	11	9	14	22	6	4	3	8	2	1
AB	0	0	0	0	0	0	17	27	34	44	57	60	42	33	29	28	22	21	29	30	35	14	21	19	12	10	2	14	0	0
SK	0	0	0	0	0	0	0	0	1	6	10	34	28	40	43	48	42	28	26	28	50	21	45	38	46	32	6	25	3	0
MB	0	0	0	0	0	0	6	11	10	13	18	61	32	50	67	69	67	27	61	39	23	15	15	12	1	0	0	3	0	0
ON	1	3	1	2	4	5	11	14	14	20	14	18	31	26	35	33	39	45	32	31	32	29	40	30	25	26	18	16	3	2
QC	30	35	32	32	31	27	36	35	32	32	27	39	18	14	21	20	23	22	15	15	15	13	19	12	1	1	0	3	0	0
NB	58	69	63	65	67	74	38	25	32	31	21	19	4	6	5	4	12	7	0	0	0	0	0	0	0	0	0	0	0	0
NS	72	78	76	78	76	82	20	15	17	19	16	14	7	6	7	2	8	4	1	2	0	1	0	0	0	0	0	0	0	0
PE	0	0	0	0	0	0	14	25	21	14	21	28	67	57	60	82	79	72	19	18	19	4	0	0	0	0	0	0	0	0
NL	0	59	32	85	58	23	28	23	59	14	39	63	60	15	2	1	3	5	12	3	7	0	0	9	0	0	0	0	0	0
CANADA	**3**	**3**	**2**	**3**	**3**	**3**	**10**	**15**	**17**	**23**	**29**	**44**	**33**	**36**	**39**	**40**	**37**	**27**	**30**	**28**	**37**	**18**	**30**	**26**	**24**	**18**	**5**	**16**	**1**	**0**

TABLE 6-3 Annual SCDs under different tillage practices for selected crops and ecoregions in Canada

		Ecoregion			
		Prince Edward Island	Lake Erie Lowland	Aspen Parkland	Mixed Grassland
Crop	Tillage	Average Annual SCDs			
Cereal Grain	Conventional	219	233	284	273
	Conservation	307	270	299	288
	No-till	320	281	308	289
Canola	Conventional	205	165	278	249
	Conservation	230	190	286	259
	No-till	265	228	291	259
Hay	Conventional	315	293	321	322
	Conservation	n/a	n/a	n/a	n/a
	No-till	n/a	n/a	n/a	n/a
Summerfallow	Conventional	n/a	n/a	201	172
	Conservation	n/a	n/a	247	220
	No-till	n/a	n/a	295	273

Of perhaps even greater importance than the adoption of reduced tillage in improving soil cover is the application of practices to enhance soil cover during the production of inherently low-residue crops such as potatoes, canola, soybeans, vegetables and nursery crops. These crops are increasing in area and can be expected to continue to expand. Planting a *green manure* or winter cover crop where feasible as soon as possible after harvesting these crops would provide a greater degree of soil cover during the long period between harvesting in the fall and planting in the spring. This may become especially important if climatic changes reduce the number of days of soil protection afforded by snow or if extreme weather events become more common in the spring before planting, when the soil is particularly vulnerable to degradation through erosion.

The desire for greater soil cover also has some research implications in the development of suitable companion and overwinter crops, in the development of cold-germination varieties of crops for use under no-till, in the development of equipment to better maintain surface residue while performing production operations satisfactorily and perhaps even in the development of crops with a greater mass of more durable foliage.

Since the early 1980s the trend in the level of soil cover has been generally positive. However, the increase in soil cover has slowed almost universally from a high rate of change in the early to mid-1990s to a much more modest increase over the past 10 years. This is indicative of the increasing technical challenges as the rate of adoption of reduced tillage practices is reaching a plateau and further expansion may not keep up with the negative influence of cropping system changes. It is also noted that the harvesting of crop residue, which is becoming more prevalent, can have a deleterious effect on soil cover.

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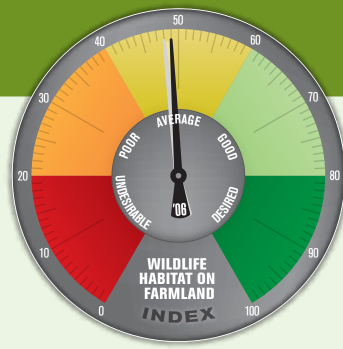
07 Wildlife Habitat



AUTHORS
S. K. Javorek and M. C. Grant

INDICATOR NAME
Wildlife Habitat Capacity on Farmland

STATUS
National Coverage, 1986 to 2006

Summary

Canada's agricultural landscape is a mosaic of cultivated, natural and semi-natural land that is used by close to 600 species of birds, mammals, reptiles and amphibians for breeding, feeding and shelter. Land cover types associated with farmland vary in their ability to support wildlife, with natural and semi-natural cover types of highest value to wildlife. Improved pasture and tame hay are the next most valuable to wildlife, while *cultivated land* sustains the fewest wildlife species. Agricultural landscapes are dynamic, with economic drivers sparking both beneficial and detrimental land cover change. It is the nature of these changes that ultimately determines the habitat capacity of the landscape and the structure and viability of wildlife populations. Assessing the capacity of farmland to support wildlife habitats is an important element in providing an understanding of the impact of agriculture on the environment. The Wildlife Habitat Capacity on Farmland Indicator assesses broad-scale trends in the capacity of the Canadian agricultural landscape to provide suitable habitat for populations of terrestrial vertebrates.

Nationally, average habitat capacity on farmland declined from 1986 to 2006 due to the loss of natural and semi-natural land cover and the intensification of agricultural operations. Although some species undoubtedly benefited from shifts in crop type (for example, summerfallow to tame hay) which resulted in increased habitat capacity, the existence and population viability of many species is very much linked to availability of natural and semi-natural land cover in the agricultural landscape. During this time period habitat capacity on farmland was constant on the majority of land but the percent of land with declining capacity was slightly greater than that with increasing habitat capacity.

The Issue

Agricultural land covers 8% of Canada's landscape and is made up of cultivated lands, hay lands and grazing lands with associated riparian, wetlands, woodlands and natural grasslands. Within this mosaic of land cover types, close to 600 species of birds, mammals, reptiles and amphibians use habitats that offer food, breeding areas, shelter or other life needs. Each of these species has unique habitat requirements that must be satisfied for viable populations to exist. Wildlife species with specific habitat (land cover) associations can be negatively affected by specific land cover loss or reduction, while newly created habitat can benefit an entirely different group of species. Conservation and enhancement of wildlife habitat takes on added importance when one considers that many of the species in Canada that are classified to be at risk, may be at risk or are sensitive, use farmland as habitat (CESCC 2006; Javorek and Grant, unpublished data) (Figure 7-1). It is the quantity, quality and spatial configuration of resource patches that determine the composition of wildlife communities in the agricultural landscape.

Although agro-ecosystems support many of Canada's *native species*, agricultural land use is dynamic and can have major impacts on wildlife. Wildlife habitat on farmland is degraded through the conversion of natural and semi-natural land to cropland, increased intensification and the loss of landscape heterogeneity. However, agricultural activity can also benefit wildlife by increasing habitat diversity within the landscape. Given that much of the most productive agricultural land in Canada coincides with areas of high biodiversity, agricultural producers, through their decisions as land managers, play a significant role in sustaining biodiversity. Producers are increasingly becoming recognized not only as providers of food but also as stewards of the earth's biodiversity and managers of multifunctional agricultural landscapes, providing both food and environmental goods and services (Bills and Gross 2005).

The Indicator

The Wildlife Habitat Capacity on Farmland Indicator provides a multi-species assessment of broad-scale trends in the capacity of the Canadian agricultural landscape to provide suitable habitat for populations of terrestrial vertebrates.

Wildlife habitat capacity was investigated on all agricultural land in Canada for the years 1986, 1996 and 2006. Data for this indicator was gathered from the Canadian Census of Agriculture, thus land use outside the agricultural extent (i.e. area not included in the census of agriculture) such as forestry and urban was not included. The use and habitat value of different land cover types to wildlife within the Canadian agricultural landscape were related to 588 species of birds, mammals, reptiles and amphibians associated with farmland in Canada. For each species the *habitat use* was identified as being used for

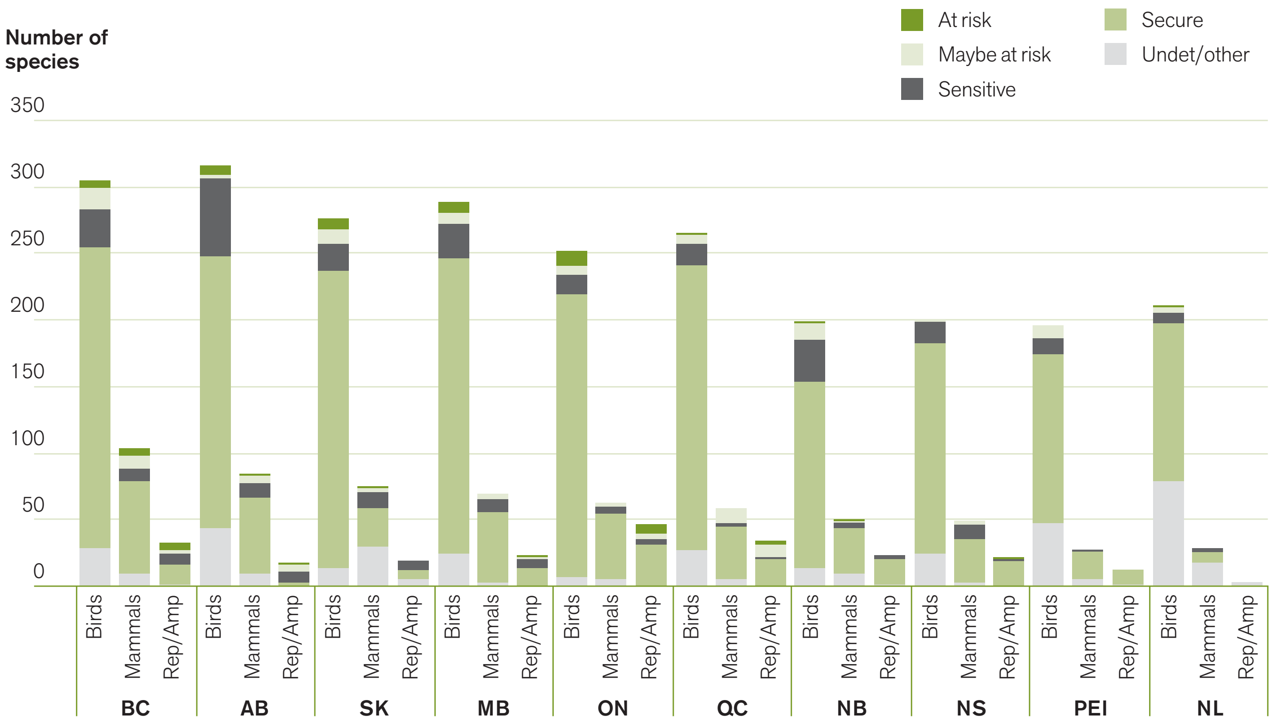


FIGURE 7-1 Provincial counts and general status ranks of birds, mammals, amphibians and reptiles associated with agricultural land in Canada

breeding, reproduction, cover, staging/migration and wintering, and *habitat value* was determined to be primary, secondary or tertiary. Primary habitat refers to land cover on which a species is dependant or that is strongly preferred. Habitat is considered secondary if a species uses it but is not dependant on it. Tertiary habitat is not needed, but a species is occasionally found there. Fifteen habitat categories (cereals, winter cereals, oilseeds, corn, soybeans, vegetables, berries, fruit trees, pulses, summerfallow, tame hay, improved pasture, unimproved pasture, other crops and all other land) were considered for this analysis. Land cover types in the 'all other land' (AOL) categories (non-cropland or non-pasture areas within the agricultural extent) are wetlands (with margins, without margins and open water), riparian (woody, herbaceous and crop), shelterbelts (including natural hedgerows), woodland (with interior, without interior, plantation), idle land/old field and *anthropogenic*. Individual species and their habitat-use information were linked to Census of Agriculture land cover data and Soil Landscapes of Canada (SLC) polygons.

The habitat value and the proportion of a land cover type providing a habitat use for an individual species in an SLC polygon were combined to produce an index of species-specific habitat availability. All species-specific habitat values were averaged in each SLC polygon to provide an index of habitat capacity for that polygon. Habitat capacities were calculated for breeding/feeding (HC_{bf}) and wintering (HC_{w}).

The range of HC_{bf} and HC_{w} values were placed into five classes (very low, low, moderate, high, very high) based on the national distribution of habitat capacity scores from all reporting SLCs.

Limitations

The Wildlife Habitat Capacity on Farmland Indicator deals only with the quantity of habitat and does not address the influence of landscape pattern (composition and configuration) on wildlife. Calculation of the indicator is limited by the lack of national land cover data required to provide spatial and temporal estimates of diverse habitats that, at present, are rolled up into the all other land category.

For proper interpretation, it must also be noted that agricultural landscapes are dynamic, with beneficial and detrimental land cover change often happening concurrently, especially when analyzed at broader spatial scales. This can lead to counterbalancing of the effects of land cover change on wildlife when assessed at large spatial scales. The broad-scale analysis (national/provincial) can mask habitat capacity changes at finer spatial scale (regional/local) and therefore must be interpreted carefully. Especially since relatively small, local changes in natural/semi-natural land cover, not captured with broad-scale assessment, can have a major impact on wildlife.

At present, the indicator deals only with terrestrial vertebrates. Including selected invertebrates and functional groups (such as pollinators) would provide a broader understanding of the impacts of land cover change on biodiversity on farmland.

The indicator does not currently relate changes in wildlife habitat capacity to actual responses of wildlife populations.

Results and Interpretation

In 2006 the majority of farmland reporting very low and low habitat capacity for breeding/feeding (HC_{bf}) was found in western and central Canada (Figure 7-2, Table 7-1) and was associated with higher intensity farming or where natural and semi-natural land comprised a relatively small percentage of the agricultural landscape. In many of these regions, agriculture

Invasive Alien Species

AUTHORS

P.G. Mason, S.I. Warwick, P. Bouchard,
R.G. Foottit, and O. Olfert

Invasive alien species (IAS) are typically aggressive, non-native species that, if left unchecked, will spread and dominate an ecosystem, reduce the existing native biodiversity and disrupt ecosystem functions. They immigrate through various natural pathways: as seeds drifting to shore, as *hitchhikers* on migrating birds, mammals and insects, as spores and arthropod-borne diseases, and through human activities. Increased global trade and travel have exacerbated the problem by creating new opportunities for species to be introduced.

Agro-ecosystems, like other ecological systems, require a certain level of biodiversity to maintain functions. These functions include nutrient cycling (encouraged by nitrogen-fixing bacteria), plant residue decomposition (supported by fungi and arthropods that feed on decaying plant tissue), and plant pollination (carried out by flies and many bee species). Natural systems comprise a variety of plant species that prevent individual weed species from dominating and that provide fewer preferred food plants for individual insect species. However, agro-ecosystems tend to be ecologically simplified and more susceptible to IAS such as weeds that germinate early in the season or insects that feed on newly germinated crop plants.

Invasive species can contribute to higher production costs in agricultural systems, for example by triggering trade embargoes (e.g. potato wart fungus, swede midge) and depressing commodity values (e.g. *Solanum* weeds in soybeans).

An Indicator of the Risk from Invasive Alien Species is in development. It will assess trends in population distribution and in numbers of IAS in agricultural habitats. Thus, it will reveal major pressures or threats to *agro-ecosystem* health and agricultural trade posed by:

1. existing IAS in Canada (actual threats),
2. established alien species with attributes that make them more likely to become invasive (imminent threats), and
3. known IAS, currently not present in Canada, but with a high potential to invade (potential threats).

The IAS indicator will be calculated as an index of *invasiveness* (indicating the potential to cause harm) for individual species. This index will be based on *taxonomic relationships*, biological attributes that provide advantages for invasion, level of damage caused and actual or potential distribution. The indicator will be calculated for single species or groups of species and applied at the local (farm), regional (county, provincial/territorial) or national level. To estimate the threat posed by a single IAS, modelling tools will be used to estimate relative abundance, seasonal variation in population numbers and the geographic distribution of a species (Sutherst et al., 1999). The indicator will allow identification of the areas that are most threatened and therefore in greatest need of farm practices to reduce the threat, as well as those areas that are least threatened or have implemented programs that have reduced the impacts of IAS.

Some beneficial management practices can help reduce the pressure exerted by IAS. These include maintaining natural habitats such as hedgerows and strips of native flowers around crop fields, which encourage native plants to thrive and provide appropriate shelter and food for native species that compete with IAS and for beneficial species that feed on IAS. *Minimum tillage* practices reduce soil disturbance, providing less opportunity for IAS to establish. Growing plant cultivars that are resistant to IAS and using biological control agents that specifically target IAS will reduce the survival of these species, increase crop yields and reduce the need for pesticides. Monitoring IAS populations will allow more precise targeting of pesticides and reduce overall use and increase profitability.

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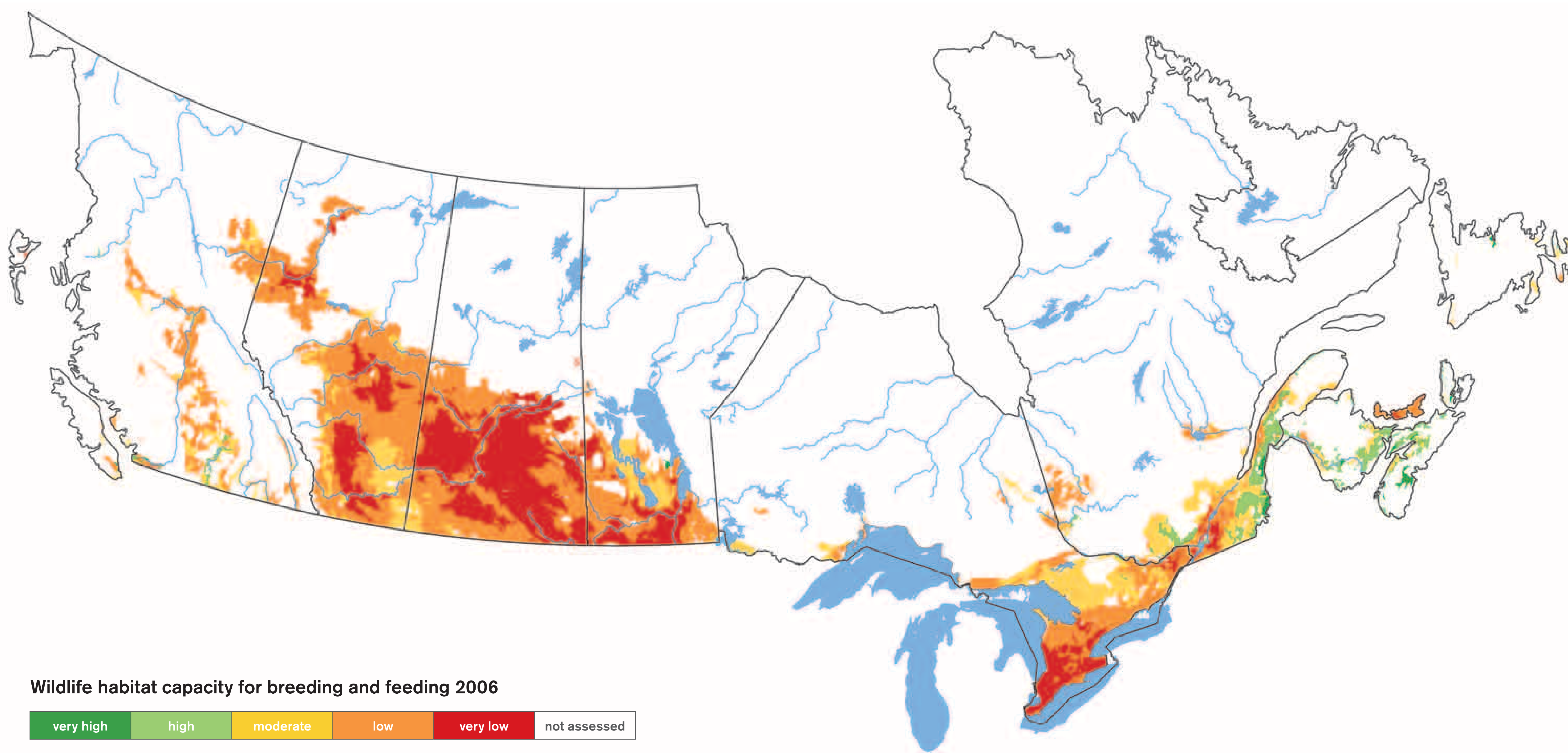

FIGURE 7-2 Wildlife habitat capacity for terrestrial vertebrates using agricultural land for breeding and feeding (HC_{bf}), 2006

TABLE 7-1 Average habitat capacity and share of farmland per class for breeding and feeding terrestrial vertebrates in 1986, 1996 and 2006.

	HC_{bf} Average			Trend (1986 base)		Very High			High			Moderate			Low			Very Low		
	1986	1996	2006	10yr	20yr	1986	1996	2006	1986	1996	2006	1986	1996	2006	1986	1996	2006	1986	1996	2006
BC	68.9	64.8	56.9	D*	D*	0	0	0	6	2	1	55	62	30	37	34	61	2	2	5
AB	51.4	51.3	50.3	D	D	0	0	0	0	1	0	14	12	14	57	61	60	29	26	25
SK	39.3	39.4	39.9	I	I	0	0	0	0	0	0	3	3	3	29	29	37	68	68	61
MB	45.6	44.1	46.1	D	I	0	0	0	0	0	0	10	2	14	47	52	45	43	46	41
ON	53.7	52.2	46.8	D*	D*	0	0	0	4	4	0	18	11	9	37	40	45	40	45	46
QC	73.0	70.7	66.4	D*	D*	1	2	1	22	21	16	39	32	35	26	29	34	12	17	13
NB	89.9	84.0	78.0	D	D*	12	8	3	53	45	57	34	42	33	1	4	7	0	0	0
NS	98.5	99.7	95.4	I	D	18	28	18	66	49	58	15	23	23	1	0	0	0	0	0
PE	57.6	50.0	48.3	D	D*	0	0	0	0	0	0	26	19	1	74	61	75	0	20	24
NL	91.3	98.5	75.0	D*	D*	26	19	7	33	69	10	23	11	64	15	1	19	3	0	0
CANADA	**57.0**	**56.4**	**51.9**	**D**	**D***	**0.3**	**0.4**	**0.2**	**2.5**	**2.2**	**1.5**	**12.4**	**10.3**	**11.2**	**40.0**	**42.6**	**46.5**	**44.9**	**44.5**	**40.6**

D= Decreasing Habitat Capacity I = Increasing Habitat Capacity * indicates significant habitat capacity change (p>0.05)

TABLE 7-2 Share of agricultural land per habitat capacity change class for 10 and 20 year intervals 1986–1996, 1996–2006 and 1986–2006.

	Habitat Capacity Change for Breeding-Feeding HC_{bf} 1986–2006 (Share of Agricultural Land)														
	Large Increase			Small Increase			Constant			Small Decrease			Large Decrease		
	86-96	96-06	86-06	86-96	96-06	86-06	86-96	96-06	86-06	86-96	96-06	86-06	86-96	96-06	86-06
BC	3	4	8	10	6	3	61	48	39	17	25	13	9	17	38
AB	2	1	1	5	8	8	83	84	82	8	5	7	2	2	2
SK	<1	<1	<1	5	8	8	94	87	88	3	2	3	<1	<1	<1
MB	<1	3	3	2	9	9	90	79	82	7	7	6	1	1	<1
ON	1	8	8	2	10	4	64	60	37	25	12	29	8	11	22
QC	10	25	27	7	8	7	50	44	26	18	6	18	15	17	23
NB	7	22	16	7	11	2	29	27	15	14	16	23	42	24	44
NS	23	23	19	10	8	13	27	19	15	22	21	19	18	28	34
PE	0	5	5	0	7	5	60	47	42	30	0	3	10	40	44
NL	53	0	23	8	0	0	27	15	12	4	4	7	8	82	57
CANADA	**2**	**3**	**4**	**3**	**9**	**7**	**83**	**78**	**75**	**8**	**6**	**8**	**3**	**4**	**6**

TABLE 7-3 Average habitat capacity and share of farmland per class for wintering terrestrial vertebrates in 2006.

	HC_w Average 2006	HC_w Share of Agricultural Land: Very High 2006	High 2006	Moderate 2006	Low 2006	Very Low 2006
BC	34.5	8	19	57	16	0
AB	22.8	0	5	28	55	12
SK	17.9	0	1	8	54	37
MB	22.0	1	2	19	49	29
ON	28.2	2	8	52	38	0
QC	37.0	21	35	33	11	0
NB	47.5	67	26	7	0	0
NS	50.4	82	17	1	0	0
PE	31.2	0	24	76	0	0
NL	42.1	26	62	12	0	0
CANADA	**30.5**	**2.0**	**6.0**	**22.0**	**48.0**	**22.0**

Risk of Wildlife Damage Indicator

AUTHORS
D. Thompson, J. Lemieux, L. Liggins,
C. Callaghan and T. Weins

Many of the wildlife species found on agricultural land have benign or even beneficial effects on agriculture, but some species can cause economic losses to crops, livestock and infrastructure.

Crops provide an enhanced food source that wildlife may access during parts of the year when they have critical energy requirements such as preparing for wintering or breeding. A recent Canada-wide survey revealed that 67% of nearly 7,000 producers surveyed have reported wildlife damage to crops on their farms during the last five years (AAFC, 2006). Damage by ungulates was the most reported (38%) followed by waterfowl (22%) and rodents/small mammals (21%). A great deal of effort has been made by producers, wildlife managers and agricultural agencies to reduce economic losses due to problematic wildlife. Following the principle that the crown or government is the owner of wildlife, many public dollars have been invested in prevention and compensation programs. Regional or provincial compensation programs have been implemented in many provinces to deal with unpreventable damage.

A Risk of Wildlife Damage Indicator is under development that will identify areas at higher risk of damage and how this risk is changing over time in response to land management changes. The indicator will consider driving forces for wildlife damage, including: area of field, climatic conditions, crop type, location of field in relation to preferred animal habitat, and wildlife numbers. A pilot project using wildlife compensation claims data in the Prairie Provinces showed wildlife damage varied across the landscape depending on their proximity to key habitat features such as staging lakes for waterfowl and winter range for ungulates. The study also found that crop type influenced the amount of wildlife damage. The area seeded to forages and pulses were major factors in ungulate damage. At the other extreme, there were few records of wildlife damage to oilseeds or winter cereals as these crops are less palatable or mature earlier and are less likely to be damaged.

The pilot also showed that weather within a growing season can greatly affect the magnitude of damage. Waterfowl or ungulate damage can increase if the period during which crops are lying in the swath is extended by wet weather. Commodity prices determine what crops producers choose to grow but careful consideration should be made about crop type in areas that receive chronic damage.

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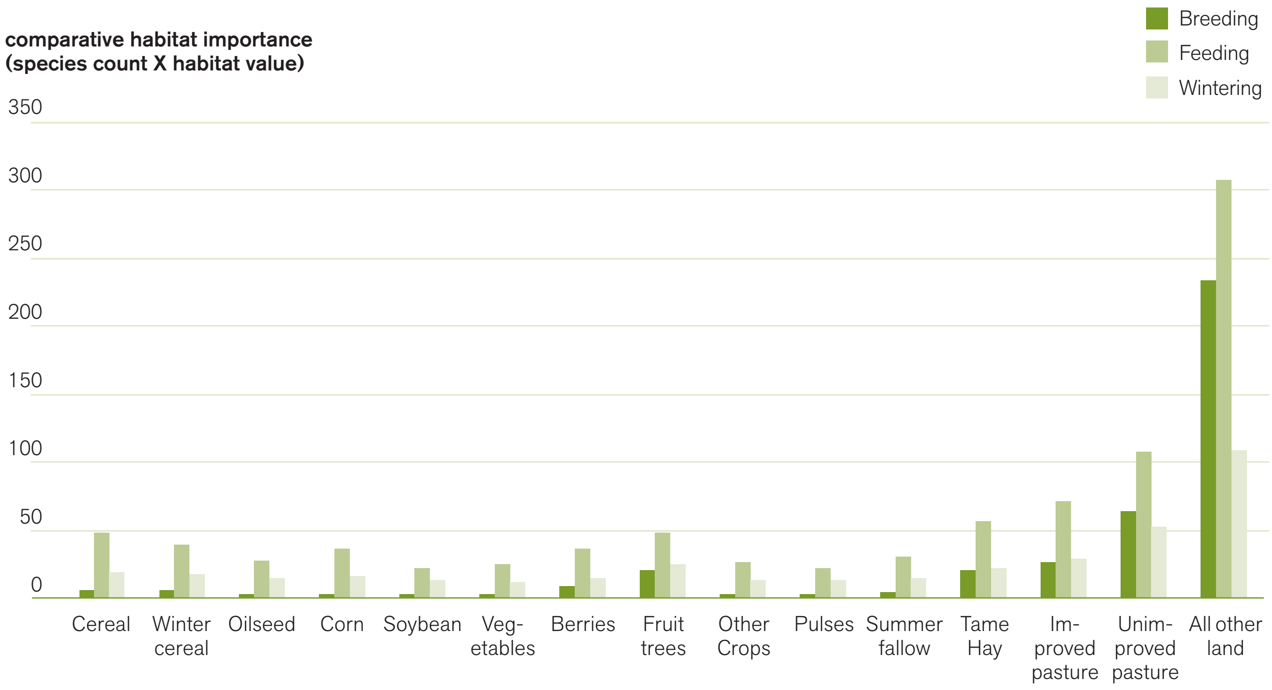

FIGURE 7-3 Comparative importance of agricultural cover types used by wildlife for breeding, feeding and wintering

made up a significant portion of the broader landscape, often being the dominant land use. Farmland with high and very high HC_{bf} was generally associated with agricultural land in Atlantic Canada and the Appalachians ecoregion of Quebec (Figure 7-2). Areas reporting high and very high HC_{bf} were characterized by a considerable natural and semi-natural land cover component and a relatively low agricultural component in the broader landscape.

Natural and semi-natural land cover types such as reported in all other land (AOL) (including woodland, *wetland* and riparian areas) and unimproved pasture have high wildlife habitat value (Figure 7-3). This is emphasized when one considers that 75% of species that use agricultural land can fulfill both their breeding and feeding habitat requirements entirely within cover types included in AOL. In contrast, only 13% of species can fulfill both these life history requirements on cropland alone. The ability of wildlife to use cropland therefore depends on the presence of complimentary cover types to provide for partial habitat needs. It is for this reason that comparatively small changes in AOL and unimproved pasture have large implications to HC_{bf} relative to changes in the other agricultural land cover types. Nationally, the proportion of farmland occupied by all other land was constant while unimproved pasture experienced a 1% decline from 1986 to 2006. The increased share of farmland under crops associated with more intensive management and comparatively low values as wildlife habitat—in particular, oilseeds, pulses and soybeans—also contributed to a decline in HC_{bf}.

Substantial benefits to biodiversity and all Canadians are realized when producers sustain natural habitat.

As with HC_{bf}, all other land and unimproved pasture were the most valuable habitats for wintering wildlife (HC_w) (Figure 7-3). The majority of farmland in Canada fell into the low (48%) and moderate (22%) HC_w categories (Figure 7-4, Table 7-3). Land with very low HC_w was found only in the Prairie Provinces while the Atlantic Provinces had no land in the very low or low categories of HC_w.

Nationally, between 1986 and 2006 HC_{bf} was constant on 75% of farmland, declined significantly on 14% and increased on 11% (Figure 7-5, Table 7-2). The average HC_{bf} over this time was stable (57.0 in 1986 and 56.4 in 1996) but declined in the subsequent 10 year period to 51.9 in 2006 (Table 7-1, Figure 7-6).

Response Options

Through their activities and decisions, Canadian producers are a major driving force of wildlife habitat capacity. Substantial benefits to biodiversity and all Canadians are realized when producers sustain natural habitat.

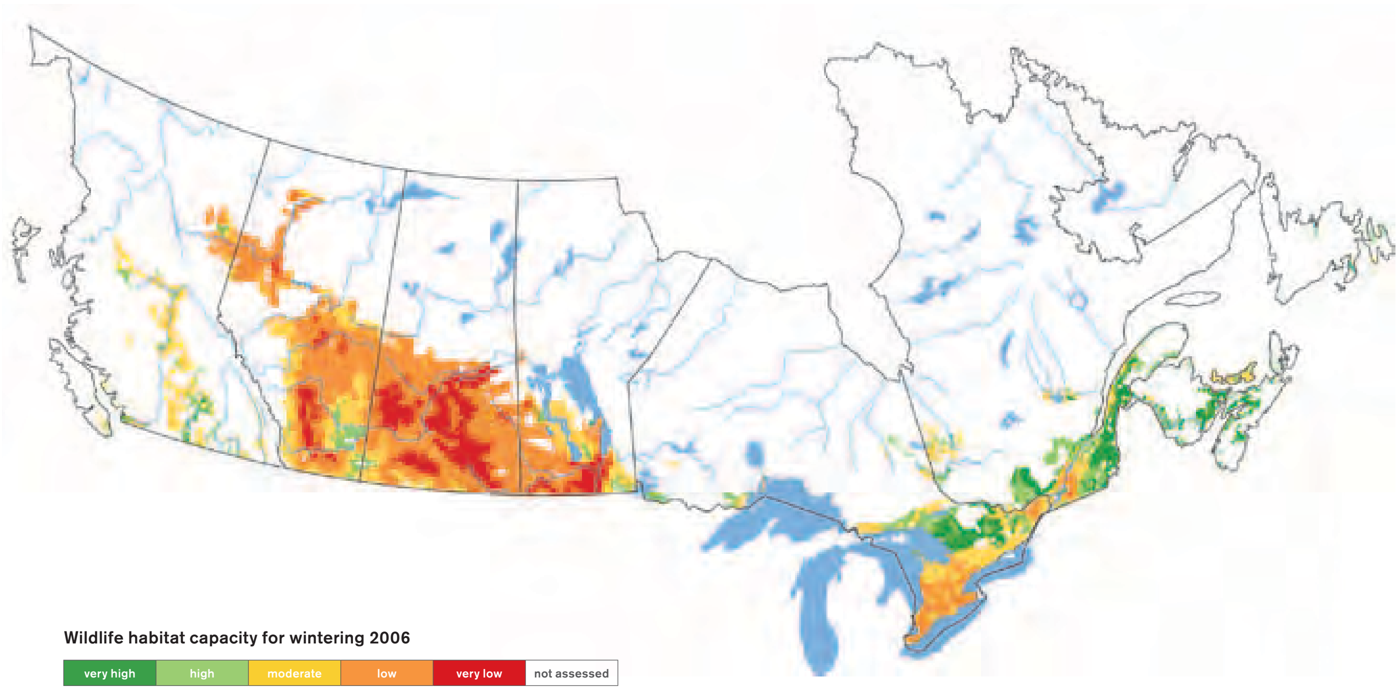

FIGURE 7-4 Wildlife habitat capacity for terrestrial vertebrates using agricultural land for wintering (HC_w), 2006

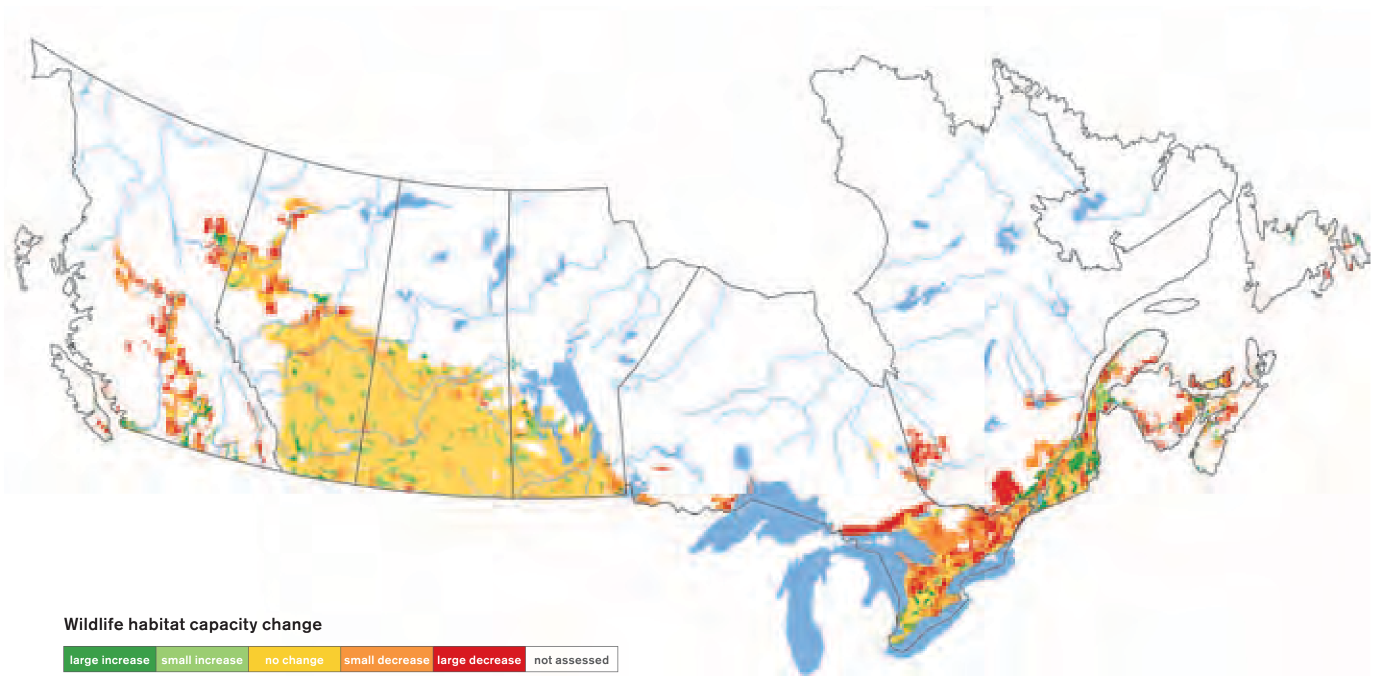

FIGURE 7-5 Change in wildlife habitat capacity on farmland for breeding and feeding terrestrial vertebrates (HC_{bf}), 1986–2006

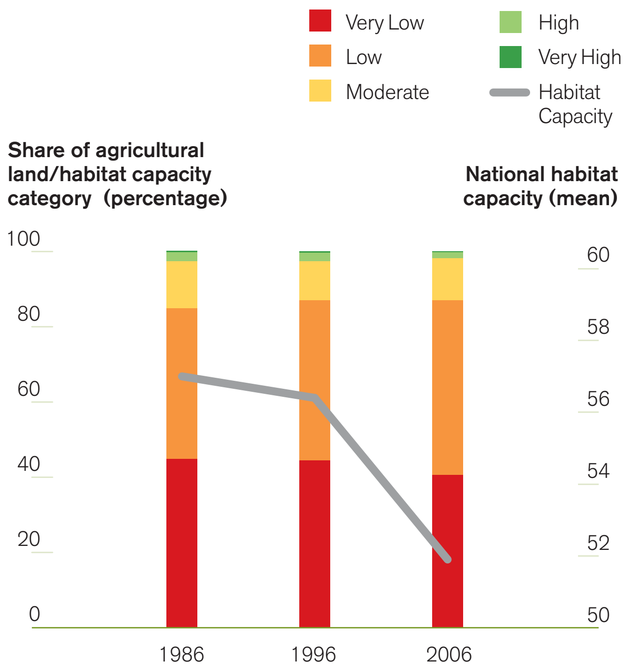

FIGURE 7-6 The national share of farmland in each habitat capacity class (bars) and average habitat capacity (line), 1986, 1996 and 2006

Maintaining or increasing the habitat capacity of agricultural land requires a systematic approach. To develop meaningful performance standards for this indicator, habitat thresholds must be established and the impact of agricultural land use decisions on individual species or guilds must be gauged against the thresholds. This would allow for habitat capacity *state* and *trend* analyses to be defined relative to a *desired state* or *target condition* of the agricultural landscape. Such information is best gathered regionally and locally, where planners can work with landowners to set habitat goals and objectives that meet the needs of a variety of species.

Most producers understand the value of conserving wildlife and wildlife habitat. Extension practices and incentive programs can further this understanding and encourage the voluntary participation of landowners in implementing land management practices that favor wildlife. Such beneficial management practices include developing and implementing environmental risk assessments and action plans, conserving riparian areas, adopting conservation tillage, managing woodlands, implementing rotation grazing, converting marginal cropland to permanent cover and conserving natural remaining habitats.

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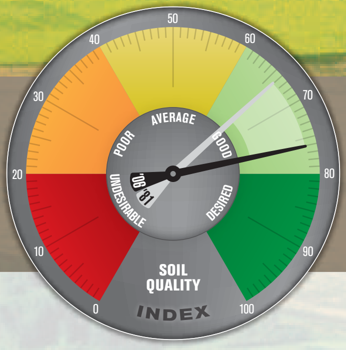
Soil Health



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SOIL QUALITY
INDEX

Soil Health

Summary

In agriculture, soil quality, or soil health, indicates the soil's ability to support crop growth without a resulting degradation to the soil or other harm to the environment. Severe soil degradation can prevent crop growth and can contribute to the degradation of other aspects of the environment. Soil quality can be degraded by natural processes such as erosion, *salinization*, loss of soil organic *carbon* (SOC) and the accumulation of trace elements (TEs) in soils. Each of these processes are influenced by agricultural practices.

Erosion removes topsoil, reduces soil organic matter and contributes to the breakdown of soil structure, which can result in low crop productivity, inefficient use of cropping inputs and adverse off-farm impacts on the environment. The combined effects of wind, water and tillage erosion must be managed to maintain soil health.

Losses of SOC contributes to degraded soil structure, increased soil vulnerability to erosion and lower fertility, ultimately leading to lower yields and reduced sustainability of soils. SOC change is an indicator of soil health and is an estimate of the amount of *carbon dioxide* (CO_2) (a greenhouse gas) that is either removed from the air and *sequestered* as SOC in agricultural soils or emitted to the atmosphere.

Desertification is the degradation of land in arid, semi-arid and dry sub-humid areas. It is mainly the result of inappropriate soil management practices, which contribute to soil erosion, a reduction of soil organic matter, fluctuating salinity, and climatic variations.

Small annual additions of TEs to soil may result in increasing concentrations that could potentially reach levels toxic to plants, animals and people.

Soil salinization results when the natural movement of water in the soil leads to the accumulation of salts in portions of the landscape. Accumulations of soluble salts at high enough levels can inhibit the ability of plants to absorb water and nutrients which causes the plants to experience drought-like conditions, thus reducing crop yields.

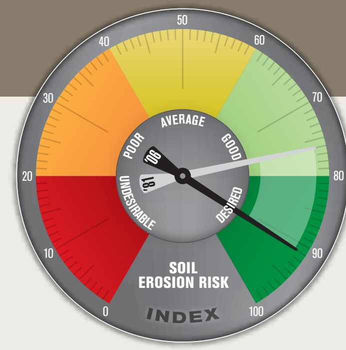
To assess the risks and trends in the effect of land use practices on soil quality, four agri-environmental indicators have been developed:

1. The Soil Erosion Risk Indicator (Chapter 8) presents the combined risk of water, wind and tillage erosion when climate, soil, topography and farming practices are considered.
2. The Soil Organic Carbon Change Indicator (Chapter 9) assesses how organic carbon levels are changing over time in Canadian agricultural soils.
3. The Risk of Soil Contamination by Trace Elements Indicator (Chapter 10) considers six key TE inputs from fertilizers, manures, municipal biosolids and the atmosphere, and estimates their concentration in agricultural soils over time given the continuation of current management practices.
4. The Risk of Soil Salinization Indicator (Chapter 11) estimates the risk of soil salinization associated with changes to land use and management practices in the Prairie Provinces.
5. The Risk of Desertification Indicator (In-box, Chapter 8) is under development to estimate areas of the Prairies at higher risk for the effects of desertification.

Generally, trends from 1981 to 2006 for soil health show improvements across Canada.

- The risk of soil erosion on Canadian cropland steadily declined between 1981 and 2006. In 2006, 80% of cropland area was in the very low risk class. The improvement in soil erosion risk reflects a reduction in all forms of soil erosion. However, the reduction in tillage erosion risk exceeded that of wind and water erosion.
- Improvements in farm management resulted in a dramatic shift from a position of neutral SOC during the mid 1980s to a situation in 2006 in which the majority of cropland had increasing SOC. The Prairies saw major increases in carbon over this time from adopting reduced tillage practices, and reducing summerfallow. From Ontario eastward however, there was an overall loss in SOC from 1981 to 2006. Overall, the management changes resulted in Canadian agricultural soils shifting from a net source of 2.5 megatonnes (Mt) of CO_2 emissions per year in 1981 to a *net sink* of 10.7 Mt of CO_2 per year in 2006.
- The risk of soil toxicity by TEs in Canada did not change appreciably from 1981 to 2006. Only 1% of agricultural land was estimated to be at risk of toxic impacts from TE accumulation after 100 years of present practices. However, this percentage is as high as 16% of the agricultural land in some provinces.
- All three Prairie Provinces showed a substantially decreased risk of salinization. In 2006, the salinization indicator estimated 80% of cropland in the very low risk category.

08 Soil Erosion



AUTHORS
D.A. Lobb, S. Li and B.G. McConkey

INDICATOR NAME
Soil Erosion Risk (integrating the risks of wind, water and tillage erosion)

STATUS
National Coverage 1981 to 2006

Summary

Soil erosion—the movement of soil from one area to another—occurs through three main processes: wind, water and tillage. It occurs naturally on cropland through the action of wind and water, processes that can be accelerated by some farming activities (e.g. summerfallow or *row cropping*). It is also caused directly by tillage, which results in the progressive downslope movement of soil from hilltops to accumulate at the base of hills.

Soil erosion is a major threat to the sustainability of agriculture in Canada. Erosion removes topsoil, reduces soil organic matter and contributes to the breakdown of soil structure. This adversely affects soil fertility, causes the movement of water into and from the soil surface and, ultimately, affects crop yields and profitability. Yields from severely eroded soils may be substantially lower than those from non-eroded soil in the same field. Erosion can also have significant off-farm adverse impacts on the environment through the physical transport and deposition of soil particles in other locations and through the release via erosion of nutrients, pesticides, pathogens and toxins. Management of the combined effects of wind, water and tillage erosion is required to maintain soil health.

The Soil Erosion Risk Indicator (SoilERI) is the combined risk of water, wind and tillage erosion when climate, soil, topography and farming practices are considered. The SoilERI was calculated for each Soil Landscape of Canada (SLC) polygon as the sum of wind, water and tillage erosion rates.

Soil loss from the combined effects of wind, water and tillage decreased in most provinces of Canada between 1981 and 2006. Over that period the proportion of cropland in the very low risk class increased from 47% to 80%. Much of this change is due to a reduction in tillage erosion in the Prairie Provinces. In 2006, 9% of cropland remained in the moderate to very high risk classes, reflecting high levels of water erosion in Ontario and the Atlantic Provinces.

The Issue

Soil erosion poses a serious threat to agricultural sustainability in Canada if management practices do not include consideration of erosion control. The loss of soil from current and past management practices is a major cause of low crop productivity and inefficient use of inputs. Soil erosion occurs through three main processes: wind, water and tillage erosion. These combined effects pose a more serious threat than individual erosion processes.

WATER EROSION

Rainfall and runoff are the driving forces behind water erosion. In addition to the degradation caused by the loss of topsoil, eroded soil is carried in runoff to agricultural drains, ditches and other waterways where suspended soil particles increase the turbidity (cloudiness) of the water, add to sediment build-up in waterways and reservoirs, and add nutrients and pesticides to water along with eroded soil.

WIND EROSION

This is a concern in many areas of Canada, from the *sandy soils* along the Fraser River in British Columbia to the coastal areas of the Atlantic Provinces. But it is in the Prairie Provinces that the potential for wind erosion is greatest. This stems from the region's dry climate and vast expanses of cultivated land with little protection from the wind.

TILLAGE EROSION

Many farm implements move soil, and on sloping land this movement is influenced by gravity which causes more soil to be moved when soil is tilled downslope than when tilled upslope. Even when tilling is done across a slope, more soil will be moved downslope than upslope. The resulting progressive downslope movement of soil from hilltops and soil accumulation at the base of hills is called tillage erosion. Evidence of tillage erosion is found on hilly land across Canada. This form of erosion is most severe on land that has many short, steep slopes and in areas where intensive cropping and tillage practices are used. Although distinct from wind and water erosion, tillage erosion influences wind and water erosion by exposing the subsoil, which is often more sensitive to these erosion processes, and by delivering soil to the areas of the landscape where water erosion is most intense. As such, tillage erosion also contributes to the off-site environmental impacts of soil erosion by wind and water.

Reducing all forms of soil erosion is a challenge since some practices are effective in reducing soil loss by one or more forms of erosion, and other practices reduce one form of erosion while increasing another form. Tillage practices that are effective in reducing wind and water erosion are not necessarily effective in reducing tillage erosion. For example, the chisel plough leaves more crop residues on the soil surface than the *moldboard plough*, thus providing more protection against wind and water erosion. However, the chisel plough can move soil over a much greater distance and cause more tillage erosion. Shelterbelts and water diversion terraces reduce wind and water erosion, but the addition of any field boundaries or obstacles within a landscape results in more widespread soil losses associated with tillage erosion. High disturbance direct seeding used in some no-till cropping systems can cause as much tillage erosion as the mouldboard plough because it moves soil great distances and with great variability. Clearly, management practices to reduce soil erosion require integrated approaches that target the combined effects of soil loss by all forms of erosion.

The Indicator

The SoilERI was used to assess the risk of soil erosion from the combined effects of wind, water and tillage erosion on cultivated agricultural lands. Calculated at the Soil Landscapes of Canada (SLC) polygon scale, this indicator and its component indicators for wind, water and tillage erosion reflect the characteristics of the climate, soil and topography and respond to changes in farming practices over the 25-year period from 1981 to 2006.

Soil erosion was calculated using landform data and the associated topographic data in the National Soil Database. Each SLC polygon is characterized by one or more representative landforms and each landform is characterized by hillslope segments (upper, mid and lower slopes and depressions). Each hillslope segment is characterized by a slope gradient and slope length.

Soil erosion risk by wind, water and tillage was calculated as soil loss on all segments of a landform. However, soil losses by wind and tillage erosion are greatest on the upper slopes and soil losses by water erosion are greatest on the mid slopes. The SoilERI was assessed as the cumulative soil loss rate for the slope segment with the greatest rate of loss—since the slope segment with the greatest rate of loss will largely determine changes in management. For analysis and reporting purposes, the erosion rates were summed across areas to SLC polygon, provincial, regional and national levels.

The erosion indicator calculation estimates the rate of soil loss. These values are reported in five classes: very low (less than 6 tonnes per hectare per year, which can also be expressed as 6 t

Desertification

AUTHORS

L. Townley-Smith and M. Black

Desertification is the degradation of land in arid, semi-arid and dry sub-humid areas. It is mainly the result of inappropriate soil management practices, which contribute to soil erosion, a reduction of soil organic matter and fluctuating soil salinity. While land degradation is a concern throughout Canada, it is in the Prairie Provinces, where most annual crop production is conducted in a semi-arid environment, that inappropriate soil management enhances the risk of desertification. As experienced during the “Dirty Thirties” on the prairies, drought can compound this risk by creating conditions where a set of soil management practices are no longer appropriate to prevent desertification. As a signatory to the United Nations Convention to Combat Desertification (UNCCD), Canada is obliged to ensure that desertification issues are integrated into national sustainable development plans and policies.

Two complementary approaches are being integrated to develop an indicator of desertification that will provide information to decision makers. The first will combine AAFC’s soil quality indicators (initially focusing on soil erosion) and evaluate the impact of erosion on crop yields to delineate areas most sensitive to desertification stresses. The second will incorporate remote sensing to estimate broad-scale, long-term plant productivity in relation to variability in weather over time. Together, these two approaches will provide information on the risk of desertification that will help decision makers mitigate this risk through improved management practices, policies or programs.

A measure of soil erosion tolerance (T) has been developed to estimate the amount of erosion that a soil can sustain and still remain productive indefinitely. Preliminary indicator results comparing the level of T with levels of erosion predicted by AAFC’s erosion indicators suggest that average soil erosion rates were usually below the soil tolerance level. This implies that under conditions existing in 2006, desertification risk due to erosion was low. Further development and enhancement of the Desertification Indicator are required to provide a more definitive analysis.

The Soil Erosion Risk Indicator (SoilERI) assesses the risk of soil erosion from the combined or cumulative effects of wind, water and tillage erosion on cultivated agricultural lands. Calculated separately using science based models, erosion estimates for wind, water and tillage processes combine to provide the overall SoilERI.

COMPONENT INDICATOR NAME
Water Erosion Risk Indicator

AUTHORS
B.G. McConkey, S. Li, J. M.W. Black and D.A. Lobb

The rate of water erosion was estimated using a model developed to combine features of the Universal Soil Loss Equation (USLE) and the Revised USLE (RUSLE2). This model accounts for rainfall-runoff, crop type, area and *erodibility*. The rainfall-runoff factor was calculated using rain gauge data from climate stations across the country. The management factor is influenced by the preceding crop in the rotation. For a given crop in the analysis year, the management factor was based on the probability of specific crops being grown in a rotation sequence. The inherent erodibility of each soil and the slope gradient (steepness) and length factors were determined.

COMPONENT INDICATOR NAME
Wind Erosion Risk Indicator

AUTHORS
B.G. McConkey, J. M.W. Black, S. Li

Based on potential prevalence of wind erosion, the rate of soil loss by wind erosion was estimated for the agricultural regions of Manitoba, Saskatchewan and Alberta, as well as the Peace River area in British Columbia. The rate of soil loss by wind erosion was estimated using the Wind Erosion Equation. The model utilizes a climatic factor based on wind speed and rainfall, soil factors related to *soil texture* and landform and a vegetation factor based on crop residue levels. The risk of wind erosion was calculated for the April to May period after seeding when residue levels are lowest and wind speeds are high. Estimates of residue levels for different crops under different tillage regimes were derived from Prairie Farm Rehabilitation Administration surveys of crop residue levels in Saskatchewan and applied across the Prairies.

COMPONENT INDICATOR NAME
Tillage Erosion Risk Indicator

AUTHORS
D.A. Lobb, S. Li

The rate of soil loss due to tillage erosion is calculated as the product of tillage erosivity and landscape erodibility. Hilly landscapes with short, steep slopes are highly erodible. Frequent tillage that moves large amounts of soil across the landscape is highly erosive. Erosivity values are assigned based on the character of the tillage operations representing each class of tillage and cropping system within the various agro-ecosystems across Canada and based on experimental data. Landscape erodibility values are calculated for each landform as a function of the gradient of the mid-slope (which determines the total soil loss on a landform), the length of the upper slope (which determines the area over which soil is lost) and the total slope length (which determines the density of hillslopes within a given area).

ha^{-1} yr^{-1}), low (6 to 11 t ha^{-1} yr^{-1}), moderate (11 to 22 t ha^{-1} yr^{-1}), high (22 to 33 t ha^{-1} yr^{-1}) and very high (greater than 33 t ha^{-1} yr^{-1}). Areas in the very low risk class are considered capable of sustaining long-term crop production and maintaining agri-environmental health under current conditions. The other four classes represent the risk of unsustainable conditions that call for soil conservation practices to support crop production over the long term and to reduce risk to water quality.

Limitations

Results from the soil erosion indicators, when interpreted at provincial and national scales and over the six census years are considered to provide reasonably accurate spatial and temporal trends. However, they are subject to limitations, which affect their accuracy. These limitations include the following:

- Landforms are represented in the National Soil Database by simple, two-dimensional hillslopes. As such, the landform data reflect neither the topographic variety and complexity that exist in real landscapes nor the effect of fence lines, tree lines, roadways, ditches and drainage ways on the slope. For many landforms, the use of these data overestimates soil loss by water erosion and underestimates soil loss by tillage erosion.
- The SoilERI represents the slope position with the greatest soil loss, the upper or mid-slope areas of a landscape. Values are averages for slope segments of representative landforms; thus, specific areas may be at greater risk than indicated by the risk class assessment.
- The SoilERI is a simple sum of the soil losses by wind, water and tillage erosion; it does not allow for interactions that occur over time among erosion processes.
- Wind and water erosion indicators do not account for some erosion control practices: *grassed waterways*, *strip cropping*, *terracing*, contour tillage and cropping, winter cover crops and shelter belts.

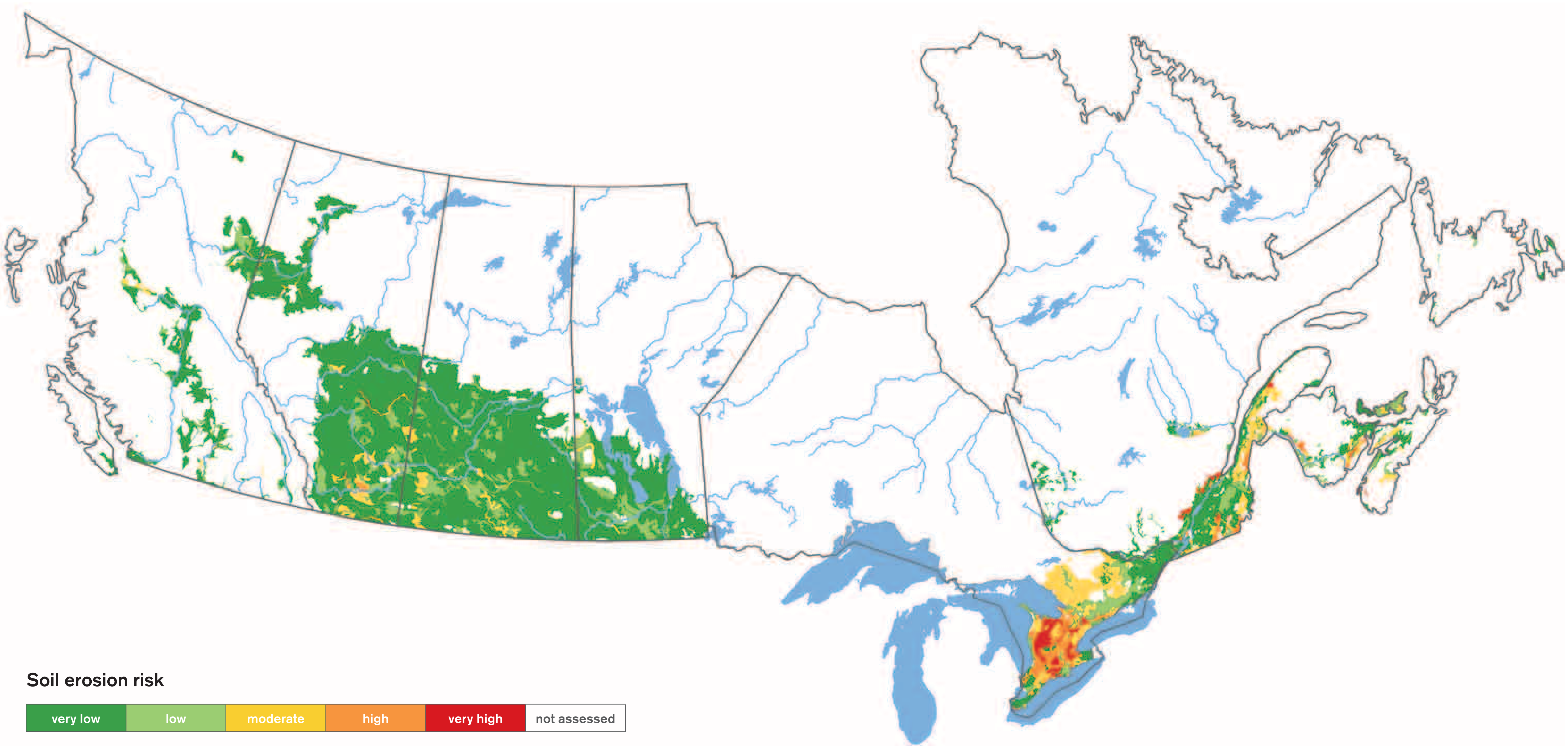


FIGURE 8-1 Risk of Soil Erosion (SoilERI) on cultivated land in Canada under 2006 management practices.

TABLE 8-1 Share (percentage) of cropland in Canada in Soil Erosion Risk classes

	Very Low						Low						Moderate						High						Very High					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	01	06	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	76	77	82	83	85	88	14	12	9	10	10	9	10	10	9	7	5	3	<1	<1	<1	<1	<1	0	<1	<1	<1	0	0	<1
AB	61	62	63	67	81	87	20	20	21	19	10	7	13	14	11	11	7	4	4	3	3	1	<1	<1	1	1	1	1	<1	<1
SK	40	45	48	55	64	87	26	26	30	34	28	9	27	23	18	9	7	3	5	5	4	2	<1	<1	<1	<1	<1	<1	0	0
MB	52	52	63	63	71	79	35	35	33	32	24	18	12	12	4	5	4	3	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0
ON	18	18	18	23	28	29	16	19	20	18	13	15	20	18	17	16	17	16	13	13	9	17	17	24	33	32	36	26	25	17
QC	71	73	74	73	69	72	15	14	14	15	17	15	5	8	8	9	7	10	6	4	3	2	7	2	3	1	<1	1	1	1
NB	40	39	37	37	39	39	25	29	26	30	27	24	20	20	21	21	18	23	7	5	6	4	7	5	8	8	9	9	9	8
NS	36	43	65	66	64	67	44	43	26	27	29	26	13	13	7	4	4	5	5	1	2	3	1	2	1	<1	<1	<1	2	<1
PE	18	19	19	20	19	25	71	70	71	70	72	66	0	0	0	4	6	10	10	11	9	6	4	0	0	0	0	0	0	0
NL	46	48	39	48	40	40	8	23	29	22	31	26	28	6	14	18	15	8	7	22	17	11	12	15	12	1	<1	1	1	11
CANADA	**47**	**50**	**53**	**57**	**66**	**80**	**25**	**24**	**26**	**28**	**21**	**11**	**20**	**18**	**14**	**10**	**8**	**5**	**5**	**4**	**4**	**3**	**2**	**2**	**4**	**3**	**3**	**3**	**3**	**2**

TABLE 8-2 Share (percentage) of cropland in Canada in Water Erosion Risk classes

	Very Low						Low						Moderate						High						Very High					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	90	90	91	93	94	94	3	3	3	6	2	6	6	7	6	1	4	<1	<1	<1	<1	<1	0	0	<1	<1	<1	0	0	<1
AB	95	95	95	95	98	98	4	4	3	3	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	1	1	1	<1	<1
SK	96	95	96	97	97	98	2	3	2	2	2	2	1	1	1	1	<1	<1	<1	<1	<1	<1	<1	0	<1	0	<1	0	0	0
MB	98	99	99	99	99	99	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0	0
ON	21	21	21	26	31	32	17	19	19	16	11	12	17	15	15	15	16	15	13	14	9	18	17	24	32	31	35	25	25	17
QC	72	75	75	74	70	74	14	13	13	14	15	13	6	8	8	9	7	10	6	3	3	2	7	2	3	1	<1	1	1	1
NB	43	41	41	44	43	43	27	32	30	30	30	28	18	15	14	20	12	23	10	10	12	4	13	6	2	1	3	2	2	<1
NS	52	53	73	74	71	72	29	33	18	19	21	20	13	13	7	4	5	5	5	2	2	3	1	2	<1	<1	<1	<1	2	<1
PE	67	68	77	76	78	90	23	22	14	13	13	<1	0	0	0	4	6	10	10	10	10	7	4	0	0	0	0	0	0	0
NL	68	71	69	74	66	65	1	11	13	4	15	11	19	15	16	20	17	15	11	2	2	1	<1	0	1	<1	<1	<1	<1	10
CANADA	**87**	**88**	**89**	**89**	**90**	**90**	**5**	**5**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**	**2**	**1**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**2**	**2**

TABLE 8-3 Share (percentage) of cropland in Canada in Wind Erosion Risk classes

	Very Low						Low						Moderate						High						Very High					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	100	100	100	100	100	100	<1	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AB	85	85	89	93	96	97	11	9	7	3	3	2	3	4	3	3	1	<1	<1	<1	<1	<1	0	0	<1	<1	0	0	0	0
SK	85	86	88	92	95	98	12	11	10	6	4	1	3	2	2	1	<1	<1	<1	<1	<1	<1	0	0	<1	<1	<1	0	0	0
MB	82	83	87	87	88	90	15	13	11	11	10	9	3	4	2	2	2	<1	0	0	0	0	0	0	0	0	0	0	0	0
CANADA	**85**	**86**	**88**	**92**	**94**	**97**	**12**	**11**	**9**	**6**	**4**	**3**	**3**	**3**	**2**	**2**	**1**	**<1**	**<1**	**<1**	**<1**	**<1**	**0**	**0**	**<1**	**<1**	**<1**	**0**	**0**	**0**

TABLE 8-4 Share (percentage) of cropland in Canada in Tillage Erosion Risk classes

	Very Low						Low						Moderate						High						Very High					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	90	91	91	92	96	95	7	7	7	7	3	3	3	3	2	2	<1	1	<1	0	0	0	<1	0	0	0	0	0	0	0
AB	87	87	87	88	92	95	7	7	7	7	6	5	6	6	6	5	2	<1	0	0	0	0	0	0	0	0	0	0	0	0
SK	72	72	72	75	91	97	24	23	23	21	8	3	4	5	5	3	1	<1	0	0	0	0	0	0	0	0	0	0	0	0
MB	92	91	92	92	94	98	8	8	8	8	5	2	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0	0	0	0	0	0	0
ON	51	54	58	73	85	88	38	35	32	19	7	5	5	6	7	7	7	7	7	5	4	1	<1	<1	0	0	0	0	0	0
QC	97	97	97	97	96	98	3	3	3	3	3	2	<1	<1	<1	0	<1	<1	0	0	0	0	0	0	0	0	0	0	0	0
NB	77	78	77	78	77	78	5	3	6	7	7	7	11	13	10	9	9	9	2	<1	1	<1	1	<1	5	5	6	6	7	6
NS	93	94	94	94	95	99	7	6	6	6	5	<1	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PE	34	35	34	35	33	41	66	65	66	65	67	59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NL	73	71	65	73	78	66	4	15	17	16	10	14	15	14	17	11	4	19	8	<1	1	<1	7	0	0	0	0	0	<1	<1
CANADA	**78**	**78**	**78**	**81**	**91**	**95**	**17**	**17**	**17**	**15**	**7**	**4**	**4**	**5**	**4**	**4**	**2**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**

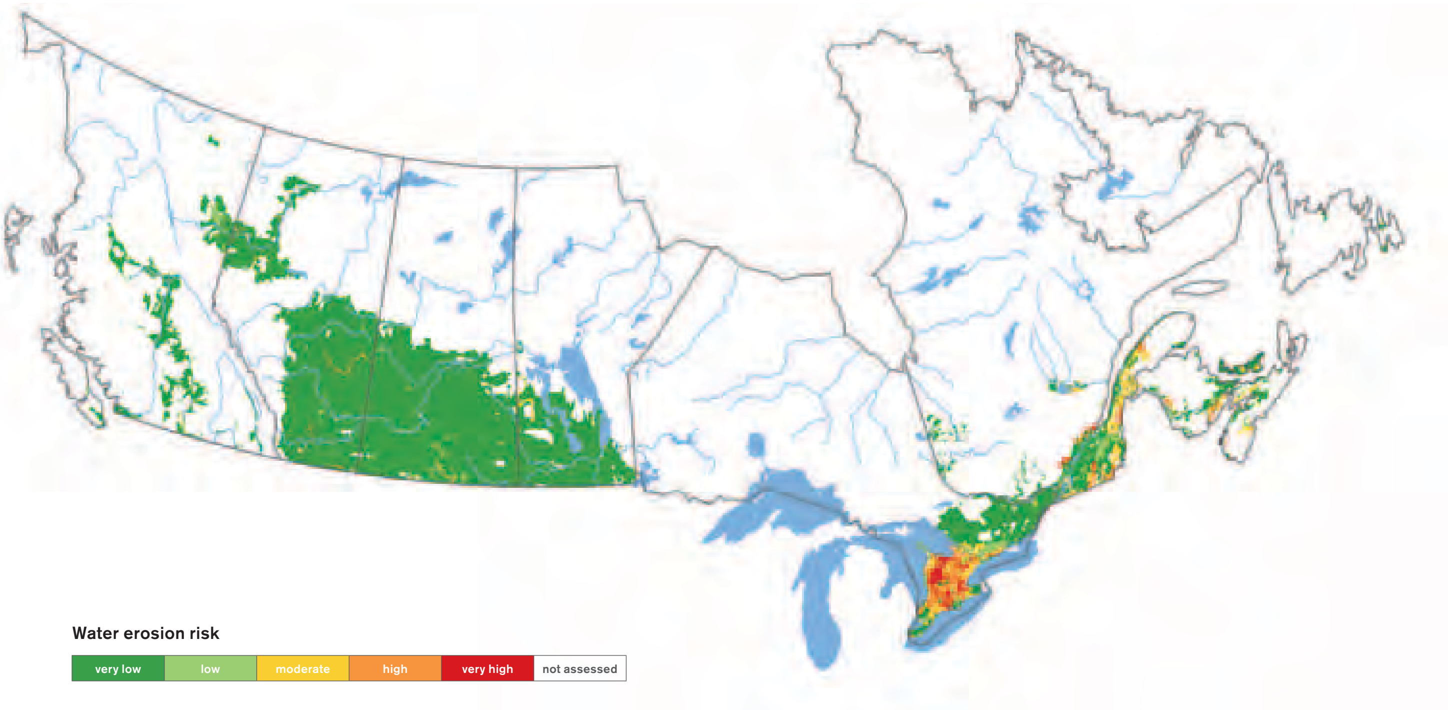


FIGURE 8-2 Risk of Water Erosion on cultivated land in Canada under 2006 management practices.

- The water erosion indicator does not include gully erosion that occurs where runoff concentrates. Water erosion risk should also be considered less accurate for locations in which significant erosion occurs when soils are frozen. In particular, the erosion risk from rainfall occurring on a thawed soil layer overlying frozen soil is likely underestimated.
- The tillage erosion indicator does not include planing or scalping caused by tillage equipment.
- Wind erosion may be significant in some years on exposed sandy and peaty soils outside of the Prairie Provinces, but these situations were not considered.

Results And Interpretation

The risk of soil erosion on Canadian cropland steadily declined between 1981 and 2006. Most of this change occurred between 1991 and 2006. In 2006, 80% of cropland area was in the very low risk class. This is a considerable improvement over 1981 when only 47% was in this risk class. The cropland area in each of the higher risk classes decreased by about one half during this period, reaching a cumulative total of 20% in 2006. The integrated erosion risk indicator results (Figure 8-1) paint a picture that is less attractive than the results from the individual component indicators for water, wind and tillage erosion (Figures 8-2, 8-3, 8-4), but that better represents the actual risk of soil degradation by erosion.

The improvement in soil erosion risk reflects a reduction in all forms of soil erosion. However, the reduction in tillage erosion risk exceeded that of wind and water erosion (17% increase in the very low risk class, compared to increases of 12% for wind erosion and 3% for water erosion) (Tables 8-1, 8-2, 8-3, 8-4).

The decrease in all forms of erosion across Canada has been largely due to the widespread adoption of conservation tillage, particularly no-till systems. Changes in the share and mix of crops grown were less of a contributing factor. Crops often produced using more intensive tillage (making them more erosive) such as corn, potatoes and beans increased in area from 6% of cropland in 1981 to 13% in 2006. This uptrend was offset by a decrease in summerfallow, from 24% in 1981 to 9% in 2006 and by an increase in high residue crops requiring very little tillage such as alfalfa and hay, from 14% in 1981 to 21% in 2006. Although most crops have seen a reduction in tillage intensity, the adoption of no-till in cereals has had the greatest influence on soil erosion owing to the large share of cropland devoted to cereals.

Of the cropping systems across Canada, the risk of soil erosion was greatest under potato and sugar beet production where there is very intensive tillage and little opportunity to reduce the intensity through conservation tillage practices. The cropping system with the next greatest risk of erosion is corn and soybean produced with conventional tillage, although there is a huge opportunity to reduce this erosion risk with conservation tillage. Of the soil landscapes across Canada, the risk of soil erosion is greatest on those with maximum slopes of 10% or more, especially those located in eastern Canada where climate produces a high inherent risk of water erosion. The most serious erosion concern occurs where cropping systems with high erosion risks are practiced on soil landscapes with high erosion risks. This is the case for a significant portion of cropland in southern Ontario and in Atlantic Canada. However, there are areas in every province with risks of unsustainable soil erosion.

Response Options

An integrated approach is needed to reduce the combined effects of soil loss to sustainable levels by all forms of erosion. This is critical to maintaining soil health. While there are many practices that farmers can implement to reduce soil erosion,

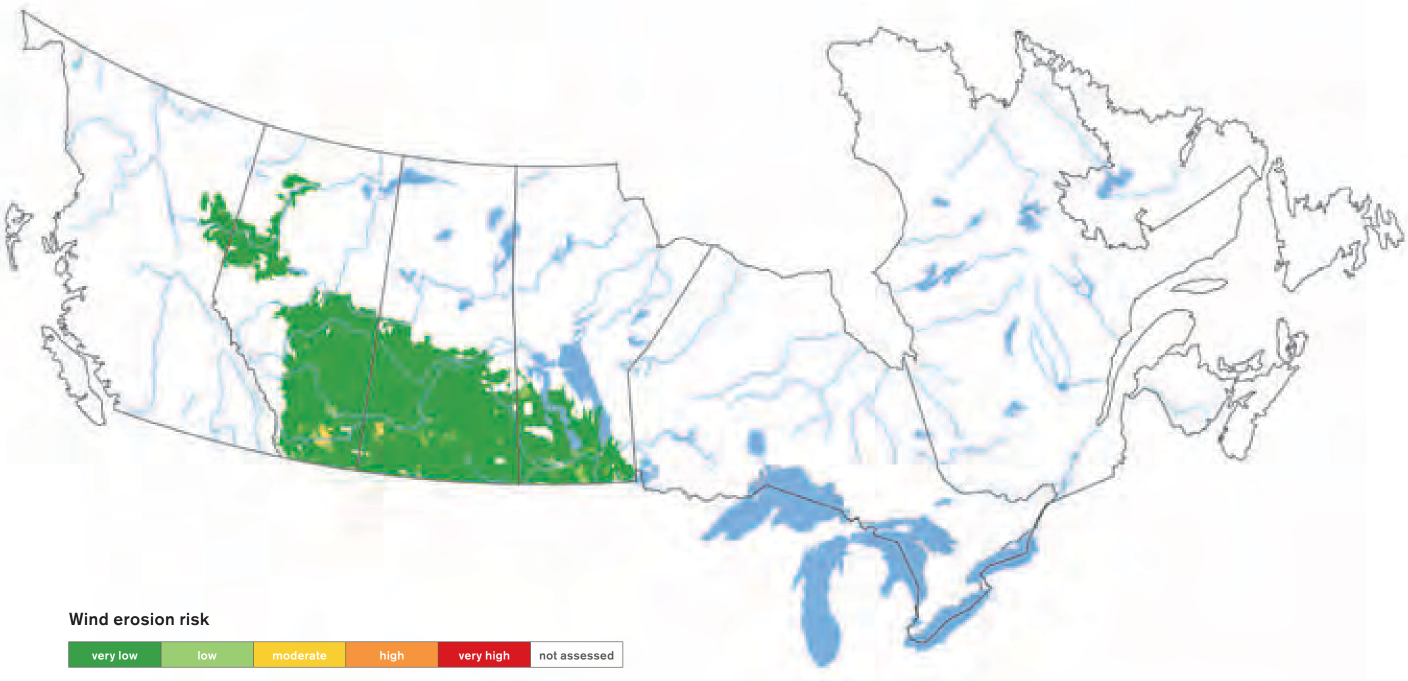


FIGURE 8-3 Risk of Wind Erosion on cultivated land in the Prairie Region under 2006 management practices.

the appropriateness of a practice depends upon the type of the farming system, the climate and characteristics of the land, such as soil texture and whether the land is level or hilly. In general, all forms of soil erosion can be reduced by using less intensive tillage. This reduces the amount and extent of soil movement and, therefore, reduces tillage erosion. It also reduces the degree of incorporation of crop residue, an effective protection against the erosive forces of wind and water.

However, types of tillage practices vary in their effectiveness in reducing wind, water and tillage erosion. Thus, practices should be tailored to account for the characteristics of the landscape. Reducing tillage intensity on hilly land, particularly land with short steep slopes, is an effective practice to reduce all forms of erosion. On level farmed landscapes tillage erosion becomes less extensive and soil texture and structure become more important. Tillage practices that maintain crop residue for protection against wind and water erosion are favoured on these landscapes. While tillage erosion is quite predictable, unusually intense storms will occur periodically and cause disastrous erosion if protection of the soil from wind or water is insufficient. Therefore, when deciding on which type erosion risk to target, producers should consider that overprotection for expected weather conditions will be beneficial during intense weather events. Producers should select practices that optimize the reduction of wind, water and tillage erosion over the long term. In doing so, they must consider the physical and environmental characteristics of the land and climate, the type of crops being produced and cropping system being employed.

WATER EROSION

This can be controlled by improving the soil's structure and protecting the soil against the impact of rainfall and flowing water, and by managing the land to reduce the amount and erosiveness of flowing water. Management practices that aid in controlling water erosion include:

- using conservation tillage, including forages in rotations,
- planting row crops across the slope,
- strip cropping
- inter-seeding row crops with other crops, and
- growing cover crops.

More research needs to be done on alternatives to no-till for areas where this practice is not viable, such as areas of intensive horticultural or potato production. Where water erosion is very high, conservation tillage and cropping systems might be inadequate to control erosion and run-off. In these areas alternative practices to control erosion include establishing terraces, or steps, to reduce slope steepness and length, and establishing permanent small earthen berms or diversions running along the contours. Addressing gully erosion usually requires engineering solutions such as constructing grassed waterways or, where grassed waterways would be inadequate, erosion control structures. In areas of higher precipitation and inherently greater risk of water erosion, low residue or high soil exposure crops such as potato, horticulture, and row crops (corn and soybean) are particularly prone to water erosion and need to be targeted for policy and conservation programs to reduce that risk.

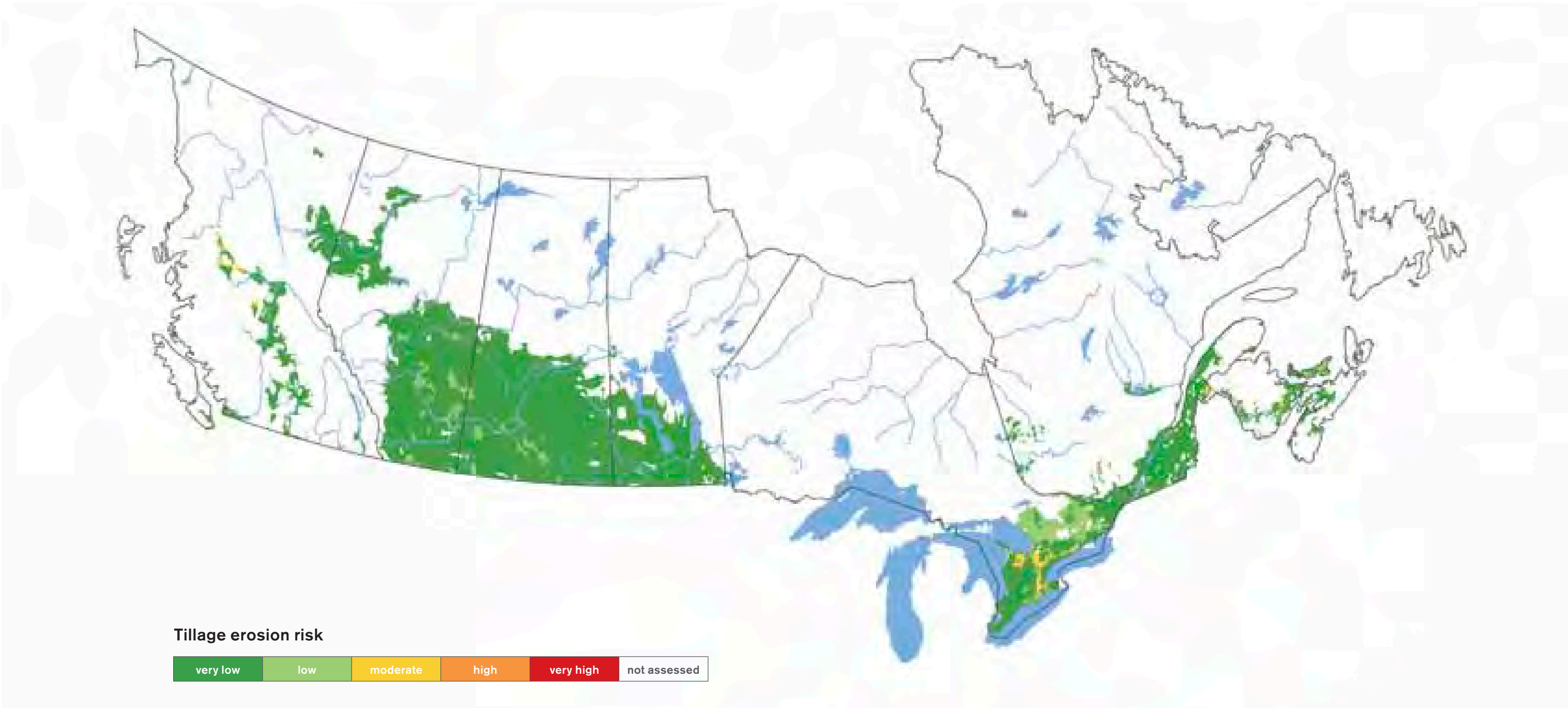


FIGURE 8-4 Risk of Tillage Erosion on cultivated land in Canada under 2006 management practices.

WIND EROSION

This is most effectively controlled by keeping the soil covered with crops and crop residues in all areas of the country. In the Prairies, soils with surface textures of *loamy sand* and sand have the greatest inherent erosion risk and planting perennial forages is the most practical response option. For sandy loam soils in this region forages are also appropriate. If sandy loam soils are cropped to annual crops, complete no-till is necessary to achieve very low erosion risk. Shelterbelts should also be considered for these soils. For other soil textures, conservation tillage or no-till are sensible ways to reduce erosion risk. Following potatoes and sugar beets, planting a *cover crop* of spring or winter cereals will help control wind erosion. Applying solid manure will also help control erosion.

TILLAGE EROSION

This is controlled by modifying tillage practices. Only by eliminating tillage can this form of erosion be completely stopped. Using no-till practices to grow crops or growing crops, such as forage, that require no tillage are the most effective means of reducing tillage erosion. However, even practices such as seeding and *fertilizer injection* can cause significant levels of soil movement and tillage erosion. Many cropping systems, such as potato production, will always entail some form of soil disturbance, leading to soil movement and tillage erosion. In these production systems, it is important to select tillage implements and carry out tillage operations in a way that minimizes tillage erosion. Implements that move less soil and move it over a shorter distance will generate less tillage erosion. Also, more uniform speed and depth of operation will lessen tillage erosion. In landscapes where contour tillage is practical, this approach may result in less tillage erosion than tilling up and down hillslopes, particularly if greater uniformity of tillage depth and speed can be achieved by tilling along the contours. With contour tillage, the rollover moldboard plough can be used as a conservation tool when the furrow is thrown upslope. The upslope movement of soil by the moldboard plough may offset the downslope movement by other tillage operations. Efforts to reduce tillage erosion should be focused on landscapes that are hilly and therefore more susceptible to such erosion.

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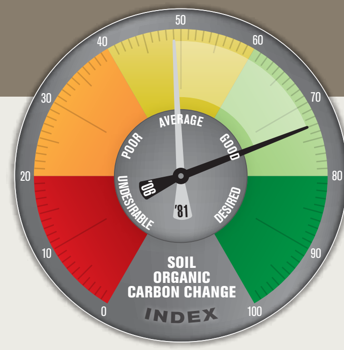
09 Soil Organic Matter



AUTHORS
B.G. McConkey, D. Cerkowniak, W.N. Smith, R.L. Desjardins and M.J. Bentham

INDICATOR NAME
Soil Organic Carbon Change

SUPPLEMENTARY INDICATOR NAME
Relative Soil Organic Carbon

STATUS
National coverage 1981 and 2006

Summary

Carbon (C) is the building block of living things and important to soil health and fertility. The Soil Organic Carbon Change (SOCC) Indicator assesses how organic carbon levels are changing over time in Canadian agricultural soils. The change in soil organic carbon (SOC) is a useful indicator of soil health and an estimate of how much carbon dioxide (CO_2) is removed from the atmosphere by plants and sequestered as SOC in agricultural soils. A supplementary indicator, the Relative Soil Organic Carbon (ROC) Indicator, also provides consistent and comparable SOC levels nationally across differing climates and soil types.

Decreasing erosion, reducing tillage intensity, reducing summerfallow, using cover crops, spreading manure effectively, and periodically producing forages and crops that leave large amounts of residue are all techniques that can be used to slow SOC losses or increase SOC gains. These practices need to be preferentially applied to soils that have a combination of low and declining SOC levels.

Canada as a whole has seen substantial increases in SOC over 25 years, which removed 11.7 million tonnes of CO_2 from the atmosphere in 2006. In the Prairies, SOC is largely increasing due primarily to a reduction in tillage and summerfallow. These increases are especially important for correcting past soil degradation that had left many Prairie soils with very low SOC levels. Conversely, east of Manitoba, SOC is generally decreasing due to steady conversion of *tame pastures* and hay land to annual crops.

The Issue

Carbon is the basic building block of all living things and the main component of soil organic matter. Carbon is first captured from the air as CO_2 by plants during *photosynthesis*. This C enters the soil upon the death of plants or animals that directly or indirectly consumed the plants. Most of this C is quickly returned to the atmosphere during initial decomposition of plant and animal remains. However, through the decomposition process, a small portion of organic C from plants and animals becomes soil organic materials that are less easily decomposed. Over time, soil organic matter builds in the soil until a *steady-state* level of soil organic matter is reached. At this point, new organic C additions from dead plants and animals exactly balance losses of organic C from decomposition. Note that in this text, the terms SOC and soil organic matter (SOM) are used interchangeably as SOM is generally considered to be a constant 58% C by mass (SOC=0.58*SOM).

Soil organic matter strongly influences many important aspects of soil quality and is a key component of good soil health. It helps hold soil particles together and stabilizes the soil structure, making the soil less prone to erosion and improving the ability of soil to store and convey air and water. Improved soil structure helps maintain soil tilth (workability) and permeability. Soil organic matter stores and supplies many nutrients needed for the growth of plants and soil organisms. It binds potentially harmful substances, such as heavy metals and pesticides. Finally, it acts as storage for CO_2 (a major greenhouse gas) captured from the atmosphere.

Losses of SOM contribute to degraded soil structure, increased soil vulnerability to erosion and lower fertility, ultimately leading to lower yields and reduced sustainability of the soil.

The Indicator

The SOCC indicator has been developed to assess how organic C levels are changing over time in Canadian agricultural soils. The indicator is based on the method used for the Canadian National Inventory Report methodology of Environment Canada (2009). The indicator uses the Century model (NREL, 2007) to predict the rate of change in organic C in Canada's agricultural soils due to the effects of land management change since 1951. These include changes in tillage, summerfallow frequency, and change between annual crops and perennial hay or pasture. It includes land-use changes such as clearing forests for agriculture or breaking native grass for cropland, but does not include the loss of C from the above-ground forest biomass. No changes in SOC were assumed if there were no indicated changes in land use or land management.

The change in SOC is a useful indicator of long-term trends in general soil health. The indicator also serves to estimate how much CO_2 is removed from the atmosphere by plants and stored (or sequestered) as SOC in agricultural soils. Thus, in addition to indicating changes in soil health, the change in SOC provides an indication of potential reductions in atmospheric CO_2, which can offset greenhouse gas emissions.

The SOCC indicator results are presented as the percentage of total cropland that falls into each of five SOC change classes expressed in kg per hectare per year (kg ha^{-1} yr^{-1}). Negative values represent a loss of SOC from the soil and positive values represent a gain of SOC. The five classes are defined as follows: large increase (gain more than 90 kg ha^{-1} yr^{-1}), moderate increase (25 to 90 kg ha^{-1} yr^{-1}), negligible to small change (-25 to 25 kg ha^{-1} yr^{-1}), moderate decrease (-25 to -90 kg ha^{-1} yr^{-1}) and large decrease (change by more than -90 kg ha^{-1} yr^{-1}). If soil is well managed over a long period, the SOM should show little change over time. Thus, increasing SOC is not necessarily preferred over a situation of no change. However, if the soil has been degraded in the past, a significant increase in SOC is clearly desirable as it indicates the soil is being restored to better soil health and function. A loss of SOC also represents a release of CO_2 into the atmosphere and so is not desirable. Therefore, the preferred values for this indicator are no loss of SOC from agricultural soils and C accumulation in soils that are currently low in organic matter.

A supplementary indicator, the ROC indicator provides a measure of the current SOC level that is comparable across differing climates and soil types. This indicator estimates the level of SOC based on data from the Canadian Soil Information System (CANSIS) plus recent changes as estimated by the SOCC indicator. The ROC is expressed as the estimated current level of SOC relative to a baseline SOC value which is estimated by the Century model for a permanent, extensively grazed grass pasture. The estimated baseline SOC level is consistent with good soil health and function, however it is not assumed to represent an optimum level of SOC quantity and quality for the diversity of cropping systems and management practices that are required within the agricultural sector. Under many farming systems on cropland, the baseline SOC is neither achievable nor necessary.

Classes of ROC developed were very low (<0.55), low (0.55 to 0.7), moderate (0.7 to 0.85), high (0.85 to 1.0), and very high (>1.0). Since cropland with annual crops will generally have lower SOC than when under this modeled pasture standard, values of the ROC indicator are expected to fall into the moderate class where there are few periods of forages or pastures, or where there are no organic matter additions through cover crops, green manures or animal manures. Areas of low or very low ROC represent opportunities for increased soil C sequestration through the adoption of appropriate management practices. The combination of low ROC values and SOC loss indicates areas with the greatest risk of soil degradation.

Limitations

The SOCC indicator does not consider soil erosion. Soil erosion causes SOC to decline as it removes the thin, SOC enriched surface layer of the soil. Therefore, even relatively low rates of soil erosion can have important effects on SOC status. As a result, the field-level SOC change in this report is biased toward smaller losses and larger gains.

The ROC indicator should be considered more uncertain than the SOCC indicator because of uncertainties in values of SOC in the CANSIS database.

> ***For Canada as a whole, improvements in farm management have resulted in a dramatic shift from a position of neutral SOC (additions=losses) during the mid 1980s, to a situation where the majority of cropland had increasing SOC in 2006.***

Results and Interpretation

For Canada as a whole, improvements in farm management have resulted in a dramatic shift from a position of neutral SOC (additions = losses) during the mid 1980s, to a situation where the majority of cropland had increasing SOC in 2006 (Figure 9-1, Table 9-1). An additional environmental benefit of enhanced cropland management practices over this period is that cropland has become an increasing soil sink for atmospheric CO_2. Soils were a net source of 1.0 megatonnes (Mt) of CO_2 per year in 1981 but have become a net sink of 11.7 Mt of CO_2 per year in 2006.

For Ontario eastward, there was an overall loss in SOC from 1981 to 2006 due to the effects of reduced hay and pasture in favour of annual crops (Figure 9-2). This shift in land use reflects declining cattle populations in those provinces. The Prairie provinces have seen major increases in C over time from reducing tillage and summerfallow (Figure 9-3). Ontario has seen some benefit in soil C from the adoption of conservation tillage, however this has not occurred in other eastern provinces because conservation tillage has been less accepted under their cooler climates..

The mean ROC indicator value for Canada's agricultural land in 2006 was 0.78 (Table 9-2). Important areas with low ROC values (<0.7) were in southwestern Ontario, the south-central Prairies, large portions of the Peace River region of Alberta and British Columbia, and much of the Atlantic Provinces (Figure 9-4).

Values of ROC in the low to very low classes, in combination with declining SOC, is the most critical soil quality concern with

TABLE 9-2 Average rates of SOCC and levels of ROC for provinces and Canada

	Soil Organic Carbon Change (kg ha^{-1} yr^{-1})						Relative Organic Carbon (Current SOC/modeled baseline SOC)	
	1981	1986	1991	1996	2001	2006	1981	2006
BC	−19	−18	−9	−1	−2	2	0.78	0.81
Prairie mean	**12**	**23**	**26**	**46**	**69**	**86**	**0.79**	**0.79**
AB	12	15	20	35	53	62	0.78	0.79
SK	3	21	23	53	84	110	0.77	0.77
MB	41	46	50	51	59	72	0.88	0.89
Central Canada mean	**−100**	**−97**	**−101**	**−100**	**−119**	**−110**	**0.73**	**0.68**
ON	−116	−109	−108	−97	−100	−89	0.62	0.58
QC	−69	−73	−86	−107	−156	−152	0.94	0.91
Atlantic mean	**−45**	**−57**	**−52**	**−54**	**−66**	**−70**	**0.69**	**0.66**
NB	−12	−23	−25	−38	−53	−70	0.75	0.72
NS	−41	−69	−55	−41	−65	−64	0.57	0.53
PE	−79	−78	−76	−79	−77	−67	0.72	0.70
NL	−90	−95	−74	−105	−112	−161	0.90	0.86
Canada mean	**−5**	**5**	**8**	**25**	**42**	**58**	**0.78**	**0.78**

regard to SOC. In 2006 over half the cropland in Central Canada was in this situation (Table 9-4), while in Atlantic Canada, 37% of land had this combination. Soil structure as indicated by poor infiltration and soil tilth is likely to be the first noticeable indication that SOC levels are less than desired. These effects will be most noticeable on sandy and clayey soils. Soils with low ROC have the most potential for increased SOC levels through improved management. In the Prairie Provinces, 27% of the land has very low and low ROC classes and almost all this land had increasing SOC. There was virtually no land with low to very low ROC with decreasing SOC on the Prairies.

In eastern Canada, the majority of land with high and very high ROC is also losing SOC. This loss does not indicate the same soil health concern as does SOC loss on soil with low SOC. In fact, loss of SOC on soils with high ROC is the expected result of shifts in farming system to grains and oilseeds from a cattle and forage based system.

Response Options

Soil health in Canada with respect to SOC is generally improving. The adoption of practices such as reduced summerfallow and less tillage remain valuable ways to address low SOC. However, some significant losses have occurred. The loss of SOC east of the Prairies is the inevitable result of converting pasture and hay land to more intensive annual crops. As this trend has been occurring for at least five decades, there is a continual loss of SOC.

TABLE 9-3 Share of land (percentage) in each ROC class in 2006.

	ROC class				
	Very High	High	Mod.	Low	Very Low
BC	1	39	31	22	7
Prairies	**4**	**37**	**33**	**23**	**4**
AB	1	36	39	21	4
SK	3	32	32	28	6
MB	15	55	16	14	0
Central Canada	**13**	**6**	**15**	**29**	**37**
ON	1	4	13	35	48
QC	39	11	20	15	15
Atlantic Canada	**3**	**3**	**47**	**31**	**17**
NB	3	7	59	28	3
NS	3	0	13	32	52
PE	0	0	67	33	0
NL	13	14	53	20	0
Canada	**5**	**33**	**31**	**24**	**8**

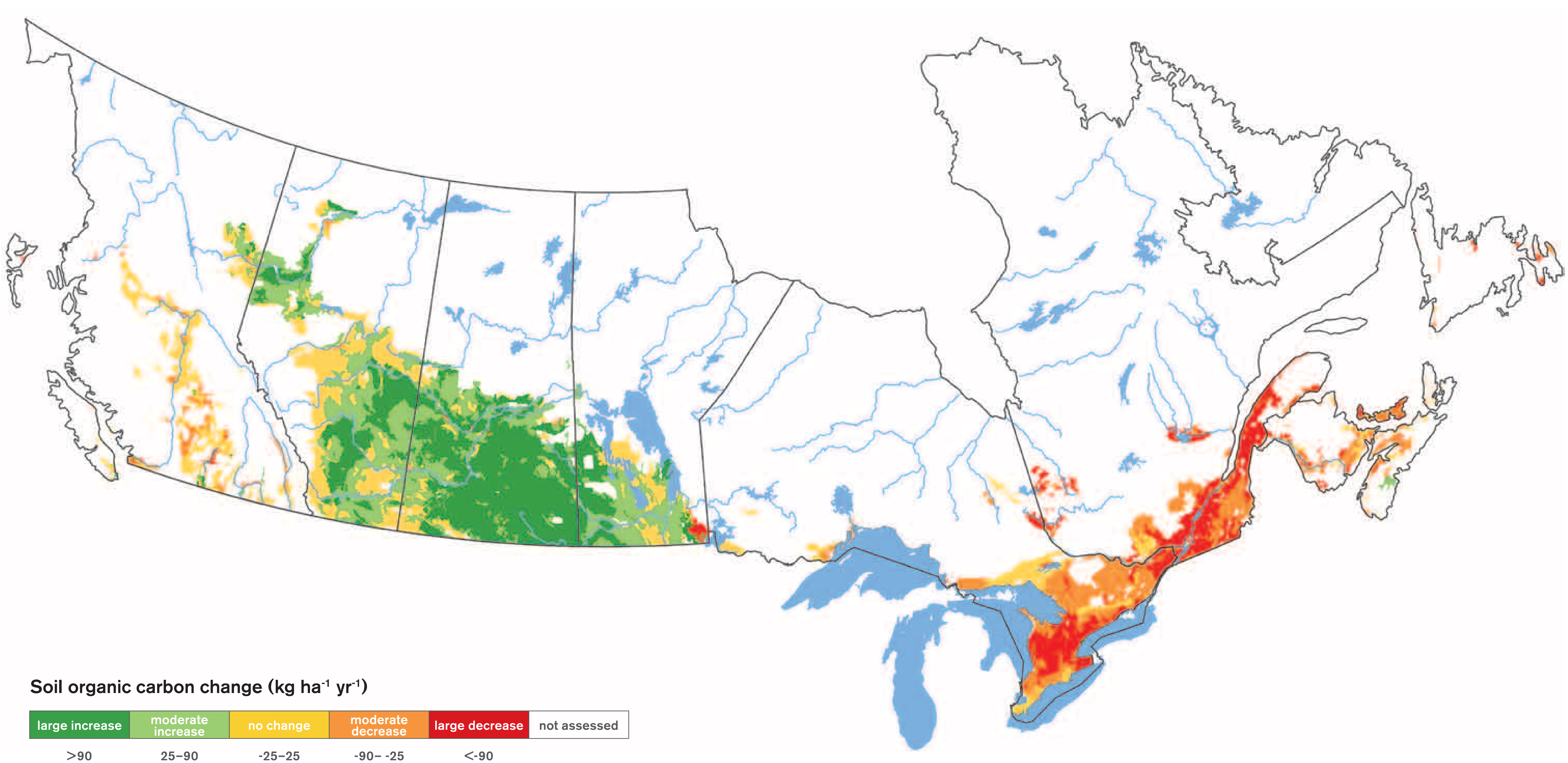


FIGURE 9-1 Indicator of Soil Organic Carbon Change (kg ha^{-1} yr^{-1}) for Canada in 2006

TABLE 9-1 Percentage of land in SOCC classes

	Share of Cropland in Different Soil Organic Carbon Change Classes (%)																													
	Large Increase more than 90 kg ha^{-1}yr^{-1}						Moderate Increase 25 to 90 kg ha^{-1}yr^{-1}						Negligible to small change -25 to 25 kg ha^{-1}yr^{-1}						Moderate Decrease -25 to -90 kg ha^{-1}yr^{-1}						Large Decrease more than -90 kg ha^{-1}yr^{-1}					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	0	1	1	1	2	2	1	5	5	11	11	13	69	65	76	75	74	71	27	25	16	10	11	10	3	4	2	3	2	4
PRAIRIE MEAN	**2**	**2**	**2**	**8**	**34**	**46**	**18**	**41**	**47**	**67**	**47**	**37**	**78**	**55**	**48**	**23**	**17**	**15**	**1**	**1**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
AB	1	1	1	3	19	28	26	33	40	59	53	45	71	65	57	37	27	26	2	1	2	1	1	1	0	0	0	0	0	0
SK	0	1	1	10	47	69	1	42	47	76	45	24	97	55	49	12	7	6	1	1	2	1	1	1	1	1	1	1	0	0
MB	12	14	14	18	25	31	57	55	70	57	51	52	31	31	15	24	23	15	0	0	1	1	1	1	0	0	0	0	0	1
CENTRAL CANADA MEAN	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**7**	**10**	**12**	**13**	**11**	**11**	**42**	**38**	**33**	**31**	**27**	**28**	**51**	**51**	**54**	**54**	**61**	**59**
ON	0	0	0	1	0	1	0	1	1	1	1	1	5	8	11	14	16	16	27	28	26	30	30	31	68	63	62	54	53	51
QC	0	1	0	0	0	0	0	1	1	1	1	1	14	14	12	10	2	1	70	59	47	37	20	20	16	25	40	52	77	78
ATLANTIC MEAN	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**3**	**1**	**1**	**34**	**25**	**25**	**22**	**17**	**17**	**56**	**61**	**62**	**60**	**61**	**57**	**7**	**11**	**10**	**14**	**20**	**24**
NB	1	1	0	1	0	0	5	6	5	6	2	1	82	58	56	34	29	20	11	32	33	54	50	59	1	3	6	5	19	20
NS	0	0	1	3	1	1	1	1	1	2	0	3	16	16	17	33	23	31	81	67	67	47	53	42	2	16	14	15	23	23
PE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	89	90	81	85	73	18	11	10	19	15	27
NL	2	3	3	0	0	1	1	1	1	3	4	2	7	5	38	25	22	3	59	51	31	25	28	46	31	40	27	47	46	48
CANADA MEAN	**2**	**2**	**2**	**7**	**28**	**41**	**15**	**34**	**40**	**57**	**41**	**31**	**68**	**49**	**44**	**24**	**18**	**16**	**8**	**8**	**7**	**5**	**5**	**4**	**7**	**7**	**7**	**7**	**8**	**8**

TABLE 9-4 Share of land (percentage) in each ROC class–SOCC class combination in 2006

	SOCC Class																								
	more than 90 kg ha^{-1}yr^{-1}					25 to 90 kg ha^{-1}yr^{-1}					-25 to 25 kg ha^{-1}yr^{-1}					-25 to -90 kg ha^{-1}yr^{-1}					loss more than -90 kg ha^{-1}yr^{-1}				
	ROC class					ROC class					ROC class					ROC class					ROC class				
	Very Low	Low	Mod.	High	Very High	Very Low	Low	Mod.	High	Very High	Very Low	Low	Mod.	High	Very High	Very Low	Low	Mod.	High	Very High	Very Low	Low	Mod.	High	Very High
BC	nil*	0	2	0	0	1	5	2	3	0	4	15	25	29	1	2	2	1	5	0	0	1	1	2	0
PRAIRIE	**3**	**13**	**14**	**19**	**2**	**2**	**8**	**13**	**12**	**2**	**0**	**2**	**6**	**5**	**0**	**0**	**0**	**0**	**nil**	**0**	**nil**	**0**	**0**	**0**	**0**
AB	1	6	10	11	0	2	10	18	16	0	0	4	11	9	0	0	nil	0	nil	nil	nil	nil	nil	nil	nil
SK	4	22	20	24	2	2	5	10	6	1	0	1	2	2	nil	nil	0	0	nil	nil	nil	0	0	0	nil
MB	nil	1	2	22	4	nil	11	10	25	9	nil	2	4	8	1	nil	nil	nil	nil	0	nil	nil	0	0	0
CENTRAL CANADA	**0**	**nil**	**nil**	**0**	**nil**	**0**	**0**	**nil**	**nil**	**0**	**4**	**4**	**3**	**1**	**0**	**10**	**7**	**4**	**2**	**5**	**22**	**18**	**9**	**4**	**8**
ON	0	nil	nil	nil	nil	0	0	nil	nil	nil	6	5	4	1	0	15	11	5	2	1	26	19	4	1	nil
QC	nil	nil	nil	0	nil	nil	nil	nil	nil	0	nil	0	0	0	0	0	1	2	2	15	14	15	18	9	24
ATLANTIC	**0**	**nil**	**0**	**nil**	**nil**	**1**	**0**	**nil**	**nil**	**nil**	**5**	**5**	**6**	**0**	**1**	**7**	**12**	**36**	**2**	**1**	**4**	**14**	**5**	**1**	**1**
NB	nil	nil	nil	nil	nil	nil	0	nil	nil	nil	1	6	10	0	2	1	14	38	5	1	1	7	10	1	1
NS	0	nil	nil	nil	nil	3	nil	nil	nil	nil	14	10	7	nil	nil	22	13	4	nil	3	12	9	2	0	nil
PE	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	9	64	nil	nil	nil	24	3	nil	nil
NL	nil	nil	0	nil	nil	nil	2	nil	nil	nil	nil	nil	nil	nil	nil	nil	5	36	4	1	nil	12	17	10	12
CANADA	**2**	**11**	**12**	**16**	**1**	**1**	**7**	**11**	**10**	**1**	**1**	**3**	**6**	**6**	**0**	**1**	**1**	**1**	**0**	**1**	**3**	**2**	**1**	**0**	**1**

* nil indicates no land in combination, 0 indicates less than 0.5% of land in that combination

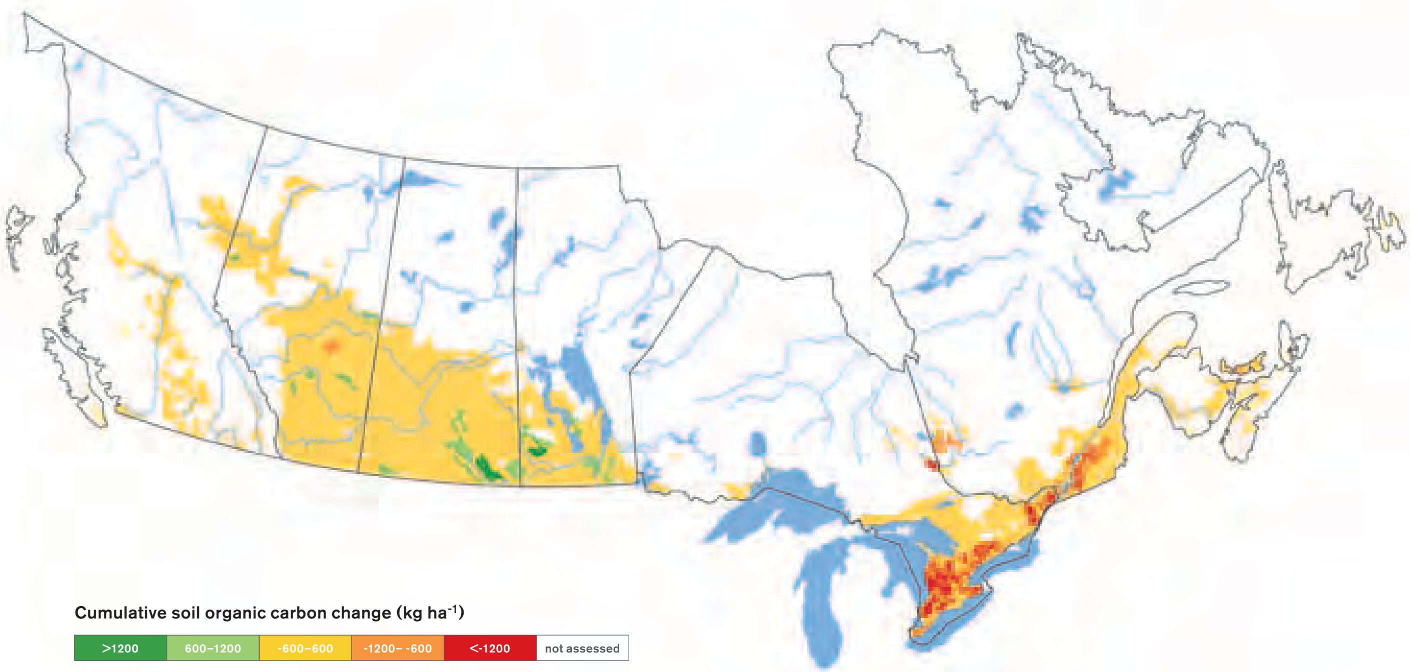


FIGURE 9-2 Cumulative SOC change (kg ha^{-1}) from 1981–2006 due to land-use change (e.g. forest to agriculture) and changes between annual and perennial crops

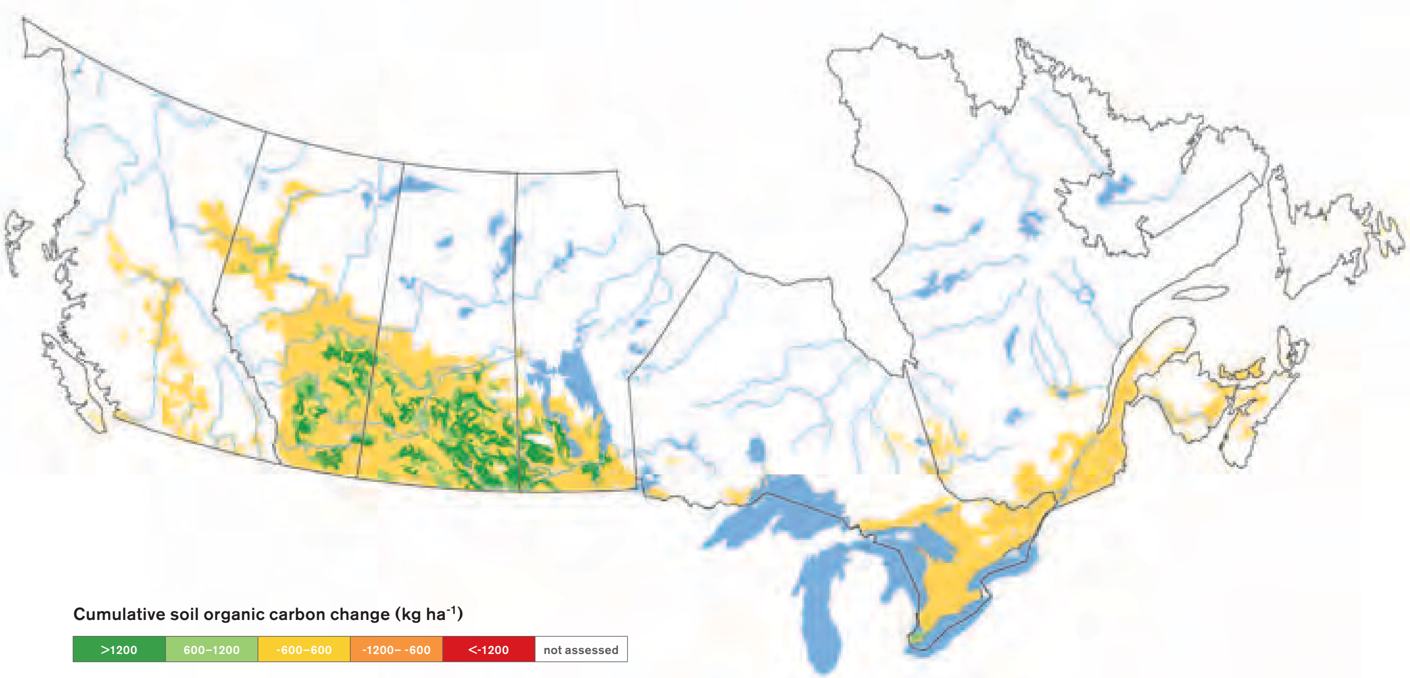


FIGURE 9-3 Cumulative SOC change (kg ha^{-1}) from 1981–2006 due to changes in tillage and summerfallow

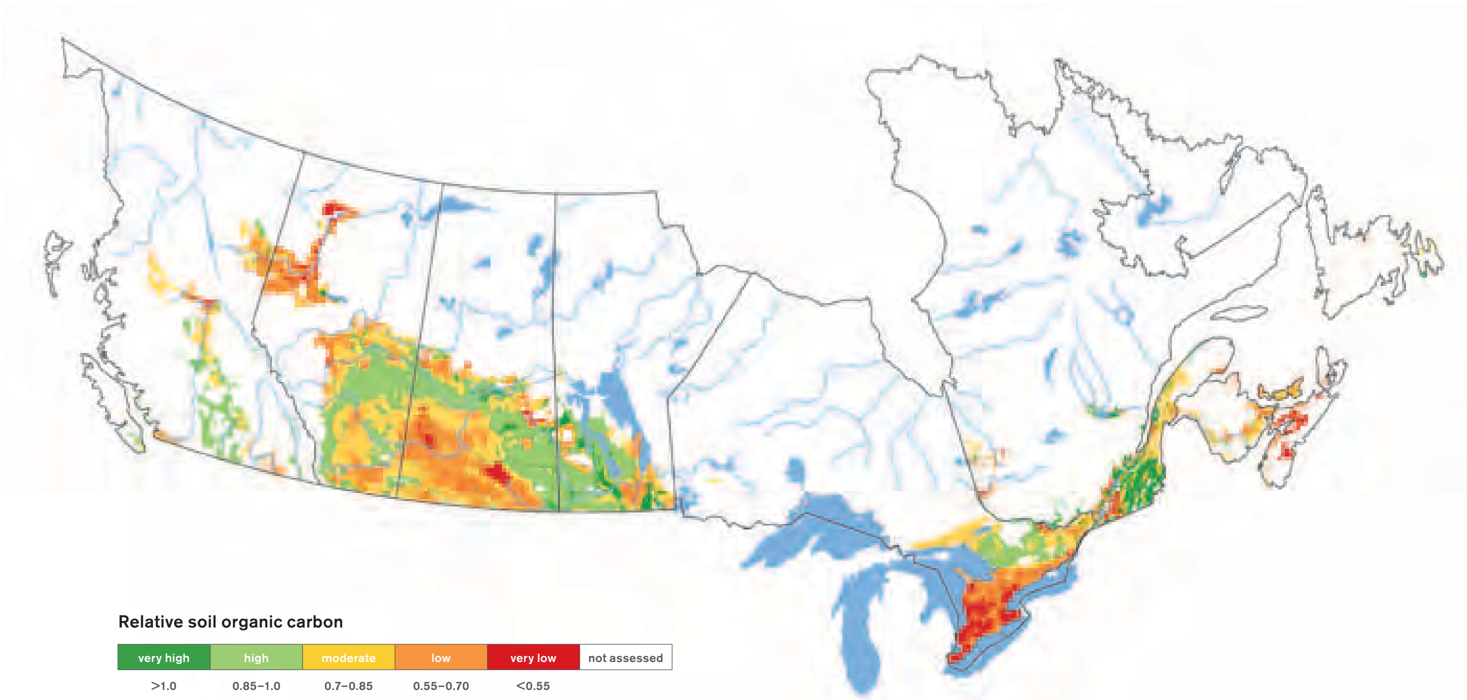


FIGURE 9-4 Relative Soil Organic Carbon (ROC) for Canada in 2006

It is important for soils with relatively low SOC that grow low residue, horticultural or root crops to be rotated with crops that produce abundant crop residues. Spreading abundant manure on soils with very low SOC provides a rapid way to increase SOC as well as soil health and productivity.

A considerable loss of SOC has also occurred in all provinces as a result of clearing trees and shrubs to expand agricultural land and, particularly in Alberta and Saskatchewan, from breaking native grassland to cropland. These land-use changes also have a significant impact on biodiversity as they disrupt important habitats, therefore careful consideration should be given before lands are converted. It should be determined whether lands brought into more intensive production will be productive enough to warrant the land-use change.

Responses for managing SOC levels need to be specific to the state of SOC in a particular area. Soils with relatively low SOC due to past management require comprehensive management changes to increase SOC. Minimizing erosion, for example, is a prerequisite for increasing SOC on these soils. Other aggressive actions include using cover crops and periodic use of perennial forages.

Meanwhile, slowing or reversing the loss of SOC is particularly important on soils that now have low ROC values. Minimizing soil erosion on these soils is the most effective method of minimizing SOC loss. Other valid methods include reducing tillage and increasing use of cover crops.

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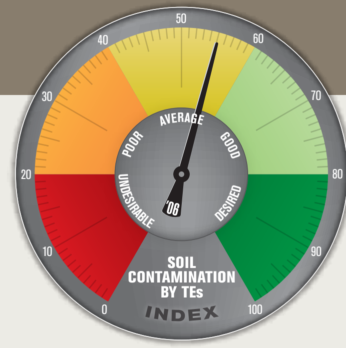
10 Trace Elements



AUTHORS
S.C. Sheppard and C.A. Grant

INDICATOR NAME
Risk of Soil Contamination by Trace Elements

STATUS
National coverage 1981 and 2006

Summary

Trace elements (TEs) are found naturally in the earth's crust and in living organisms in relatively small concentrations. Some TEs are essential for life, some have no apparent effect on the environment or organisms and some are potentially toxic at elevated concentrations. TEs that are essential to life and productive growth are sometimes used in higher concentrations in agriculture in mineral feed supplements and fertilizers. However, small annual additions of TEs to the soil may result in increasing concentrations that could eventually reach levels of concern.

The Risk of Soil Contamination by Trace Elements Indicator considers six key TE's that are added from the atmosphere, fertilizers, manures and municipal biosolids, and estimates their concentration in agricultural soils over time given the continuation of current management practices. An early warning of areas at risk of TE build-up in soil may allow for mitigation by changes in management practices.

The indicator projects that in 100 years soil concentrations (called *century* soil concentrations) of TEs may be up to three times higher than present background concentrations. A total of 1% of the agricultural land in Canada could be at risk from toxic impacts from TE accumulation after 100 years of present practices. As management practices change, the risk of toxic accumulation of TEs will also change.

The Issue

The term TEs refers to a very broad range of chemical elements, many of which have no apparent effect at concentrations found in the environment. However, some TE's are essential for life, some are highly toxic, and some can be both essential and toxic depending on the concentration. Many TEs, and especially metals such as cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn), are strongly retained by soils and will remain there for very long periods. Even small annual additions can eventually lead to concentrations high enough to be problematic.

High TE accumulations can cause various problems; however, the most direct negative effect may be the production of food crops with unacceptable metal concentrations (see text box). Additions of TEs such as Cd to soils can increase the TE accumulation in crops grown on those soils (Figure 10-1). This can be toxic to plants or can present unacceptable risk to people eating these plant products. Direct toxicity to plants and soil organisms, including microbes involved in nutrient cycling, is another potential impact. Finally, negative impacts on higher life forms that feed on soil organisms could be a future concern.

The TE issue has economic importance for several reasons. Phosphate fertilizers are necessary inputs in some areas because the P available from the soil is too low to support economic crop production. However, P fertilizers are not highly

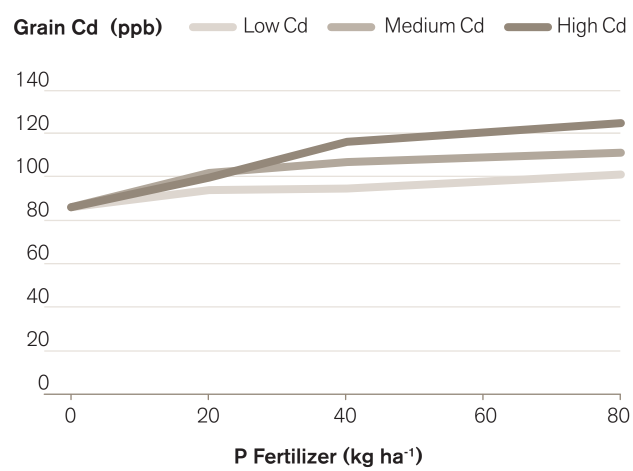


FIGURE 10-1 Cadmium concentration in durum wheat as a function of P fertilizer rate and fertilizer Cd content.

Limitations on export of durum wheat from Canada due to cadmium levels approaching or exceeding the international standard for safe food crops have been experienced in the past. Research into crop genetics and regulation of permissible levels of Cd in fertilizers applied to these crops has largely resolved this issue. Nevertheless this points to an issue that will continue to require vigilance. Phosphate (P) fertilizers that inadvertently contain Cd can increase Cd concentration in food crops (Figure 10-1). Similarly, additions of Cd and other trace elements from agricultural additives have the potential to influence food safety if not managed properly.

refined chemicals, and a host of TEs that are inevitably present in fertilizer accumulate in the soil.

Meanwhile, deficiencies of important TEs in animal diets, especially Cu, selenium (Se) and Zn are common throughout the world and would also be common in Canada if these TEs were not added to animal feeds. Deficiencies cause poor productivity from the animals and raise ethical issues of animal health and welfare. The financial cost of such TE additives to feeds is very low, so common practice is to use them to maximum allowable amounts in feed. However, a high percentage of the TE in feed is ultimately passed to farmland by way of manure. Finally, TEs are present in human waste, and some of the sewage *sludge* produced in Canada is spread on farmland near cities. With continued population growth and a finite land base, it is likely that even more TEs will reach agricultural soils in the future.

The Indicator

The Risk of Soil Contamination by Trace Elements Indicator was developed to evaluate the environmental impact of TEs on soils from agricultural inputs such as fertilizer and feed mineral supplements. The indicator considers six elements: arsenic (As), Cd, Cu, Pb, Se and Zn. The indicator is a soil balance indicator (Öborn et al., 2003), that estimates TE inputs based on the amounts of fertilizer, feed supplements and biosolids used per hectare on agricultural land and the TE loss from leaching, crop removal and volatilization. The soil balance calculates what the concentration of TE in agricultural soils will be after 100 years of inputs and losses (century concentration) if current management practices are continued over that period. Given the risk is calculated for 100 years in the future, the indicator provides a means to identify those soil and management practices that require attention in advance of the development of a TE contaminant problem.

Losses of TEs from the soil are proportional to how much TE is in the soil. However, at constant levels of TE input, at some distant point in the future the TE concentration in the soil will reach a steady state where inputs equal losses. The century concentration, while not a steady state, is used as a reasonable projection for planning purposes.

The toxicity guidelines of the Canadian Council of Ministers of the Environment (CCME) indicate the concentration at which the soil may be toxic to certain organisms—often soil-dwelling organisms—but the guidelines for some TEs apply specifically to human health. To account for these toxicity guidelines in the indicator, a risk quotient (RQ) is calculated to indicate potential toxicity, which is the estimated soil concentration of TE divided by the CCME guideline concentration. This RQ can be summed across elements. If the RQ summed for the six elements is greater than 1, then the land area is classed as potentially at risk.

Background concentrations of some TEs in some soils in Canada already exceed their CCME guidelines. Presumably, the *biota* on these soils have adapted to naturally elevated TE concentrations, making the CCME guidelines, which were established to protect all soils, overly protective. In these cases, the RQ is misleading. Therefore, an alternative is used that estimates the degree to which the century soil concentrations exceed the background soil concentrations. The results are presented in categories of <10%, 10–30%, 30–50%, 50–100% and >100%. Due to the range and variability of background concentrations, an increase above the background concentration of ~50% is statistically significant. Each of the six TEs is considered separately, and the highest level of increase above background among the six is used for the indicator. This class of increase above background concentrations also provides a more sensitive measure of the influence of management practices on the rate of TE accumulation in soil.

If present practices continue or if TE inputs increase, there is potential for effects on crop productivity, market access and on human and animal health.

Limitations

This indicator is limited by the availability of data on TE concentrations in agricultural products and background concentrations of TE in soils. All changes in TE concentrations were calculated; however, increases in concentrations of less than 50% may not be statistically significant. Note that the only model inputs that were changed between 1981 and 2006 were the animal populations and the crop acreages.

TE additions may be very site specific, creating *hot spots* of high concentration that may be important but that are obscured by the broad national and provincial scales used for the TE Indicator.

The RQ is only an indicator, not a certainty of risk. It could result from one TE surpassing its CCME guideline or from several TEs, each merely approaching their respective CCME guidelines. Thus, this indicator serves as a flag to show where more detailed investigation would be appropriate.

The increase above background concentrations does not provide an estimation of risk or harm because the doubling of a very low background concentration may still not be harmful, whereas even a slight increase from a high background concentration could result in toxicity.

Results And Interpretation

The Risk of Soil Contamination by Trace Elements Indicator shows that present practices are causing TE accumulation in many Canadian agricultural soils (Figure 10-2) and that if present

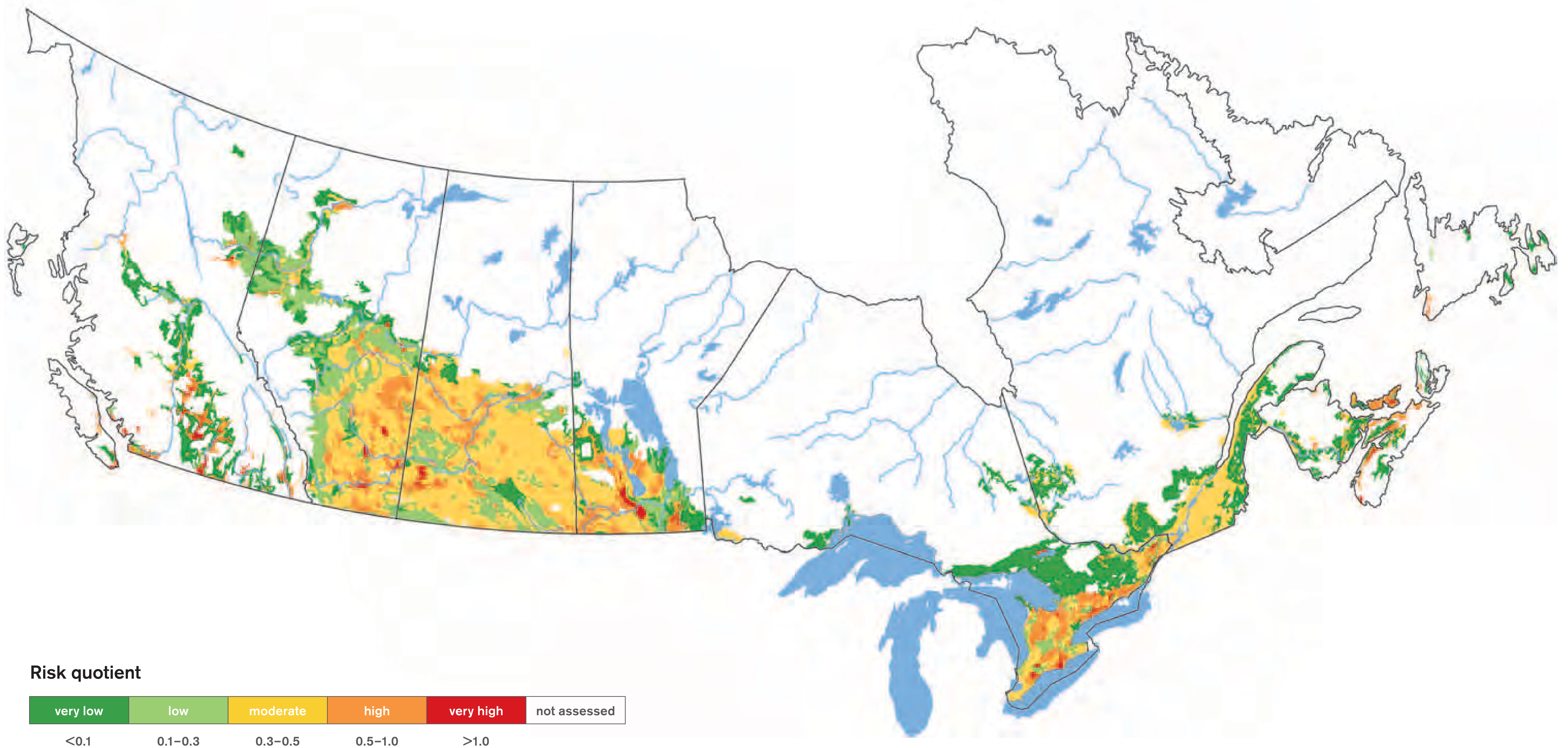


FIGURE 10-2 Trace element indicator, 2006, showing potential for toxic impact from one or more of As, Cd, Cu, Pb, Se and Zn

TABLE 10-1 Proportion of farmland in various TE risk classes, 1981 and 2006

	Proportion of Farmland in Different Risk Classes (percentage)									
	Very Low (RQ<0.1)		Low (0.1<RQ<0.3)		Moderate (0.3<RQ<0.5)		High (0.5<RQ<1)		Very High (RQ>1)	
	1981	2006	1981	2006	1981	2006	1981	2006	1981	2006
BC	8	4	35	30	16	17	31	33	10	16
AB	5	5	38	38	43	42	14	14	<1	<1
SK	3	3	21	22	66	65	10	9	<1	<1
MB	12	12	16	16	46	46	23	23	2	2
ON	4	4	29	29	41	41	22	22	3	3
QC	0	0	0.2	0.2	99	98	0.4	0.2	0	0
NB	0	0	70	69	21	21	10	10	0	0
NS	0	0	26	27	41	41	31	31	1	1
PE	0	0	4	5	86	86	10	9	0	0
NL	0	0	56	67	20	22	12	5	11	6
CANADA	**5**	**5**	**26**	**26**	**54**	**54**	**14**	**14**	**1**	**1**

TABLE 10-2 Proportion of farmland in which various levels of TE accumulation above background concentrations are expected, 1981–2006

	Proportion of Farmland in Different Classes of TE accumulation over background (percentage)									
	Very Low (<10% above background)		Low (10%–30% above background)		Moderate (30%–50% above background)		High (50%–100%, up to doubling of background)		Very High (>100%, over doubling of background)	
	1981	2006	1981	2006	1981	2006	1981	2006	1981	2006
BC	0	0	84	72	15	26	1	1	<1	<1
AB	0	0	87	90	13	10	0	0	0	0
SK	0	0	95	96	5	4	0	0	0	0
MB	0	0	81	82	19	17	0	1	0	0
ON	0	0	28	31	64	61	7	6	<1	<1
QC	0	0	47	25	42	49	10	24	<1	1
NB	0	0	20	11	63	59	17	30	<1	<1
NS	0	0	35	31	44	44	21	25	<1	<1
PE	0	0	9	0	85	76	5	24	0	<1
NL	0	0	18	43	57	47	25	9	<1	<1
CANADA	**0**	**0**	**81**	**84**	**17**	**14**	**1**	**2**	**<1**	**<1**

TABLE 10-3 Most common (median) TE influx rates (grams per hectare per year) among the 2780 Soil Landscape of Canada polygons

Source of TE	As	Cd	Cu	Pb	Se	Zn
Influx from atmosphere onto all lands	0.05	0.06	2.2	0.36	0.09	2.6
Influx from fertilizer onto fertilized lands	6.2	3.3	11	2.2	0.58	42
Influx from feeds onto manured lands	0.0	0.34	300	1.3	1.5	1500
Influx from biosolids onto biosolids-treated lands	14	64	2200	170	9.7	1400

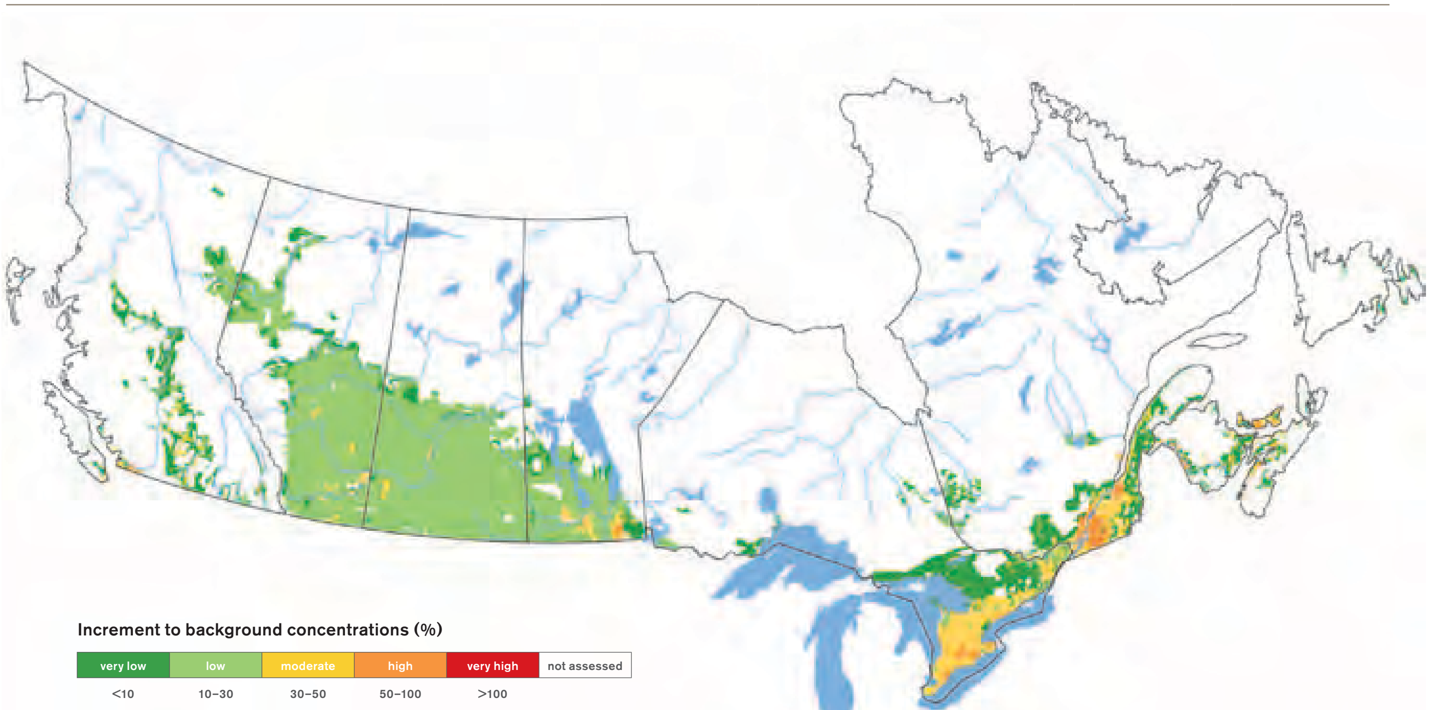


FIGURE 10-3 Estimated percentage increase above background concentrations after 100 years of present practice, 2006

TABLE 10-4 Percentage of farmland area where each TE influx dominates the estimated soil concentrations

Fraction	As	Cd	Cu	Pb	Se	Zn
Fraction where atmospheric and fertilizer influx dominates (%)	32	45	0.00	11	0.00	0.00
Fraction where feed influx dominates (%)	0.0	3.3	8.4	1.4	8.5	8.5
Fraction where biosolids influx dominates (%)	0.04	0.05	0.24	0.24	0.24	0.24

TABLE 10-5 Percentage change in number of animals or people from 1981 to 2006

	Beef	Dairy	Swine	Broiler chickens	Humans
BC	11	–17	–50	146	74
AB	71	–30	64	53	62
SK	41	–67	127	32	21
MB	54	–47	208	56	12
ON	–19	–34	17	48	69
QC	38	–41	23	35	65
NB	1	–30	22	63	27
NS	–9	–37	–32	61	22
PE	21	–39	7	2060*	77
NL	–2	102	–92	–100	24
CANADA	**41**	**-37**	**46**	**55**	**64**

* Although this percentage increase is large, the increase in actual numbers of birds is not so notable. There was probably only one broiler farm in 1981 on Prince Edward Island.

practices are not modified or if TE inputs increase, there is potential for effects on crop productivity, market access and on human and animal health. These effects are most probable on sandy soils under intensive livestock operations or crop production.

Overall, about 1% of the agricultural land in Canada was estimated to be in the very high risk class for toxic impacts (RQ > 1) resulting from estimated TE accumulation after 100 years of present practices (Table 10-1). However, this percentage is as high as 16% of the agricultural land in some provinces. As a group, soils at very high risk tend to be light-textured, sandy soils under intensive livestock operations or crop production. Areas of these very high risk soils are found throughout Canada. The lack of clay particles that tend to immobilize TEs and hinder their uptake by plants results in the TEs being more biologically available in sandy soils.

The risk related to toxicity by TEs in Canada has not changed appreciably from 1981 to 2006.

A more sensitive measure of the influence of management practices on the rate of TE accumulation in soil is the increasing concentrations of TE above background levels. Although rates of increase above background levels do not indicate harm to recognizable biota they are a notable and at least partially avoidable change in the soil resource related to our production practices. Based on 2006 agricultural census data, about 16% of agricultural soils in Canada would have a 30% or higher increase in concentration in 100 years (Table 10-2). The location of these increments to background concentrations (Figure 10-3) shows the relationship to human population and agricultural activity. The majority of this land is located in the highly populated Windsor to Quebec City corridor (Figure 10-3). Not only are there a lot of biosolids produced in this region, but there are also many animals and relatively intensive, high-input crop production. Potato-growing areas in the Maritimes also have above-average potential to accumulate TEs because of high requirements for P fertilizers on light-textured soils. In the Prairies, the area around Winnipeg is notable, again because of an urban centre and newly developed and expanding animal production. A few isolated locations in the interior of British Columbia are notable, probably because of sandy soils and intensive crop production.

The source of TE is an important factor in the estimation of the risk that TEs will eventually accumulate in soils. Even within a given source, the actual levels of TEs vary considerably, which will affect the actual levels entering the soil. Table 10- 3 shows common rates of TE influx in soils from four major sources. On average, biosolids are the source with the highest influx of TE to soil for all six TEs considered (Table 10-3). Influx of As and Cd from fertilizers is generally higher than from feeds, while influx of Cu and Zn from feeds is higher than fertilizers. An important factor to consider is that each source is not equally relevant across the land base. Biosolids present the highest TE influx. However, they are applied on a fairly limited portion of the land base and thus represent the dominant source of TE for less than 0.3% of the total farmland. Table 10-4 provides the share of farmland area in Canada in which each source of TE is the dominant one. Fertilizer is the dominant source of As and Cd in 32% and 45% of the farmland in Canada, respectively. Feed is the dominant source of Cu, Se and Zn in approximately 8% of farmland area. The dominant TE source varies from region to region, depending on the mix of crops and animals present.

Response Options

TE contamination is an almost inevitable feature of civilization. Under current modern agriculture and with growing urban populations, neither zero contamination (no new TE influx to soil) nor zero accumulation (no net increase in TE concentrations) in soil is a plausible objective. Given the potential for future technological changes or research that might mitigate or reduce TE addition to soils, a reasonable objective might be to define a time horizon of 100 years and aim to avoid potential toxicity in soils for that time. As there are continuous losses of TE from soils by leaching, crop removal and volatilization, a cessation of TE inputs will cause a return, albeit very slow, to background concentrations. More practically, a decrease in TE inputs may ensure sustainability of soil health.

For areas where there is risk of TE accumulation to toxic or near toxic levels, the following key points should be considered:

- For producers, caution is advised in the use of TE in animal feeds at concentrations above nutritional requirements. At present, there is a tendency to supply the maximum allowable TE, because TEs are inexpensive and it is argued that animal heath and welfare is paramount to production.
- There is interest in the use of As and Zn in pseudo-pharmaceutical dosages, and a holistic analysis is required to compare the benefits of this use of TE versus the risk of possible negative effects of soil contamination.
- Decision-makers require information on long-term (centuries-long) sustainability versus immediate farm profitability. Given that the basic flux of TE from mines to soils and accumulation in soils is nearly a certainty, research is required on the length of time before an impact might occur. The timeframe could be clarified with research focusing on the processes by which TEs are lost from soils. Research to more closely match TE feed sufficiency levels to modern livestock productivity is needed to reduce excess use of TE in feeds.

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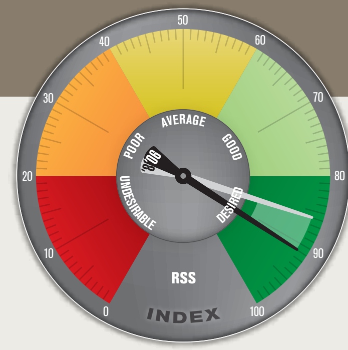
11 Soil Salinity



AUTHORS

B.H. Wiebe, W.D. Eilers and J.A. Brierley

INDICATOR NAME

Risk of Soil Salinization (RSS)

STATUS

Provincial coverage (Alberta, Saskatchewan, Manitoba), 1981 to 2006

Summary

Soluble salts are an inherent component of the soils and groundwater in the Canadian Prairies. Soil salinization results when the natural movement of water in the soil leads to the accumulation of these salts in portions of the landscape. Accumulations of soluble salts at high enough levels can inhibit the ability of plants to absorb water and nutrients and thus reduce crop yields. Land use practices can have a significant impact on the flow of water into and through the soil. Some practices, such as summerfallow, encourage the storage of water within soil and may result in elevated water tables and increased levels of soluble salts in the plant root zone in susceptible portions of the landscape. However, permanent cover crops such as forage, pasture, or tree crops maximize the use of soil moisture and may thereby lower water tables, reducing the potential for soil salinization. The Risk of Soil Salinization (RSS) Indicator has been developed to evaluate the impact of changing land use practices on the risk of dryland soil salinization on the Canadian Prairies.

In 2006, 80% of the agricultural land in the Canadian Prairies was classified as having very low risk of salinization, representing a 12% increase from 1981. The areas in the moderate, high and very high risk of salinization classes decreased from 16% in 1981 to 9% in 2006. These improvements were largely the result of a steady decline in the area of summerfallow, which decreased by 6 million hectares (a 64% decrease) and an 11% increase in the area under permanent cover to 3.8 million hectares. Improvements were seen in each of the Prairie Provinces with the largest improvement occurring in Saskatchewan. Although changes in land use practices since 1981 have lessened the risk of salinization and indicate a trend to improved soil health and agri-environmental sustainability, caution is required to ensure that future practices, which may change as a result of economic or market demands, are able to maintain or further improve this performance.

The Issue

Dryland soil salinization is a natural process that occurs in regions that have moisture deficits and inherently high salt content in the soils and groundwater. While small, isolated areas of saline soils may occur in other regions of Canada, it is in the Prairie region where this is a significant issue. The process begins in areas where rain and snowmelt water is in excess of what plants need. This water infiltrates below the root zone, dissolving and carrying salts to the ground water. Ground water flow carries these salts to other portions of the landscape where the water table is near the soil surface. When the water is near the surface, it evaporates and concentrates the salts at or near the soil surface or in surface water bodies. (Figure 11-1).

Regional groundwater flow is from left to right along the downward sloping bedrock/slowly permeable layer. Salts are dissolved from the soil matrix above and below the water table as water flows through it.

High levels of salts in the soil water reduce plants' ability to absorb water and nutrients, which causes the plants to experience drought-like conditions. At low concentrations, salts are not harmful and in fact provide some important nutrients to the plant. However, as salt concentrations increase, the drought effect can become so severe that the growth of even salt-tolerant plants is no longer possible. Weakly saline soils will affect the growth and yields of most crops and moderate to severe soil salinity reduces yields of most cereal and oilseed crops by at least 50%.

Sensitivity to salts varies with crop type. For example, salt-sensitive crops such as edible beans are affected at lower salinity levels and to a greater extent than cereal and oilseed crops. The degree of salinity (amount of soluble salts) in the soil therefore has a significant impact on which crops or crop varieties can be successfully grown. Steppuhn (1996) estimated that 10 million hectares of *arable land* and permanent pasture on the Canadian Prairies, while not considered saline, were affected by low-level salinity and may be unable to attain production levels equivalent to the plants' potential. Approximately 1 million hectares of surface soils on the Prairies are affected by moderate to severe soil salinity (Wiebe et al., 2006). The quality of surface and shallow ground waters may also be affected by the influx soluble salts from dryland salinization (Miller et al. 1981).

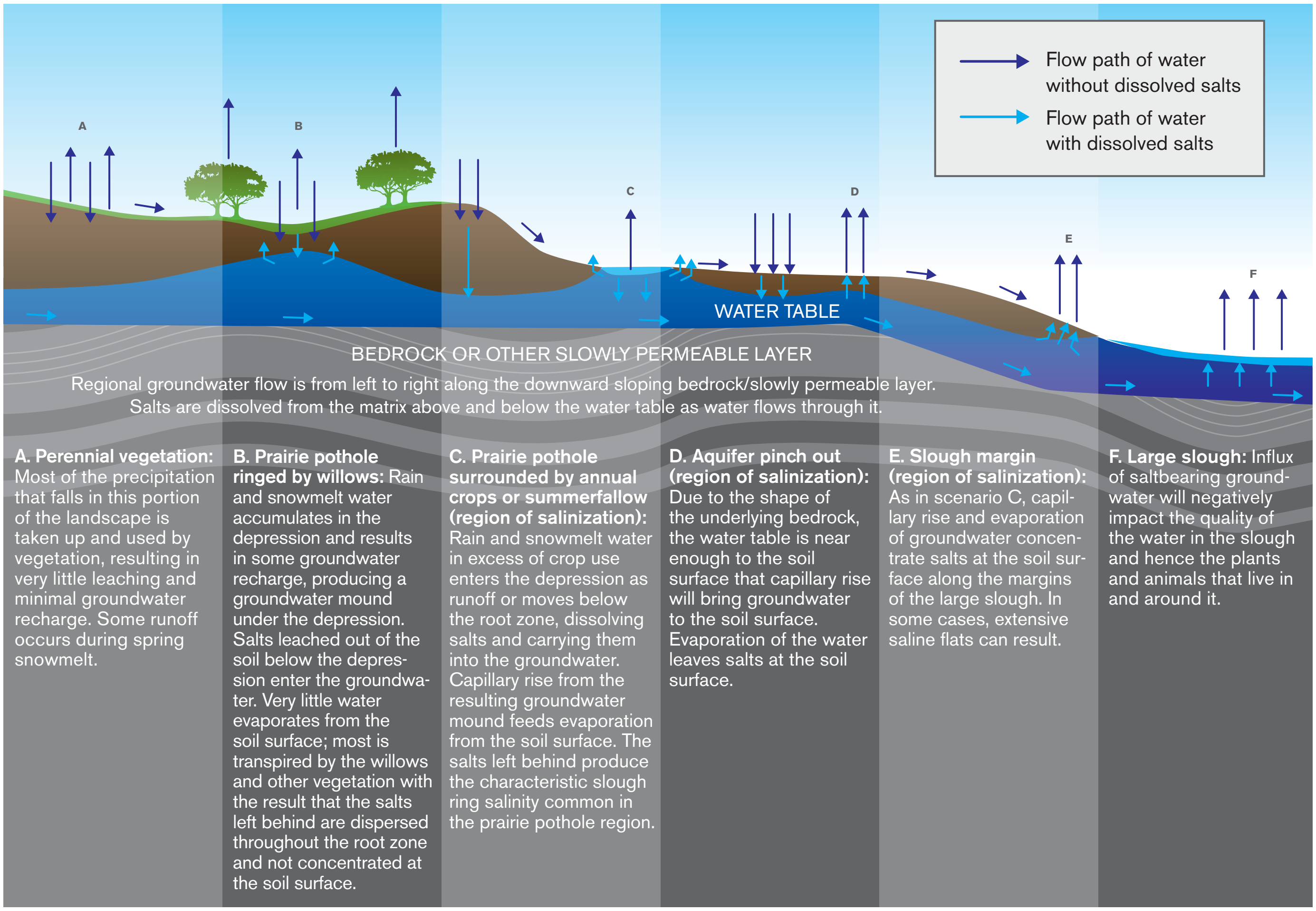


FIGURE 11-1 Conceptualized water and salt redistribution in a regional landscape, illustrating potential dryland soil salinization processes

The soil salinization process is influenced by many factors not under human control. These include climate (degree of water deficit), the inherent salt content of the soil, topography, and underlying geology and hydrology. This means that where saline soils exist, there are natural environmental conditions favourable to the salinization process. Land use practices, however, can dramatically influence the process of salinization either positively or negatively by changing water use in the landscape.

The Indicator

The Risk of Soil Salinization (RSS) Indicator estimates the risk for increased salinization associated with changes to agricultural land use and management practices. It is calculated as a unitless Salinity Risk Index (SRI) that combines weightings for factors that control or influence the salinization process. The factors used in the calculation are:

- soil salinity status within the landscape, based on a Prairie-wide compilation of the presence and extent of moderate to severe soil salinity (Wiebe et al., 2006; 2007),
- topography—including slope steepness and slope position,
- soil drainage,
- growing season climatic moisture deficits, and
- land use, from the Census of Agriculture for 1981, 1986, 1991, 1996, 2001 and 2006.

The first four index factors are considered to remain constant over time while changes in land use result in changes to the index. Salinity experts developed a weighting for each factor based on the factor's influence on the process of soil salinization. For example, land under summerfallow was considered to be at highest risk. Land under permanent cover was associated with the lowest risk. Land under annual cropping was deemed to be at an intermediate risk. Therefore, the land use factor was based on the relative proportions of summerfallow, permanent cover, and annual cropland in each SLC polygon.

The index values were divided into five risk classes based on consultation with salinity experts in each of the Prairie Provinces.. Since individual soils and landscape combinations have variable risk of salinization, an area-weighted SRI value was also calculated for each SLC polygon and used to assign a risk class to the polygon for mapping purposes.

Limitations

Some components of the indicator calculation are held constant to allow an assessment of risk based on current and evolving land use and cropping practices. However moisture deficits during the growing season vary from year to year. Therefore significant yearly variation in the risk of salinization due to weather variability is not considered in the indicator. Additionally, non agricultural uses of land such as roads, ditches and traffic corridors influence the flow of surface and subsurface water and can affect soil salinization. They are not currently reflected in this broad-scale analysis.

The various land use and cropping practices reported in the Census of Agriculture were combined into three categories: cropland, permanent cover and summerfallow. Different crops utilize water with different degrees of efficiency and, therefore, theoretically influence the salinization process differently. However, not enough is known on this broad scale to differentiate by specific crops. Therefore, all crops were summed to the cropland category. Similarly, permanent cover included both improved and unimproved pasture, all hay and forage crops, as well as all other land census categories.

The majority of land at risk of soil salinization in Saskatchewan and Alberta is in the more arid south (the brown and dark brown soil zones).

Results and Interpretations

In Canada, the moisture deficits and inherent salt content of soils and/or groundwater necessary for dryland salinization occur to a significant extent only in the Prairie region. Therefore, the RSS Indicator is calculated only for the agricultural regions of Manitoba, Saskatchewan and Alberta (Figure 11-2). The majority of land at risk of soil salinization in Saskatchewan and Alberta is in the more arid south (the brown and *dark brown soil* zones). Even though Manitoba has a more humid climate than the other Prairie Provinces, it has significant areas with high natural risk factors for salinization such as relatively level landscapes and poor drainage as well as extensive regions with near-surface saline groundwater.

The land area at risk of salinization has shown a decline for each census period between 1981 and 2006 (Table 11-1). There has been a Prairie-wide increase in the amount of land in the very low risk class while land in all other classes decreased. Between 1981 and 2006, the share of agricultural land at very low risk increased from 66% to 80%, while land at low risk decreased from 19 % to 11% and land at moderate to very high risk of salinization declined from 16% to 9% of the area. Although provincial values demonstrated greater fluctuations from census to census, all three Prairie Provinces showed substantial decreases in salinization risk over the six census years included in the analysis. Of the SLC polygons that changed risk class between 1981 and 2006, the majority improved by one risk class and several improved by two risk classes, while a few showed a one-class increase in risk (Figure 11-3). The greatest gains in land area at very low risk have occurred since 1996, with Saskatchewan showing the largest improvement.

The main drivers of the improvement shown by the indicator have been the decrease in summerfallow and an increase in the area of permanent cover. Since 1981, summerfallow has decreased in the Prairies by over 6 million hectares (64% reduction) with the largest decrease occurring in Saskatchewan (Figure 11-4). Permanent cover has increased by 3.8 million hectares (11%) over the same period with the largest change again occurring in Saskatchewan, particularly since 1996 (Figure 11-5). Reasons for the decline in summerfallow include the adoption of management practices that make more efficient use of available moisture and allow continuous cropping or extended crop rotations under rainfed agriculture; the availability of suitable and affordable chemical weed-control options; and the conversion of marginal land to permanent cover or pasture throughout the region. Although there was an overall improvement, there were a few areas which showed an increased risk of salinization due to an increase in summerfallow and/or a decrease in permanent cover.

Response Options

The management of soil water is fundamental to reducing the risk of salinization and to improving existing saline soils. Uneven distribution and infiltration of precipitation due to rainfall or snowmelt runoff contributes significantly to the salinization process by raising the water table in susceptible portions of the landscape. Reducing this runoff and increasing the amount of precipitation used by plants or crops where it falls is the most effective method for reducing redistribution of salts within a landscape—and thereby preventing soil salinization.

Although excess moisture will leach salts and reduce soil salts at the point of leaching, the salt-bearing groundwater may flow to and evaporate from lower regions within the landscape and result in salinization at these points. Beneficial management practices (BMPs) that address this moisture and salt redistribution include:

- reduction of summerfallow,
- increased planting of perennial forages, pastures and tree crops,
- managing snow to provide for more uniform distribution of melt water (preventing large drifts),
- increasing no-till and minimum till (encourages more uniform infiltration of precipitation), and
- using inputs such as fertilizers and manure effectively to support healthy crops. This makes plants capable of using more water.

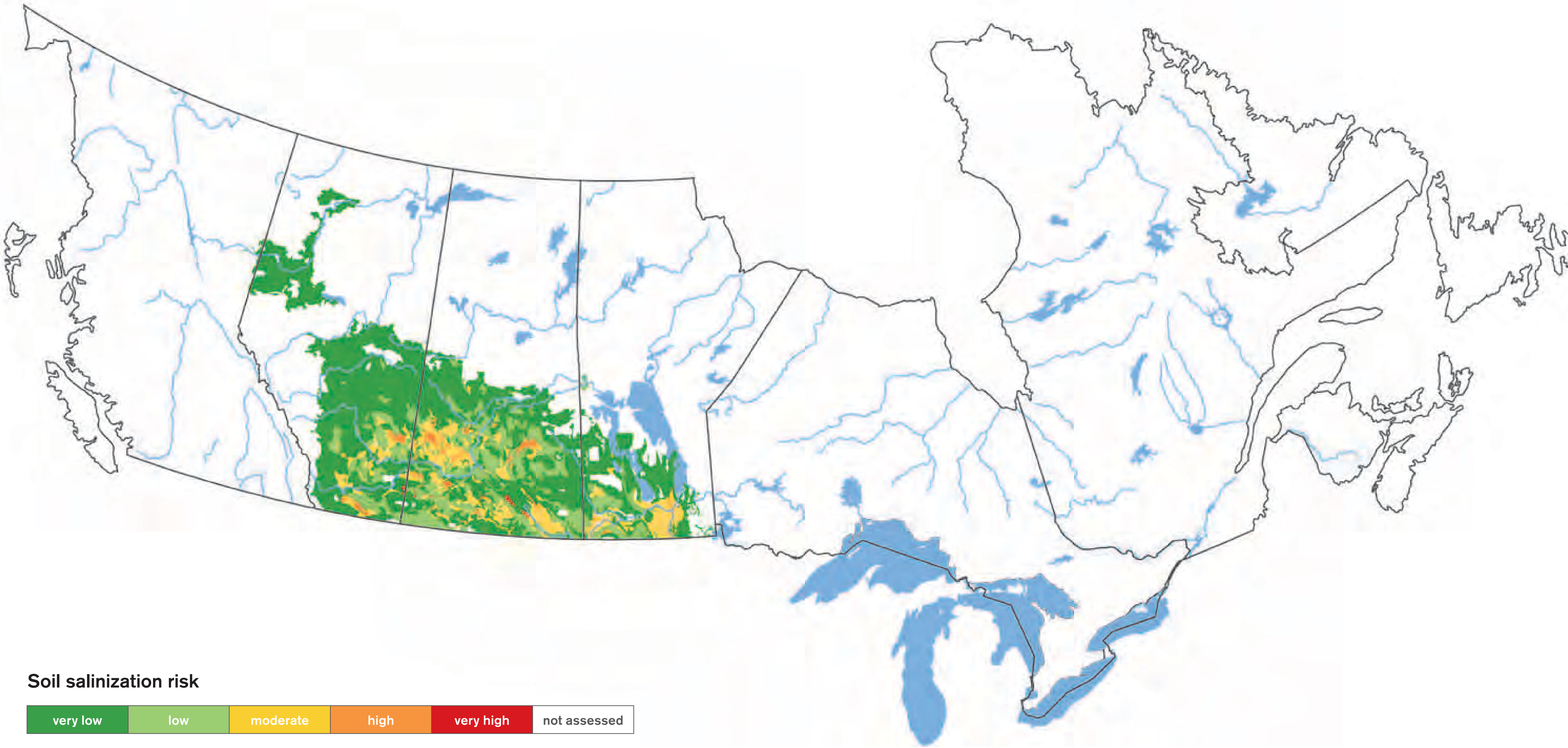


FIGURE 11-2 The risk of dryland soil salinization on the Canadian Prairies, based on land use practices in 2006.

TABLE 11-1 Percentage of agricultural area in each RSS class, 1981–2006 *

	Very Low						Low						Moderate						High						Very High					
	81	86	91	96	01	06	81	86	91	96	01	06	81	86	91	96	01	06	81	86	91	96	01	06	81	86	91	96	01	06
AB	81	82	85	86	86	89	12	12	9	9	9	7	4	4	4	3	3	2	2	1	1	1	0	1	1	1	1	1	1	1
SK	65	63	69	66	69	72	8	11	9	12	10	10	18	17	16	17	17	15	7	7	5	5	4	3	3	2	1	1	1	0
MB	53	56	56	61	69	75	28	26	26	24	20	15	11	11	11	9	5	4	2	2	2	2	3	3	6	5	5	4	3	3
PRAIRIES	**66**	**67**	**69**	**71**	**75**	**80**	**19**	**18**	**17**	**16**	**14**	**11**	**9**	**9**	**9**	**8**	**6**	**5**	**3**	**3**	**2**	**2**	**2**	**2**	**4**	**3**	**3**	**3**	**2**	**2**

* due to rounding, the values may not sum exactly to 100%.

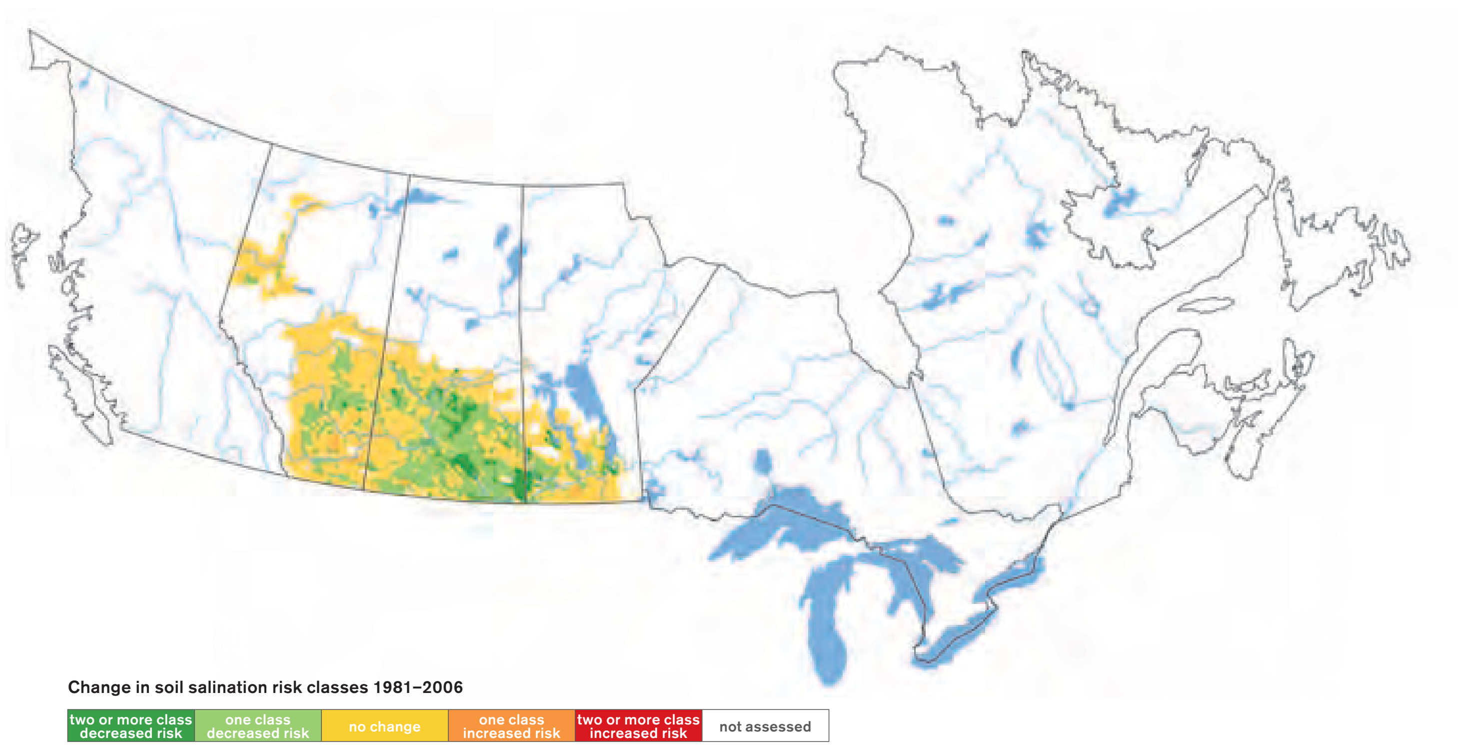


FIGURE 11-3 Change in soil salinization risk classes due to changes in land use practices between 1981 and 2006 (Prairies only)

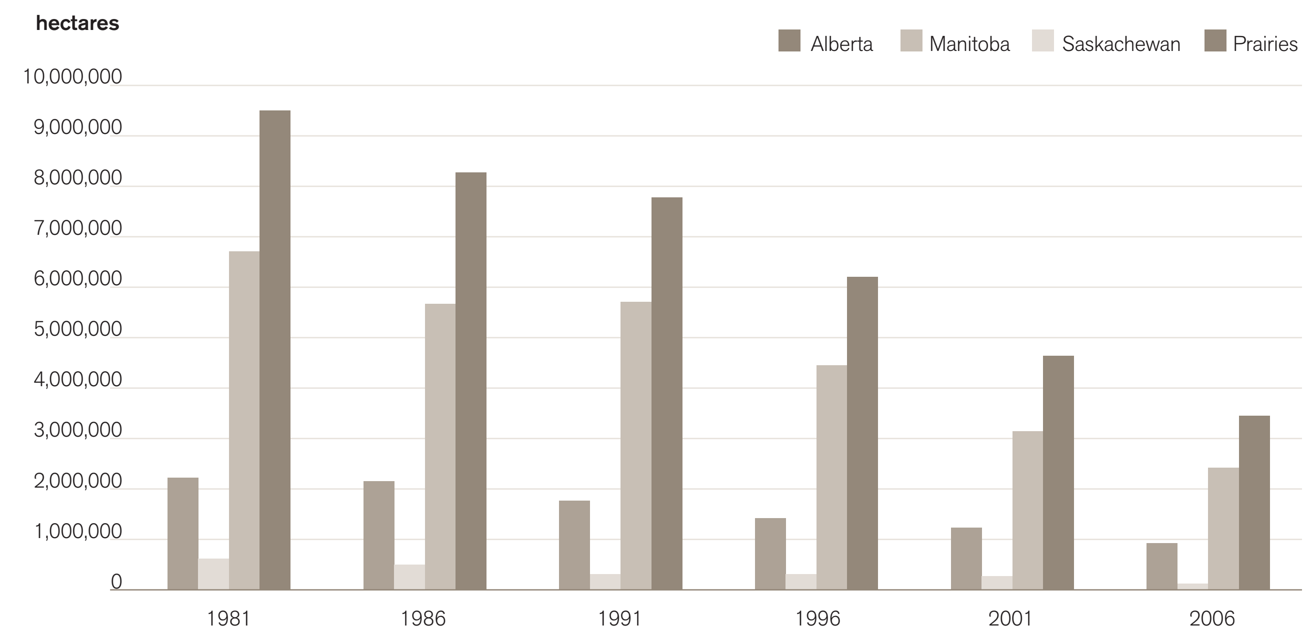


FIGURE 11-4 Area of summerfallow on the Canadian Prairies from 1981–2006.

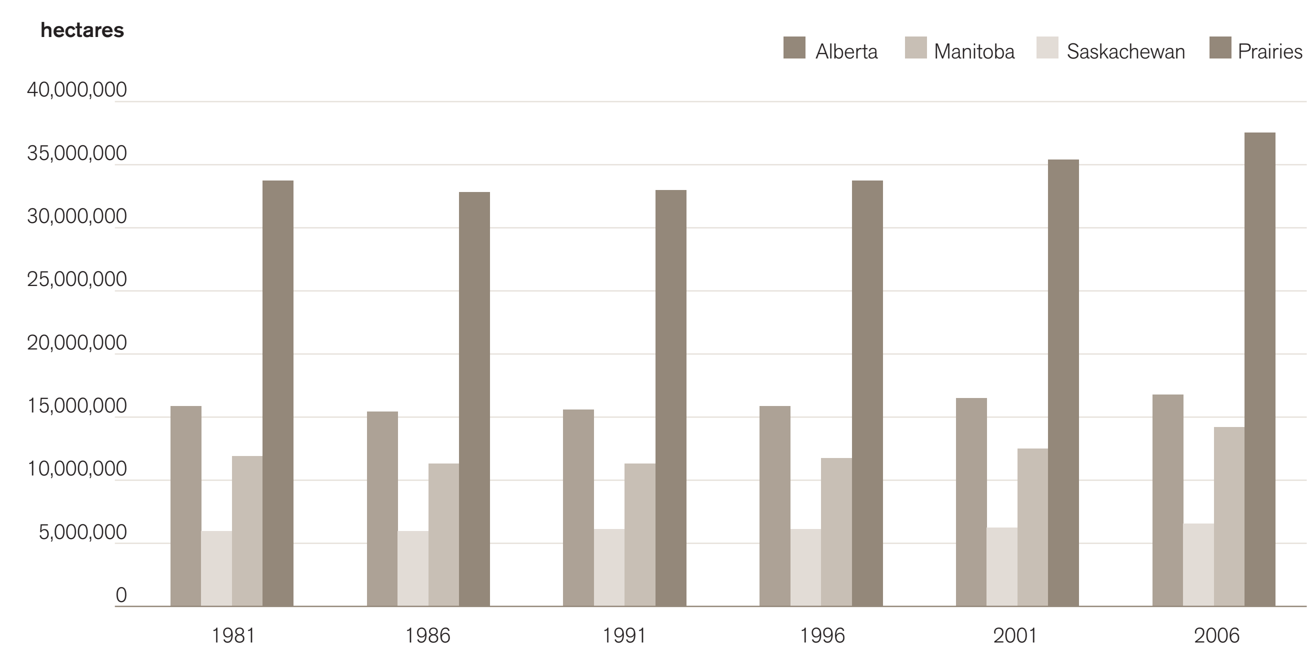


FIGURE 11-5 Area of permanent cover/perennial crops on the Canadian Prairies from 1981–2006.

Where water tables are already so near the surface that they pose a salinization risk, methods to lower the water table should be employed. These can include:

- planting deep-rooted perennials to draw down the water table,
- planting salt-tolerant crops where salinity is developing (maximizes water use to reduce salt movement to the soil surface),
- installing interceptor *perennial forage* or tree crop strips to reduce groundwater flow to the area at risk,
- using strategic subsurface tile (plastic) drainage,
- using appropriate surface drainage to reduce recharge, and
- monitoring groundwater depths in sensitive areas to aid in land use planning and to allow for the implementation of appropriate BMPs.

The practice of reducing salinization risk needs to include both refinement and further development of BMPs, and improvement in BMP implementation. Since groundwater flow often crosses property lines, the effective management of salinization risk may require coordination of BMPs or incentives by conservation districts or government agencies. Better information on the extent and degree of soil salinization in Canada and its cost to Canadian agriculture would increase the incentive for such activities.

More emphasis on salinity tolerance in crop breeding programs would provide producers with more cropping options in at-risk areas. Conservation tillage (no-till and minimum-till) is increasing, and although we know that this can improve distribution of snowmelt water and can reduce the need for summerfallow, it may also increase groundwater recharge via intact root channels. More information is needed on its effect on hydrology to better assess its impact on salinization risk.

Salinization occurs most rapidly in arid regions after wetter than normal years because water tables become elevated. Including more real-time weather data for both annual precipitation and growing season aridity should improve the assessment of risk over the current methodology, which uses only 30-year normals for growing season aridity in the climate component. Research is required to determine how best to incorporate such real-time data.

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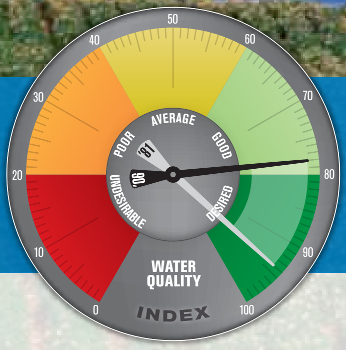
Water Quality



Water Quality

Summary

Agriculture uses many inputs to help meet an ever-increasing demand for food, fiber and energy. Plant nutrients nitrogen (N) and phosphorus (P) are added to agricultural crops in the form of fertilizers and manure to increase yields. Pesticides are applied to crops to prevent losses in crop yield and quality. The potential exists, however, for these inputs to find their way into the broader environment, particularly into ground and surface water bodies.

Nitrogen and Phosphorus are essential nutrients required by all plants for growth. The loss of N and P to the broader ecosystem represents an economic loss to producers and has potential environmental impacts as the nutrients enter the surrounding environment. Excess N can be lost to the atmosphere as nitric oxide (NO), nitrous oxide (N_2O) (a greenhouse gas), or nitrogen gas (N_2), and is at risk of leaching into nearby water bodies as nitrate (NO_3^-). Most residual soil N is in a water soluble form as NO_3^- and therefore at risk of moving to nearby water bodies where high levels in surface water can contribute to algae growth and eutrophication and have been linked to human health impacts. Similarly, P may move in a dissolved form or bound to soil particles. Excessive P in surface water can also contribute to eutrophication of rivers and lakes and to *algal blooms*, which reduce water quality and lead to limitations on water use.

Animal manure is a valuable organic fertilizer for agriculture. However, manure applied on agricultural land can become a source of pathogens into the environment including viruses, bacteria and protozoa. Water contamination by these pathogens can lead to increased costs for water treatment, loss of use of recreational waters, constraints to the expansion of the livestock industry and potential negative human health effects.

There is also concern that pesticides applied to agricultural land may move into the broader environment and eventually contaminate surface and ground waters, with potential environmental and human-health implications.

Five agri-environmental indicators have been developed and are reported here to assess the risk to water quality associated with the management of these inputs:

1. The Residual Soil Nitrogen Indicator (RSN) (Chapter 12.1) estimates how efficiently N is managed by providing the estimate of excess N remaining in the soil after harvest.

2. The Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N) (Chapter 12.2) links the Residual Soil Nitrogen Indicator with climatic conditions and soil characteristics to assess the risk of N leaching to groundwater.

3. The Indicator of the Risk of Water Contamination by Phosphorus (IROWC-P) (Chapter 13) estimates the relative risk of agricultural P reaching surface water bodies in Canadian watersheds. The indicator estimates both the source levels of P and the likelihood of transport.

4. The Indicator of the Risk of Water Contamination by Coliforms (IROWC-Coliform) (Chapter 14) assesses the relative risk of enteric microorganisms from agricultural sources contaminating surface water bodies using coliforms as a marker.

5. The Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest) (Chapter 15) estimates the relative risk of pesticides reaching surface and groundwater in agricultural areas in response to agricultural management practices and chemical properties of the pesticides.

While high risk of water contamination as assessed by these five indicators was rare in Canada in 2006, all of them trended toward increasing risk from 1981 to 2006:

- While the majority of farmland (78%) is at very low risk of N contamination, there was a gradual shift of land to higher IROWC-N classes due to a gradual increase in RSN values over the same period.
- In 2006, 33% of farmland was in the very low IROWC-P risk class, a decrease from 89% in 1981. The increase in livestock production and the use of mineral fertilizers continue to create regional P surpluses and increase the risk of agricultural soil P release and transport to surface water bodies.
- The area of farmland in the very low IROWC-Coliform risk class decreased from 83% in 1981 to 29% in 2006. High to very high risk classes for coliform contamination were found in watersheds in British Columbia, Alberta, and Ontario in 2006, comprising 7% of Canadian farmlands. These are watersheds where regionally concentrated livestock feeding operations and coliform transport factors pose a significant risk to water quality.
- In 2006 the majority of farmland (86%) was in the very low and low risk classes of contamination by pesticides. However, this is a reduction from 98% in these classes in 1981. An increased area under crop production, along with increased use of reduced tillage systems and shifts in crop types and crop areas resulted in the use of more pesticides over that period.

12 Nitrogen

Summary

Increasingly, nitrogen (N) is being added to farmland as fertilizer and manure to optimize crop yields and meet a growing demand for food, animal feed and fiber. However, excess *inorganic* N in the soil can pose risks to the environment and human health. Therefore, a primary goal for producers is to determine the optimal amount of N that needs to be applied as fertilizer or manure to produce healthy crops without creating excess inorganic N. Making this determination and applying N correctly will minimize N losses from the agricultural system.

The Residual Soil Nitrogen (RSN) Indicator assesses the efficiency of N use by estimating the amount of N remaining in the top 60 cm of soil at the end of the cropping season. A second indicator, the Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N) assesses the risk that RSN will move from agricultural areas into groundwater or nearby surface water bodies.

The national average RSN value increased by 175% from 1981 to 2002. RSN was at 9.3 kg of N per hectare (kg N ha^{-1}) in 1981, increased to 25.6 kg N ha^{-1} in 2002 and decreased to 17.7 kg N ha^{-1} in 2006. This fluctuation was exaggerated by reduced crop yields (reduced N outputs) in both 2001 and 2002 caused by unfavorable weather conditions throughout much of Canada. Higher levels of RSN were found in Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador as farmers applied more N per hectare to take advantage of the higher yield potential in these humid climatic zones.

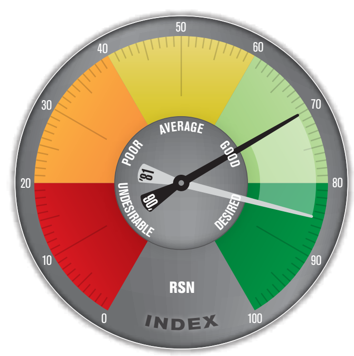
Between 1981 and 2006, more than three quarters of farmland (78%) in Canada was in the very low risk class for water contamination by N, largely reflecting the risk in the three Prairie Provinces, where 85% of Canada's farmland is located. Central and Atlantic Canada had significantly more negative trends, with farmland moving into the higher risk classes, particularly in the Atlantic Provinces. Climatic factors such as low precipitation in 2001 also affect IROWC-N results by affecting yields, N uptake and N leaching in many regions of Canada.

12.1 Residual Soil Nitrogen

AUTHORS
C. F. Drury, J. Yang, R. De Jong, T. Huffman, X.Yang, K. Reid and C. A. Campbell

INDICATOR NAME
Residual Soil Nitrogen

STATUS
National coverage, 1981 to 2006



The Issue

Nitrogen (N) is an essential nutrient required by all plants. The amount of N removed from agricultural fields during harvest or from grazing is much greater than the amount of N received from atmospheric deposition. Some leguminous crops fix atmospheric N and do not require supplemental N, however to maintain optimum yields for most other crops, N must be added to soils by applying fertilizer or manure.

When N remains in the soil after harvest there is a risk it will be lost from the soil through leaching into groundwater or through gaseous losses into the atmosphere. Most residual soil nitrogen (RSN) is in the form of nitrate (NO_3^-), which is soluble in water and can readily move through the soil profile into the groundwater, or enter surface waters through runoff and tile drainage (Drury et al., 1996; 2009). High NO_3^- levels in surface waters can be detrimental to aquatic life (Guy, 2008) whereas high NO_3^- levels in potable water can lead to human health issues (Chambers et al., 2001). Wet soil conditions can lead to *denitrification*, a bacterial process whereby the NO_3^- is converted and lost to the atmosphere as nitric oxide (NO), nitrous oxide (N_2O), a greenhouse gas, or nitrogen gas (N_2). The loss of N from the soil through leaching or denitrification is also an economic loss to producers because of the high cost of applying supplemental N as fertilizer or manure.

The amount of RSN in a given area is determined by a number of factors that also affect crop growth and yields, including uncontrollable weather factors, insect pests or plant pathogens,

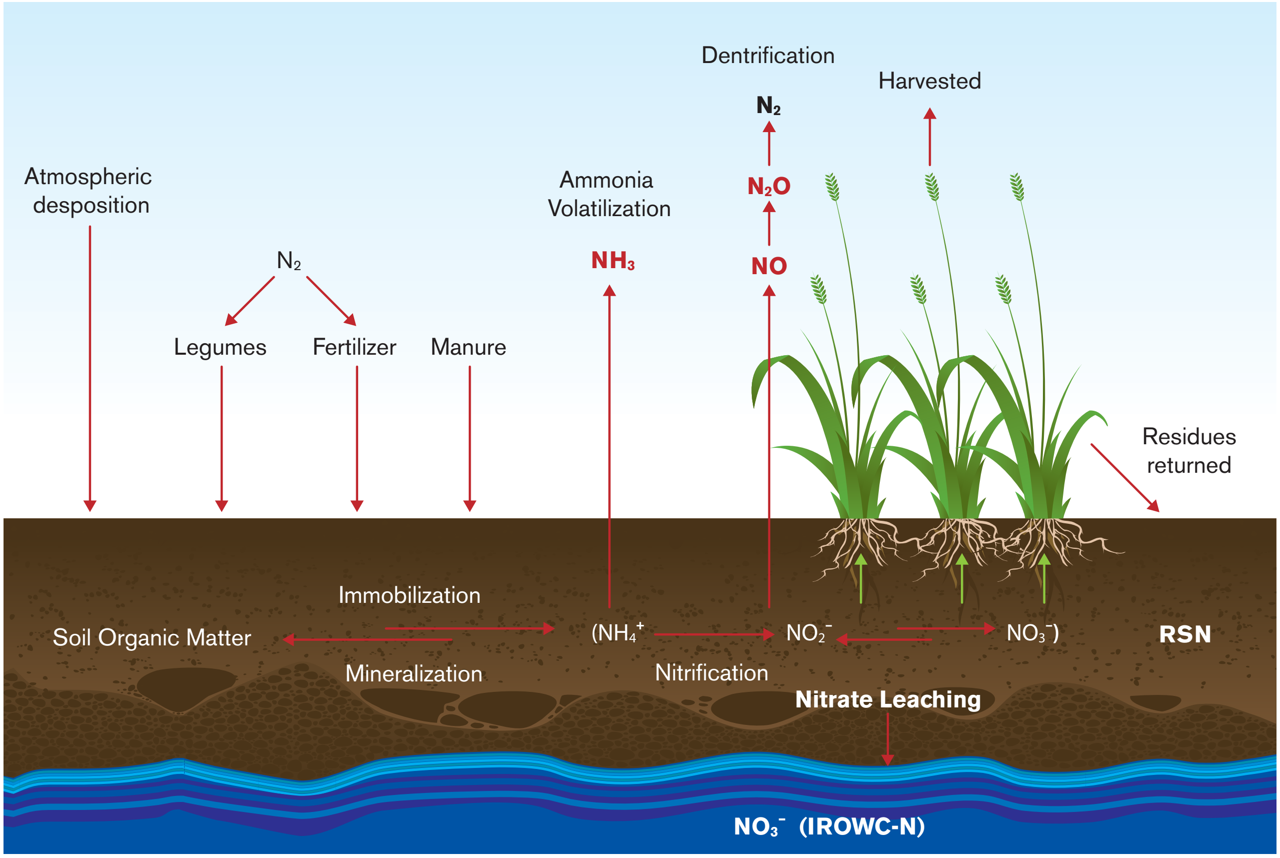


FIGURE 12.1-1 Conceptual view of the nitrogen (N) cycle in agricultural soils. Residual soil nitrogen (RSN) is the residual soil N content in the top 60 cm of soil after harvest.

weed infestation, and soil problems such as soil compaction, a poor capacity to hold water or poor aeration. RSN can also be affected by the rate or timing of the mineralization of organic N from manures or legume crop residues. If the mineralization to inorganic N occurs after the crop has reached maturity, it may remain in the soil after harvest. Finally, there are controllable factors that can affect N uptake and crop production, including the quantity, timeliness and method of applying fertilizers or manures.

The Indicator

The RSN indicator is calculated as the difference between all N inputs (fertilizer and manure addition, N fixation by leguminous plants, wet and dry atmospheric deposition) and all N outputs (N removal from the soil via crop uptake, plus N losses through volatilization of ammonia, N_2O and N_2 emissions) as depicted in the N cycle (Figure 12.1-1). The RSN indicator provides an estimate of the amount of unused N that remains in the soil at the end of the cropping season.

A model was derived to estimate the RSN indicator in agricultural regions across Canada on the basis of Soil Landscape of Canada (SLC) polygons (Yang et al., 2007). RSN is estimated for each year from 1981 to 2006 using annual data where available (e.g. yields and fertilizer sales) and by interpolating the census of agriculture data between census years (e.g. crop area and livestock number). When both fertilizer and manure N sources are present in a SLC polygon, the model splits the N input from fertilizers and manure based on the crop type. Estimates of manure N losses from storage and land applications are based on the livestock type, type of manure storage systems, and typical times and methods of application and incorporation of manure into the soil. The mineralization of organic N from manure and legume crop residues is estimated for the current year, as well as for the second and third years after application.

Farmland was assigned to very low, low, moderate, high, and very high RSN classes based on the RSN level present in the soil at the end of the growing season (Table 12.1-1). Using this modeling approach, the agricultural regions where N is used very efficiently (very low and low RSN areas) can be identified, as well as those that need to be monitored (moderate RSN areas), and those that may require remedial action because they may pose an environmental risk (high and very high RSN areas). By evaluating the RSN indicator over a 25-year period, trends over time can be identified as well as agricultural regions that have chronically high levels of inorganic N in the soil.

Although the RSN indicator is a way of estimating how efficiently N is used in soils, it in itself does not provide estimates of the environmental consequences associated with elevated RSN levels. Surplus N may remain in the soil over the winter and be used by the subsequent crop or it may be lost to the environment. Thus, a second agri-environmental indicator, the Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N), has been developed to estimate the leaching losses of nitrate (NO_3^-) from agricultural soils (see Chapter 12.2).

Limitations

Limitations associated with the RSN indicator are primarily related to differing scales of input data and the necessary data transformations required to use these data. The agricultural census data (farm area, livestock types and numbers, crop types and areas), fertilizer sales, crop yield, climatic data, and soil landscape information (soil types, slopes, etc.) are the primary data sources used in the model. Since the RSN indicator is calculated at the SLC scale and not at the farm scale, data transformations to the SLC scale were required. For instance, estimates were made of the amount of fertilizer and manure N that are applied to soils in each SLC polygon, but further assumptions were required about the proportion of each N source that is applied to a particular crop in each SLC polygon (Huffman et al., 2008).

Results And Interpretations

In 2006 the majority of farmland in Canada was in the very low (37%) and low (29%) RSN classes (Table 12.1-1). Seventeen percent of farmland was in the high and very high RSN class, the majority of which occurs in Central and Eastern Canada. This coincided with relatively high agriculture intensity, including livestock, with sporadic occurrences of land in these classes in western Canada where agriculture is generally less intensive (Figure 12.1-2). Since 1981 there has been a considerable shift of farmland towards the higher RSN classes. In 1981, 85% of land in Canada was in the very low and low RSN classes, whereas in 2001 only 52% was still in these two classes. There was some improvement in 2006 as 66% of agricultural land was in these two lower risk classes (Table 12.1-1). In 1981, 5% of agricultural land in Canada was in the moderate class but by 2001 the proportion of land in this class had increased to 19% and then dropped slightly to 17% by 2006. Land in the high and very high classes increased by a factor of three, from 10% in 1981 to 30% in 2001, then decreased to 17% by 2006.

The overall residual soil N level for agricultural soils in Canada increased steadily from a low of 9.3 kg N ha^{-1} in 1981 to a high of 25.6 kg N ha^{-1} in 2002 and then decreased to an RSN value of 17.7 kg N ha^{-1} in 2006 (Table 12.1-2 and Figure 12.1-3). The estimated N inputs increased at a greater rate than N outputs, accounting for the rising RSN levels in Canadian soils. Averaged over the 25-year period, inputs increased by 2.3% per year while outputs increased at a slower pace by 1.9% per year. On a national basis, there was about 575,000 tonnes of inorganic N remaining in Canadian soils following harvest in 1981 which increased about 2.7-fold to 1,547,000 tonnes in 2001, then decreased to 1,089,000 tonnes in 2006, which was still 89% greater than 1981.

Increased legume crop acreage accounted for 51% of the increase in N inputs over the 25 years, whereas increased fertilizer application accounted for 41% of the increase in N inputs. Increased livestock population and manure production was responsible for the remaining increase in N inputs (8%). The decrease in RSN between 2001 and 2006 was due to an increase in N output (greater yields and N uptake) combined with fairly constant N inputs. In 2006, legume N fixation represented 42% of the N inputs, fertilizer represented 38% and manure application 16%, the balance due to atmospheric deposition. Nitrogen outputs were considerably lower in drought years, such as in 2001 and 2002. However, producers had no way of knowing about imminent drought at the beginning of the cropping season and applied fertilizers and/or manures based upon the expectation that yields would be average or above average. Hence, RSN levels tended to be the highest in years in which weather had a negative impact on crop growth and yields.

The increased use of N fertilizer, increased N fixation by legume crops and an increased application of manure to agricultural land intensified the risk of high RSN in soils.

These results demonstrate that, in Canada, from 1981 to 2006, the increased use of N fertilizer, increased N fixation by legume crops and an increased application of manure to agricultural land intensified the risk of high RSN in soils. This was particularly apparent during years when crops were stressed and N uptake was reduced. The requirement for supplemental N (i.e. manure and fertilizer) is reduced in legume crops as they fix atmospheric N_2 in the nodules contained within their roots for crop growth. However, all three N inputs—fertilizers, manures and legumes—increased over these census years.

Response Options

Management techniques to reduce the RSN levels in Canadian soils are aimed at maximizing crop yield potential. If the factor limiting yield is poor soil physical quality, management practices that increase soil organic carbon levels—such as increasing crop residue and manure inputs—are a possible solution. Drought conditions during the growing season are more difficult to alleviate. However, where possible, irrigation or subirrigation may be a solution. Also, a recycling system may be the most efficient method of dealing with drought, where water and nutrients from surface runoff or tile drainage are stored in a pond or constructed wetland and pumped back onto the land during drought periods (Tan et al. 2007).

Methods to use N inputs more efficiently include testing soil for inorganic N, splitting the fertilizer application over the growing season to reduce losses, analyzing the nutrient content of manures prior to application, adjusting the manure or fertilizer application rate based on soil and manure analysis, and measuring in-season crop N to determine if supplemental N is required

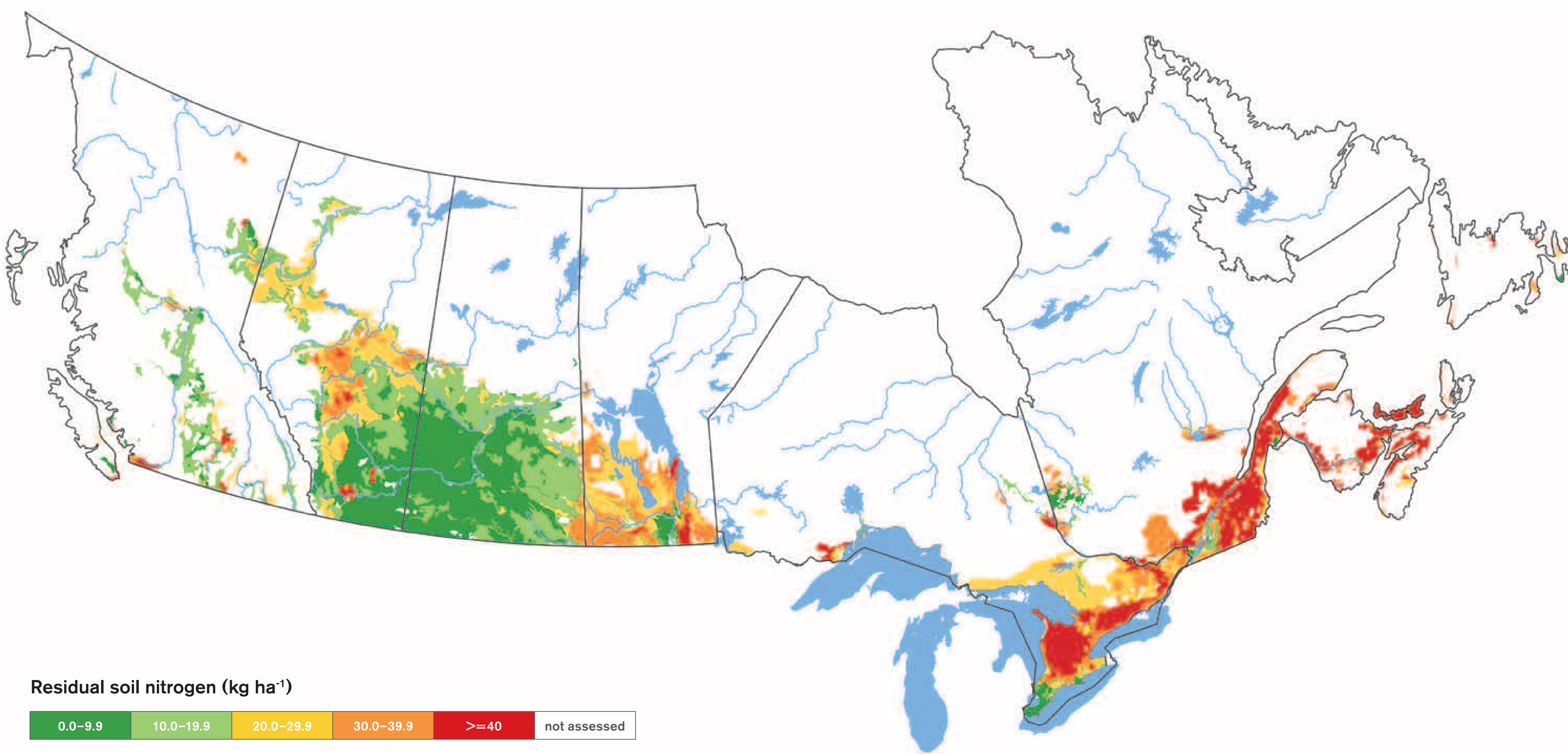


FIGURE 12.1-2 Residual Soil N (RSN) levels on Canadian farmland in 2006

TABLE 12.1-1 Percentage (%) of farmland in the very low, low, medium, high and very high RSN classes from 1981 to 2006. (* A= Average)

	RSN Class																																		
	Very Low (0-9.9 kg/ha)							Low (10-19.9 kg/ha)							Moderate (20-29.9 kg/ha)							High (30-39.9 kg/ha)							Very High (≥40 kg/ha)						
	1981	1986	1991	1996	2001	2006	A*	1981	1986	1991	1996	2001	2006	A	1981	1986	1991	1996	2001	2006	A	1981	1986	1991	1996	2001	2006	A	1981	1986	1991	1996	2001	2006	A
BC	46	29	45	19	6	21	**28**	33	40	34	49	38	53	**41**	9	17	10	18	26	14	**16**	4	5	4	7	20	5	**8**	8	9	6	7	11	7	**8**
AB	59	76	57	34	17	34	**46**	34	20	30	34	27	28	**29**	7	4	11	22	31	27	**17**	0	0	2	9	18	8	**6**	0	0	0	1	7	2	**2**
SK	100	100	100	88	34	57	**80**	0	0	0	12	52	39	**17**	0	0	0	0	14	3	**3**	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**
MB	64	13	3	1	0	8	**15**	33	73	42	14	2	6	**28**	3	14	50	46	24	42	**30**	0	0	5	37	48	40	**22**	0	0	0	2	26	4	**6**
ON	1	1	6	5	0	10	**4**	9	8	5	5	0	7	**6**	12	7	8	13	3	16	**10**	23	12	18	21	5	17	**16**	55	72	63	56	92	51	**65**
QC	3	3	0	0	0	1	**1**	8	5	2	3	0	11	**5**	24	17	8	10	0	11	**11**	40	23	13	19	4	20	**20**	26	53	77	68	96	57	**63**
NB	0	1	0	0	0	0	**0**	22	4	0	1	0	1	**5**	67	25	4	10	2	2	**18**	9	49	22	33	8	8	**22**	2	21	74	56	89	89	**55**
NS	0	0	0	0	2	0	**0**	10	5	0	3	1	1	**3**	56	31	3	22	3	8	**21**	22	36	42	36	5	8	**25**	12	28	55	39	90	83	**51**
PE	0	0	0	0	0	0	**0**	6	0	0	0	0	0	**1**	94	6	0	0	0	0	**17**	0	81	12	10	0	0	**17**	0	13	88	90	100	100	**65**
NL	42	1	18	4	1	14	**13**	20	3	13	8	9	8	**10**	14	18	20	17	7	12	**15**	7	24	12	6	13	13	**12**	17	55	37	65	69	53	**49**
CANADA	**69**	**68**	**62**	**49**	**20**	**37**	**51**	**16**	**17**	**16**	**19**	**32**	**29**	**21**	**5**	**5**	**11**	**14**	**19**	**17**	**12**	**4**	**3**	**3**	**10**	**13**	**9**	**7**	**6**	**8**	**8**	**8**	**17**	**8**	**9**

TABLE 12.1-2 Nitrogen input, N output and RSN (kg of N ha-1) between 1981 and 2006. (*A = average)

	N input							N output							Residual Soil Nitrogen						
	1981	1986	1991	1996	2001	2006	A*	1981	1986	1991	1996	2001	2006	A	1981	1986	1991	1996	2001	2006	A
BC	59	60.4	58.3	60.3	66	53.6	59.6	41.9	40.1	41.4	39	37.9	33.6	39	17.1	20.3	17	21.3	28.1	20.1	20.6
AB	41.5	42.3	45.6	54.2	60.4	59.6	50.6	32.9	36.2	36.2	38.8	37.6	43.3	37.5	8.6	6.1	9.4	15.4	22.7	16.3	13.1
SK	18.2	24.4	22.7	36.1	43.2	46.3	31.8	18.1	24.1	22.5	32.4	29.7	37.7	27.4	0.1	0.3	0.2	3.6	13.5	8.6	4.4
MB	45.3	58.3	64.8	75.2	82.2	83.1	68.2	36.7	42.7	44.5	48.2	46.8	55.3	45.7	8.6	15.6	20.3	27.1	35.4	27.9	22.5
ON	121.6	135.3	135.1	136.2	142.2	151.8	137	79.4	86.8	91.4	92.8	82.3	111.9	90.8	42.2	48.5	43.7	43.3	59.9	40	46.3
QC	109.5	128.5	125.5	141.2	151.8	142.7	133.2	75.2	85.1	75.3	94.3	89	98.3	86.2	34.4	43.3	50.3	46.9	62.8	44.4	47
NB	83.5	98.6	102	109.6	123.2	127.6	107.4	59.7	65	57.3	68.6	70.4	70.3	65.2	23.8	33.6	44.7	41	52.9	57.3	42.2
NS	92.7	106	108.6	125.3	118.1	124.2	112.5	63.9	70	62.4	84.9	61.6	66.2	68.1	28.9	36.1	46.2	40.4	56.6	58	44.3
PE	88.3	103	108.4	123.2	131.5	145.1	116.6	64.1	67.9	63.5	77.8	66.6	79.6	69.9	24.3	35.1	44.9	45.4	64.9	65.5	46.7
NL	50.7	83.8	72.7	114.6	105.3	100.7	87.9	30.6	42.4	40.6	67	52	48	46.8	20	41.4	32.1	47.6	53.3	52.7	41.2
CANADA	**42.6**	**47.8**	**48.4**	**59**	**65.6**	**66.8**	**55**	**33.3**	**37.9**	**37.1**	**43.5**	**40.7**	**49.1**	**40.3**	**9.3**	**10**	**11.3**	**15.5**	**25**	**17.7**	**14.8**

Only Soil Landscapes of Canada (SLC) polygons with > 5% farmland area were included in the scaling-up process for all provinces, except for New Brunswick, Nova Scotia and PEI and Newfoundland where all agricultural land was included.

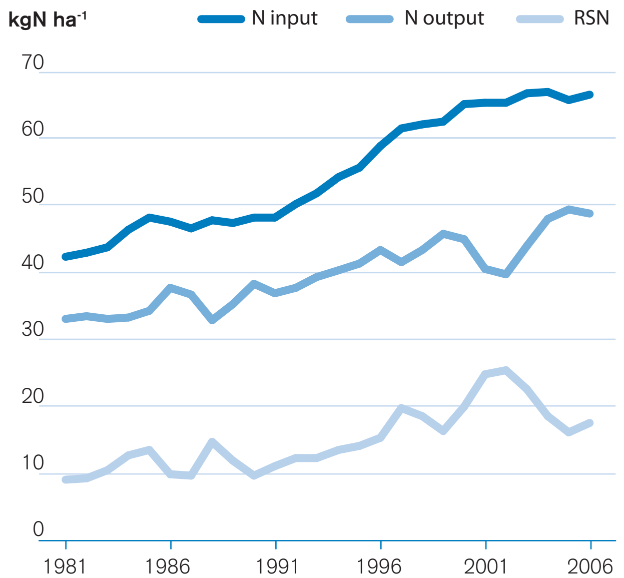


FIGURE 12.1-3: The estimated N input, output and residual soil N level in Canadian soils from 1981–2006

Residual Soil Nitrogen Validation

The RSN estimates were derived from many data sources, including crop areas, yields, livestock type, numbers, manure type and storage methods, and N fertilizer sales. In the fall of 2005, a study was initiated to validate the RSN model predictions using measured field data. More than 1,200 soil samples were collected from 134 farm fields across Ontario (Figure 12.1-4) representing 58 corn, 42 soybean, 27 winter wheat and seven hayfield sites. The samples were taken from the top 60 cm of soil after harvest. The fields were located in 38 SLC polygons.

In the 2006 census year, the average RSN values in southern Ontario, where soils were sampled, ranged from very low levels in the agricultural land near Windsor, to very high in the regions north of London and west of Ottawa as a result of the varied N inputs and N outputs across this region (Figure 12.1-4). The average RSN for all crops and agricultural regions in Ontario in 2005 was estimated to be 35.6 kg N ha^{-1} in the 0 to 60 cm depth. However, if the RSN estimates were restricted to the crops sampled as part of the validation process (corn, soybean, winter wheat and hay), which were the dominant field crops in Ontario on a per-acre basis, RSN was predicted to be 38.5 kg N ha^{-1}.

When the inorganic N was measured after harvest from the field sites, the measured RSN across these 134 field sites was 38.0 kg N ha^{-1}, which is very close to the predicted value. When the predicted and measured RSNs were compared for each of the crop types, it was found that the predicted RSN was lower than the measured RSN for corn, hay and soybean but was higher for winter wheat (Figure 12.1-5). Nevertheless, given all of the assumptions involving both N inputs (organic N mineralization from manure and legume residues, atmospheric deposition of N, etc.) and N outputs (ammonia volatilization losses and denitrification losses), the measured values satisfactorily validated the predictions for Ontario soils (in 2005).

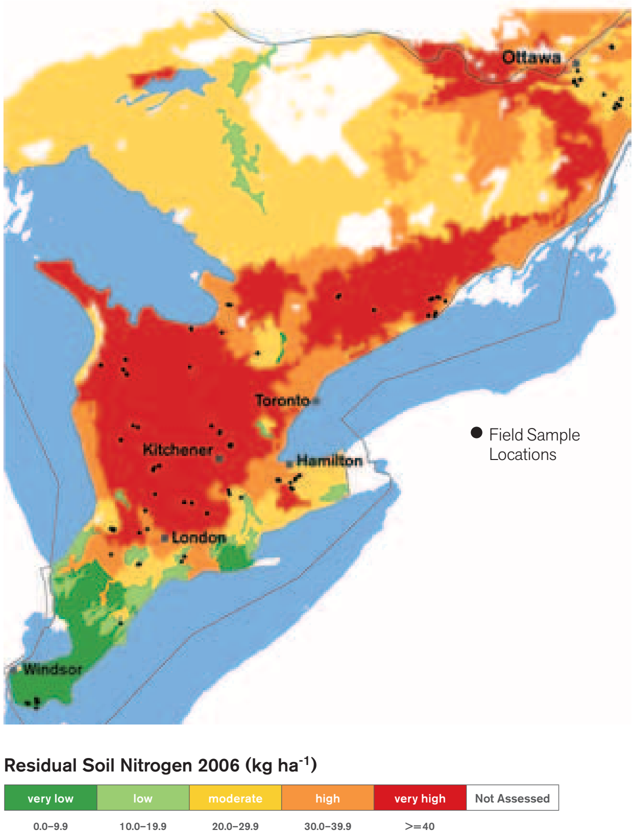


FIGURE 12.1-4 Sampling locations in Ontario used to validate the estimates of the residual soil N levels in soils

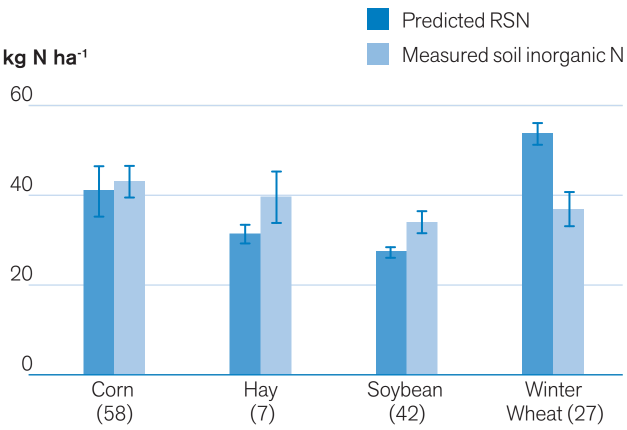


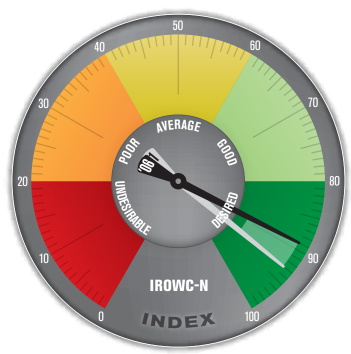
FIGURE 12.1-5 Comparison between the residual soil N estimates for corn, hay, soybean and winter wheat versus the measured quantities of ammonium and nitrate in the soil. Numbers beside the crop type refer to the number of field sites and the bars are standard error.

(Zebarth et al., 2009). In some cases, manure may have to be applied on farm fields which are a considerable distance from where the manure originated to more evenly distribute nutrients into agricultural soils. Since, on a national basis, 26% of manure N produced is estimated to be lost to ammonia volatilization and denitrification, improved management practices for manure storage and application are required to increase the efficiency of manure N and perhaps reduce the amount of fertilizer required.

When crop yields are low as a result of uncontrollable factors—such as climate, pests and diseases—management practices such as growing a cover crop could be adopted. The cover crop would capture the unused inorganic N in the soil, which could reduce N losses. Further, if the cover crop is a green manure crop, then when it is killed it may release the assimilated N into the soil for use by the following crop.

Eliminating N fertilization and the addition of manure to crops are not answers to the RSN issue, as evidenced by a long-term study established in southwestern Ontario in 1959 in which fertilized corn produced yields significantly higher than unfertilized corn (Drury and Tan, 1995). Further, in a Western Canada study, inadequate fertilization was found to limit crop growth, nutrient and water uptake and mineralized soil N was at greater risk of leaching through the soil profile (Campbell et al. 2006). Clearly, management objectives should be aimed at achieving a closer balance between N inputs from fertilizer and manure addition and N outputs from crop N uptake and harvest.

12.2 Water Contamination by Nitrogen



AUTHORS

R. De Jong, C. F. Drury and J. Y. Yang

INDICATOR NAME

Indicator of the Risk of Water Contamination by Nitrogen

STATUS

National Coverage 1981 to 2006

The Issue

Increased amounts of N are being added to agricultural crops and pastures through fertilizer and manure to meet the ever-growing demand for food, fiber and energy. However, incomplete N uptake by crops inevitably results in some inorganic N remaining in the soil at the end of the growing season. (See Chapter 12.1, Residual Soil Nitrogen). Environmental risks are higher when large surpluses of N are present in the soil, especially between cropping seasons in *humid regions*. Most of the residual inorganic N, in the form of nitrates, is water soluble and therefore susceptible to leaching through the soil into groundwater or to loss through tile drains into ditches, streams and lakes (Drury et al., 1996; Tan et al., 2002). High nitrate levels in surface waters contribute to algae growth and eutrophication and have been linked to human health impacts (Chambers et al., 2001).

Public interest is high about human health issues that involve N and Canadians remain concerned with the safety of their drinking water and food supply. There is a need to gain greater insight into the risks N poses to human health and the environment. There is also a need to evaluate and quantify the effectiveness of agricultural management practices that are put in place to reduce these risks of N. Since N is the most commonly applied nutrient for the production of food and animal feed, its cost is a major concern to producers, just as its possible negative impact on the environment is of major concern to society as a whole. Consequently, an optimal balance between the amount of N crops require and the amount of N actually used can minimize losses from the agricultural system and mitigate negative impacts on the environment.

The Indicator

The Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N) is the link between the quantity of mineral N remaining in the soil at harvest (Residual Soil Nitrogen, or RSN) and subsequent climatic conditions during the winter (MacDonald, 2000; De Jong et al., 2007; Yang et al., 2007). A simplified conceptual model of soil N components and flow in agro-ecosystems illustrates the biophysical principles behind the indicator (Figure 12.1-1). The amount of RSN is the difference between N inputs and N outputs. The inputs consist of additions of fertilizer and manure to farmland, fixation of N by leguminous plants, and atmospheric dry and wet deposition of N. The outputs from

TABLE 12.2-1 IROWC-N classification based on the N concentration in the water and the total amount of nitrate-N lost during the over-winter (or non-growing) season.

		Nitrate Lost (kg of N/ha)			
		0–4.9	5.0–9.9	10.0–19.9	≥ 20.0
Nitrate concentration (mg of N/L)	0–4.9	very low	very low	low	moderate
	5.0–9.9	very low	low	moderate	high
	≥ 10.0	low	moderate	high	very high

the system include N removal in plant products that leave the field, N lost in gaseous form to the atmosphere (denitrification and ammonia volatilization), and N leached to ground water. This nitrate-N leaching is what the IROWC-N attempts to capture.

Because agro-ecosystems are complex, computer simulation techniques are among the most practical methods for assessing the environmental sustainability of Canadian agriculture. The RSN indicator (see Chapter 12.1) is coupled with a daily soil water balance calculation procedure (Baier and Robertson, 1966; Baier et al., 1979; Baier et al., 2000; Akinremi et al., 1996), to compute the IROWC-N indicator. Over-winter (non-growing season) N leaching from the soil and N concentration in drainage water is estimated from the amount of residual soil nitrate-N at harvest, the cumulative amount of water drained from the soil profile during the over-winter period and the water content of the soil. Unlike previous publications (MacDonald, 2000; De Jong et al., 2005), the current IROWC-N model gives a more complete and accurate description of the soil water balance. However, the model does not account for N losses from surface runoff, which are generally believed to be small compared to the N losses via leaching (Drury et al., 1993; 1996; 2009).

The IROWC-N indicator is expressed as the proportion of agricultural land that falls in each of five risk classes (Table 12.2-1). These classes are derived from a combination of two components:

1. N leached from the soil profile during the over-winter period (N_{lost}, expressed in kg of N per hectare (ha) of land)
2. Nitrate-N (NO_3-N) concentration in drainage water (N_{conc}, expressed in mg of N per litre (L) of water).

The nitrate-N concentration classes are related to the Canadian drinking water guideline of 10 mg NO_3-N per L (Canadian Council of Ministers of the Environment, 1999). In addition, the lower concentration limit of 5 mg N per L is close to the proposed new Canadian long-term exposure limit for aquatic life in fresh waters (4.7 mg NO_3-N per L) (Guy, 2008). We use these two factors to classify IROWC-N, as they both influence the potential environmental impacts of N losses.

Limitations

The methodology used to calculate IROWC-N is based on many assumptions and approximations, made particularly to enable reporting for large spatial scale units at a coarse *temporal scale*. The results, as portrayed in Figure 12.2-1 for 2006 farm management practices, are estimates only and should be interpreted accordingly. A lack of measured data prevents validation and hence the results are appropriate only for comparing different years and regions in Canada. They can, however, be used to identify areas that are at risk for potential N accumulation and loss of nitrate into the environment via leaching. The results should be confirmed by field testing, particularly in those areas showing a high risk.

Results And Interpretation

The majority of farmland in Canada was at very low risk of water contamination by N in 2006 (Figure 12.2-1), and between 1981 and 2006 (Table 12.2-2). However, during this period, the proportion of farmland in the very low risk class decreased gradually from 88 to 78% while the proportion in the low risk class increased from 2 to 12%. Combined, 90% of the farmland area fell into these two categories in every year (Table 12.2-2). The proportion of farmland area in the moderate risk class decreased from 6% to 3%, while the proportion in the high and very high risk classes increased from 4% to 6%.

As 85% of Canadian farmland is located in the three Prairie Provinces, the national results strongly reflect what is happening in the prairies and to a lesser extent in Ontario and Quebec. In the Prairie Provinces there was very little change in farmland area in the moderate, high and very high risk classes, with close to 100% of the area falling into the two lowest risk classes. However, the situation was more dynamic in central Canada, representing 11% of Canadian farmland. In Ontario, the proportion of farmland in the high and very high risk classes fluctuated between a low of 32% in 1981 to a high of 47% in 2001, declining to 43% in 2006. Similarly, in Quebec, the proportion of farmland in the two highest risk classes increased from 19% in 1981 to 66% in 2001 (due to an increase in N inputs without sufficient uptake and removal by crops) and declined to 61% in 2006. In Atlantic Canada, there was a general shift of the

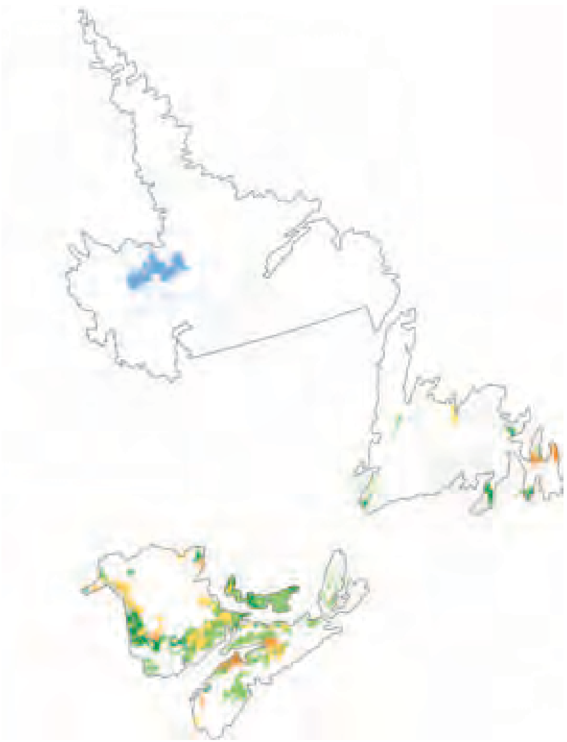


FIGURE 12.2-2 Risk of water contamination by nitrogen on farmland in the Atlantic Provinces under 1981 farm-management practices

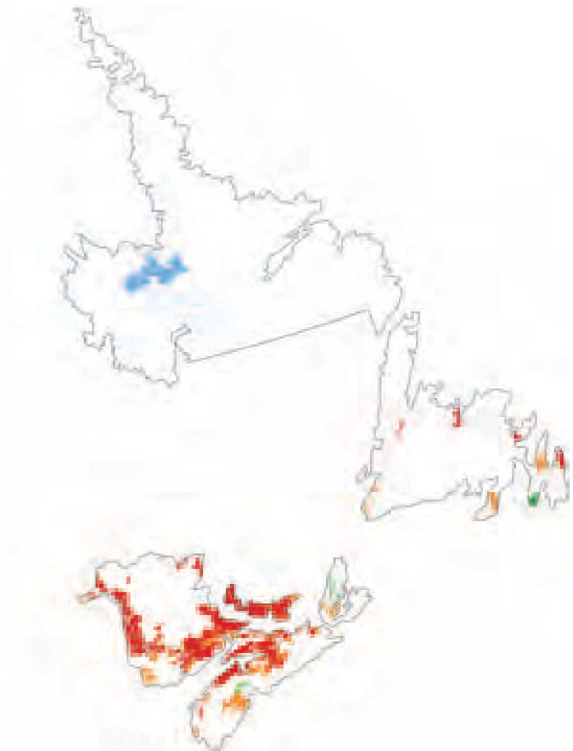


FIGURE 12.2-3 Risk of water contamination by nitrogen on farmland in the Atlantic Provinces under 2006 farm-management practices

majority of land into the high and very high risk classes (Figures 12.2-2 and 12.2-3).

The changes in proportion of national farmland in various IROWC-N risk classes are largely due to changes in RSN estimates, which are discussed in Chapter 12.1 and changes in weather conditions. The gradual shift of land to higher IROWC-N classes between 1981 and 2006—for example, the high and very high classes increased from 4% to 6%—can be largely explained by the gradual increase in RSN values during the same period (from 9.3 to 17.7 kg N ha^{-1}), with the exception of 2001. The 2001 RSN estimate of 25.0 kg N ha^{-1} was considerably higher than in any other year (see Drury et al., 2007) and coincided with the greatest national share of land in the high and very high risk classes. This is attributed to lower than normal over-winter drainage in 2001, resulting in an N_{lost} estimate (Figure 12.2-4) similar to previous years (1981, 1986 and 1991) and an increased N_{conc} (Figure 12.2-5) because of less dilution (Table 12.2-3). In 2006, the RSN value was 29% lower than in 2001. However, the over-winter drainage was close to normal and therefore both the N_{lost} and N_{conc} estimates increased from 2.4 to 2.6 kg N ha^{-1} and 4.6 to 5.3 mg N per litre (mg N L^{-1}), respectively, and there was no national shift of land to lower-risk classes.

TABLE 12.2-3 Mean (1981, 1986, 1991, 2001 and 2006) over-winter precipitation and over-winter drainage from September 1st until March 31st.

	Over-winter precipitation (mm)	Over-winter drainage (mm)
BC	271	90
AB	155	4
SK	175	5
MB	232	7
ON	513	186
QC	558	202
NB	616	264
NS	722	367
PE	753	333
NL	782	414
CANADA	**222**	**31**

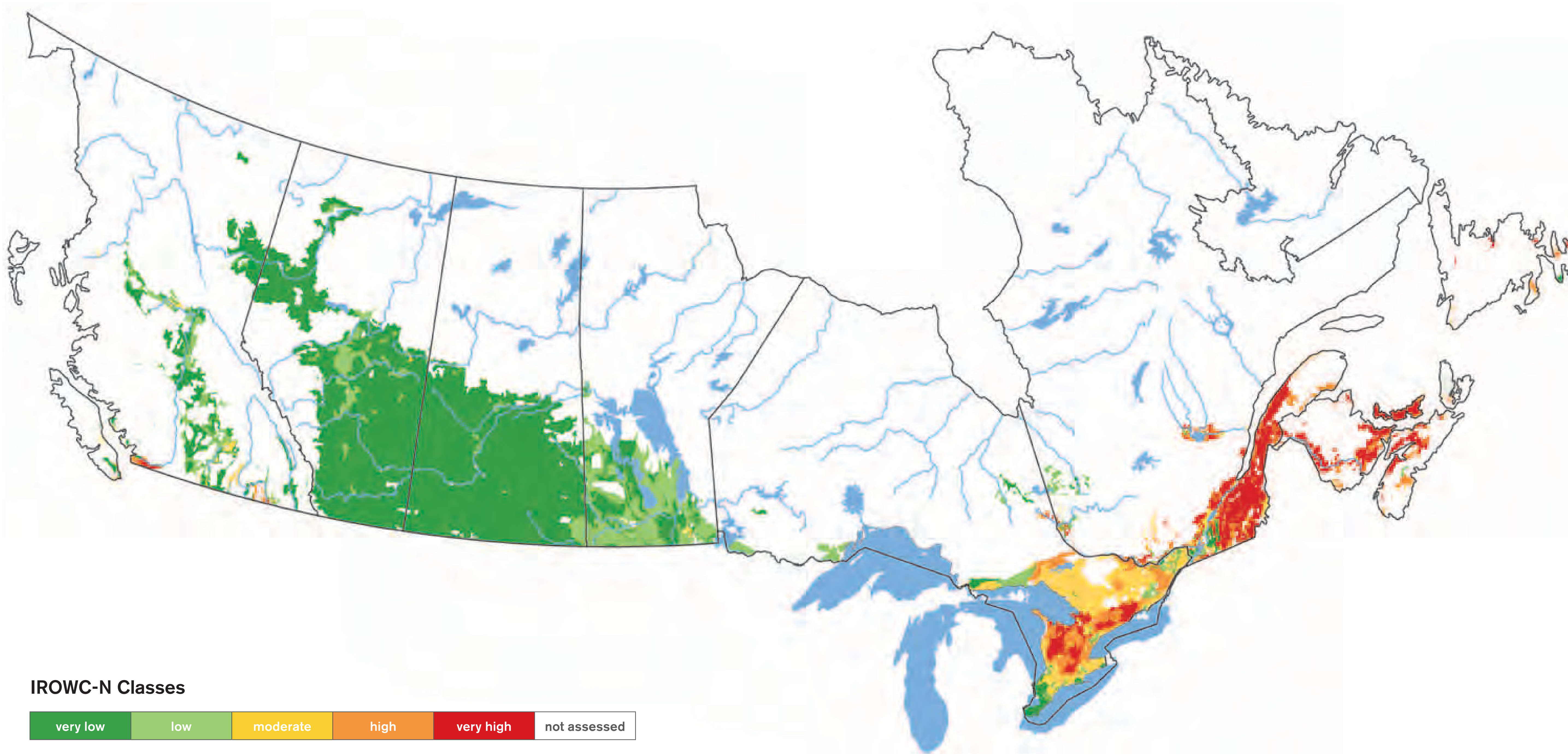


FIGURE 12.2-1 Risk of water contamination by nitrogen on farmland in Canada under 2006 farm management practices

TABLE 12.2-2 Proportion* of farmland in various IROWC-N risk classes,** 1981–2006

	Proportion (%) of Farmland in Different Risk Classes																													
	Very Low (0–9.9 kg/ha)						Low (10–19.9 kg/ha)						Moderate (20–29.9 kg/ha)						High (30–39.9 kg/ha)						Very High (≥40 kg/ha)					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	76	80	78	74	67	71	16	11	13	14	21	18	2	2	2	5	4	4	3	3	4	3	3	2	2	2	1	3	3	3
AB	100	99	100	98	96	93	0	1	1	2	4	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SK	100	100	100	100	99	98	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MB	98	94	82	56	51	36	2	6	18	44	49	64	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
ON	19	14	16	21	12	11	6	4	4	6	11	12	43	37	36	36	31	34	17	16	20	18	29	23	15	29	25	20	18	20
QC	20	7	8	9	2	8	9	7	3	4	14	10	46	50	44	42	13	17	7	8	11	12	20	12	12	24	29	28	46	49
NB	40	6	4	6	0	0	21	10	3	4	1	0	36	66	51	36	10	5	2	7	26	36	40	9	0	11	16	19	49	87
NS	5	1	1	1	2	1	54	10	23	33	3	3	15	48	12	14	2	3	26	29	58	41	54	27	0	12	6	11	39	67
PE	31	0	0	0	0	0	65	31	9	5	0	0	4	69	20	68	0	0	0	0	71	28	67	7	0	0	0	0	33	93
NL	48	2	23	0	0	24	22	37	22	37	4	0	2	5	6	5	10	0	27	52	43	58	46	35	0	4	7	0	41	40
CANADA	**88**	**88**	**87**	**83**	**81**	**78**	**2**	**2**	**3**	**7**	**9**	**12**	**6**	**5**	**5**	**5**	**3**	**3**	**2**	**2**	**2**	**2**	**3**	**2**	**2**	**3**	**3**	**3**	**3**	**4**

* The proportion of farmland in the five risk classes does not always add up to 100% because some polygons were excluded from the calculations due to missing weather data and missing soil data. ** Indicator Risk of Water Contamination by Nitrogen.

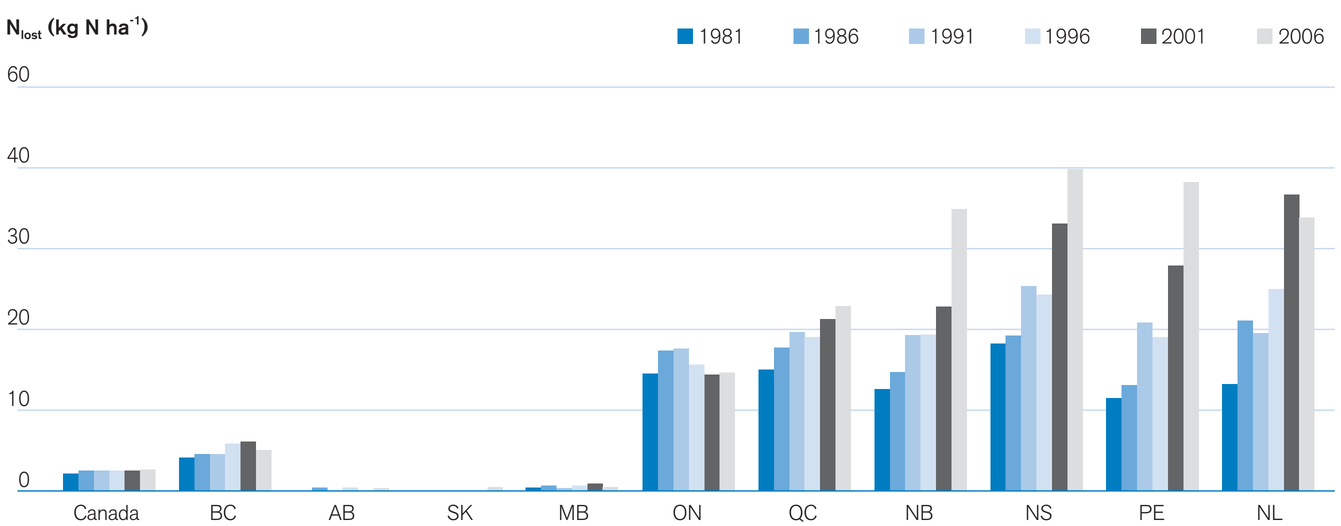


FIGURE 12.2-4 National and provincial N losses 1981–2006.

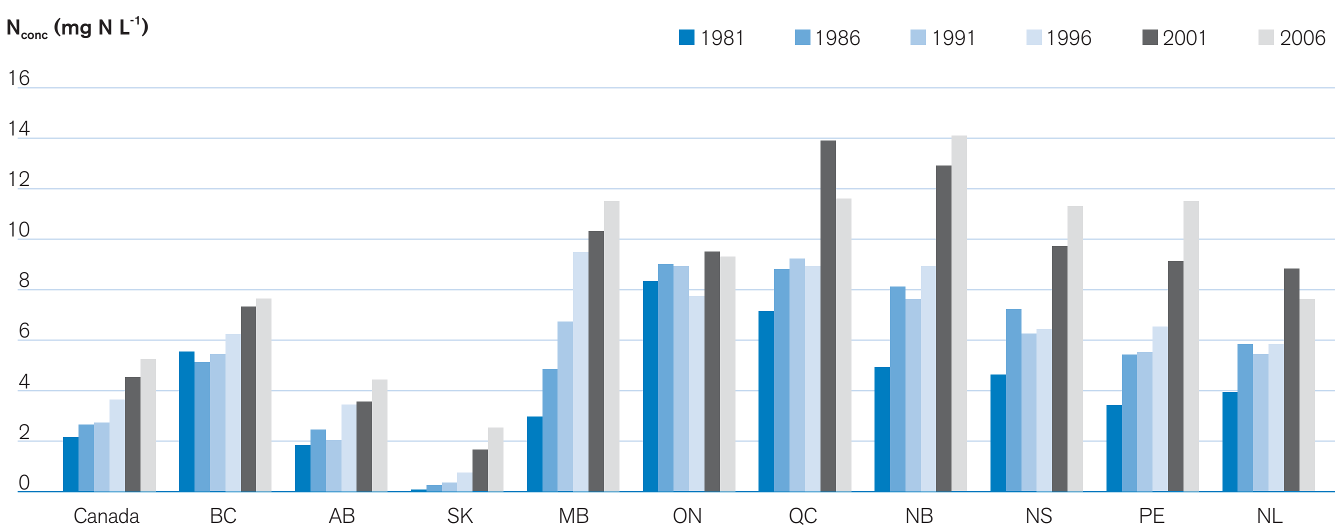


FIGURE 12.2-5 Nitrate-N concentration in drainage water, 1981–2006.

Response Options

In areas that fall into the high risk class, measures that minimize the amount of N leaching from the soil will help to reduce the risk. These measures might include the following:

- growing catch crops, usually a lower-value crop planted in the fall after the main higher-value crop has been harvested (Thorup-Kristensen et al., 2003; Strock et al. 2004),
- intercropping or using rotations that include crops that take up excess soil N (Ofori and Stern, 1987; Hesterman et al., 1992),
- agroforestry practices in which trees extract water and nutrients from greater depths than most agricultural crops (Van Noordwijk et al., 1996), and
- installing controlled water table management systems to reduce nitrate leaching in tile drained land (Drury et al., 1996; 2009).

Response options also include many nutrient management practices (Zebarth et al., 2009), such as:

- properly accounting for all major sources of N, including N added in animal manure, crop residues and legume fixation,
- improving estimates of the amount of nutrients crops need,
- further developing and using N tests for soil and crops, and basing N inputs on the results of such tests;
- timing and placement of N applications to match times of maximum crop need and avoiding times of major leaching.

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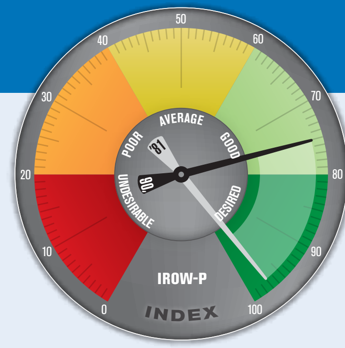
13 Phosphorus



AUTHORS

E. van Bochove, G. Thériault, J.-T. Denault,
F. Dechmi, A.N. Rousseau and S.E. Allaire

INDICATOR NAME

Risk of Water Contamination by Phosphorus (IROWC-P)

STATUS

National Coverage 1981 to 2006

Summary

Phosphorus (P) is an important nutrient for plant and animal growth. However, additions of P to the land as livestock manure and inorganic fertilizer may lead to an increased risk of soil P saturation and resulting movement of P to water bodies. Excessive amounts of P in surface water contributes to eutrophication of rivers and lakes and to *Cyanobacteria* blooms. These result in decreased water quality and limitations on water use. The Risk of Water Contamination by Phosphorus (IROWC-P) Indicator was developed to assess the trends over time for the risk of surface water contamination by P from Canadian agricultural land at the watershed scale.

Overall risk of water contamination by P is increasing in Canada. Increases in livestock production and the use of mineral fertilizers repeatedly created regional P surpluses between 1981 and 2006. The wide range of soil types across Canada have different characteristics for retaining nutrients such as P and therefore some soils are better able than others to sustain intensive agriculture. Surface runoff, deep drainage and soil erosion by water on agricultural land contribute significantly to the risk of P contamination of surface water in eastern Canada. In western Canada, surface runoff seems to be the major factor contributing to P transport. Local implementation of nutrient management plans, regulations, conservation practices and beneficial management practices (BMPs) have considerably decreased the P surplus in some areas. However, cumulative P surpluses over time continue to enrich soil P levels. Increased efforts at controlling both P sources and transport are required to reduce the risk of P loss to water and prevent surface water eutrophication and algal blooms.

The Issue

Phosphorus is an essential nutrient for all plants and animals. It is applied to soils through inorganic P fertilizers, manures and biosolids to sustain crop yields. Since the early 1950s, intensified cropping and animal production have increased soil nutrients in some regions to levels in excess of what crops need. Over time, cumulative P surpluses have enriched the soil and increased the risk that soil P will be released and transported from agricultural fields to surface water bodies.

In natural freshwater systems, P occurs in very low concentrations but may vary significantly as a function of stream size and ecosystem characteristics. Excessive amounts of P in surface fresh water contribute to eutrophication of rivers and lakes and to Cyanobacteria blooms. These result in decreased water quality and limitations on bathing, drinking and recreational activities (Carpenter et al., 1998). Government programs and regulations have extensively promoted a reduction in agricultural P contamination from manure storage structures as well as during manure application. Nutrient management plans including P have been developed specifically for farming operations to reduce the risk of contamination by nutrients of adjacent surface water bodies in Quebec (1997), Ontario (2002) and Manitoba (2006).

The Indicator

The IROWC-P Indicator was developed to assess the status and trends over time for the risk of surface water contamination by P from Canadian agricultural land and is reported for agricultural watersheds. IROWC-P first estimates the annual amount of dissolved P that may potentially be released from agricultural soils (P source). P source is estimated as a function of cumulative P additions and removals (P-balance) over a 30-year period up to 2006 and the resulting degree of soil P saturation. IROWC-P then integrates the P source through a *transport-hydrology* function, which considers such processes as surface runoff, drainage and water erosion. IROWC-P also considers *hydrological connectivity*, which includes a topographic index, tile drainage, surface drainage and *preferential flow*. The indicator uses information from the transport and hydrological functions to estimate the likelihood for P to enter streams or water bodies.

The IROWC-P was calculated for 280 watersheds (Natural Resources Canada. 2003) across Canada that contain more than 5% agricultural land. Results were tested against P water quality monitoring data collected in 88 agricultural watersheds in Canada from 1981 to 2001. IROWC-P values were grouped separately for western and eastern Canada into five risk classes (very low, low, moderate, high and very high). The risk classes are relative rankings wherein 50% of watersheds are classified in the very low risk class and that the highest 5% of IROWC-P values fall into the high and very high risk classes in each of the two regions.

Limitations

IROWC-P assesses the risk originating from agricultural P; non-agricultural P is not considered. Calculations of cumulative P balance follow Census of Agriculture data from 1976 to 2006. There were insufficient data to allow accounting for soil P enrichment before 1976 in Canada, except for in Ontario where trends reported by the Potash and Phosphate Institute were available.

Risk classes were defined separately for eastern Canada and western Canada to more accurately reflect the different conditions in different parts of the country, and are therefore not comparable.

Hydrological *connectivity factors* represent the pathways of P transfer to water bodies and were assumed to have equal weight in all agricultural areas across Canada.

The calculation of IROWC-P accounts for most BMPs that lower P levels at the source but accounts for few BMPs that mitigate the movement of P in the landscape. This is due to a lack of comprehensive national BMP adoption data such as buffer strips.

This indicator was calibrated using the annual median P concentrations of 88 watersheds located across the country. In these cases, the P may have come from a variety of sources, including urban wastewater and forest. Since agricultural activity may be concentrated on relatively small proportions of watershed area, the IROWC-P value may be influenced by the remaining non-agricultural area.

Results and Interpretation

In 2006, four watersheds classed as very high risk and twelve at high risk of water contamination by P were located in both eastern Canada (Nova Scotia, Quebec, Ontario) and western Canada (Saskatchewan, Alberta and British Columbia) where the combination of agriculture intensity and P transport factors pose a significant risk to water quality and mitigation measures are likely required (Figure 13-1). Forty-eight watersheds were estimated to be at moderate risk.

Between 1981 and 2006, 43% of the 280 watersheds moved to higher risk classes (Figures 13-2 and 13-3), indicating that more adoption and implementation of P control measures are needed to protect surface water at risk of being significantly degraded. The general analysis of trends over time across Canada (Table 13-1) shows that approximately 7% of the farmland located in British Colombia shifted from low risk in 1981 to very high risk of P water contamination in 2006. A shift to higher risk classes has occurred since 1991 in Alberta, Saskatchewan and Manitoba, mainly because the P balance has increased steadily (Figure 13-4). However, risk values are highly dependant on climate, as shown in Table 13-1 where the proportion of farmland in the IROWC-P very low risk class for the drier year (2001) (Figure 13-5) was higher than in 1996 and 2006. In eastern Canada, the risk in Ontario has remained stable. The risk in Quebec, New Brunswick, Nova Scotia and Prince Edward Island has shown the same gradual shift to higher classes since 1991 that was observed in the Prairie Provinces (Table 13-1).

Any BMPs that have the potential to decrease P so that it is not in excess of crop needs or reduce the transport of P to surface water will decrease the risk of water contamination by P.

IROWC-P values and trends are a function of agricultural intensity and its influence on P source, and of transport processes that are highly dependent on regional climatic variations (Figure 13-5). There has generally been an increasing trend in the P-source levels in the surface of agricultural soils in Canada since 1976 as intensified agricultural practices have resulted in the application of P in excess of crop uptake (also called positive annual P balance) and have therefore increased soil P saturation (Figure 13-6). In 2006, very high concentrations of P (more than 4 mg of P per kg per year, or >4 mg P kg^{-1}) at risk for release by storm events were located in regions where the agricultural production has been historically intensive and where soils have reached high P saturation values. These regions are located around Abbotsford, British Columbia; Lethbridge, Alberta, some areas in the Great Lakes basin in Ontario; the St. Lawrence Lowlands in Quebec; Grand Falls, New Brunswick; and Annapolis Valley, Nova Scotia (Figure 13-7, Table 13-2). High risk (3 to 4 mg P kg^{-1}) areas were also identified surrounding these regions as well as in Manitoba and Prince Edward Island.

Response Options

Any BMPs that have the potential to decrease P so that it is not in excess of crop needs or reduce the transport of P to surface water will decrease the risk of water contamination by P. For example, appropriate use of the enzyme *phytase* in monogastric animal feed enables producers to reduce the quantities of P supplement they introduce in the animal ration and, consequently, reduce the P concentration of manures. As the proportion of animals fed with phytase increases nationally, the quantities of P in manure will decrease. Another example of a BMP that can potentially reduce P source is the introduction of crops with high P uptake into crop rotations on P-enriched soils. These crops take up large amounts of P, which is removed at harvest. Conducting regular soil nutrient testing and manure

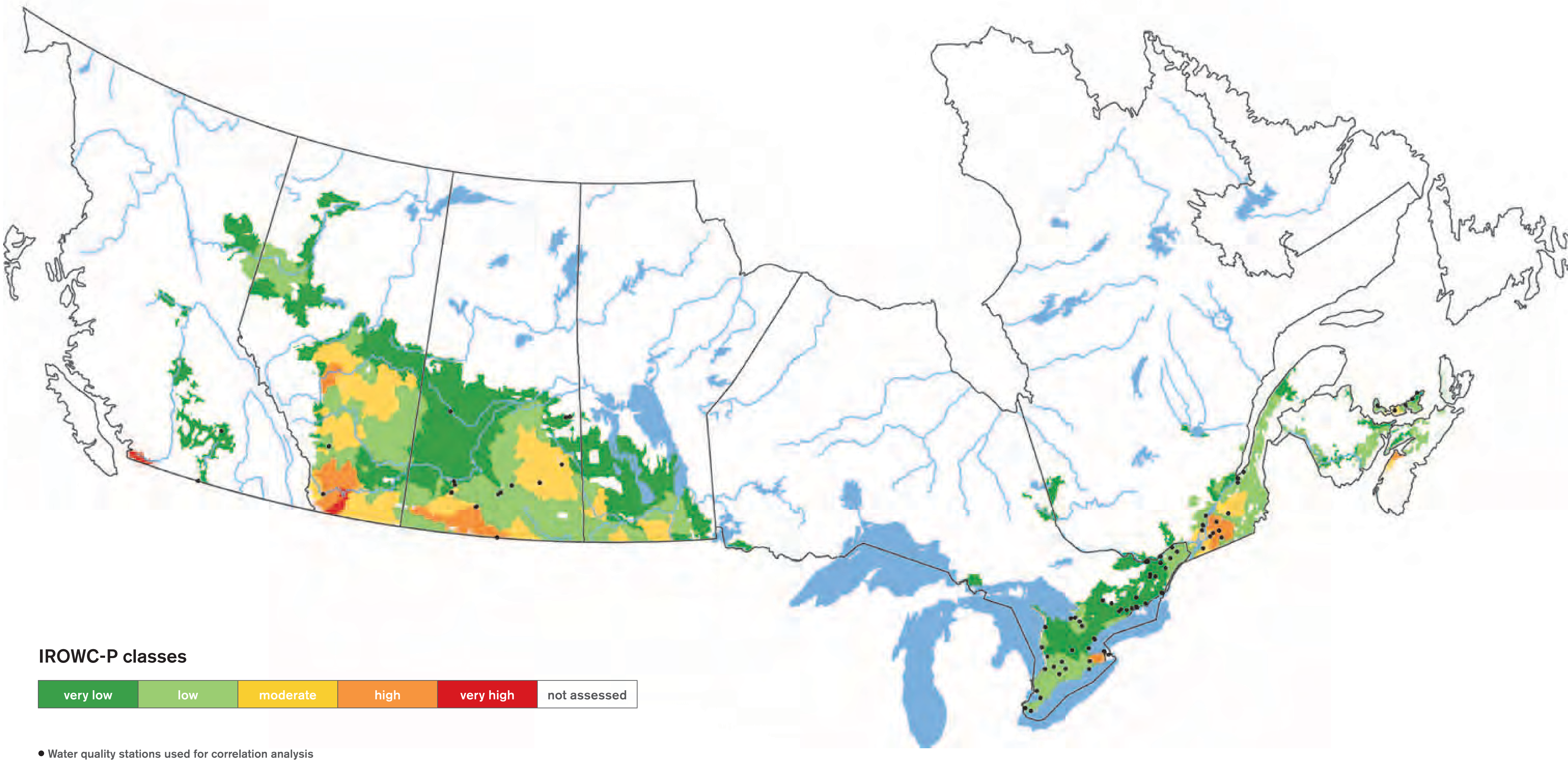


FIGURE 13-1 Risk of water contamination by phosphorus in agricultural watersheds under 2006 management practices

TABLE 13-1 Proportion of farmland in various IROWC-P classes, 1981–2006*

	Proportion (%) of Farmland in Different Risk Classes																													
	Very Low						Low						Moderate						High						Very High					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	93	93	93	93	93	93	7	7	0	0	0	0	0	0	4	0	0	0	0	0	3	4	4	0	0	0	0	3	3	7
AB	98	76	59	32	95	21	1	19	37	28	5	48	1	4	3	37	0	24	0	1	1	3	0	6	0	0	0	0	0	1
SK	88	59	43	50	80	43	12	31	24	48	16	32	0	6	30	2	3	17	0	4	2	0	0	7	0	0	0	0	0	0
MB	100	81	83	53	54	36	0	19	11	34	35	45	0	0	6	14	5	19	0	0	0	0	6	0	0	0	0	0	0	0
ON	53	49	49	33	37	47	36	37	48	22	47	50	11	11	3	42	16	0	0	3	0	3	0	3	0	0	0	0	0	0
QC	37	34	31	8	32	13	55	39	38	38	40	46	8	27	23	17	20	22	0	0	8	29	8	18	0	0	0	8	0	0
NB	100	100	100	30	100	40	0	0	0	70	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NS	63	63	28	18	28	18	37	37	54	48	54	48	0	0	18	16	18	16	0	0	0	18	0	18	0	0	0	0	0	0
PE	34	100	34	21	34	6	66	0	66	79	66	56	0	0	0	0	0	38	0	0	0	0	0	0	0	0	0	0	0	0
NL	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CANADA	**89**	**68**	**56**	**41**	**77**	**33**	**9**	**25**	**29**	**35**	**18**	**42**	**1**	**6**	**13**	**21**	**4**	**19**	**0**	**2**	**1**	**3**	**1**	**6**	**0**	**0**	**0**	**0**	**0**	**1**

* Proportion calculated as percentage of farm land classified for the whole watershed over the total amount of farm land in the province

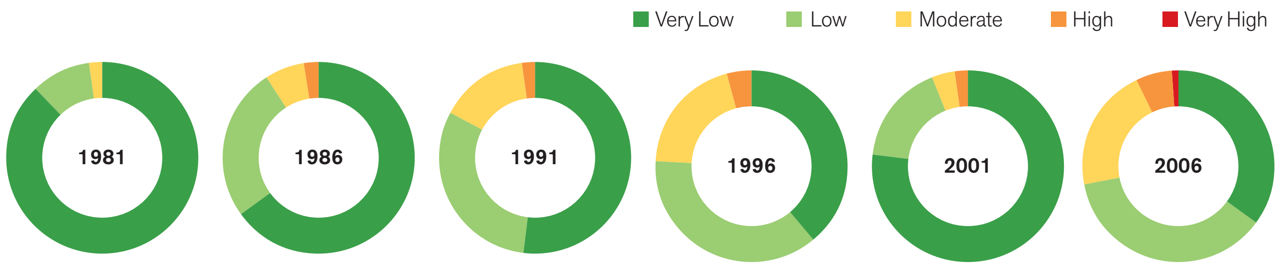


FIGURE 13-3 Percentage area of farmland in risk classes, by census year

TABLE 13-2 Proportion of farm land in various P-Source classes, 1981–2006

	Proportion (%) of Farmland in Different Risk Classes																													
	Very Low						Low						Moderate						High						Very High					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	6	0	0	0	0	0	88	91	81	70	48	32	4	2	11	21	40	54	1	3	1	1	3	4	0	2	4	5	6	6
AB	59	54	47	35	17	7	41	45	53	63	81	83	0	0	0	1	1	9	0	0	0	0	1	1	0	0	0	0	0	1
SK	68	63	64	62	53	39	31	37	36	37	46	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MB	100	100	92	87	77	61	0	0	8	12	23	36	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
ON	37	25	19	17	15	14	56	60	58	49	45	42	7	15	23	29	31	35	0	0	1	5	9	10	0	0	0	0	0	0
QC	48	2	0	0	0	0	50	69	56	31	18	15	0	27	25	38	44	42	0	0	16	17	17	19	0	0	0	12	18	21
NB	72	2	0	0	2	2	26	88	64	47	13	4	2	8	26	41	62	60	0	2	8	10	14	24	0	0	2	2	9	11
NS	64	1	0	0	0	0	36	96	60	12	6	6	0	3	38	81	74	48	0	0	2	7	17	39	0	0	0	0	3	7
PE	66	0	0	0	0	0	34	100	74	32	0	0	0	0	26	67	69	54	0	0	0	0	30	46	0	0	0	0	0	0
NL	32	3	0	0	0	0	54	56	21	21	3	3	5	18	37	37	18	18	0	14	18	0	33	0	9	9	23	41	41	74
CANADA	**68**	**60**	**55**	**49**	**37**	**26**	**31**	**38**	**42**	**45**	**54**	**61**	**0**	**1**	**2**	**4**	**5**	**9**	**0**	**0**	**1**	**1**	**1**	**2**	**0**	**0**	**0**	**1**	**1**	**1**

* Proportion calculated as percentage of farm land classified for the whole watershed over the total amount of farm land in the province

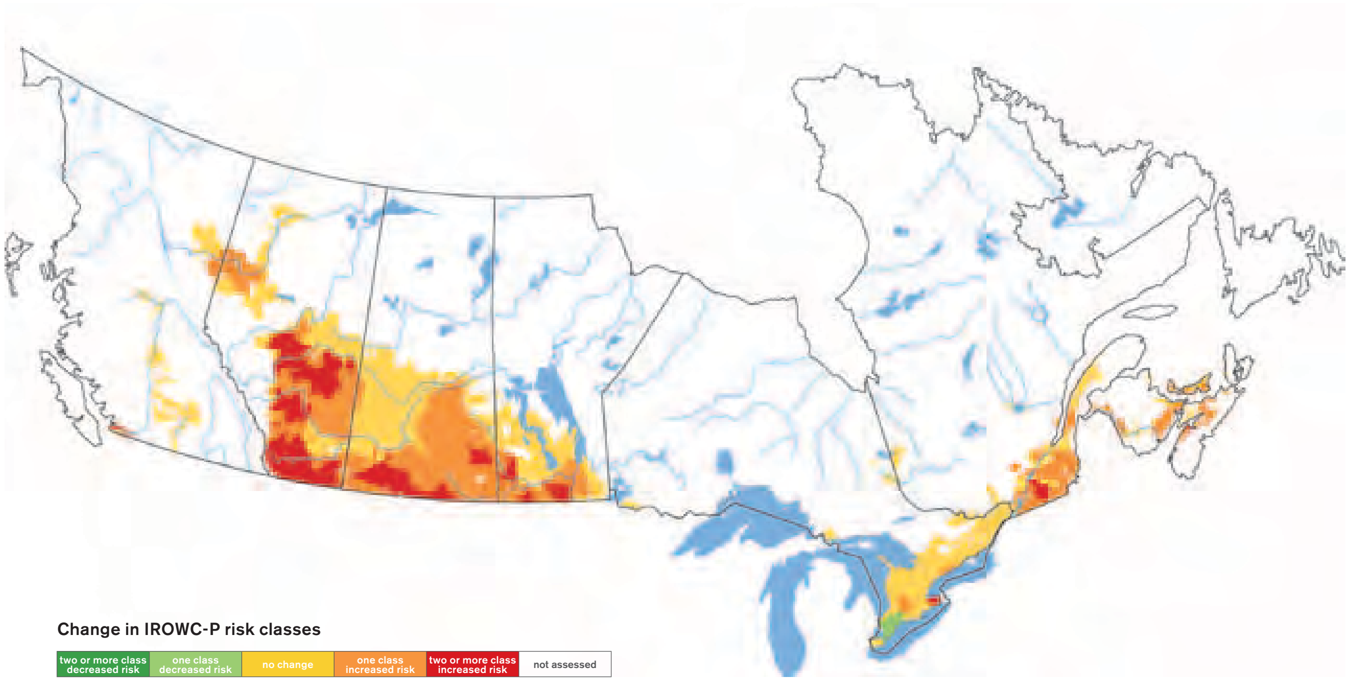


FIGURE 13-2 IROWC-P risk class change, 1981–2006

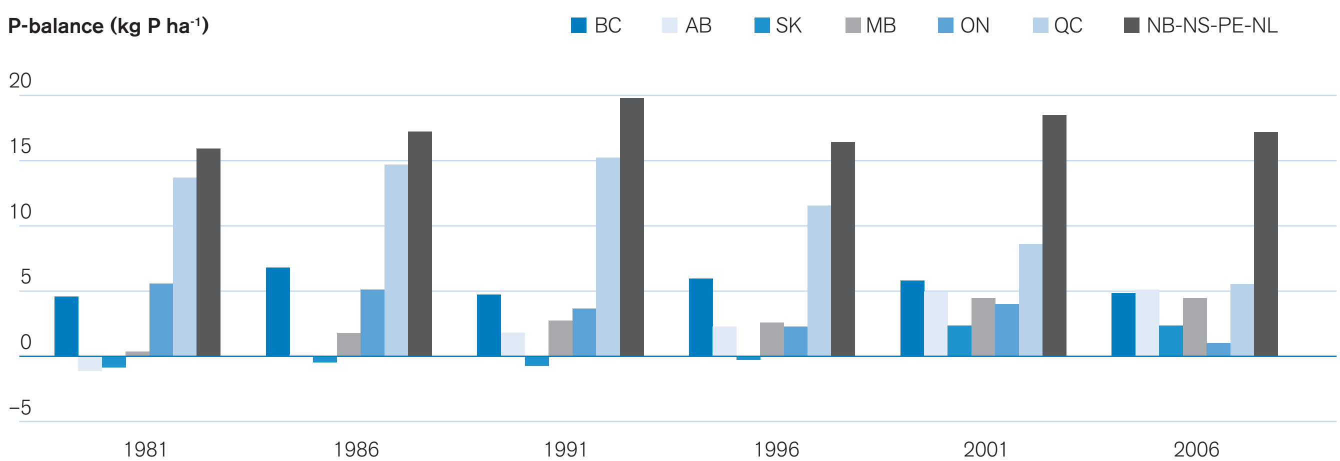


FIGURE 13-4 P balance (kg P ha^{-1}) by province, 1981–2006

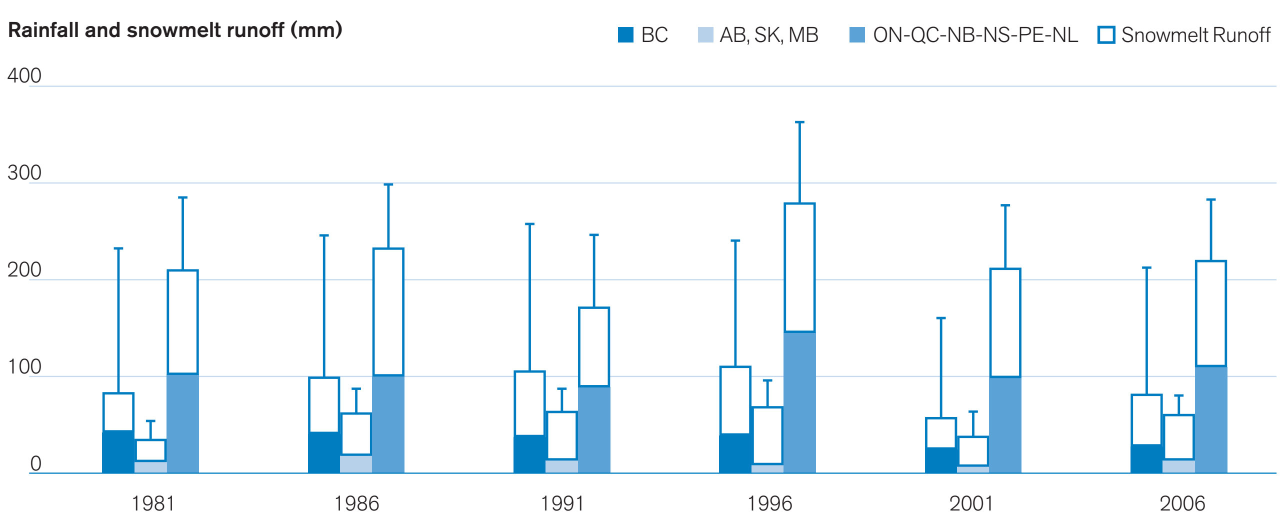


FIGURE 13-5 Rainfall (blue) and snowmelt runoff (white); error bars indicate standard deviation of total runoff.

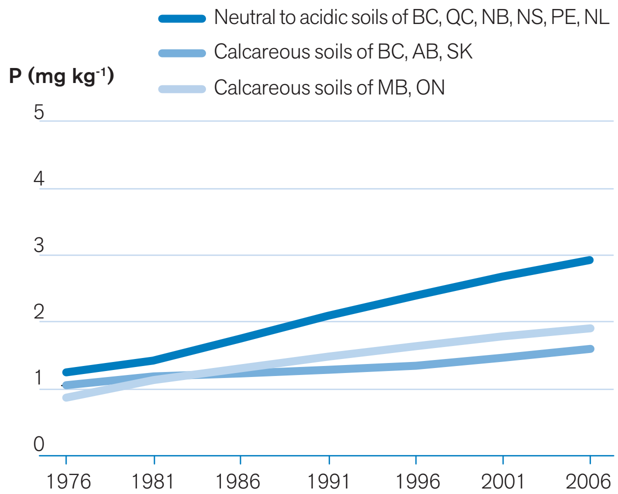


FIGURE 13-6 P source (mg P kg^{-1}), 1976–2006

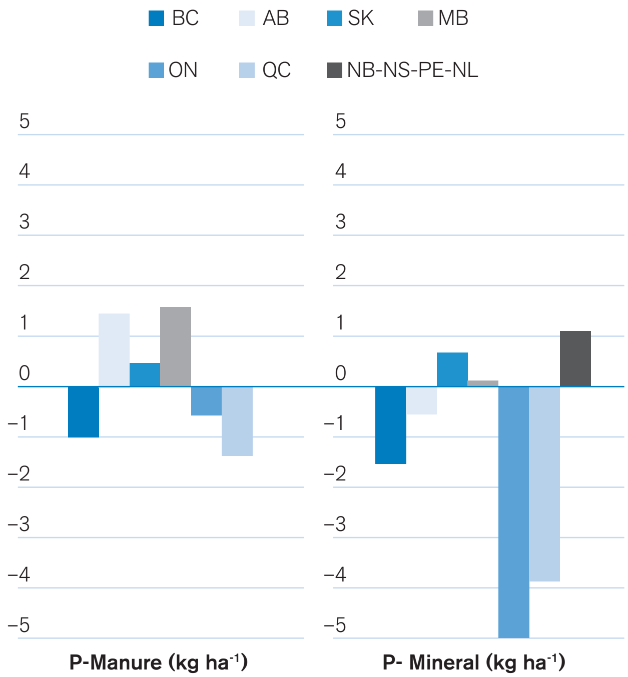


FIGURE 13-8 Change of P inputs, 1981–2006

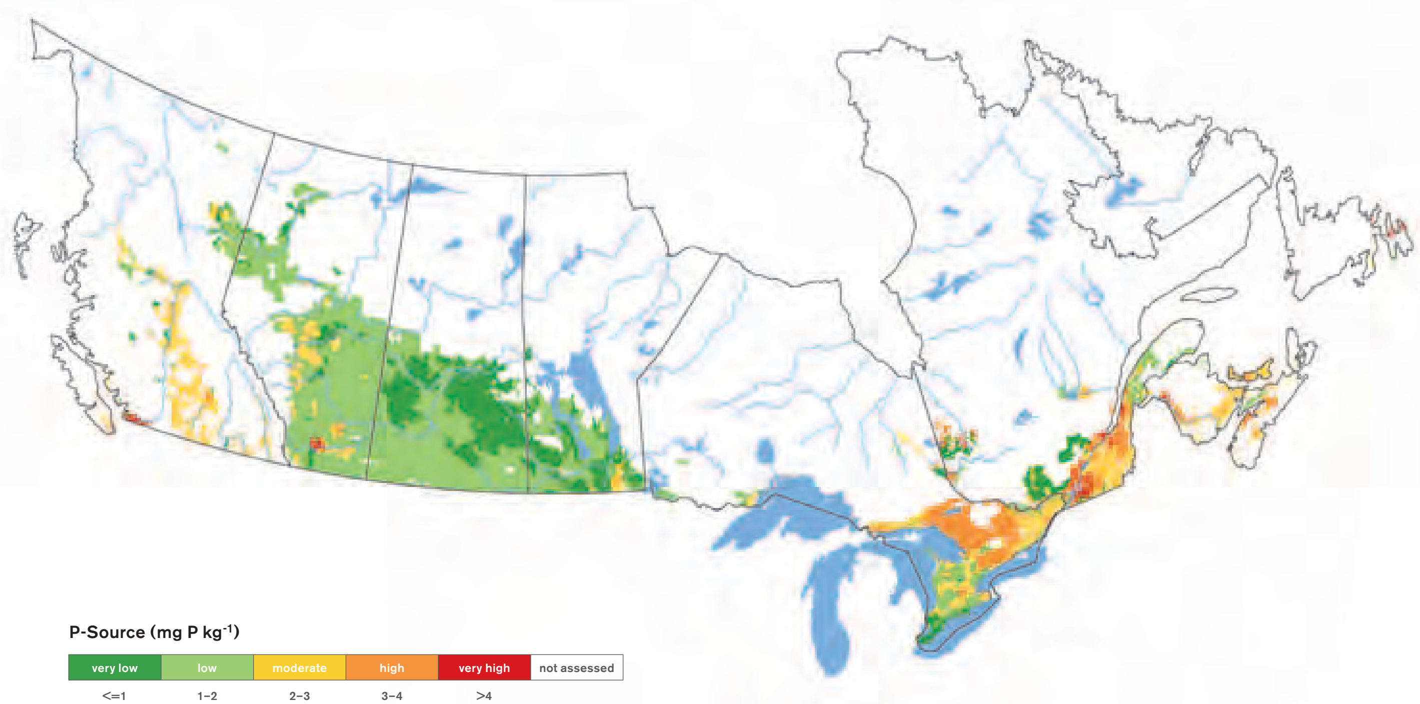


FIGURE 13-7 Risk of P release in agricultural land under 2006 management practices

nutrient testing can help producers have a better idea of the level of nutrients already present in the soil, and how much is potentially being added, which can have both economic benefits and help manage P levels in the soil. In the long run, such crop management can progressively reduce the quantity of soil P available for transport to surface waters and return agro-ecosystems to lower risk classes.

Implementation of BMPs to impede the movement of P into the drainage network, such as the establishment of buffer strips around surface water bodies will reduce the risk of P contamination of surface waters. However, buffer strips can impede agricultural activities. In order to render this BMP more economically acceptable for producers, plant species that offer potential economic return to producers should be prioritized for buffer strips.

IROWC-P enables the identification of areas with a high risk of water contamination by P from agricultural sources. A more detailed examination of agricultural practices in these regions could reveal which regional characteristics contribute to the risk of water contamination by P. This could facilitate targeted mitigation practices or research efforts.

IROWC-P could be further developed by incorporating information about new or existing BMPs that have been adopted and have significantly impacted P source and P transport. Currently, there is a lack of national data on the extent and location of such BMPs. This means that few BMPs associated with the transport component of the IROWC-P are adequately taken into account by the indicator algorithm. Infrastructures that address surface runoff could easily be included in the IROWC-P assessment. For example, as national data on buffer strips around surface water bodies become more extensively available, their integration into the IROWC-P calculation will reflect their impact on P transport to surface waters.

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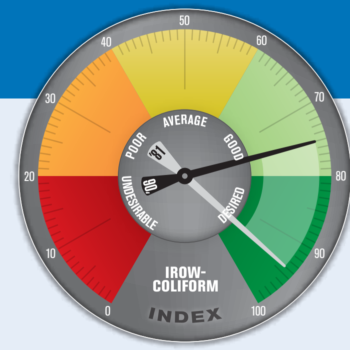
14 Coliforms



AUTHORS
E. van Bochove, E. Topp, G. Thériault, JT. Denault,
S. Allaire, F. Dechmi and A.N. Rousseau

INDICATOR NAME
Indicator of the Risk of Water Contamination by Coliforms

STATUS
National coverage, 1981 to 2006

Summary

Animal manure can be used as a valuable organic fertilizer for agricultural soils. However, animal manure may also be a potential source of pathogens including viruses, bacteria and protozoa. In modern agriculture, the intensive use of manure as a soil fertilizer has heightened the risk of contaminating surface water with pathogens. More recently, Canadian citizens have become increasingly concerned about the quality of the water they consume or use for everyday activities. Water quality is often assessed using coliform bacteria levels as an indicator of fecal contamination.

The Indicator of the Risk of Water Contamination by Coliforms (IROWC-Coliform) was created to assess the risk of water contamination by enteric microorganisms from agricultural sources. The IROWC-Coliform indicator has two major components: one quantifies the source of fecal material and the coliform bacteria coming from it, and the other describes transport processes and connectivity between agricultural land and water bodies.

Environmental exposure to manure across Canada varies widely. Manure is deposited on pastures by high densities of animals in the Prairies, and is spread from confined livestock operations in Eastern Canada. In the Prairies, the pasture/runoff combination accounts for almost 90% of the risk to water. In Eastern Canada, the risk is primarily related to spread manure and is highly sensitive to climatic conditions during the spreading periods.

Overall, in 2006 a few watersheds at high and very high risk of water contamination by coliforms were found in British Columbia, Alberta and Ontario, principally due to the high level of coliforms from concentrated livestock feeding operations. Saskatchewan, Quebec and New Brunswick followed closely with watersheds showing a persistent moderate risk. All other watersheds in Canada were either at very low or low risk.

The Issue

With the recent intensification of Canadian agricultural production, Canadians are more conscious than ever before about agriculture and its effects on their environment, including contamination of water by fecal material. The potential for this is assessed by the presence of thermotolerant coliforms, bacteria universally found in animal feces. Some of the consequences of water contamination by coliforms include increased cost for water treatment, loss of use of recreational waters, constraints to the expansion of the livestock industry and potential for human health effects. In mixed watersheds, sources of surface water contamination are often numerous and can include municipal wastewater discharge, leaking septic systems, wildlife and livestock operations.

Livestock manure is commonly used in agriculture as a valuable source of nutrients for crop growth. The microbial composition of manure varies widely with respect to the type of livestock (e.g. poultry, swine and cattle) and herd health. As a consequence, the use of animal manure as crop fertilizer may pose some risks to environmental and human health when coliforms from the manure contaminate nearby surface water. The risk of contamination of water by coliforms is likely highest in areas with high manure production, dense water drainage networks and high susceptibility to surface runoff, preferential flow and soil erosion.

In Canada, there has been a notable intensification of dairy, beef, swine and poultry production onto fewer and larger farms (Figure 14-1). One of the consequences is the production of larger volumes of manure that need to be disposed of in increasingly restricted areas. Manure management in agricultural production is of critical importance for environmental and water quality protection and to ensure agro-ecosystem sustainability.

The Indicator

IROWC-Coliform assesses the relative risk of fecal material from agricultural sources contaminating surface water bodies using thermotolerant coliforms as a marker. It also evaluates how this risk is changing over time. It provides a tool to predict and evaluate which farm practices can be managed differently to minimize the risk.

IROWC-Coliform is determined by considering both an estimate of potential numbers of coliforms of agricultural origin (coliform source) and an estimate of the likelihood of their movement to

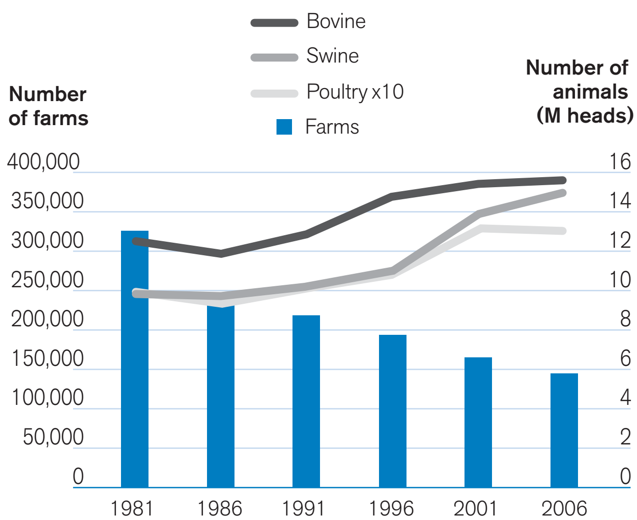


FIGURE 14-1 Temporal trends in the bovine (beef and dairy), swine and poultry production (lines) and the number of farms (bars), 2006.

surface waters (transport). Risk is indicated in one of five classes (very low, low, moderate, high and very high). The risk classes are relative rankings such that 50% of watersheds are classified in the very low risk class and the highest 5% of IROWC-Coliform values fall into the high and very high risk classes.

The coliform source component considers the manures of the four main livestock types (cattle, swine, sheep and poultry) comprising at least 80% of Canadian livestock production. The average populations of coliforms from pastured animals and from confined animals were estimated on a daily basis using manure production coefficients, fecal coliform coefficients (ASAE, 2003) and a daily decay rate (Himathongkham *et al.,* 1999). Coliforms from pasturing-animal manure were considered to be available for transport the same day they were produced, while those from confined-animal manure were assumed to be available for transport only when manure was spread on fields. Four spreading periods per year were assumed for each province based on the first and the last day of soil freezing, and harvest dates.

The transport component was adapted from IROWC-Phosphorus (van Bochove et al., 2008) (see Chapter 13) and integrates three transport processes (surface runoff, deep drainage and soil water erosion) as well as factors accounting for connectivity between coliform sources and water bodies (a topographic index, tile drainage, surface drainage and preferential flow). The impact of different manure management strategies (e.g. soil incorporation, surface spreading and *composting*) on the availability of coliform bacteria for transport by surface runoff was also included in the calculations.

Limitations

Coliform contamination from municipal wastewater discharge, leaking septic systems and wildlife were not considered within the scope of this indicator. Also, it was assumed that grazing livestock have no direct access to surface water bodies. Manure spreading periods and climatic data were respectively available at provincial and *ecodistrict* levels and uniformly applied to polygons within the data scale. When unavailable, thermotolerant coliform concentrations in the fresh manure of some animal categories were extrapolated from closely related animal categories.

The IROWC-Coliform values reflect the timing of surface runoff from storm events in relation to the active population of coliforms present on agricultural land when such events occur. Days when surface runoff occurs are random because such events are triggered by particular climatic conditions that vary from year to year. National daily climate data for 2006 were not available. Therefore, the 2006 risk map was produced using an average climate condition estimated from humid (1996) and dry (2001) year climate data.

Results And Interpretations

In 2006 three watersheds at very high risk and eleven watersheds at high risk of water contamination by coliforms were located in British Columbia, Alberta and Ontario where agriculture intensity and coliform transport factors pose a significant risk to water quality and mitigation measures are likely required (Figure 14-2). Nationally, this represented 7% of farmlands (Figure 14-3). Twenty-six watersheds were estimated to be at moderate risk, comprising 16% of farmland. All other watersheds in Canada were either at very low or low risk. IROWC-Coliform was variable from one year to another between 1981 (Figure 14-4) and 2006 (Figure 14-2). However, there was a general increasing risk as the area of farmland in the very low risk class decreased significantly while all other risk classes, particularly the low and moderate classes, increased (Table 14-1).

Watersheds at moderate to high risk generally correspond to areas with high rates of coliform input due to intensive animal production—and consequently high volumes of manure. The most intense production that involved manure left on pasture—and therefore made coliforms readily available for transport by runoff—occurred in western Alberta. Smaller pockets of high manure production were also observed in southeastern Saskatchewan and in Manitoba (Figure 14-5). Various regions showed a high incidence of coliforms from spread manure, including the Lower Fraser Valley of British Columbia, southwestern and eastern Ontario, and eastern Quebec (Figure 14-6).

The change in the IROWC-Coliform risk between 1981 and 2006 was due to changes in the coliform source and weather variability in these census years. Coliform source increased on 31% of farmland in Canada over 25 years as a result of increased numbers of livestock (Figure 14-7). However, the intensive agricultural regions of Ontario reduced coliform source mainly due to a small decline in the cattle sector. Other regions such as the Saint John River Valley in New Brunswick and the central portion of British Columbia also showed a reduction in coliform source because of respective reductions in the dairy cattle population and in animal production in general.

Watersheds at moderate to high risk generally correspond to areas with high rates of coliform input due to intensive animal production–and consequently high volumes of manure

Weather conditions have a significant impact on the risk of water contamination by coliforms in any particular year. From 1981 to 2006 the area of farmland in Canada at very low risk was the least in 1996, a wet year, at 15%. This can be compared to the area at very low risk in a drier year (2001) at 67% (Table 14-1).

The timing of runoff events in relation to the availability of coliform source also plays a critical role in determining risk. In the western provinces, some animals remain outside during winter, keeping the amount of coliform available for transport high throughout the year (Figure 14-8). In the Prairies spring snowmelt runoff represents almost the entire annual runoff, and this pasture-runoff accounts for almost 90% of the risk value.

In Eastern Canada, the risk is more evenly distributed across seasons. Most animals (approximately 98% of the dairy herd and 85% of the beef herd) are confined during winter months and the manure is stored for warmer season spreading. The largest volume of stored manure (approximately 60% of the manure stored annually) is spread in the spring before planting (March to April) with other major applications in May when crops emerge and in the fall (Figure 14-9) The timing between the period of spreading and the weather conditions during or following these periods has a critical impact on the risk value.

Response Options

At the national scale, manure excreted by pastured animals was the largest source of coliform potentially available for transport to surface water. Independent of storm events, direct access of animals to surface water bodies, while not currently reflected in the indicator model, presents a risk of contamination of water by coliforms. Implementation of good practices such as fencing surface water bodies will reduce this risk.

For manure spreading, any practice that incorporates manure into the soil immediately or shortly after application will substantially reduce the risk of coliform transport to streams. Also, efforts to minimize soil water erosion on lands receiving manure will reduce transport to adjacent surface water. Practices that reduce the amount of manure per animal production unit, and manure handling practices that stabilize the waste (e.g. composting) will reduce the coliform population and thus the risk of water contamination by coliforms from livestock production.

The agriculture industry has moved towards the intensification of animal production operations, both with respect to the size of individual farms and their proximity within regions. Under these conditions, where the nearby land base is too small to accept the waste sustainably, strategies to reduce the microbial loads in manure become more important. For example, the increasing costs of energy and inorganic crop nutrients (N and P) can result in increased adoption of advanced manure management techniques such as biogas digestors and slurry fractionation that stabilize manures and capture nutrients. A number of practices can mitigate the transport of microorganisms to adjacent water. These include using fencing to deny access of pastured animals to streams, and discouraging access through off-site watering. Spread-manure transport risks can be managed by establishing suitable spreading set back distances from water bodies or streams, establishing buffer strips around waterways, and considering slope, antecedent soil moisture and climate conditions at the time of application.

The use of IROWC-Coliform identifies the regions where the risk of water contamination from fecal contamination is high. A detailed analysis of the IROWC-Coliform components and the agricultural activities of these high-risk regions could reveal regional characteristics responsible for the high risk. Depending on the recurrence of such regional characteristics, research or intervention priorities can be put in place to mitigate the risk.

A sensitivity analysis of the IROWC-Coliform results can identify which component of the indicator plays the greatest role in the final risk value. Different beneficial management practices (BMPs) can then be suggested to mitigate the situation. However, several BMPs are costly with respect to labour, cultivated land loss or farm expenses. Research priorities have to investigate ways to make BMPs more acceptable and receivable at the farm level. For example, implementation of buffer strips with valuable plant species such as switchgrass, shrubs and trees should be evaluated.

Finally, research priorities should seek to develop specific source components for other waterborne pathogens that present a threat for both human and ecosystem health.

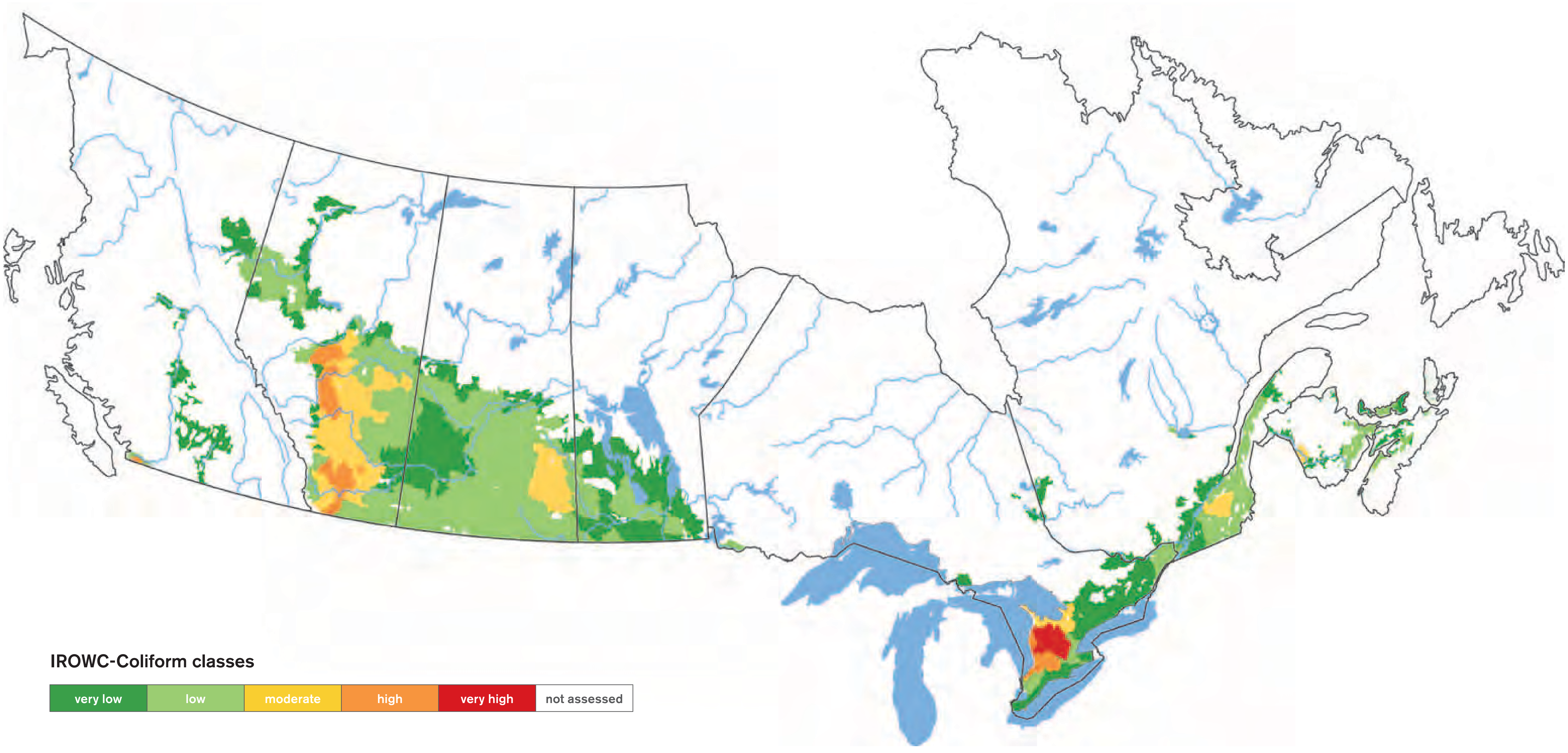


FIGURE 14-2 Risk of water contamination by coliforms in agricultural watersheds under 2006 management practices

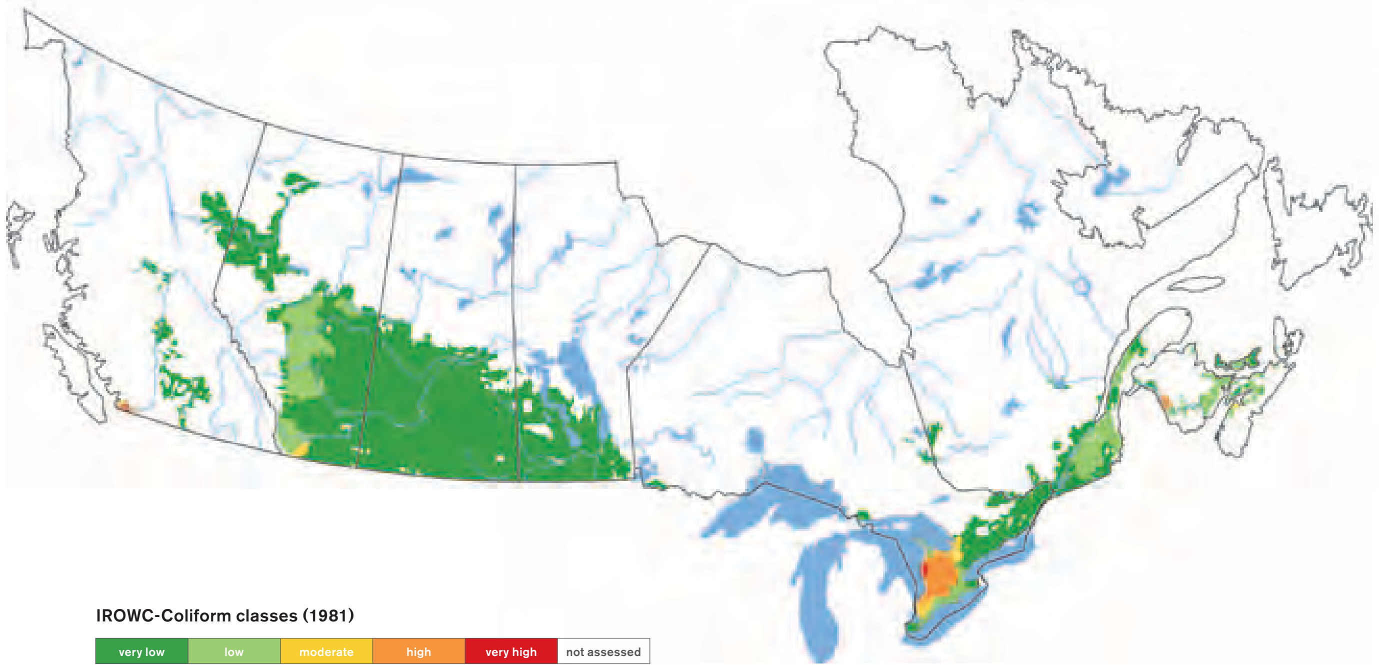


FIGURE 14-4 Risk of water contamination by coliforms in agricultural watersheds under 1981 management practices

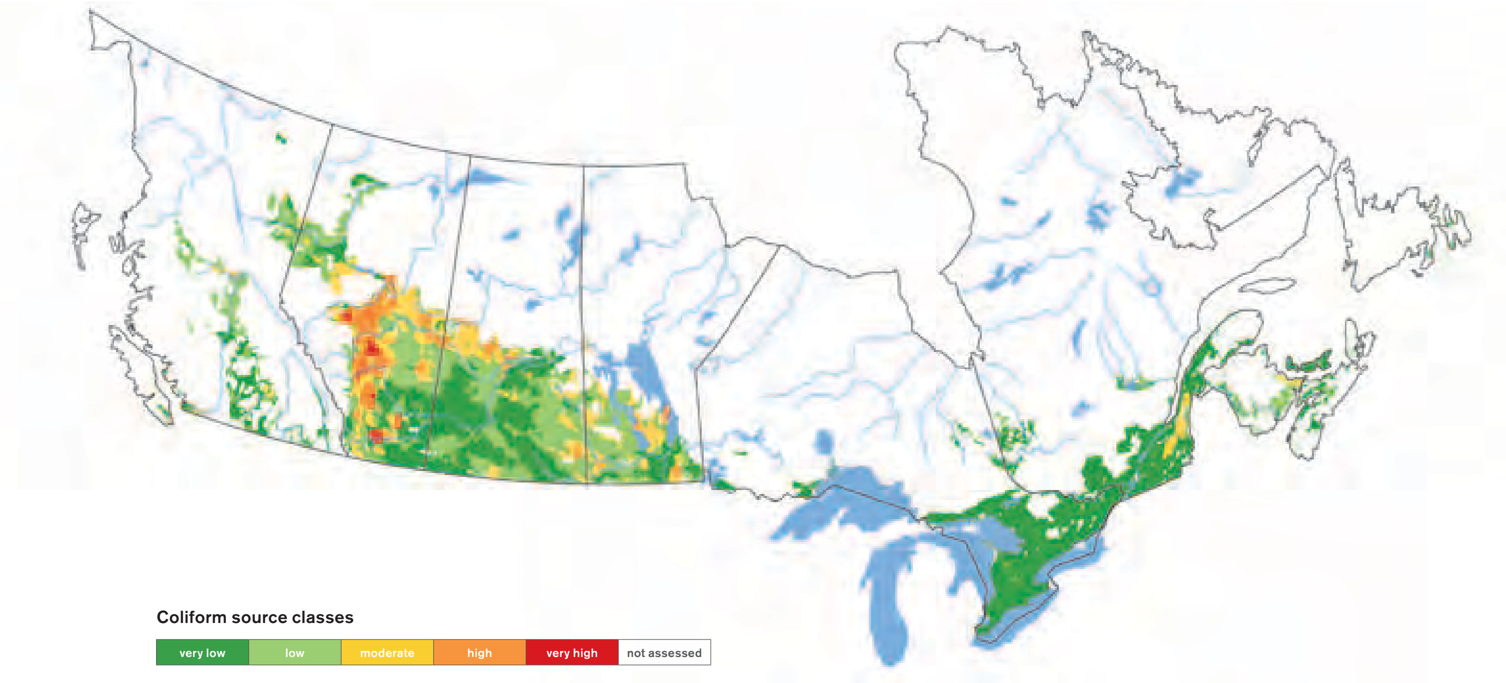


FIGURE 14-5: Coliform source on pasture lands under 2006 management practices

TABLE 14-1 Proportion of farm land in various IROWC-Coliform classes, 1981–2006*

	Proportion (%) of Farmland in Different Risk Classes																													
	Very Low						Low						Moderate						High						Very High					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	93	93	93	93	93	93	0	0	5	0	5	5	5	5	0	5	0	0	0	0	0	0	0	3	3	3	3	3	3	0
AB	77	26	25	13	46	14	22	40	32	24	48	47	1	26	26	34	5	30	0	9	17	28	0	10	0	0	0	0	0	0
SK	100	94	100	6	94	24	0	6	0	61	6	66	0	0	0	30	0	10	0	0	0	4	0	0	0	0	0	0	0	0
MB	100	82	85	24	82	64	0	18	15	67	18	36	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ON	42	15	34	26	39	43	18	37	32	37	25	21	12	12	11	19	6	8	26	11	14	18	7	12	2	25	10	0	23	16
QC	52	54	50	26	42	43	48	32	50	62	46	44	0	14	0	12	12	12	0	0	0	0	0	0	0	0	0	0	0	0
NB	17	17	17	17	50	30	60	43	43	43	26	46	0	17	17	17	23	23	23	23	23	23	0	0	0	0	0	0	0	0
NS	28	10	28	26	82	44	54	46	54	57	18	56	18	26	18	18	0	0	0	18	0	0	0	0	0	0	0	0	0	0
PE	34	34	34	34	34	34	66	66	66	66	66	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NL	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CANADA	**83**	**57**	**61**	**15**	**67**	**29**	**12**	**24**	**19**	**45**	**27**	**49**	**2**	**11**	**11**	**27**	**3**	**16**	**3**	**5**	**8**	**14**	**1**	**5**	**0**	**2**	**1**	**0**	**2**	**2**

* Proportion calculated as percentage of farm land classified for the whole watershed over the total amount of farm land in the province

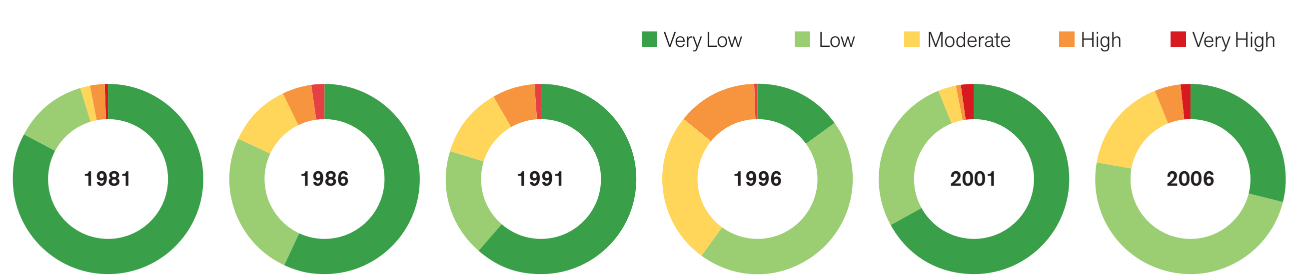


FIGURE 14-3 Percentage area of farmland in IROWC-Coliform risk classes 1981–2006.

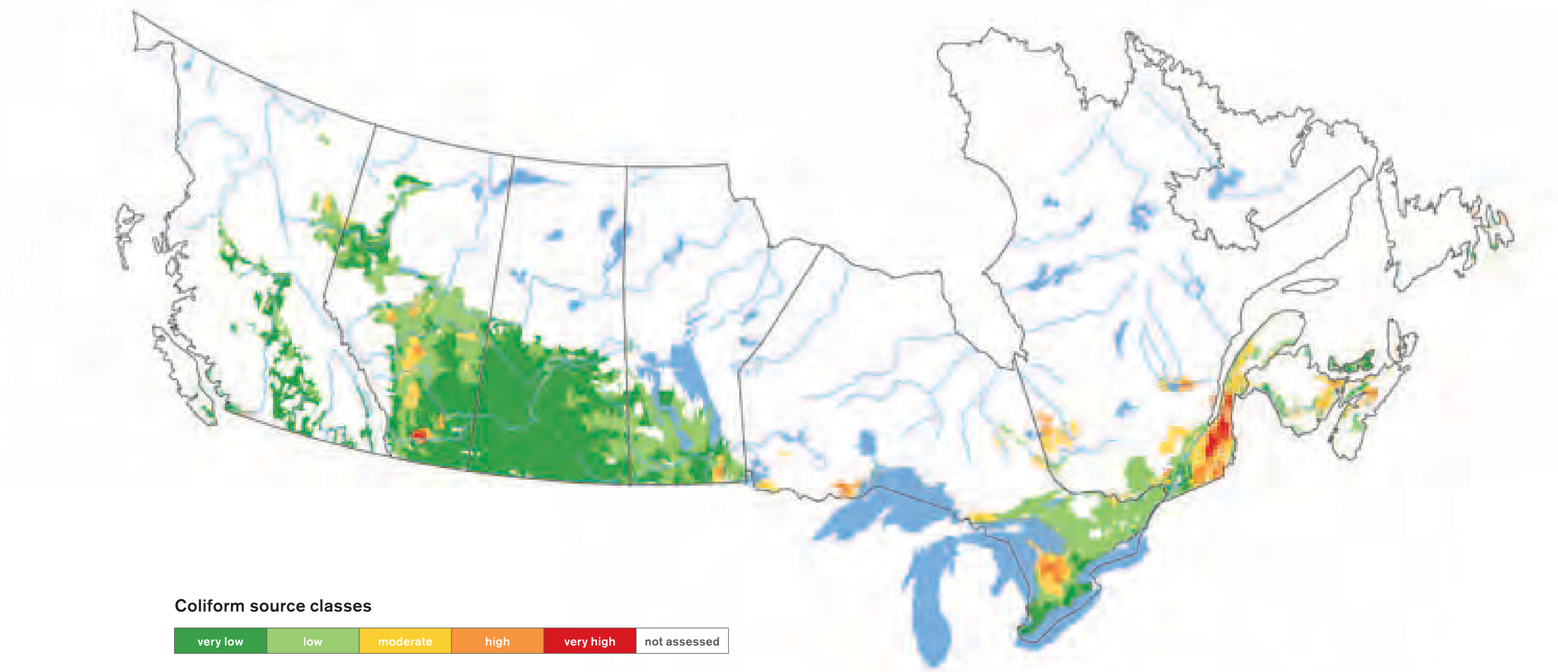


FIGURE 14-6 Coliform source spread on agricultural land under 2006 management practices

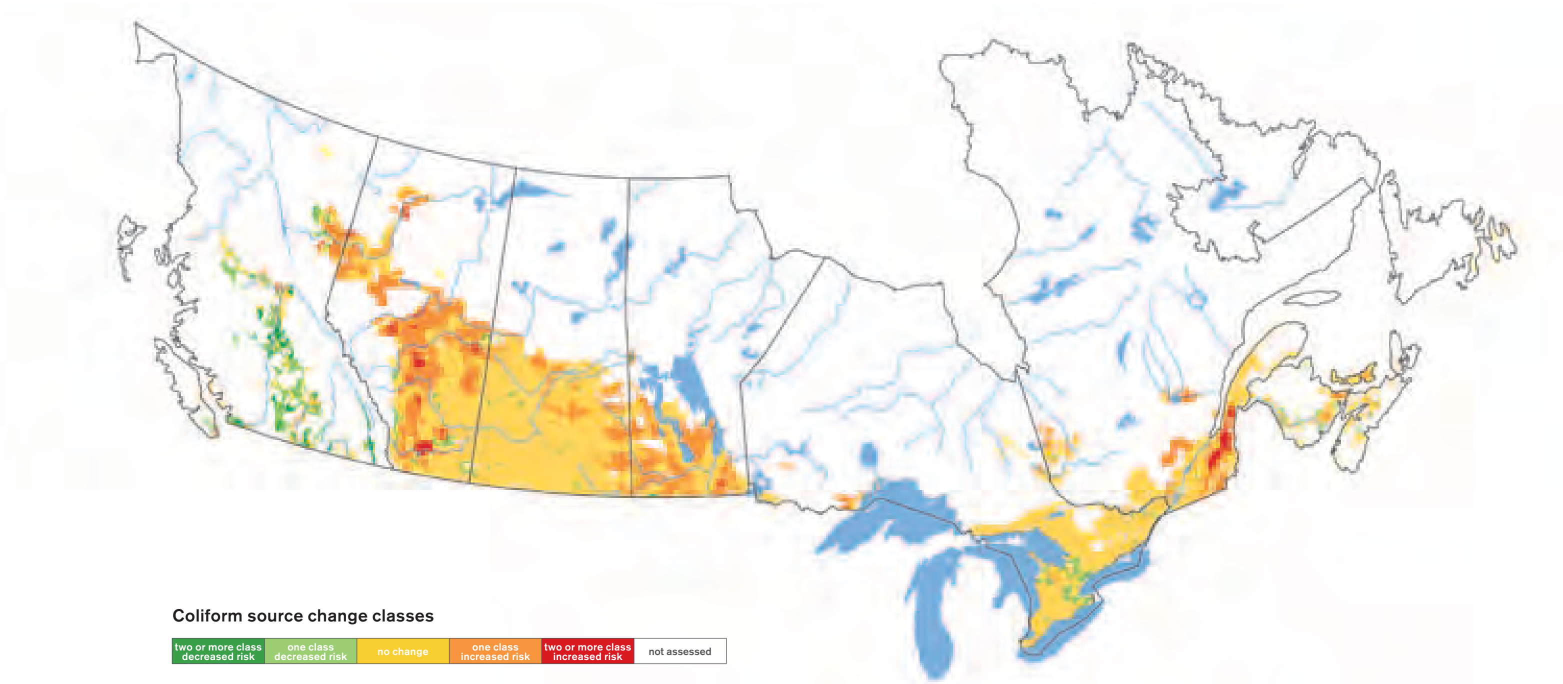


FIGURE 14-7 Coliform source risk-class change, 1981–2006

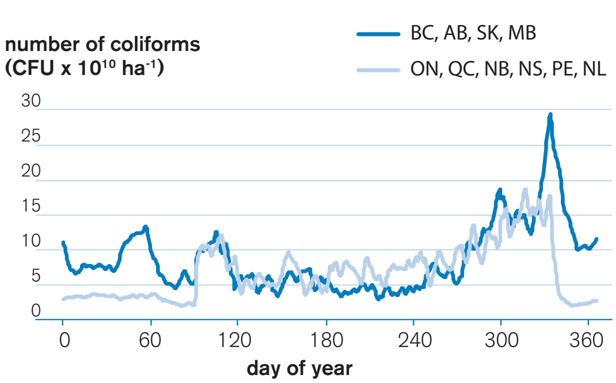


FIGURE 14-8 Daily mean coliform population intensity on pasture lands, 2006

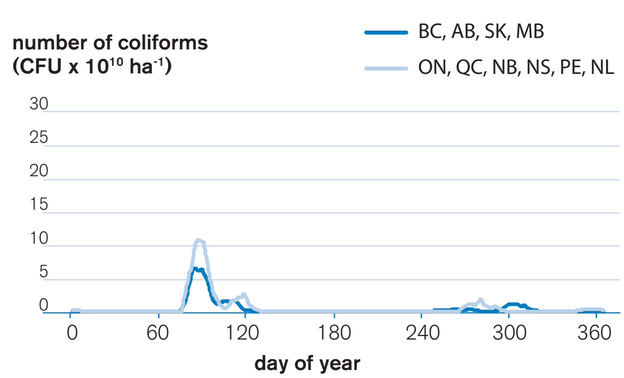


FIGURE 14-9 Daily mean coliform population intensity on croplands, 2006

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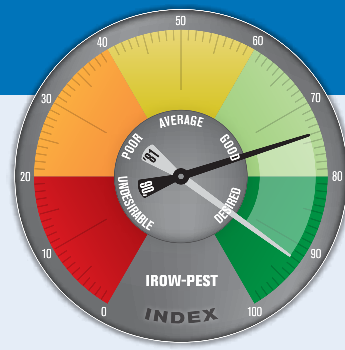
15 Pesticides



AUTHORS

A.J. Cessna, C. Sheedy, A. Farenhorst and D.A.R. McQueen

INDICATOR NAME

Indicator of the Risk of Water Contamination by Pesticides

STATUS

National Coverage 1981 to 2006

Summary

The use of agricultural pesticides for the control of weeds, insects and diseases is an important component of Canadian agriculture. However, there is concern that a portion of pesticides applied to agricultural land may move into the broader environment and eventually contaminate surface and ground waters, with potential environmental and human-health implications.

The Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest) was developed to assess the relative risk of contamination of surface and ground waters by pesticides in Canada's agricultural areas. These estimates of risk consider the quantity of the pesticide applied, pesticide physical-chemical properties, soil-landscape characteristics, cropping patterns and climate. The national analysis indicates that the risk of contamination to groundwater is generally much less than that to surface water. In 2006, more than 99% of farmland in Canada was classified as very low risk for groundwater contamination and this had been the case since 1981. Thus, the estimate of risk of surface water contamination represents the overall risk of water contamination by pesticides. This overall risk has increased from 1981 to 2006 such that cropland in the very low and low risk classes decreased from 98% in 1981 to 86% in 2006, with a simultaneous increase in the high and very high risk classes from 0 to 5%.

The Issue

Pesticide use is important to Canadian agriculture to prevent economic losses from weeds, insects and diseases. Although pesticide use has helped increase agricultural productivity, pesticides may move from agricultural land into the broader environment, thus contributing to environmental contamination of surface and ground waters (Figure 15-1).

Over the last two decades, monitoring studies have shown that pesticide residues are present in some Canadian ground and surface waters (Cessna et al., 2005). Pesticides have been detected in surface waters in all provinces and in 2% to 40% of water wells surveyed in British Columbia, Alberta, Saskatchewan, Ontario, Nova Scotia and Prince Edward Island. Although some monitoring programs for surface waters are in place, water quality guidelines have not been established for the majority of the pesticides used in Canadian agriculture.

There is increasing awareness among the Canadian public that pesticides and other agrochemicals can enter the environment and have the potential to affect environmental quality and human health. Since long term environmental and human health impacts of pesticide use are not well understood, Canadians remain concerned with the safety of their drinking water and food supply, and the effects of pesticides on wildlife habitat and biodiversity. Agriculture and Agri-Food Canada is addressing these concerns by encouraging farmers to adopt management practices that either mitigate the movement of pesticides or reduce the amount of pesticides used.

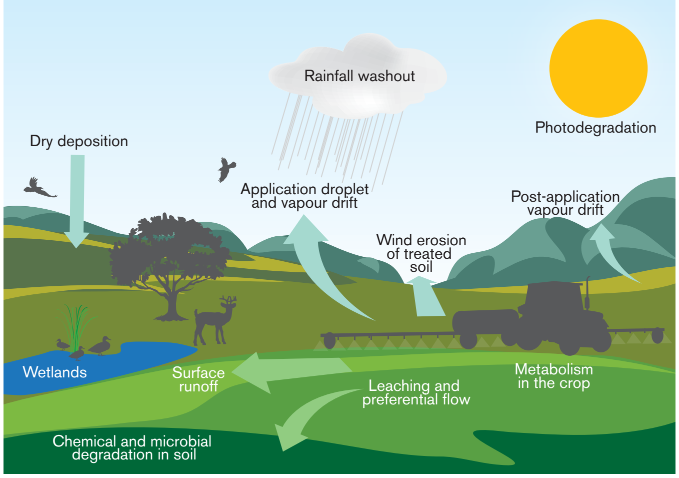


FIGURE 15-1 Processes involved in the movement of pesticides from the site of application (Cessna et al. 2005)

The Indicator

The Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest) has been developed to assess the relative risk of water contamination, i.e presence of pesticides in water, by agricultural pesticides and is responsive to changes in agricultural

TABLE 15-1 IROWC-Pest risk classes, based on the concentration of pesticides in water and the total amount of pesticides transported

		Pesticide Transported (g/ha)				
		0–3.99	4.00–7.99	8.00–11.99	12.00–16.00	>16.00
Concentration (µg/L)	0–0.49	very low	very low	low	moderate	high
	0.50–1.00	very low	low	moderate	high	very high
	>1.00	low	moderate	high	very high	very high

management practices that affect pesticide use and transport. (Note: risk does not signify biological risk due to the toxicity of pesticides.) The indicator uses the Pesticide Root Zone Model (PRZM) (Carsel et al., 1998) to estimate the amount of pesticides moving into the surrounding environment based on pesticide application rates, climate data, soil and landscape data, pesticide physical-chemical properties and management practices data. As an estimate of potential groundwater contamination, IROWC-Pest calculates the proportion of pesticide applied that leaches through the soil to a depth of one metre. As a measure of potential surface water contamination, PRZM estimates of the number of days that rainfall runoff occurred and IROWC-Pest estimates the proportion of the pesticide originally applied that has been transported in surface runoff (both in the dissolved phase and bound to eroded soil particles) to edge-of-field.

The five relative risk classes (Table 15-1) generated by the indicator for surface and ground waters are based on two factors: i) the mass of pesticide moved per hectare either to edge-of-field in surface runoff water or to a depth of one metre in soil in the infiltrating water and ii) the concentration of pesticide in the runoff water at the edge-of-field and in the infiltrating water at a depth of one metre. Because more than one pesticide may be applied per hectare, pesticide mass in the water is the sum of the masses of all types of pesticides applied. Similarly, pesticide concentration in the water is the sum of the concentrations of all pesticides applied. The pesticide mass ranges used to define the risk classes are based on data published in the scientific literature whereas the concentration ranges consider the European Union water quality guideline for mixtures of pesticides in drinking water (0.5 µg/L; European Union 1998). The pesticide use data used to determine risk to surface and ground water were derived from three sources of information: i) the Census of Agriculture for information on crops grown, ii) the Pesticide Management Regulatory Agency for pesticide application rates, and iii) commercially available pesticide use databases which provided information at either the provincial or national scale (rather than at the Soil Landscapes of Canada (SLC) polygon scale) on which pesticides were applied to each crop and the proportion of each crop treated with each pesticide. The overall relative risk of water contamination by pesticides is assessed by assigning the highest risk (to either surface water or ground water) to the respective SLC polygon.

Limitations

Estimates of pesticide use in individual SLC polygons in a particular census year are based on the relation between crops grown in a SLC polygon in that census year and the pesticides applied to those crops in 2006. Since pesticide use data were only available for 2006 and were collected at the provincial level, changes in the types and amounts of pesticides applied in previous census years are not reflected in the national analysis of the indicator for each of those years. Consequently, differences in the national analysis between any two census years are the result of the change in area of each crop type between those two years, not the change in types and amount of pesticides applied. Since the amount applied and physical-chemical properties of a pesticide have a significant impact on pesticide movement in the environment, the resulting uncertainty of pesticide use in census years other than 2006 limits the reliability of the indicator calculations, particularly when comparing trends over a number of census years.

The timing of pesticide applications in relation to pest pressures and weather is an important management practice which is not currently considered in IROWC-Pest.

Atmospheric deposition of pesticides is not considered in calculations using IROWC-Pest. This could result in an underestimation of total deposition as atmospheric deposition may account for a significant proportion of pesticide concentrations in surface waters (Donald et al., 1999; Waite et al., 2005).

Results and Interpretations

Nationally, in 2006, all cropland, regardless of province, was at very low risk of groundwater contamination by pesticides, a condition that has not changed since 1981. Thus, the estimate of risk of surface water contamination represents the overall risk of water contamination by pesticides reported in Table 15-2. Most cropland (86%) in 2006 showed very low to low risk of contaminating surface waters (Figure 15-2). Cropland showing moderate risk of water contamination (8%) was situated primarily in

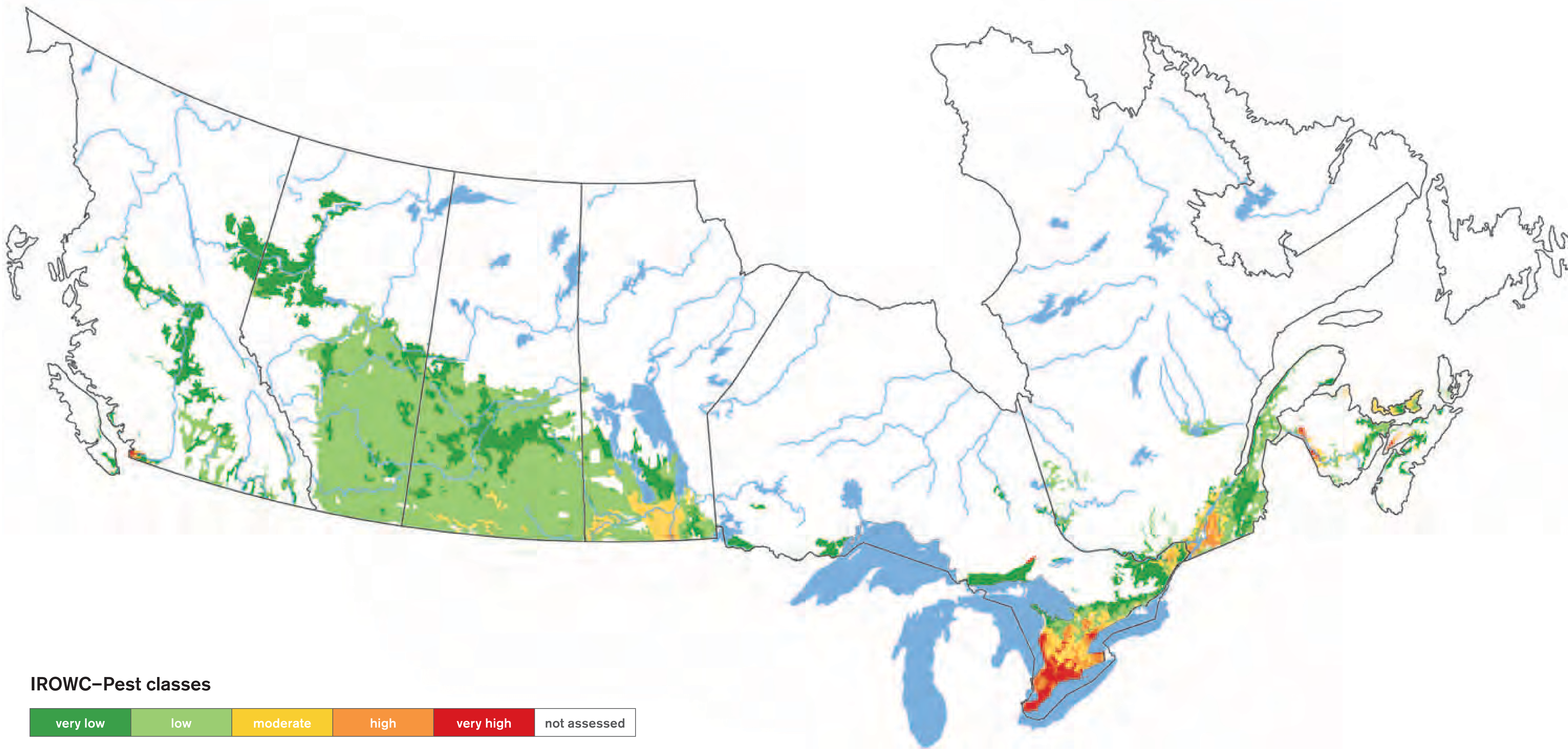


FIGURE 15-2 Relative risk of water contamination by pesticides on cropland under 2006 management practices

TABLE 15-2 Percentage of farmland in each risk of water contamination by pesticides class in Census years 1981–2006

	Very Low						Low						Moderate						High						Very High					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	46	49	29	86	31	81	51	47	64	9	59	14	0	1	2	2	2	1	0	0	2	0	1	1	0	1	2	0	5	0
AB	47	23	5	24	14	18	52	76	94	74	85	81	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SK	81	7	12	19	10	19	18	80	87	80	83	79	0	11	0	0	6	1	0	0	0	0	0	0	0	0	0	0	0	0
MB	73	0	0	5	1	3	26	53	88	74	20	63	0	45	10	19	42	31	0	0	0	0	16	1	0	0	0	0	19	0
ON	68	32	32	49	12	12	18	24	31	19	21	13	13	28	29	17	40	30	0	14	5	13	14	15	0	0	0	0	9	28
QC	99	71	19	52	3	24	0	27	51	28	40	38	0	1	29	19	34	21	0	0	0	0	20	14	0	0	0	0	0	0
PE	82	0	13	0	0	12	14	71	59	50	0	27	3	28	27	49	14	60	0	0	0	0	56	0	0	0	0	0	29	0
NB	25	18	15	35	2	18	60	33	31	61	37	34	14	36	21	2	13	19	0	12	23	0	2	14	0	0	7	0	43	12
NS	81	13	0	40	3	64	18	79	53	58	45	26	0	6	28	1	32	5	0	0	4	0	12	2	0	0	13	0	7	0
NL	70	57	91	100	89	88	10	20	8	0	10	5	5	17	0	0	0	5	9	4	0	0	0	1	3	0	0	0	0	0
CANADA	**70**	**16**	**11**	**24**	**10**	**18**	**28**	**68**	**83**	**69**	**68**	**68**	**1**	**13**	**5**	**5**	**13**	**8**	**0**	**2**	**1**	**1**	**5**	**2**	**0**	**0**	**0**	**0**	**3**	**3**

TABLE 15-3 Percentage of farmland in each runoff class for Census of Agriculture years 1981–2006

	Number of days when runoff occurred (yearly average)																													
	Very Low (0–6.9 Runoff Days)						Low (7.0–13.9 Runoff Days)						Moderate (14.0–20.9 Runoff days)						High (21.0–27.9 Runoff Days)						Very High (>28 Run off Days)					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	32	64	40	28	41	59	53	23	43	59	41	29	9	8	11	10	11	10	5	4	4	0	1	0	0	0	0	0	4	0
AB	21	38	11	9	28	39	75	60	85	88	68	59	1	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
SK	42	41	14	20	25	20	30	28	53	49	44	50	26	28	28	28	28	18	0	1	3	2	1	10	0	0	0	0	0	0
MB	2	4	0	0	0	1	37	35	39	41	40	40	54	57	59	26	31	19	5	2	0	31	26	38	0	0	0	0	0	0
ON	6	3	3	2	4	5	23	5	16	6	8	9	18	30	21	29	28	27	14	21	40	20	47	33	36	39	17	41	11	23
QC	0	0	1	1	1	1	30	23	29	21	27	17	39	35	54	39	33	31	29	40	14	36	35	47	0	0	0	0	1	1
PE	0	0	5	4	4	4	48	5	67	88	88	87	45	88	20	0	0	0	6	6	6	7	6	7	0	0	0	0	0	0
NB	5	0	6	5	6	5	5	6	58	36	64	32	79	73	29	50	23	44	8	16	5	3	5	16	2	4	0	3	0	0
NS	9	0	9	10	9	9	17	10	34	29	37	32	58	34	47	50	49	49	15	52	8	5	4	8	0	3	0	3	0	0
NL	1	1	3	0	1	5	4	0	37	4	25	69	80	65	46	90	58	13	7	12	5	0	4	5	5	19	6	5	9	5
CANADA	**27**	**31**	**11**	**12**	**21**	**22**	**43**	**36**	**57**	**55**	**48**	**47**	**24**	**25**	**26**	**21**	**22**	**15**	**4**	**5**	**5**	**9**	**9**	**15**	**2**	**2**	**1**	**2**	**1**	**1**

TABLE 15-4 Percentage of farmland in each mass of applied pesticide class 1981–2006.

	Mass of pesticide applied (kilograms per hectare)																													
	Very Low (0–0.49 kg/ha)						Low (0.50–0.99 kg/ha)						Moderate (1.00–1.49 kg/ha)						High (1.50–1.99 kg/ha)						Very High (>2.00 kg/ha)					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	56	80	75	92	63	81	39	14	19	3	30	13	2	2	2	2	1	1	2	2	2	3	1	3	2	2	2	1	5	2
AB	19	5	7	10	9	6	81	95	93	90	89	90	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0
SK	62	0	0	0	0	0	38	50	98	100	36	59	0	49	2	0	63	41	0	0	0	0	0	0	0	0	0	0	0	0
MB	8	2	3	5	4	5	92	64	94	95	43	71	0	34	3	0	52	24	0	0	0	0	0	0	0	0	0	0	0	0
ON	36	31	27	28	14	17	56	49	43	65	38	45	7	18	29	6	46	36	0	1	1	1	1	2	1	1	1	0	1	1
QC	93	76	58	58	37	41	6	22	37	37	30	30	1	1	4	4	27	25	0	0	1	1	4	3	0	0	1	1	1	1
PE	0	1	0	0	0	0	57	53	47	45	0	0	14	22	9	49	14	26	29	25	44	5	28	29	0	0	0	0	58	45
NB	45	41	33	50	39	39	11	12	20	33	14	17	15	17	15	14	2	3	17	14	18	2	12	15	12	15	14	0	33	25
NS	66	57	50	69	49	47	9	15	16	10	18	28	14	6	4	13	7	9	6	10	4	8	3	11	5	12	26	1	23	5
NL	36	57	59	82	65	58	29	21	32	18	26	30	23	7	5	0	9	5	2	12	4	0	0	6	10	2	0	0	0	0
CANADA	**43**	**9**	**8**	**9**	**7**	**7**	**56**	**62**	**87**	**89**	**50**	**65**	**1**	**29**	**4**	**1**	**41**	**27**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**

* Proportion calculated as % of farm land classified for the whole watershed over the total amount of farm land in the province

In 2006, approximately 35.4 million kilograms of pesticides were used in crop production in Canada. The amount of pesticide used in each province is generally proportional to the corresponding area of the cropland. Almost half (~ 17.4 million kg; Figure 15-3) of the amount applied nationally was applied in Saskatchewan, which has the largest area of cropland (17.9 million hectares), followed by Alberta (~ 8.4 million kg/10.6 million hectares) and Manitoba (~ 4.6 million kg/5.0 million hectares). Consequently, in 2006, approximately 84% of the mass of pesticides applied in Canada was applied in the Prairie region. The smallest amount was applied in Newfoundland. With the exception of 1981 (21.1 million kg), pesticide use on cropland in Canada has been relatively constant between 1981 and 2006, ranging from 29.7 to 35.4 million kg per year.

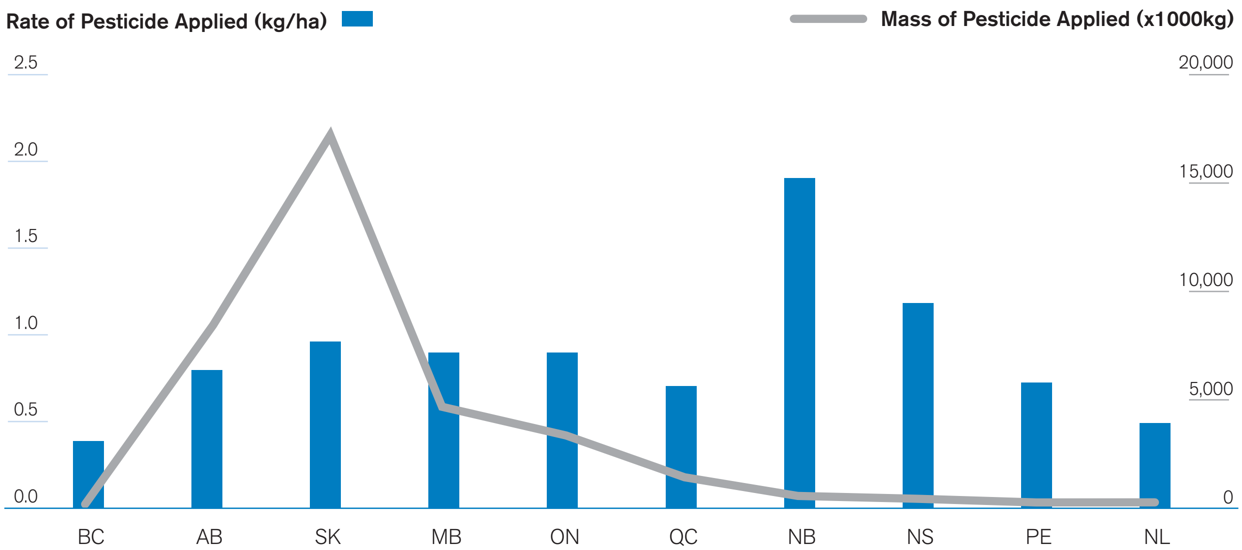


FIGURE 15-3 Mass of pesticide applied and average rate of pesticide application in each province (2006)

Although the amount of pesticide applied can exceed 2 kg per hectare, on average, each hectare of cropland in Canada in 2006 received approximately 0.8 kg of pesticide (Figure 15-3). Pesticide use per hectare of cropland was highest in New Brunswick and Prince Edward Island and could reflect the significant production of potato in these provinces as this crop typically receives more pesticide than others. The lowest use per hectare occurred in British Columbia where much of the cropland is in forage production which requires less pesticide.

Nationally, pesticides applied to cropland consisted of herbicides (94%), fungicides (4%) and insecticides (2%) (Figure 15-4). Herbicide use represents more than 80% of total pesticide use in British Columbia, the Prairie Provinces, Ontario and Quebec. In contrast, in New Brunswick, Prince Edward Island and Nova Scotia, more than 50% of pesticides used are fungicides.

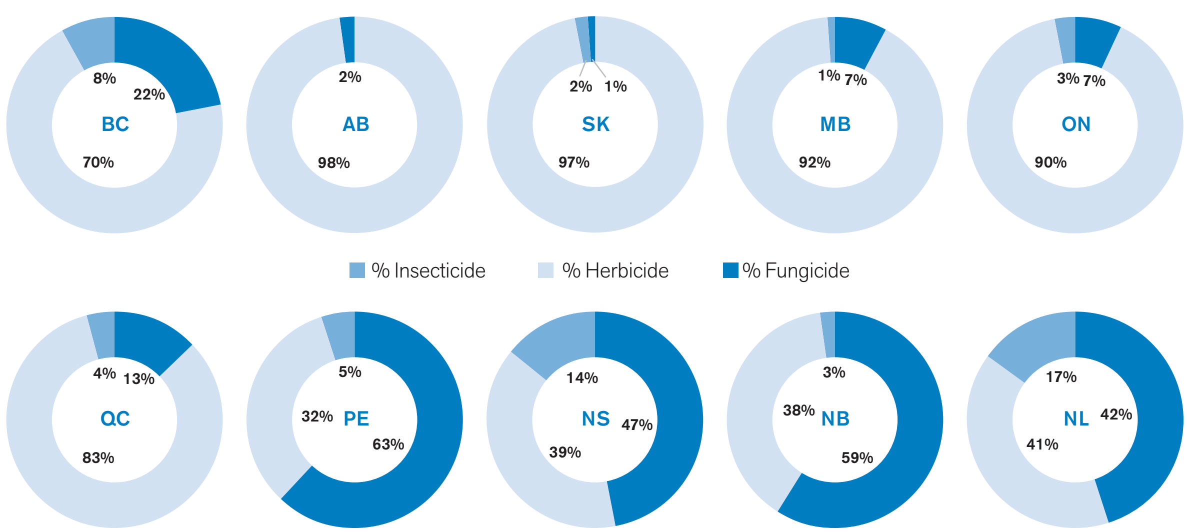


FIGURE 15-4 Percentage of pesticides that were insecticides, herbicides and fungicides in 2006

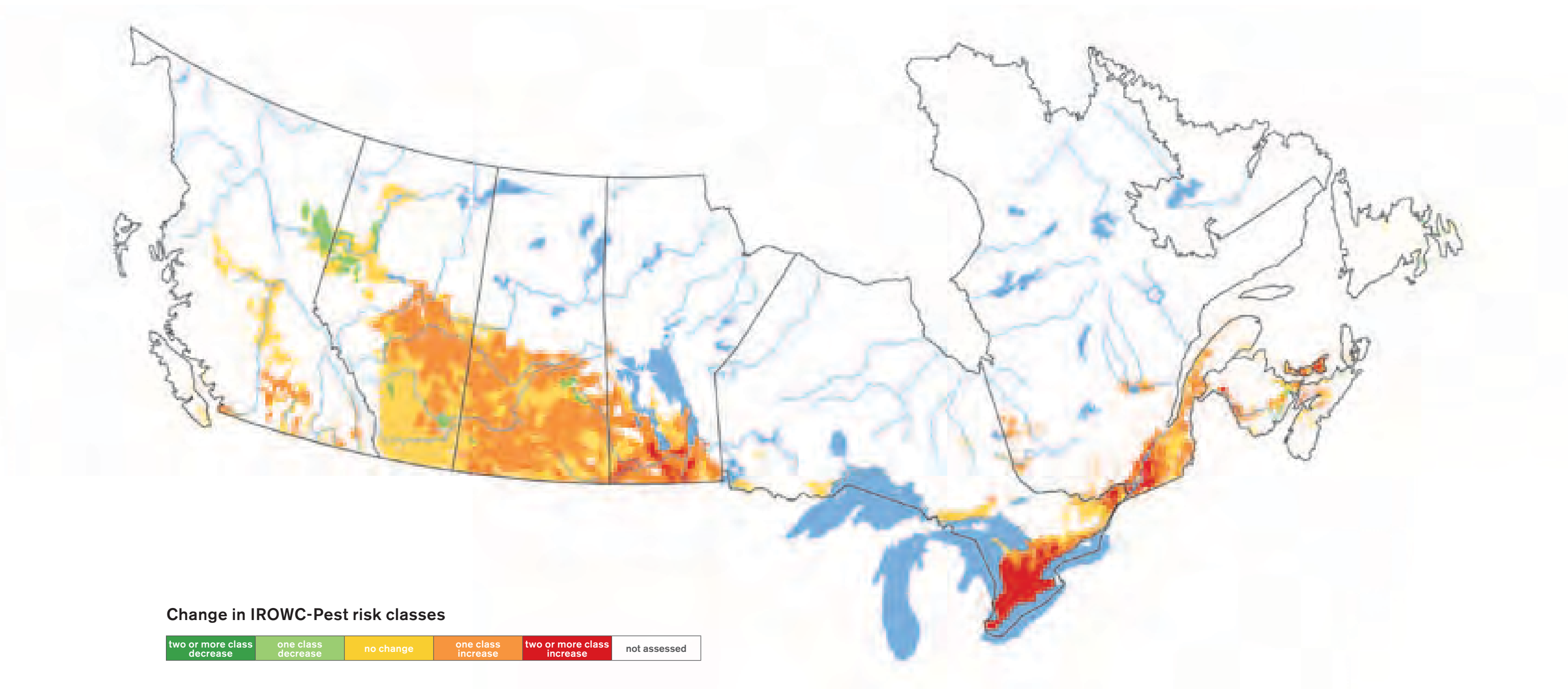


FIGURE 15-5 Change in IROWC-Pest risk class from 1981–2006

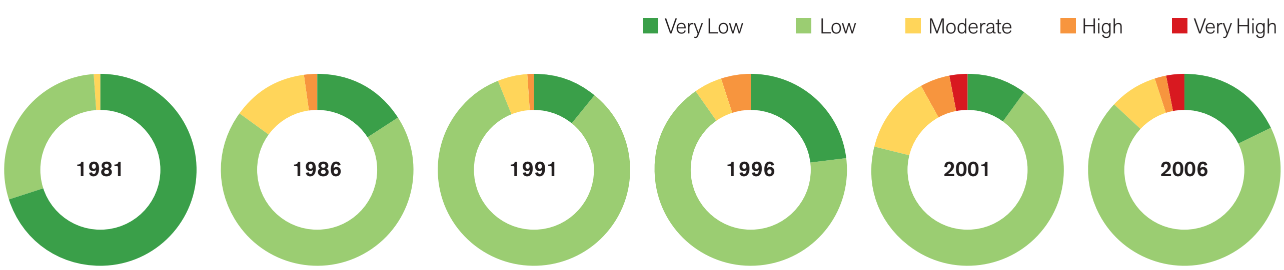


FIGURE 15-6 Proportion of farmland in each IROWC-Pest risk class, 1981–2006.

Manitoba, Ontario, Quebec, New Brunswick and Prince Edward Island. Less than 3% of cropland presented high to very high risk of water contamination by pesticides. Not surprisingly, the risk of contamination of waters by pesticides was largely related to the number of days in which runoff from cropland occurred (Table 15-3).

In the 25-year period from 1981 to 2006, the relative risk posed by farmland to contamination of water by pesticides changed. During this period, the least change occurred in British Columbia, Alberta, Saskatchewan and Newfoundland, where risk classes either remained the same, decreased by one class, or increased by one class (Figure 15-5). In Manitoba, Ontario, Quebec and Prince Edward Island, substantial areas of farmland increased by two or more risk classes along with smaller areas in New Brunswick and Nova Scotia.

Approximately 70% of cropland in Canada showed very low risk of contaminating water with pesticides in 1981, however, only 21.1 million kg of pesticides were applied (Figure 15-6). Pesticide use was greater from 1986 to 2006 and hence the proportion of cropland in the very low risk category decreased to 16% in 1986 with little variability to 2006. Most of this land shifted to the low risk class which increased from 28% of cropland in 1981 to approximately 68% in 1986 through 2006 with the exception of 1991 at 83%. Much of the cropland in these very low and low risk categories occurs in British Columbia, Alberta, Saskatchewan and Newfoundland (Figure 15-2).

The proportion of cropland posing a moderate risk of contamination of water by pesticides generally increased from 1981 to 2006. (Table 15-2; Figure 15-6). Much of this area was situated in Manitoba, Ontario, Quebec and Prince Edward Island (Figure 15-2). There was also a concurrent increase in the proportion of cropland in the high and very high risk of contamination by pesticides (Table 15-2). This increase in risk is due to increased pesticides use as a result of changes in crop types, areas and crop production systems (for example, increased area of oilseed and row crops and a shift to reduced tillage systems) combined with climatic conditions that resulted in more frequent runoff events.

Response Options

Higher adoption of management practices that reduce pesticide use will reduce the risk of pesticides contaminating water. Management practices include choosing crops less susceptible to pests, using better application technologies, choosing appropriate types of pesticides, using pest damage thresholds for pesticide application and implementing integrated pest management (a combination of cultural, biological and chemical pest control).

Other management practices that are effective in reducing the risk of water contamination by pesticides are those that reduce the movement of pesticides, such as applying pesticides under recommended environmental conditions, and using management practices that increase soil organic carbon content and reduce the amount of surface runoff and leaching.

Research to develop new or improved management practices for pesticide application and to develop pesticides applied at lower rates of application and with shorter half-lives in soil can help reduce the risk of pesticide contamination of water.

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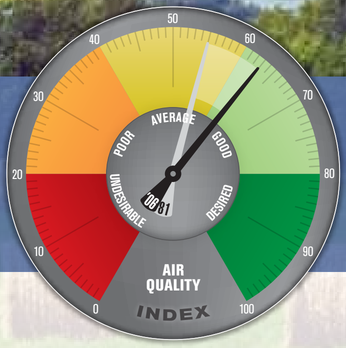
Air Quality and Greenhouse Gas



Air Quality and Greenhouse Gas

Summary

Atmospheric emission of greenhouse gases (GHG), ammonia (NH_3), *suspended particulate* matter (PM) and odour from agricultural activities can cause climate change and affect air quality.

Greenhouse gases perform an essential role in the atmosphere, trapping radiant energy and maintaining the earth at a temperature that can support life. However, the emission of GHGs from human activities including agriculture has resulted in global atmospheric concentrations that are greater than at any point in the last 650,000 years and that are likely to bring about unpredictable climate modification (IPCC, 2007). The main GHGs emitted from agricultural activities are nitrous oxide (N_2O) and *methane* (CH_4,) while carbon dioxide (CO_2) can be either emitted or absorbed.

Ammonia, a natural waste product of animal and microbial metabolism, is a colourless gas that in excessive amounts can be harmful to animals and plants, can react with other pollutants to generate secondary particles contributing to *smog*, can be a eutrophying nutrient in sensitive aquatic ecosystems, and can also be a plant nutrient beneficially used by agricultural crops.

Suspended PM decreases visibility, contributes to stratospheric ozone depletion, acid rain and smog formation, and can influence climate by altering the surface energy balance. Inhalation of PM, particularly fine PM, is associated with adverse health effects. PM emitted from agriculture includes dust from soil and plant or animal material, bacteria and droplets or particles from agro-chemicals.

Odour nuisance can adversely affect quality of life, lead to social issues with alternate land users and can cause genuine physical symptoms. Although these symptoms are triggered at concentrations often well below those that may cause toxic reactions, they cannot be dissociated from the concept of human health. Odour emissions are present in all agricultural activities and particularly in livestock activities.

In an effort to help quantify these emissions and to assess their status and trends in relation to changes in agricultural management practices over time, four agri-environmental indicators are being developed:

1. The Agricultural Greenhouse Gas Budget Indicator (Chapter 16) provides an estimate of net on-farm GHG emissions of nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2).

2. The Ammonia Emissions from Agriculture Indicator (Chapter 17) estimates agricultural NH_3 emissions.

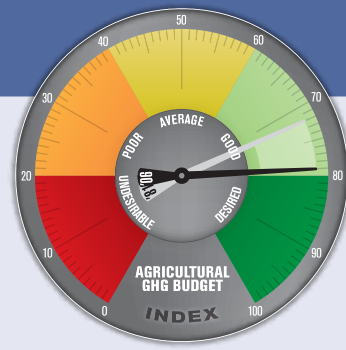
3. The Agricultural Particulate Matter Emissions Indicator (Chapter 18) estimates the contribution to airborne primary PM from agricultural operations.

4. The Agricultural Odour Emissions Indicator (In-box, Chapter 17) is currently being developed and will assess performance based on the rate at which odour mitigation methods are adopted by Canadian farms.

These indicators show mixed results in the extent to which agriculture has affected air quality issues.

- There was an overall 1% reduction of net GHG emissions from 1981 levels due to large-scale adoption of soil conserving beneficial management practices such as conservation tillage and no-till practices, and the decrease in the area of summerfallow land. Soil has become a net sink for carbon from the atmosphere (from a source of 1.0 Mt CO_2 in 1981 to a sink of about 11.7 Mt CO_2 in 2006). The sequestered carbon (carbon that is stored in the soil) has offset the increased emissions of CH_4 and NO_2 (from 21.7 to 27.9 Mt CO_2e and from 22.6 to 28.7 Mt CO_2e respectively between 1981 and 2006) that have resulted from increases in livestock numbers and increased use of manure and fertilizer.
- Estimates of agricultural ammonia emissions are available only for 2001 and 2006. During that period, emissions have increased by about 2%, primarily due to increases in the number of livestock.
- Since 1981, there has been a decreasing trend in PM levels, including a 48% decrease in total suspended particles, a 40% decrease in PM_{10} and a 47% decrease for $PM_{2.5}$. Like GHGs, the decreased PM emissions are due to large-scale adoption of soil conserving beneficial management practices such as conservation tillage and no-till practices and the decrease in the area of summerfallow land.

16 Agricultural Greenhouse Gases



AUTHORS

R.L. Desjardins, D.E.,Worth, X.P.C. Vergé, B.G. McConkey, J.A. Dyer, and D. Cerkowniak

INDICATOR NAME

Agricultural Greenhouse Gas Budget Indicator

STATUS

National coverage, 1981 to 2006

Summary

Greenhouse Gas (GHG) emissions from human activities have resulted in global atmospheric concentrations that are greater than at any time in the last 650,000 years and that are likely to bring about unpredictable changes to our climate (IPCC, 2007). Agriculture can be both a source and a sink of greenhouse gases. The main GHGs emitted from agriculture are nitrous oxide (N_2O) and methane (CH_4), while carbon dioxide (CO_2) can be either emitted or absorbed. In 2006, the net GHG emissions (sources minus sinks) from agricultural production excluding fossil fuel use amounted to 44.8 million tonnes of CO_2 equivalents (Mt *CO_2e*)[1] which is equal to about 6% of Canada's overall GHG emissions. Net agricultural emissions have decreased by about 1% from 1981 levels.

Between 1981 and 2006, emissions of CH_4 and N_2O increased by 29% from 21.7 to 27.9 Mt CO_2e and by 27% from 22.6 to 28.7 Mt CO_2e, respectively. Methane emissions have been on the rise because of an increasing animal population, especially in the beef-cattle sector. Similarly, N_2O emissions have risen due to expanding animal populations and increased use of synthetic nitrogen (N) fertilizers. However, during this time, agricultural soils have changed from a source of 1.0 Mt CO_2 to a sink (meaning CO_2 is absorbed, or sequestered) of about 11.7 Mt CO_2. The change in soil CO_2 emissions is primarily due to the widespread adoption of beneficial management practices in agriculture, which has resulted in a substantial increase in carbon sequestration, particularly in the Prairie Provinces.

Adoption of improved management practices has also led to a significant reduction in GHG emission intensity, or emissions per unit of product. Therefore, while agricultural N_2O and CH_4 emissions have increased, in most cases the GHG emissions per unit of production have decreased.

1 1 Mt CO_2e = 1 million tonnes of carbon dioxide equivalents

The Issue

Greenhouse gases (GHGs) perform an essential role in the atmosphere, trapping radiant energy and maintaining the earth at a temperature that can support life. Although GHGs are necessary in the atmosphere, the ongoing anthropogenic (from human activity) addition of such gases is undesirable as they are likely to bring about major climate modifications. The anthropogenic emissions of CO_2, CH_4 and N_2O have resulted in global atmospheric concentrations that are greater than at any point in the past 650,000 years (IPCC, 2007). International treaties have been developed that are designed to limit these emissions, with the goal of preventing a dangerous modification of the global climate system.

Agricultural activities inevitably result in GHG emissions (Janzen et al., 2008). Figure 16-1 illustrates the multiple agricultural sources of GHG emissions. Nitrous oxide emissions can originate directly from field-applied organic and inorganic fertilizers, crop residue decomposition, cultivation of organic soils and from the storage of manure. Indirect N_2O emissions can originate from N moved offsite such as from the volatilization and re-deposition of ammonia and from N leaching and run-off. Methane emissions from agricultural sources in Canada are mainly a result of enteric *fermentation* in ruminant animals and from the anaerobic decomposition of stored manure. When organic matter in feed or manure decomposes under anaerobic conditions, a portion is released as CH_4. Agricultural soils can either emit or absorb CO_2 (Desjardins et al., 2008). The difference is determined by the net effect of CO_2 absorption from the atmosphere by growing crops, and subsequent storage in the soil in the form of crop residues and soil organic matter, and the emission of CO_2 to the atmosphere via decomposition of crop residue and soil organic matter. Management practices that typically sequester carbon in soils include decreasing tillage intensity, reducing the frequency of summerfallow and converting annual crops to perennial crops. For a more detailed explanation of soil carbon exchange, please refer to chapter 9 of this report.

Carbon dioxide is emitted during fossil-fuel combustion by farm machinery and from the manufacture of fertilizers and machinery used in agriculture. These indirect emissions of CO_2 are typically reported by the transportation and manufacturing sectors and are therefore not included in the agricultural GHG budget indicator calculations. (See GHG Emissions from Energy use and fossil fuel consumption in agriculture text box, below)

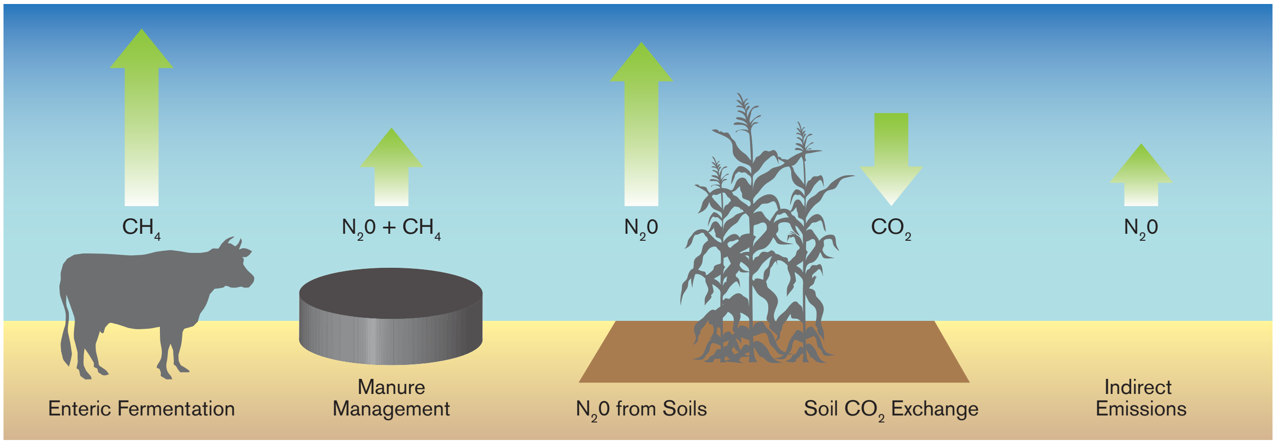


FIGURE 16-1 Net sources and sinks of GHGs from Canadian agriculture exclusive of emissions from fossil fuels and energy use. The size of the arrows indicates the relative magnitude of the source or sink.

For most indicators, the objective is to see improvement of environmental performance values over time, such as a net reduction in GHG emissions. However, given the increasing national and international demand for agricultural products due to an increasing global population, it is important to present not only the emissions, but also the GHG emission intensity or the GHG emissions per unit of production. Trends in emission intensity reflect progress made towards enhancing the efficiency of agricultural production. (See GHG Emission Intensity in-box)

In 2006, Canada's total GHG emissions were 721 Mt CO_2e (Environment Canada, 2008). Approximately 81% of these emissions originated from the energy sector, which includes the consumption of fossil fuels to produce electricity and heat, as well as the consumption of gasoline and diesel to power cars and trucks (Figure 16-2). About 3% of these emissions were associated with energy use in agriculture. Agriculture was responsible for 8% of national GHG emissions, not including soil CO_2 exchange.

Agricultural GHG emissions often reflect a measure of inefficiency and therefore a potential loss of income for the producer. For instance, CH_4 emitted by ruminant animals represents feed energy that is not converted into meat, milk or fibre, and N in fertilizer that is lost to the atmosphere as N_2O can no longer be used by crops for growth. Although some GHG emissions from agriculture are unavoidable, large emissions are generally indicative of inefficient farming practices. Through improved management practices and by sequestering carbon in agricultural soils the agricultural sector has the potential to reduce its GHG emissions and to mitigate the rise in atmospheric CO_2 concentration. In so doing, the sector supports Canada's reduction commitment, enhances returns for producers and benefits the environment.

The Indicator

The Agricultural Greenhouse Gas Budget Indicator provides an estimate of net GHG emissions of N_2O, CH_4 and CO_2 from agroecosystems in Canada. The methodology of the Intergovernmental Panel on Climate Change (IPCC), adjusted for Canadian conditions (Vergé et al., 2006; Rochette et al., 2008), was used to calculate N_2O and CH_4 emissions, and models were used to estimate net CO_2 exchange from croplands (Smith et al., 2000). The IPCC methodology involves three basic steps: 1) collecting information on agricultural activities producing GHGs, 2) estimating the *emission factors* associated with environmental/soil conditions and agricultural activities, 3) calculating the GHG emissions by multiplying the emission factors by the amount of activities, the population or the area involved. These three steps were conducted separately for CH_4, N_2O and CO_2.

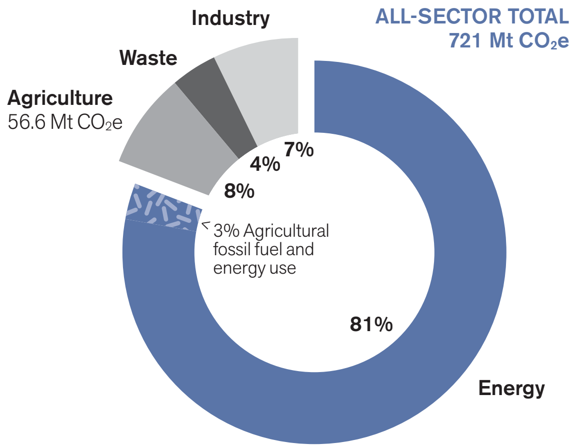


FIGURE 16-2 A breakdown of Canada's GHG emissions in 2006 (Environment Canada, 2008)

The *Global Warming Potential* (GWP) of each gas was used to allow comparison and combined reporting. GWP is the contribution that a gas makes to the greenhouse effect according to its capacity to absorb radiation and the amount of time it remains in the atmosphere. In this report, the GWPs commonly accepted for international reporting will be used, namely 1 for CO_2, 21 for CH_4 and 310 for N_2O (IPCC, 1996). This means that as a greenhouse gas on a mass basis, N_2O and CH_4 are 310 and

21 times more powerful than CO_2, respectively. Combined CO_2, CH_4 and N_2O, emissions are reported in million tonnes of CO_2 equivalents or Mt CO_2e (Table 16-1).

Limitations

Agricultural activities in Canada are highly diversified and are spread out over 60 million hectares of land. To estimate agricultural GHG emissions at the provincial and national levels, assumptions are made to simplify the complex agricultural landscape. For instance, it is necessary to assume that beef cattle within a province at a certain growth stage all have the same average weight and it is also necessary to assume that emission factors determined through experimentation can be applied to a much larger spatial area. These and other assumptions, although necessary, introduce uncertainty into the estimate of GHG emissions. Uncertainty is also introduced into our calculations as several of the emission factors are derived from international, rather than Canadian research. This is especially true for indirect N_2O emissions.

In this report, we have not considered CO_2 emissions from land conversions. The conversion of forest land to cropland has recently been estimated to be a source of about 10 Mt of CO_2 but

GHG emissions from energy use and fossil fuel consumption in agriculture

Energy and fossil-fuel related agricultural GHG emissions can be divided into six categories: field operations, farm transport, heating, electricity, machinery supply and agrochemical supply. Carbon dioxide emissions from these energy-use categories are presented in Figure 16-3. The 16% decrease in CO_2 emissions from field operations from 5.8 to 4.9 Mt CO_2 between 1981 and 2006 is primarily due to the increased adoption of reduced and no-till practices by Canadian farmers as well as the development of more efficient machinery (Dyer and Desjardins, 2003). Emissions associated with heating increased by 19% from 1.6 to 1.9 Mt CO_2. This increase is primarily due to a doubling of energy use in the greenhouse industry between 1991 and 2001. Emissions associated with farm machinery supply have decreased by 17% from 4.1 to 3.4 Mt CO_2, primarily because of a decrease in the purchase of large equipment (Dyer and Desjardins, 2006).

Agrochemical supply, primarily nitrogen fertilizer production, is the largest source of CO_2 emissions from fossil-fuel combustion. The synthesis of nitrogen fertilizers occurs at high pressure and temperature and consumes a significant quantity of natural gas in the process. Since nitrogen fertilizer consumption has increased by 64% between 1981 and 2006, CO_2 emissions associated with the production of nitrogen fertilizers have increased similarly, from 3.8 to 6.2 Mt CO_2.

Contrary to other agricultural sources of GHG emissions, at the national level fossil fuel CO_2 emissions have been relatively constant over the last 25 years, and are estimated at 18.5, 20.0, 19.3, 20.7, 20.7 and 20.0 Mt CO_2e for the census years between 1981 and 2006, representing an increase of 8% between 1981 and 2006. More details on how these emissions are calculated can be found in Dyer and Desjardins (2007, 2009).

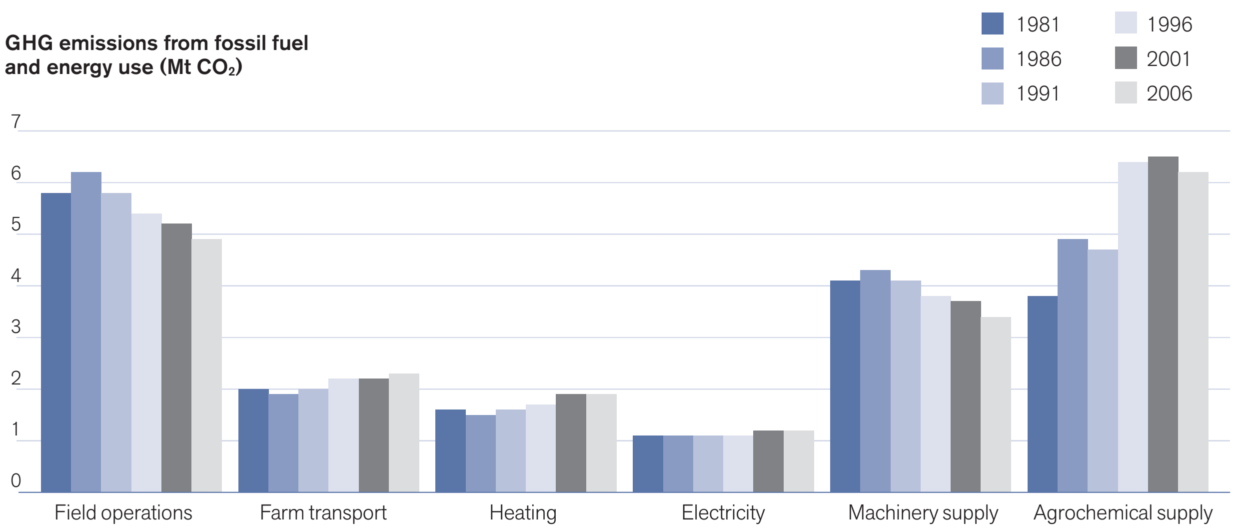


FIGURE 16-3 Carbon dioxide emissions from major energy and fossil fuel activities in Canadian agriculture, 1981–2006.

because it involves only a small area, equal to 1% of cultivated land in Canada and because it is a highly uncertain estimate, we have not included it in this report.

Results and Interpretation

Between 1981 and 2006, net national GHG emissions from agriculture in Canada decreased by 1%, from 45.3 to 44.8 Mt CO_2e (see Table 16-1). This decrease in emissions has occurred despite a 29% increase in CH_4 emissions from 21.7 to 27.9 Mt CO_2e and a 27% increase in N_2O emissions from 22.6 to 28.7 Mt CO_2e. The reason for a declining net GHG emission indicator is that increased CH_4 and N_2O emissions have been more than offset by a 12.8 Mt CO_2 change in agricultural soil CO_2 emissions, which were a 1.0 Mt CO_2 source of emissions in 1981 and have become a 11.7 Mt CO_2 sink in 2006.

Figure 16-5 shows the net GHG emissions across Canada expressed on a per hectare basis, and Figure 16-6 shows the change in net GHG emissions between 1981 and 2006 across Canada. In Western Canada, emissions are generally small, less than 1,000 kg CO_2e per hectare (which can also be expressed as <1,000 kg CO_2e ha^{-1}), with the exception of locations with intensive animal production. Reductions in net GHG emissions between 1981 and 2006 are common, especially in Saskatchewan, due to soil-carbon sequestration. Small emissions in many parts of Alberta, Saskatchewan and Manitoba reflect the high adoption rate of management practices that sequester carbon, the growth of crops such as wheat, which are less demanding of nitrogen fertilization, and the drier climatic conditions which result in a reduced rate of N_2O emissions. In contrast, in Eastern Canada, GHG emissions are frequently larger (>2,000 kg CO_2e ha^{-1}) which reflects intensive animal production, the growth of high yielding crops such as corn that

GHG emission Intensity

GHG emission intensity measures the N_2O, CH_4 and CO_2 emissions per unit of production. At present, only emissions associated with on-farm production are included in these estimates. Soil carbon sequestration is not included at this time.

Farmers in Canada have made significant improvements in their management practices, including improved nutrient management, reduced energy consumption and better use of animal breeds, increasing the efficiency of production. Therefore, while national N_2O and CH_4 emissions have increased, the GHG emissions per unit of production have decreased.

For example, in the dairy industry, an increase in milk produced per cow allowed a 41% reduction in the dairy cow herd without reducing total milk production. Cows on average produced approximately 6,200 kg of milk per year in 1981 (AAFC, 1981), whereas they produced 9,500 kg of milk per year in 2006 (AAFC, 2007). Although the higher-producing cattle do produce more GHG emissions per head, this increase is less than the increase in milk productivity. As a result, GHG emissions per kg of milk produced have declined by 20% (Figure 16-4) from 1.23 kg CO_2e in 1981 to 0.98 kg CO_2e in 2006 (Dyer et al., 2008).

The beef industry has also seen a very significant reduction in GHG emission intensity. In 1981, GHG emissions per kg of beef cattle live weight were 16.4 kg CO_2e (Figure 16-4). By 2006, this had decreased by 36% to 10.5 kg CO_2e (Vergé et al., 2008). The pork industry in Canada has seen similar reductions in GHG emission intensity between 1981 and 2006. It

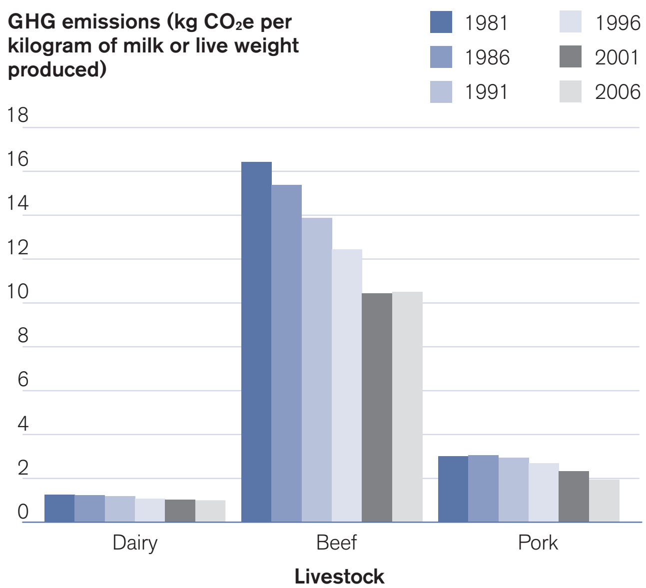


FIGURE 16-4 Greenhouse gas emission intensities for milk, beef and pork production in Canada, 1981–2006.

has been estimated that in 1981, 3 kg CO_2e was emitted for each kg of pork live weight (Figure 16-4). However, by 2006, this value had been reduced by 37% to 1.9 kg CO_2e per kg of pork live weight (Vergé et al., 2009). These improvements in GHG emission intensity have been possible primarily because of improved feeding practices and breeding.

Preliminary results suggest that a similar trend is occurring in the poultry industry however, the results are not available at this time.

demand a high level of nutrients, and wetter climatic conditions which result in an increased rate of N_2O emissions. Increases in net emissions between 1981 and 2006 are common in Quebec and the Atlantic Provinces and parts of southwestern Ontario.

The adoption of management practices such as the decreased use of summerfallow, increased use of conservation tillage systems and the conversion of annual cropland to perennial cropping systems can all reduce CO_2 emissions by sequestering carbon in agricultural soils as crop residue and soil organic matter. These beneficial management practices (BMP), widely adopted in Canada (Figure 16-7) and especially in the Prairie Provinces, have resulted in agricultural soils changing from being a source in 1981 to being a sink in 2006. Soil carbon sequestration is not evenly spread throughout the country, however. In eastern Canada, soil CO_2 emissions have increased largely because of the conversion of perennial crops to annual crops such as corn and soybean, which tend to release stored soil carbon.

The decrease in net GHG emissions between 1981 and 2006 occurred in the first 10 years. During this period, increases in soil carbon sequestration, combined with slight decreases in beef and dairy cattle populations and a moderate increase in nitrogen fertilizer consumption, resulted in a declining net GHG budget. However, between 1991 and 2006 net emissions increased slightly because of increasing animal populations (Figure 16-8) and greater nitrogen fertilizer use (Figure 16-9). Net GHG emissions peaked in 1996 when near-record nitrogen fertilizer use and a significant increase in the beef cattle population resulted in an increase in emissions of CH_4 and N_2O that were greater than the reduction in emissions due to carbon sequestration.

The increase in CH_4 emissions has been driven by increasing animal populations. Most animal populations in Canada have increased between 1981 and 2006 (Figure 16-8) with a 36% increase in beef cattle population being particularly significant because of the relatively large emissions due to enteric fermentation. The swine population has increased by 45% which has resulted in increasing CH_4 emissions from manure management. The poultry population (hens, chickens, turkeys) has increased by 33%, however this has not been as significant in terms of GHG emissions because poultry does not emit a large quantity of CH_4 when compared to cattle or swine. The increased CH_4 emissions have been partly offset by a 41% decrease in the dairy cow population. Increased milk productivity of dairy cows over this time period has meant that farmers were able to maintain a constant milk production while keeping fewer cows.

Similar to CH_4 emissions, the increase in N_2O emissions between 1981 and 2006 has largely been driven by an increasing animal population, especially beef cattle. The accompanying increased manure production results in direct N_2O emissions from manure applied as fertilizer, manure stored in a manure-management system and manure deposited directly on pasture by grazing animals. Nitrous oxide emissions have also increased as a result of the growing use of synthetic nitrogen fertilizers which have increased by 64% between 1981 and 2006, from 0.9 to 1.5 million tonnes (Figure 16-9). Indirect emissions from manure and fertilizer occur from volatilization and *redeposition* of ammonia (NH_3^+) and nitrogen oxides (NO_x), as well as indirect emissions from leaching and runoff. Crop residue decomposition provides another source of nitrogen that can result in N_2O emissions, however crop residues vary from year to year depending on climate and the types of crops planted. The increase in total crop production between 1981 and 2006 has meant that the amount of nitrogen in crop residues increased by 40% from 0.8 to 1.2 million tonnes with a minimum in 2001 when poor growing conditions in the Prairie Provinces significantly decreased crop production.

Response Options

Providing an adequate supply of safe and nutritious food despite growing pressures on natural resources is among the most important challenges facing Canada. Driven by both human population increases and the global demand for higher-protein diets, the demand for food is expected to continue to increase. Given that GHG emissions are an inevitable result of producing food, it is very likely that CH_4 and N_2O emissions will continue to increase. There is potential to reduce GHG emissions by improving management practices such as introducing new animal feeding strategies and new waste-treatment techniques. Often, economic or technological barriers prevent the widespread adoption of these practices. For instance, adding fat to a ruminant diet can reduce CH_4 emissions from enteric fermentation and the biodigestion of animal wastes can significantly reduce CH_4 emissions from manure management. However, adding fat to a ruminant diet is generally not economically feasible and the start-up cost and technological expertise required for a biodigestion plant may prevent its construction.

Other methods to enhance carbon sequestration resulting in a reduction in soil CO_2 emissions exist, however the ability of soils to sequester carbon is finite and cannot continue indefinitely. In the future, Canadian agricultural soils will reach a new equilibrium in terms of soil carbon, at which point annual CO_2 uptake will be equal to annual CO_2 emissions. Furthermore, the maintenance of sequestered carbon depends on the continuation of the improved management practices that led to the carbon sequestration.

Due to the likelihood of sustained and increased demand for agricultural products, it is important to recognize and further encourage the increase in efficiency that has been made by producers across the country. In many cases, producers have adopted management practices that have resulted in improved nutrient use by crops and animals, improved feed efficiency, decreased energy use and decreased disturbance of the soil. All these have combined to reduce GHG emissions per unit of product. For example, the increase in milk productivity per cow in the dairy industry has resulted in greater enteric CH_4 emissions per cow, however when expressed per kg of milk produced, net GHG emissions from the Canadian dairy industry have decreased by 20% between 1981 and 2006 (Dyer et al., 2008)

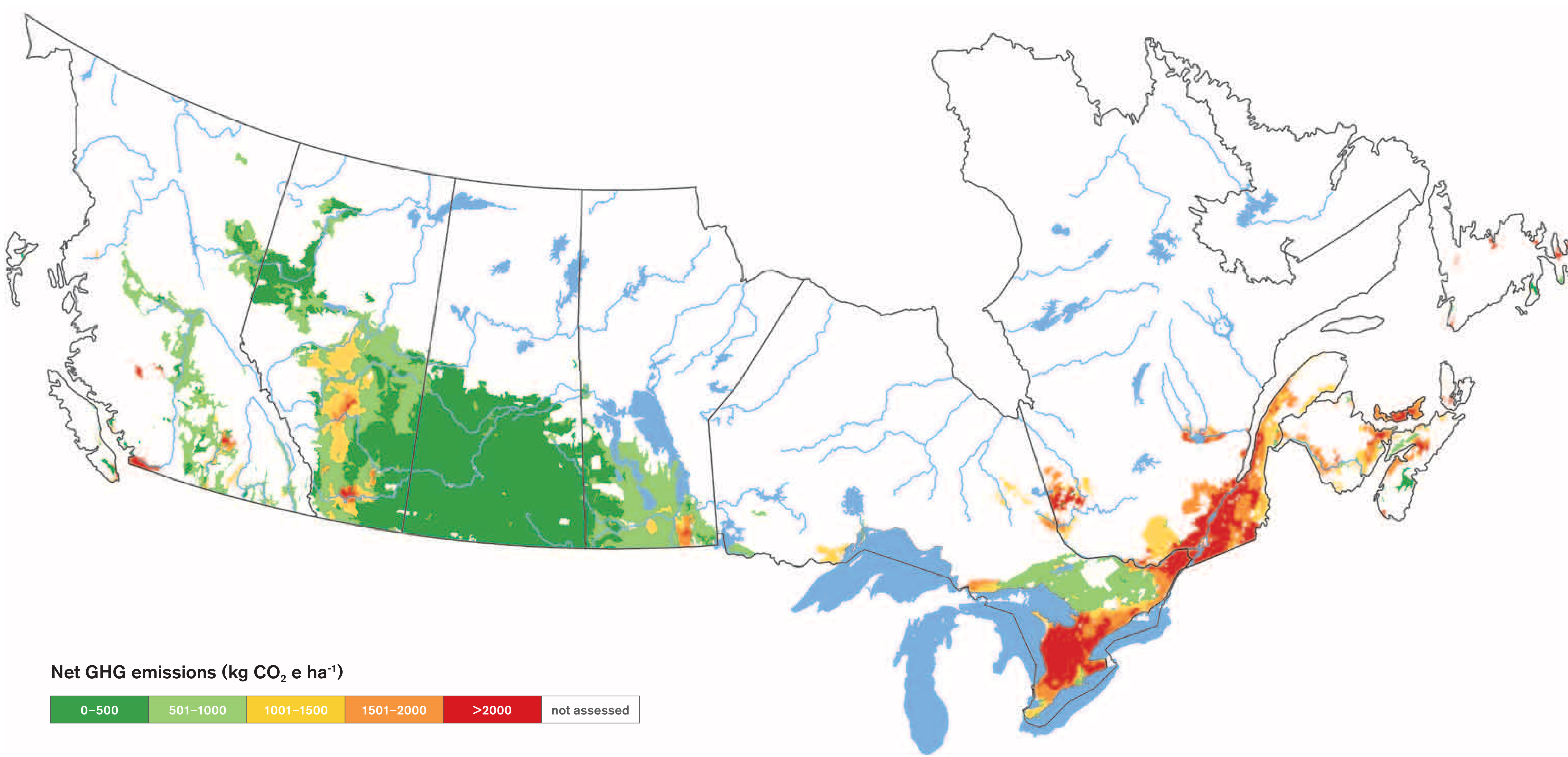


FIGURE 16-5 Agricultural net greenhouse gas emissions, 2006

TABLE 16-1 Greenhouse gas emissions from Canadian agriculture, 1981–2006, Mt CO_2e

	Methane (CH_4)						Nitrous Oxide (N_2O)						Carbon Dioxide (CO_2)						Net Emissions						
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	% CHANGE
BC	1.2	1.2	1.3	1.5	1.5	1.4	0.9	0.9	0.8	0.9	0.9	0.9	0.1	0.1	0.1	0.0	0.0	0.0	2.3	2.2	2.2	2.4	2.4	2.3	4
AB	6.0	6.0	7.3	8.8	9.9	9.7	5.9	6.1	6.0	7.1	7.3	8.1	-0.7	-0.9	-1.2	-2.2	-3.4	-4.1	11.1	11.1	12.0	13.7	13.8	13.8	24
SK	3.1	2.8	3.1	4.0	4.1	4.9	3.8	4.8	4.0	5.7	5.1	6.0	-0.3	-1.8	-1.9	-4.4	-6.9	-9.1	6.6	5.8	5.3	5.4	2.3	1.8	-73
MB	1.7	1.7	1.7	2.2	2.3	2.8	2.4	3.0	2.7	3.2	3.1	3.8	-1.0	-1.1	-1.2	-1.2	-1.4	-1.7	3.0	3.5	3.2	4.2	4.1	4.8	59
ON	5.4	4.9	4.9	5.0	4.7	4.8	5.7	5.5	5.1	5.1	4.9	5.8	2.2	2.0	1.8	1.6	1.7	1.5	13.3	12.4	11.8	11.7	11.2	12.0	-10
QC	3.7	3.4	3.5	3.7	3.6	3.7	3.2	3.2	3.1	3.2	3.3	3.4	0.6	0.7	0.9	1.1	1.5	1.4	7.6	7.3	7.5	8.0	8.4	8.5	12
AP	0.7	0.7	0.7	0.7	0.6	0.6	0.7	0.6	0.7	0.7	0.7	0.7	0.1	0.1	0.2	0.2	0.2	0.2	1.4	1.4	1.5	1.6	1.5	1.6	13
CANADA	**21.7**	**20.7**	**22.5**	**25.8**	**26.7**	**27.9**	**22.6**	**24.1**	**22.4**	**25.9**	**25.4**	**28.7**	**1.0**	**-1.0**	**-1.4**	**-4.8**	**-8.3**	**-11.7**	**45.3**	**43.9**	**43.5**	**46.9**	**43.8**	**44.8**	**-1**

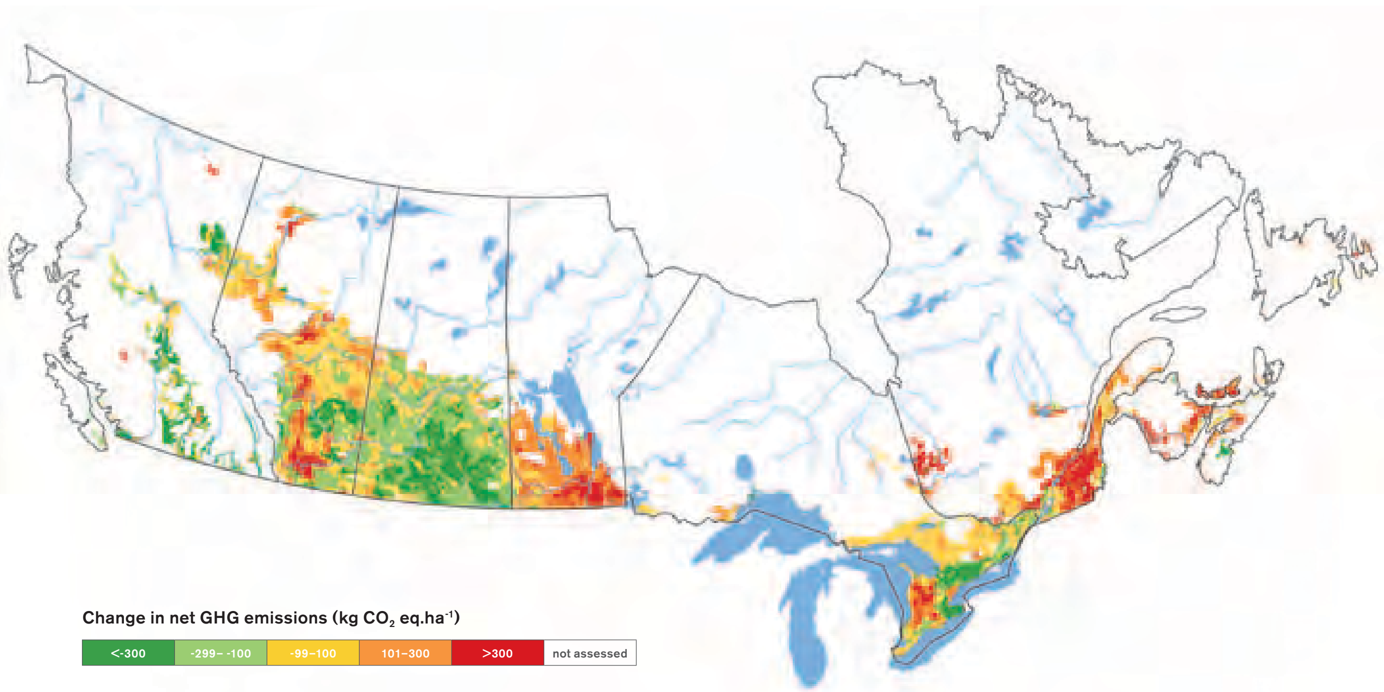


FIGURE 16-6 Change in net greenhouse gas emissions 1981–2006. A negative value means a reduction in net GHG emissions.

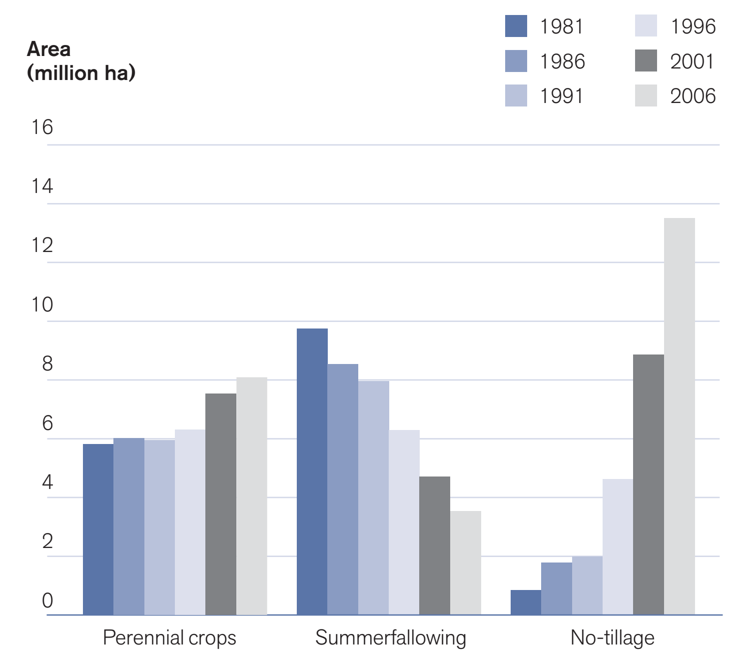


FIGURE 16-7 Changes between 1981 and 2006 of management practices that promote carbon sequestration in agricultural soils such as more perennial crops, less summerfallowing and increased no-till farming

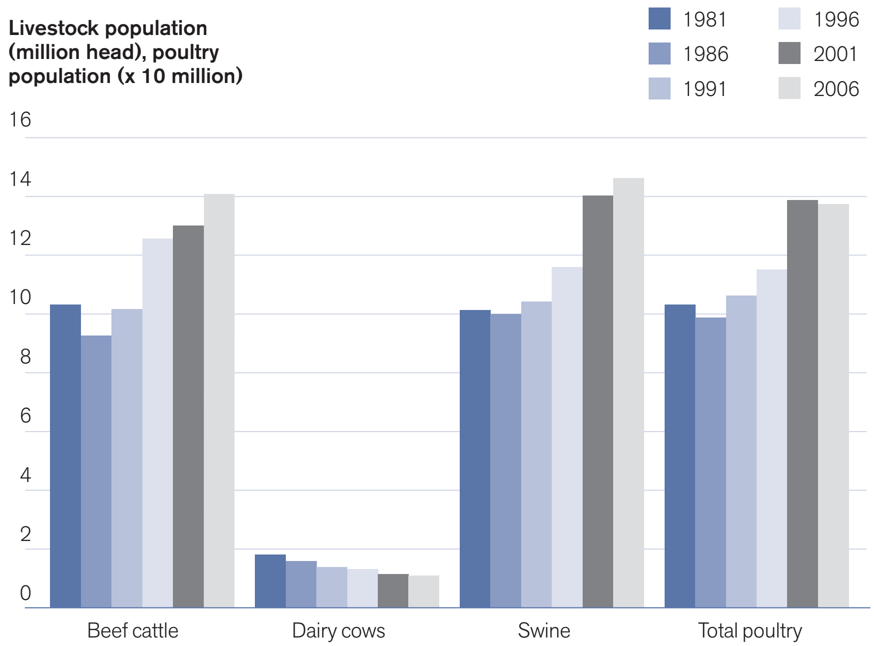


FIGURE 16-8 Livestock and poultry population in Canada, 1981–2006

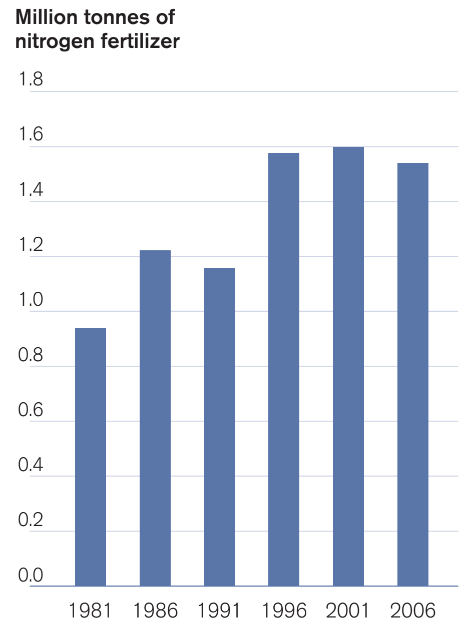


FIGURE 16-9: Nitrogen fertilizer use in Canada, 1981–2006

and the adoption of BMPs by the beef and pork industries have led to a 36% and 37% reduction, respectively, in emissions per unit of live weight produced between 1981 and 2006.

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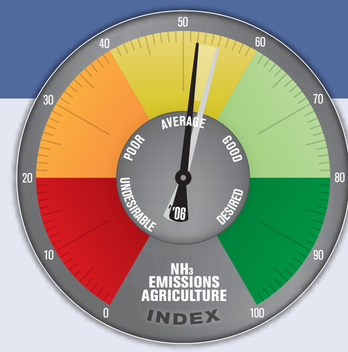
17 Ammonia



AUTHORS
S. Sheppard and S. Bittman

INDICATOR NAME
Ammonia Emissions from Agriculture Indicator

STATUS
National Coverage, 2001 to 2006

Summary

Ammonia (NH_3) is a reactive and toxic gas with important implications for environmental and human health. It is also an important plant nutrient that can be absorbed through roots or through leaves as dissolved ammonium (NH_4^+). Agricultural NH_3 emissions are a concern for the environment as gaseous NH_3 can be directly toxic to animals and plants at higher concentrations. It can also react with other pollutants to generate particles that can be hazardous to human health. Atmospheric NH_3 will deposit onto soil and vegetation within a few hundred metres of a source, however as NH_4^+ it may travel hundreds of kilometres downwind where it can damage sensitive ecosystems by direct toxicity or contribute to the enrichment of low-nutrient natural ecosystems (such as bogs) or eutrification of surface waters. Ammonia also contributes to soil acidification and to releases of nitrous oxide (N_2O), a greenhouse gas. The Ammonia Emissions from Agriculture indicator was developed to estimate agricultural NH_3 emissions based on Canadian agricultural production and management practices.

Agriculture releases about 85% of all of the atmospheric NH_3 in Canada. Of this, 78% originates from the livestock sector and 22% from the use of nitrogen (N) fertilizers. Intensive emissions occur where there is concentrated livestock production, especially in Alberta and southern parts of Quebec, Ontario and Manitoba, and the lower Fraser Valley of BC. Emissions from all livestock production are highest in May and lowest during the winter. Most losses of NH_3 from livestock occur from housing, feedlots and grazing, (45%) and from applying manure to land (45%). Fertilizer use results in a widespread but relatively low rate per land area of NH_3 emission, most notably in western Canada. Nitrogen losses from fertilizer applied to arable cropland ranged from 8% of applied N in eastern Canada to 3% in western Canada. Loss of NH_3 from agriculture is the loss of an expensive and critical nutrient, and is generally considered undesirable. The loss of 440,000 tonnes (t) of NH_3 (362,000 t of N) from farms in 2006 is equivalent to approximately 25% of all the fertilizer used in Canada.

The Issue

Agriculture contributes about 85% of the total anthropogenic NH_3 gas emitted to the atmosphere. Ammonia is produced from urea in mammal urine, uric acid in poultry manure and from the breakdown of organic N compounds (animals excrete urea and uric acid as a byproduct of protein digestion). Fertilizer containing urea and NH_3 is also a source of NH_3 emissions. Atmospheric NH_3 is deposited to soils where it can be an important source of N to plants or can be detrimental to sensitive plant and ecosystem health. In the soil NH_3 can transform to nitrogen gas (N_2) or several forms of environmentally important N such as N_2O, nitric oxide (NO) and nitrate (NO_3). In the atmosphere, NH_3 may also react with other pollutants to form smog and particulate matter; much of the haze in Southern Ontario and the Lower Fraser Valley can be attributed to NH_3-induced particles.

Ammonia from agricultural operations is of concern for the following reasons:

- its role as a precursor to the production of respirable particles and smog,
- the problem of direct animal and human inhalation toxicity inside barns,
- the problem of outright loss of an essential and expensive-to-replace plant nutrient,
- ecological degradation related to oversupply of N to sensitive plant communities, and
- its potential role in the release of the greenhouse gas N_2O.

As an atmospheric gas, NH_3 is very mobile and can move across political boundaries. As a result, NH_3 falls under the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol), which guides signatories to reduce their NH_3 emissions to 1990 levels. Member nations are mostly European; Canada is a signatory to the protocol, but has not yet ratified it. The sections of the Gothenburg Protocol relating specifically to ammonia are only applicable to Europe. Canadian emissions are among the highest of the countries reporting to the United Nations Economic Commission for Europe (UNECE) (Figure 17-1), however this should be interpreted in light of the fact that Canada, in size, equates several European countries.

The Indicator

The Ammonia Emissions from Agriculture Indicator estimates the annual emission of NH_3 to the atmosphere from livestock and fertilizers expressed per hectare of farmland in each agricultural Soil Landscapes of Canada polygon. This approach allows the NH_3 indicator to be integrated with other N indicators.

The indicator is based on a series of computer models that estimate total NH_3 emission to the atmosphere per animal or quantity of fertilizer used. The models were developed separately for poultry, swine, dairy, beef and fertilizers because each of these sectors has different controlling features. The livestock models have several key attributes:

- They were based on total ammoniacal N (TAN) in manure, so this includes urea and uric acid.
- For housed animals, the models calculate the amount of NH_3 available for emission at any one stage, from excretion to housing to storage and to landspreading (Figure 17-2). Losses from grazing animals are considered a single stage.
- The amount of TAN excreted is assumed to be equal to the amount of protein-N consumed by the animal, minus the protein-N retained in animal tissue or product (eggs and milk). TAN is a proportion of excreted N.
- Wherever possible, functions from the literature that relate excretion or emission to environmental factors were used because these typically summarize a large amount of data and they allow interpolation to ecoregion-specific conditions. Where available, Canadian data were used.

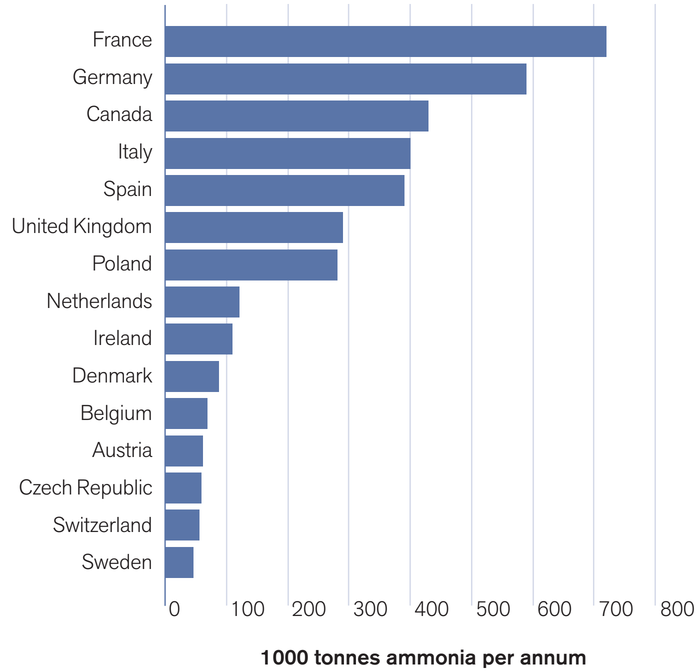


FIGURE 17-1 NH_3 emissions (1000 tonnes of NH_3 per annum) from agricultural sources, comparing Canada to EU countries for the year 2006 (adapted from CEIP 2006)

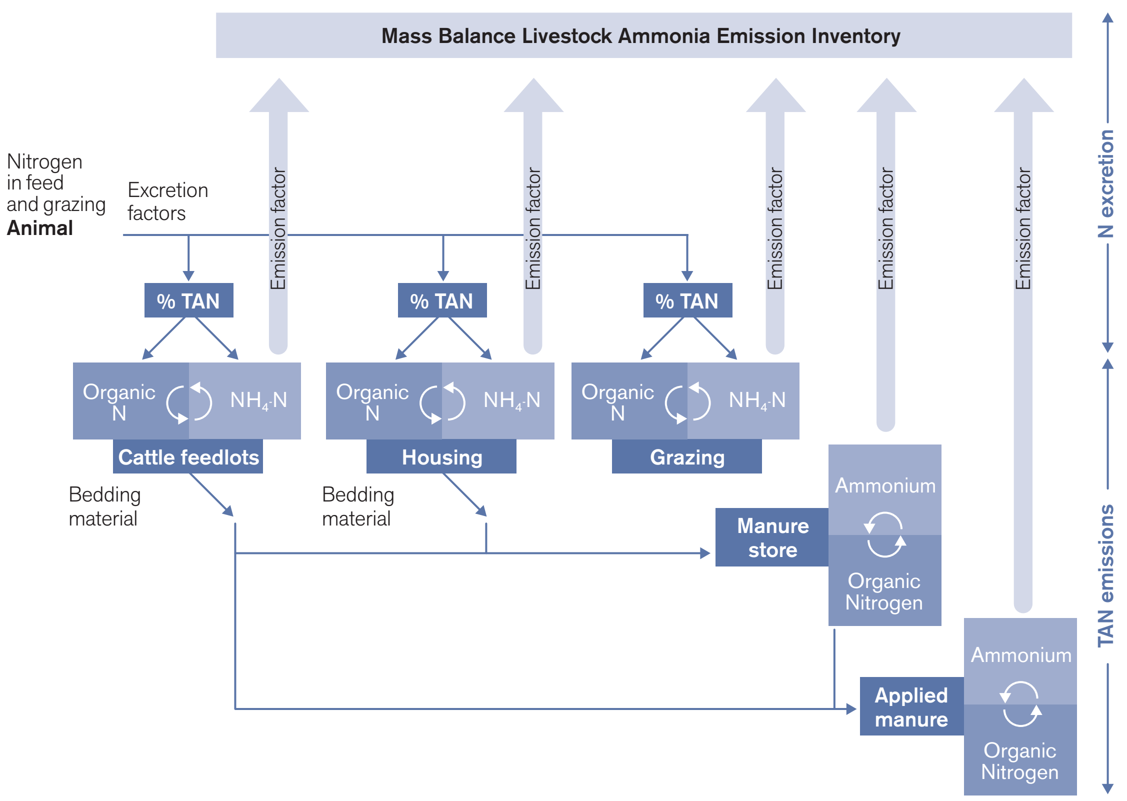


FIGURE 17-2 Structure of mass balance NH_3 emission inventory showing the excretion and emission components (adapted from S.G. Sommer, 2003). In the current model, conversions between organic and inorganic N are not considered.

TABLE 17-1 Percentage of total farmland in each province that was in each of the five NH_3 emission intensity classes (<3, 3–4, 4–6, 6–10 and >10 kg per hectare of agricultural land). The data for 2006 coincide with Figure 17-1.

	2001					2006				
	<3	3–4	4–6	6–10	>10	<3	3–4	4–6	6–10	>10
BC	24	33	31	4	8	32	36	24	2	7
AB	14	15	24	36	11	8	18	28	35	11
SK	51	26	21	2	0	36	31	30	3	0
MB	0	6	48	41	5	0	3	39	49	9
ON	0	0	5	16	78	0	0	6	16	77
QC	0	0	4	19	76	0	1	3	21	75
NB	1	1	18	43	38	1	1	18	45	35
NS	9	4	8	32	48	8	9	6	36	40
PE	0	0	6	29	66	0	0	5	28	67
NF	25	5	3	24	44	16	0	19	17	48
CANADA	**26**	**17**	**23**	**19**	**15**	**18**	**20**	**27**	**20**	**15**

- The numbers of animals per hectare of land were derived from the Census of Agriculture.

The fertilizer emission model (Sheppard, Bittman and Bruulsema, 2009) computes the NH_3 emission per area of land for 37 crops. Emissions from fertilizers are estimated as the product of the amount of N fertilizer applied per hectare and the fractions of applied N that are emitted as NH_3, based on the N products and application practices.

Emissions intensity classes are based on the range of total emission values calculated, divided into five classes.

Limitations

The indicator has been calculated only for the census years 2001 and 2006 due to a lack of appropriate information on livestock feeding practices, housing and manure-management practices in previous census years. The composition of feed materials varies by animal types, feed source and feed mix. This information was not reliably available previous to 2001.

This indicator requires careful interpretation because the emission rates vary markedly throughout the year, the transport of emissions is affected by the weather, and emission rates in some regions have much greater impact than the same emission rates in other regions. The latter is a particular limitation as NH_3 emissions can be significant in the formation of smog events. Smog events can occur over hours or days, depending on presence of other atmospheric pollutants that can react with NH_4 (Chu, 2004).

The indicator requires data that are inherently uncertain in some respects. Where Canadian emission data were not available, *emission-factor* data from Europe and the United States were used and corrected to Canadian conditions where possible.

Results and Interpretation

Ammonia emissions increased by 2% in Canada between 2001 and 2006, with Manitoba and Saskatchewan recording the largest increases, mostly due to increased livestock numbers. The greatest densities of high-emission rates were in southwest Ontario and southern Quebec (Figure 17-5), due to the high animal populations in these areas (Table 17-1). In the Prairies, there were high emission rates in specific regions, related to livestock densities, but a dominant feature was the vast area of agricultural land with low emissions, related to fertilizer application (Figure 17-5, Table 17-2).

There was a decrease from 26% to 18% of cropland in the lowest emission-intensity class (less than 3 kg per hectare) between 2001 and 2006. This decrease was reflected in small increases across the other emission-intensity classes; however, there was no change in the percentage of cropland in the highest emission-intensity class (more than 10 kg per hectare) during this time.

Across Canada, the majority of NH_3 emissions are attributed to the livestock sector, which accounted for approximately 78% of the total (Figure 17-6). The beef sector alone accounted for 46% of total emissions (Figure 17-7), whereas emissions from poultry are a relatively minor contributor nationally at 5%. Emissions from fertilizers accounted for 22% of the total. Emissions of NH_3 (440,000 t of NH_3 or 362,000 t of N) from farms in 2006 is equivalent to approximately 25% of all the fertilizer used in Canada.

Across all livestock sectors, 50 to 63% of excreted TAN was lost from a combination of housing, storage and land application. Approximately 50% of TAN excreted by animals in the dairy sector was lost as NH_3 emission, as was 50% of TAN for beef, 60% for poultry and 60% for swine. Of the losses, typically 45% occurred in housing (including pasture), 5 to 14% during storage and 40 to 54% from land application. Emission rates from fertilizer applied on arable crops during the month of May varied from 3% loss in western Canada to 8% loss in eastern Canada. The regional difference is largely due to greater use of fertilizer injection in western Canada.

Annual total emission values can mask important issues. Most emissions from fertilizer occur thinly across the Prairies because of the area's very large expanses of cropland (Figure 17-3), which translates into little exposure for Canadians to NH_3. In contrast, poultry, dairy and, to some extent, swine are usually located near population centres in Canada. For example, they are major industries in the Lower Fraser Valley and southern Ontario where the formation of particulate matter with aerodynamic diameter of less than 2.5 micrometers ($PM_{2.5}$) related to agricultural NH_3 emissions has been reported. Ammonia emissions

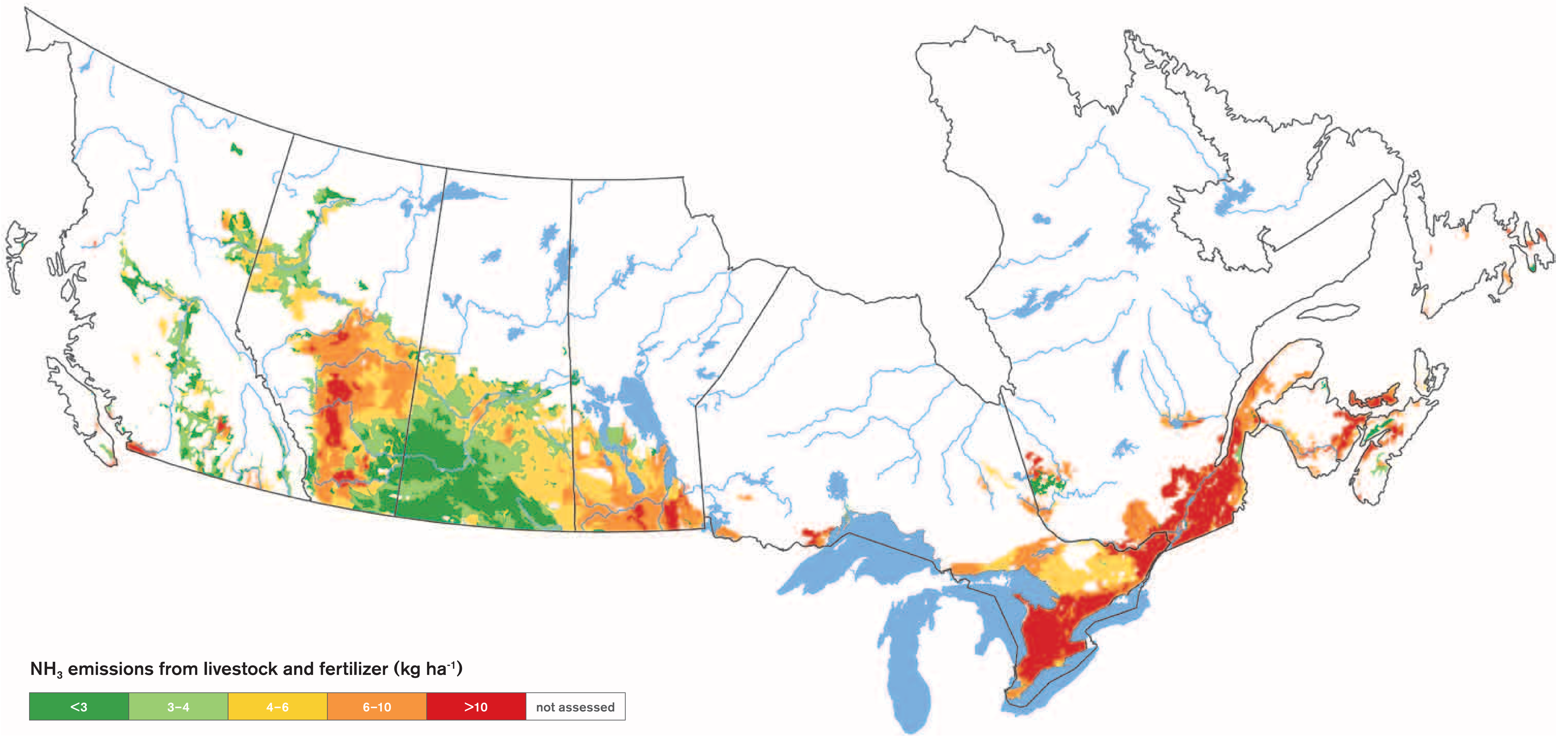


FIGURE 17-3 Total ammonia emission per hectare of agricultural land in 2006 from major livestock sectors and fertilizer

Agricultural Odour Emissions

AUTHORS
D.I. Massé, A. Narjoux, F. Granger, T. Pagé and M. Cournoyer

The Issue

Odour is an important component to consider when assessing the quality of ambient air. Odour can adversely affect quality of life, lead to socio-emotional nuisances and cause genuine physical symptoms. Odour nuisance has become an economic issue for the agriculture industry. New projects have become impossible to implement in certain geographical areas because of increasingly strict regulations regarding where production sites can be located, the distances that certain agricultural enterprises must be from residences and restrictions on the timing of fertilizer, pesticides and manure application. Livestock operations are major sources of odour, but other sources include the production of compost, application of organic fertilizers from waste material, decomposition of crop residues in the field and the application of pesticides to land. Odour emissions from livestock operations are caused primarily by ventilation of livestock housing, storage of animal wastes, application of manure to land, and the disposal of dead-animals (Huang et al., 2005). The major factors contributing to odour nuisances for human populations are the origin of the odours, the frequency of exposure to odours, odour levels during exposures and the length of the episodes.

The Indicator

An agri-environmental odour indicator is under development and will be based on reliable, science-based information. It will gauge the extent to which odour *abatement* techniques have been adopted and assess the industry's approach to addressing the odour issue. Using data from the Census of Agriculture, the Farm Environmental Management Survey (FEMS) and the Livestock Farm Practices Survey, the indicator will consider the various emission sources (eg. livestock buildings, feedlots, manure storage, manure application to land, etc.) and odour mitigation methods (e.g. air filters, building and manure management, storage covers and treatment, land application methods) (Figure 17-4). At the farm level, the indicator will consider factors related to livestock types, odour-mitigation practices and where emission sources are located in relation to neighbouring homes. The odour indicator will offer useful information to decision-makers to assess the current situation and evaluate the efficiency of proposed programs and policies to address the odour issue.

Response Options

Whether or not a livestock-production site adopts beneficial management practices to reduce odour emissions–and the specific practices a site adopts–will depend on the site's size, type and location. Generally speaking, odour-control methods associated with livestock production facilities can be grouped under four areas of action:

1. changes in feed regime, (e.g. reduce nutrient contents of manures),
2. improved management and treatment of excreta, e.g. coverage of manure storage tanks,
3. capture and treatment of gaseous emissions, e.g. physical and biological *biofilters*, and
4. improved conditions for the dispersion of odours into the atmosphere, e.g. rows of trees.

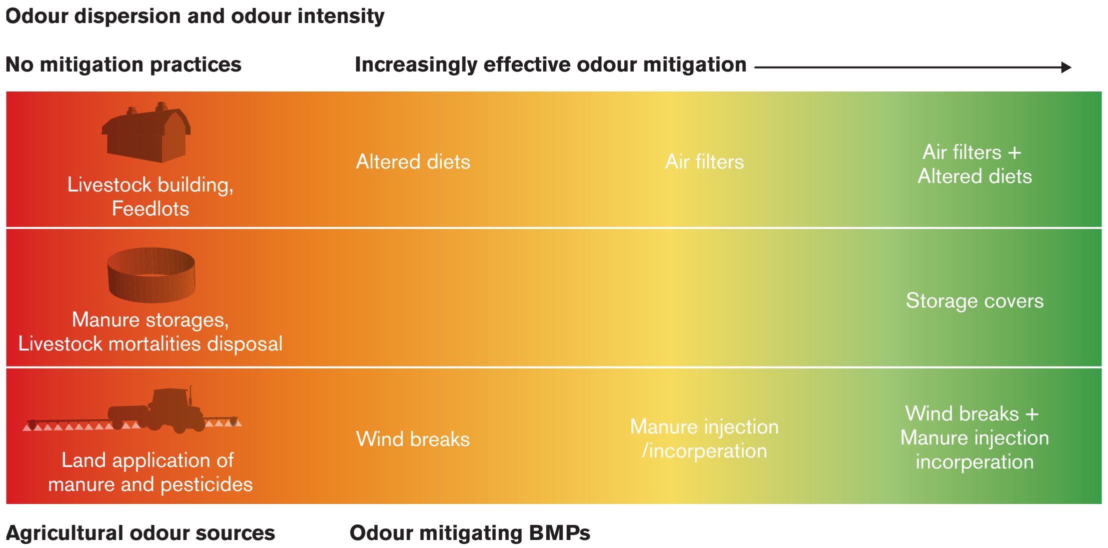


FIGURE 17-4 Conceptual framework for the Agricultural Odour Emission Indicator

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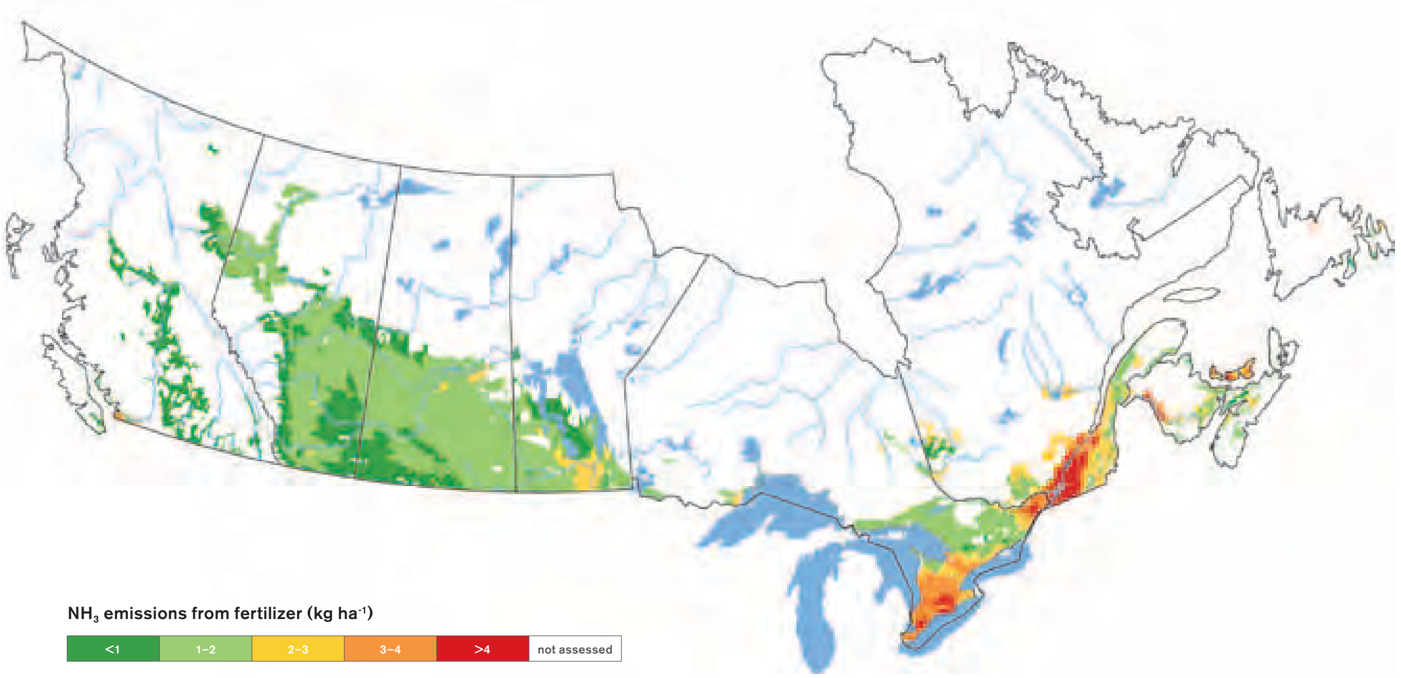

FIGURE 17-5 Ammonia emission from fertilizer per hectare of agricultural land in 2006

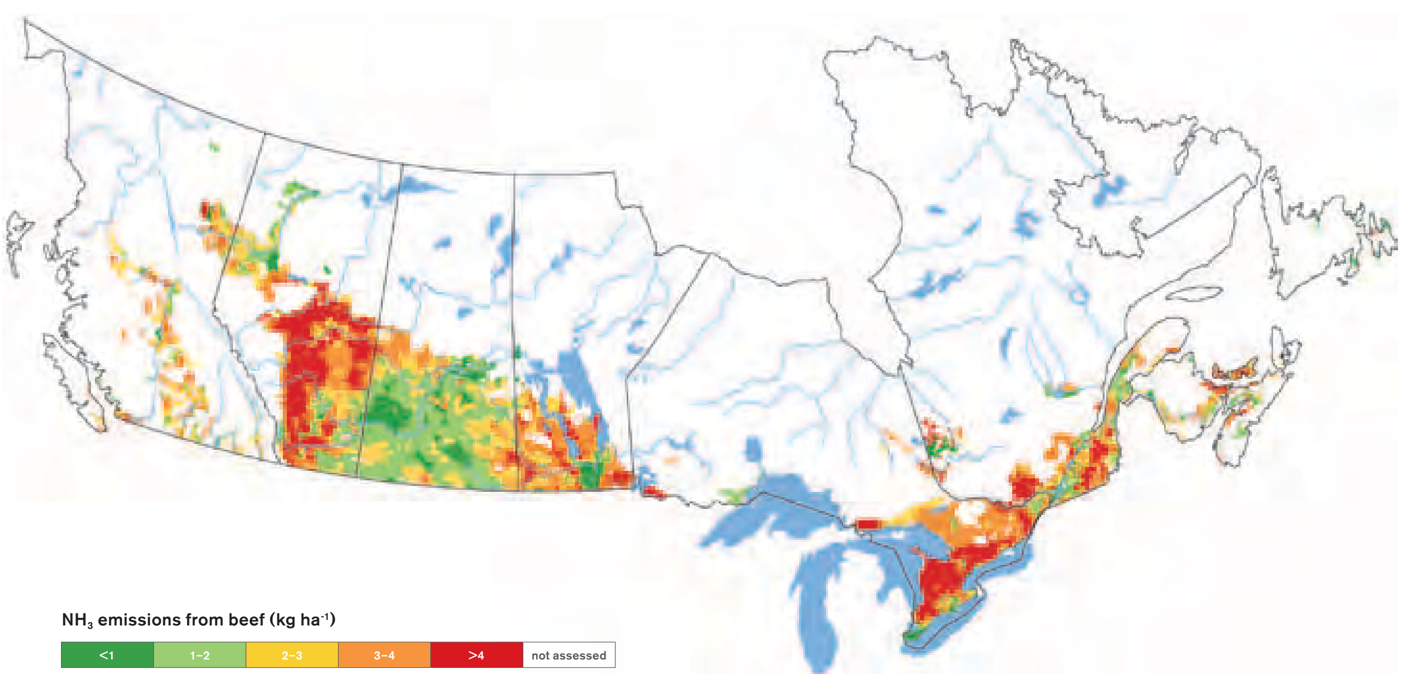

FIGURE 17-6 Total ammonia emissions from beef per hectare of agricultural land in 2006

TABLE 17-2 Distribution of NH_3 emissions among livestock sectors and fertilizers, and among provinces in 2006, and total emissions for 2001

	Poultry	Beef	Dairy	Swine	Fertilizer	Provincial Share of National Emissions (percentage)	
	Sector percentage contribution to 2006 NH_3 emissions					2001	2006
BC	18.8	45.6	21.3	4.2	10.0	4.0	3.6
AB	1.8	70.0	4.4	7.9	20.0	27.9	27.3
SK	1.0	51.1	1.5	7.2	39.4	20.9	21.4
MB	3.2	44.0	4.2	22.0	26.0	10.7	11.4
ON	9.0	32.9	20.7	23.2	15.9	18.8	18.6
QC	7.4	18.5	27.7	35.4	12.9	14.7	14.8
NB	14.8	27.0	25.9	16.7	16.7	0.7	0.6
NS	19.7	30.0	27.4	14.8	8.4	0.8	0.7
PE	2.0	32.3	21.7	22.3	22.3	0.7	0.7
NF	16.9	11.2	61.5	2.3	7.7	0.1	0.1
CANADA	4.8	45.5	11.1	16.1	22.3	100	100
			Total National Emissions (tonnes NH_3 yr^{-1})			430,000	440,000

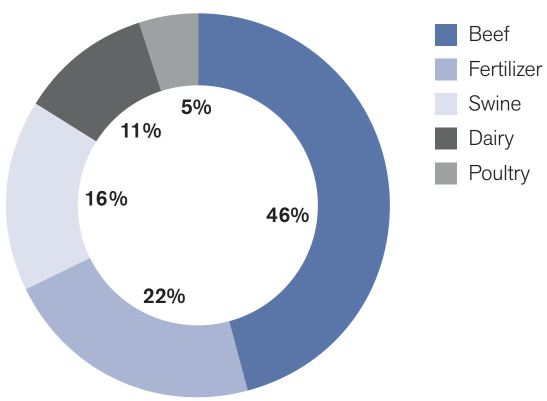

FIGURE 17-7 Proportion of total agricultural emissions by sector in Canada in 2006

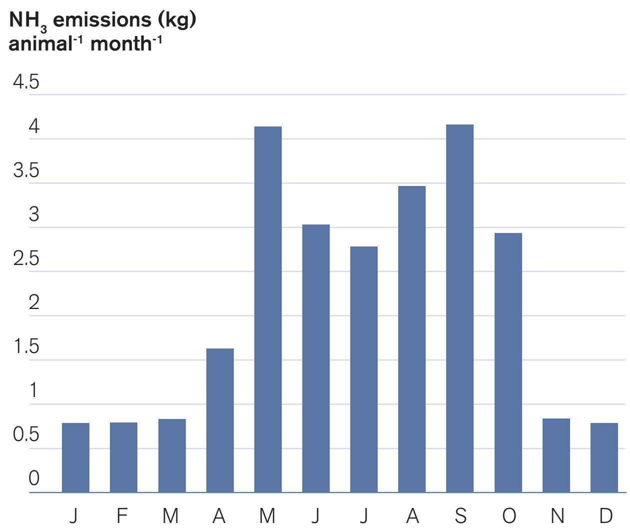

FIGURE 17-8: Estimated monthly NH_3 emissions per animal for beef steers, averaged across Canada (the model calculates ecoregion-specific emission rates)

from both beef and fertilizers further contribute to emissions in the densely populated Windsor-Montreal corridor (Figure 17-3) to influence the formation of $PM_{2.5}$. (For more information about particulate matter and its effect, please see Chapter 18)

For beef steers and most other livestock types, emissions peak in May and again in the fall when storage is emptied, barns are cleaned and manure is applied to arable and forage land prior to seeding or spring growth or following crop harvest (Figure 17-8). Winter emissions are low, in part because lower temperatures decrease emissions, but primarily because there is little landspreading of manure. The emissions from fertilizer (Figure 17-9) are highly concentrated in May; fertilizer applications on perennial forages are somewhat more spread out than on arable lands, as might be expected.

Response Options

Beneficial management practices (BMPs) for reducing NH_3 loss from the livestock sector are complex. Ammonia has a high propensity to escape to the atmosphere, so retaining NH_3 in one place only enhances its potential to escape from another place

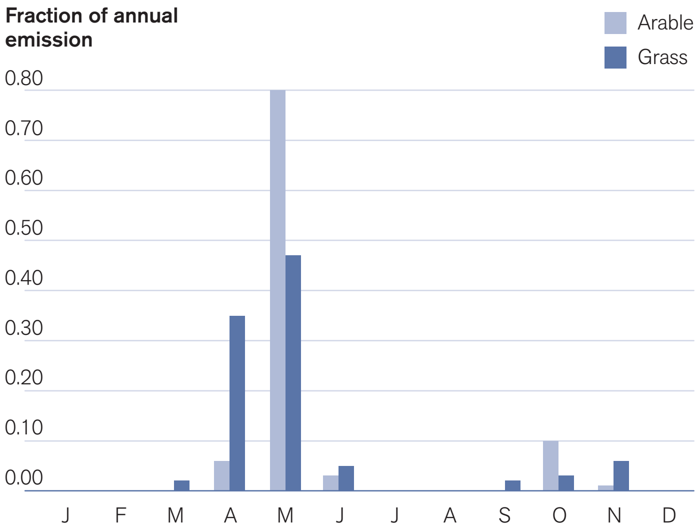

FIGURE 17-9 Estimated fraction total annual NH_3 emission that occurs in each month following fertilizer application to arable land, versus forage land in Western Canada, where most Canadian fertilizer is applied

unless it is adsorbed or taken up by crops. The indicator models suggest that to mitigate NH_3 emissions, animals should not be supplied with protein above their nutritional needs and there should be a focus on better injection or incorporation of manure. Emission rates and the effectiveness of mitigation practices are affected by conditions such as temperature, solar radiation, wind and probability of rainfall.

Altering feed protein inputs is likely to achieve a proportionately greater effect than emission controls, because a portion of the NH_3 conserved at one stage (e.g. in housing or manure storage) is lost in subsequent stages (storage and spreading). However, precisely managing feed protein is more easily done in the poultry and swine sectors than in cattle sectors because of the complexities of ruminant digestion, the extensive use of homegrown forages with varying and untested quality, and grazing.

In Canada, emissions from storages are lower than in other countries due to a cold-storage period. Losses from housing can be reduced by adding chemicals to bedding (e.g. acidifying agents) or barn designs that separate faeces from urine. There is a need for research into the effectiveness of BMPs for beef production in confinement and on pasture.

The regional and local impacts of NH_3 emissions need to be investigated in relation to timing. Smog is often a summer phenomenon, and in that case the peak NH_3 emissions occur too early in the year to have a significant effect. However, there are summertime emissions, especially from barns. Early-spring emissions are likely associated with the ecological effects of excess N because high levels in the atmosphere may harm new plant tissue in sensitive species and because invasive plants, such as grasses that respond strongly to N, undergo major growth in the spring.

The potential loss of NH_3 from urea fertilizers is very high and in the cropping sector there is an economic incentive to reduce losses by adopting BMPs. Effective fertilizer-application methods such as injection (*side-banding* and *side-dressing*) are increasingly used to improve the efficiency of urea-containing fertilizers. However, these methods are not available for established crops such as forages or growing winter wheat. Reducing application rates by precision farming will also reduce emissions.

Mitigating NH_3 emissions requires a thorough understanding of how these emissions represent a loss of resources. There are many ways for producers to increase their efficiency. Any policy or economic factor that leads to increased value of N fertilizer is likely to encourage better ways to reduce NH_3 losses. However, BMPs to mitigate NH_3 emissions must be considered as part of a suite of BMPs for managing N on farms, as NH_3 can have direct and indirect effects in water, air and soil and therefore affect BMPs to improve water, air and soil quality.

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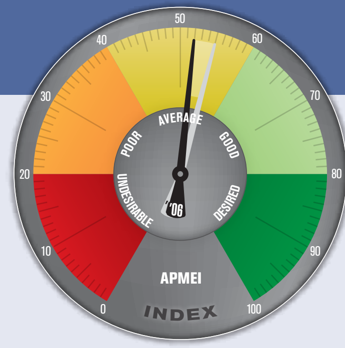
18 Particulate Matter



AUTHORS
E. Pattey, G. Qiu and R. van Haarlem

INDICATOR NAME
Agricultural Particulate Matter Emissions Indicator

STATUS
National coverage 1981–2006

Summary

Particulate Matter (PM) is recognized as an air pollutant due to its adverse health and environmental impacts. PM decreases visibility and influences climate by altering the amount of solar energy reaching the earth's surface and the amount of energy radiating back into space. It contributes to stratospheric ozone depletion, acid rain and smog. The emission of PM from agricultural operations is an emerging air quality issue, especially for agricultural workers and animals. The Agricultural Particulate Matter Emissions Indicator (APMEI) has been developed to estimate the PM contribution from agricultural operations and to assess emission-reduction measures. The APMEI estimates primary PM emissions from animal-feeding operations, wind erosion, land preparation, crop harvest, fertilizer application, grain handling and pollen for the census years of 1981 to 2006.

In 2006, PM emissions from agricultural operations were estimated to be 1637.4 kilotonnes (kt) for total suspended particles (TSP), 652.6 kt for PM with diameter of less than 10 micrometers (PM_{10}) and 158.1 kt for PM with diameter of less than 2.5 micrometers ($PM_{2.5}$), which represents approximately 9% of TSP, 11% of PM_{10} and 11% of $PM_{2.5}$ emissions in Canada. In 2006, PM emissions from wind erosion and land preparation accounted for most of the PM emissions from agricultural operations in Canada. Results from the APMEI indicate a decreasing trend in PM emissions from agricultural operations between 1981 and 2006, with a decrease of 48% for TSP, 40% for PM_{10} and 47% for $PM_{2.5}$. This trend is mainly attributed to an increase in the use of conservation tillage and no-till practices and a decrease in the area of summerfallow land.

The Issue

Particulate matter is a mixture of solid particles and liquid droplets of various sizes and chemical make up suspended in the air. It is classified in two ways: either primary particles emitted directly into the air or secondary particles formed in the air by chemical or physical processes. Epidemiological studies show that increases in PM concentrations, especially fine particulate matter ($PM_{2.5}$), is associated with adverse health effects such as increased respiratory diseases and premature death (Donham and Thelin 2006; Samet and Krewski, 2007; US EPA, 2004). Additionally, PM is recognized as an air pollutant that decreases visibility, contributes to stratospheric ozone depletion, acid rain and smog, and influences climate by altering both the amount of solar energy reaching the earth's surface and the amount of energy radiating back into space.

Agricultural operations have been recognized as a significant source of atmospheric PM (Saxton, 1996; Edwards and Bradley, 2004). The main agricultural sources of primary PM include dust from soil and biological material, droplets and particles from agrochemicals, and bacteria affecting both indoor and outdoor air quality. Outdoor air quality in rural environments is mostly unknown as monitoring stations are sparse. However, indoor PM emissions are a primary concern for agro-industry workers who can be exposed to high concentrations of PM in animal-feeding operations and during grain handling both on the farm and at grain terminals.

Agricultural sources of primary particulate matter

Inorganic PM is a complex composition of minerals that is composed chiefly of dust particles generated from the soil matrix. These dusts are primarily made up of quartz and other silicates. Inorganic dusts, especially quartz, have been linked to numerous health ailments including lung cancer.

Biological PM consists of a broad range of material from organic sources. Examples include animal dander, dust from manure, urine droplets, grain dusts, mold spores, bacteria and pollen. These may include infectious pathogens. Health risks may include allergic reactions, and general respiratory infections.

PM emissions from agriculture show temporal and spatial variations. For example, land preparation and harvest emissions tend to be seasonal, and emissions from livestock operations vary by type of livestock and buildings. Improved estimates of PM emissions from various agricultural sources can be made when temporal and spatial variations are considered and when the impact of mitigation measures such as changes in land use and management practices are taken into account.

The Indicator

The APMEI was developed to estimate primary PM emissions from agricultural operations and to assess the impact of practices adopted to mitigate these emissions. The indicator estimates annual emissions for three classes of PM (TSP, PM_{10}, and $PM_{2.5}$ in kilotonnes per year) from agricultural sources. Agricultural PM sources include wind erosion, land preparation, crop harvest, crop-residue burning, grain handling, pollen emission, fertilizer application, chemical application, animal-feeding operations and animal cremation (Figure 18-1).

The APMEI collects activity data for each agricultural PM source then applies a corresponding emission factor to estimate the total amount of PM emission. For example, primary PM emissions from harvest are calculated by multiplying an emission factor (kg PM per hectare of crop type per year) by area of the crop. Activity data are largely derived from the Census of Agriculture and the Farm Environmental Management Survey (FEMS). PM emission calculations were completed for each census year at the Soil Landscape of Canada (SLC) polygon level then PM emissions for each SLC polygon were summed to estimate emissions at provincial and national scales. The range of emissions was divided into five classes to highlight both the changes within an individual SLC over the time period (1981 to 2006) and the differences between SLCs on an annual basis. The classes of PM emissions from each agricultural

Particulate matter explained

WHAT IS THE DIFFERENCE BETWEEN PRIMARY AND SECONDARY PARTICULATE MATTER?

Primary PM refers to particles released intact into the air and results from processes such as wind erosion or tillage (dust), burning (soot), harvesting or grain handling (grain dust). Secondary PM refers to particles that are formed in the air. For example, ammonia may react with other airborne pollutants to form particles that contribute to smog (Figure 18-1).

WHAT DO THE DIFFERENT SIZE CLASSES OF PARTICULATE MATTER REPRESENT?

Particulate matter comprises millions of different chemical compounds, dust and biological material, including feather fibres, dander and bacteria. These particles are classified depending on their *aerodynamic diameter* and are defined as follows:

$PM_{2.5}$ Particles with an aerodynamic diameter of less than 2.5 micrometers. These particles are easily inhaled into the lower airway (the gas-exchange regions of the lung) where they may be deposited and result in adverse health effects.

PM_{10} Particles with an aerodynamic diameter of less than 10 micrometers, including $PM_{2.5}$. These particles are inhaled and can settle in the bronchi and lungs and cause health problems.

TSP All PM suspended in the atmosphere with an aerodynamic diameter of less than 100 micrometers.

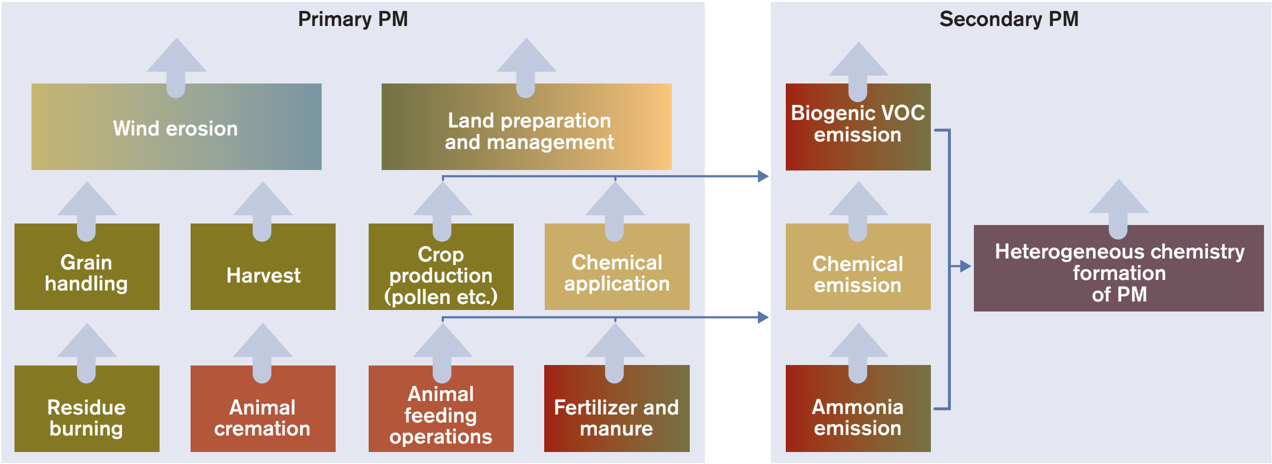


FIGURE 18-1 Main activities and factors contributing to primary and secondary PM emissions in agriculture

SLC polygon are an indicator of PM contribution, but are not directly related to the regional air quality. Local and regional air quality is influenced by numerous environmental factors that ultimately control the dispersion and distribution of PM from the original source. Additionally, the time-related variation of PM emissions from most agricultural sources is not obvious when results are presented on an annual basis.

Limitations

To provide a comprehensive estimation of primary PM emissions, the indicator considers as many agricultural-activity sources of emissions as possible. There are, however, limitations mainly due to the quality of activity data and the corresponding emission factors. Where possible, missing activity data—such as for some aspects of grain handling—were estimated based on expert opinion or were obtained from other government agencies such as PM from chemical pesticide application. Many emission factors have not been determined for Canadian agricultural systems, making it necessary to use factors from studies conducted in the United States where conditions may not exactly match those in Canada.

The emphasis of the indicator is on primary PM from agricultural operations. However, secondary PM emissions are also important to the agricultural PM contribution. A complete estimate of the contribution of agriculture to PM should account for secondary PM emissions. However, this is currently beyond the scope of the APMEI.

Results And Interpretation

Total PM emissions from agriculture in Canada showed a decreasing trend from 1981 to 2006 (Table 18-1), by 48% for TSP, 40% for PM_{10} and 47% for $PM_{2.5}$. In 2006, agricultural PM emissions were 1637 kilotonnes (kt) of TSP, 653 kt of PM_{10} and 158 kt for $PM_{2.5}$.

TSP, PM_{10} and $PM_{2.5}$ emissions in Canada in 2006 (Figure 18-2, 18-3, 18-4, Table 18-2) predominately emanate from the Prairie Provinces. This is expected as the Prairies contain the largest proportion of agricultural land for any region in Canada. A few key areas in Ontario and Quebec are also large contributors to PM emissions (Figures 18-2, 18-3, 18-4). The limited extent of agriculture and limited information available precluded PM emissions calculations for Newfoundland and Labrador.

The decreased PM emissions between 1981 and 2006 strongly reflect changes in land use and management practices. Although wind erosion, land preparation and harvesting are the main contributors to PM emissions (Figure 18-5), the shift to conservation tillage and no-till practices and the reduction in summerfallow were the main contributors to the overall decrease of PM emissions. These changes more than offset emissions from increases in animal populations, fertilizer application and cropland area.

Practices that effectively reduce PM emissions include increasing soil crop cover and decreasing the area of summerfallow.

Response Options

There are many ways to mitigate PM emissions from agricultural operations by improving land use practices. The specific mitigating practices that will prove to be useful, however, depend on the type of agricultural operation. Practices that effectively reduce PM emissions include increasing soil crop cover and decreasing the area of summerfallow.

Primary PM from animal-feeding operations is generated through the animals' activities in barns or feed lots. PM emissions can be reduced by changing the production environment: decreasing animals' confinement time (or increasing the grazing period), collecting litter and manure more frequently, installing dust extraction or filtered ventilation systems and sprinkling mist or oil to reduce dust.

Wind blowing across exposed agricultural land, causing wind erosion, results in PM emissions. Increasing soil cover can significantly decrease PM emissions from wind erosion. The major practices used to increase soil cover include reduced tillage and no-till, decreasing the amount of land under summerfallow, increasing the amount of land used for permanent grass, use of forages in rotations, use of winter cover crops, strip cropping, *contour cultivation* and *windbreaks*.

Airborne soil PM emissions are generated during tillage by the mechanical operations used to prepare the soil. PM emissions from agricultural tillage are proportional to the area tilled, the type of tillage implement used (e.g., plough) and the number of tillage operations performed in a year. Reducing tillage or using no-till practices reduces PM emissions. In addition, using chemical weed control on summerfallow land can also reduce PM emissions by decreasing the number of tillage operations used in a year, though it may increase PM drift from chemical application.

PM emissions from crop harvest are generated when combines and vehicles travel over fields. PM emissions from harvesting vary with the crop type, however there are few specific practices that can reduce PM emissions from crop harvesting. Harvesting during high relative humidity and low wind-speed conditions can mitigate PM emissions. Also, some practices used for wind-erosion control, such as the use of terraces, contouring, and strip-cropping suppress the transport of harvested crop fragments in the wind. Using reduced tillage or no-till practices and

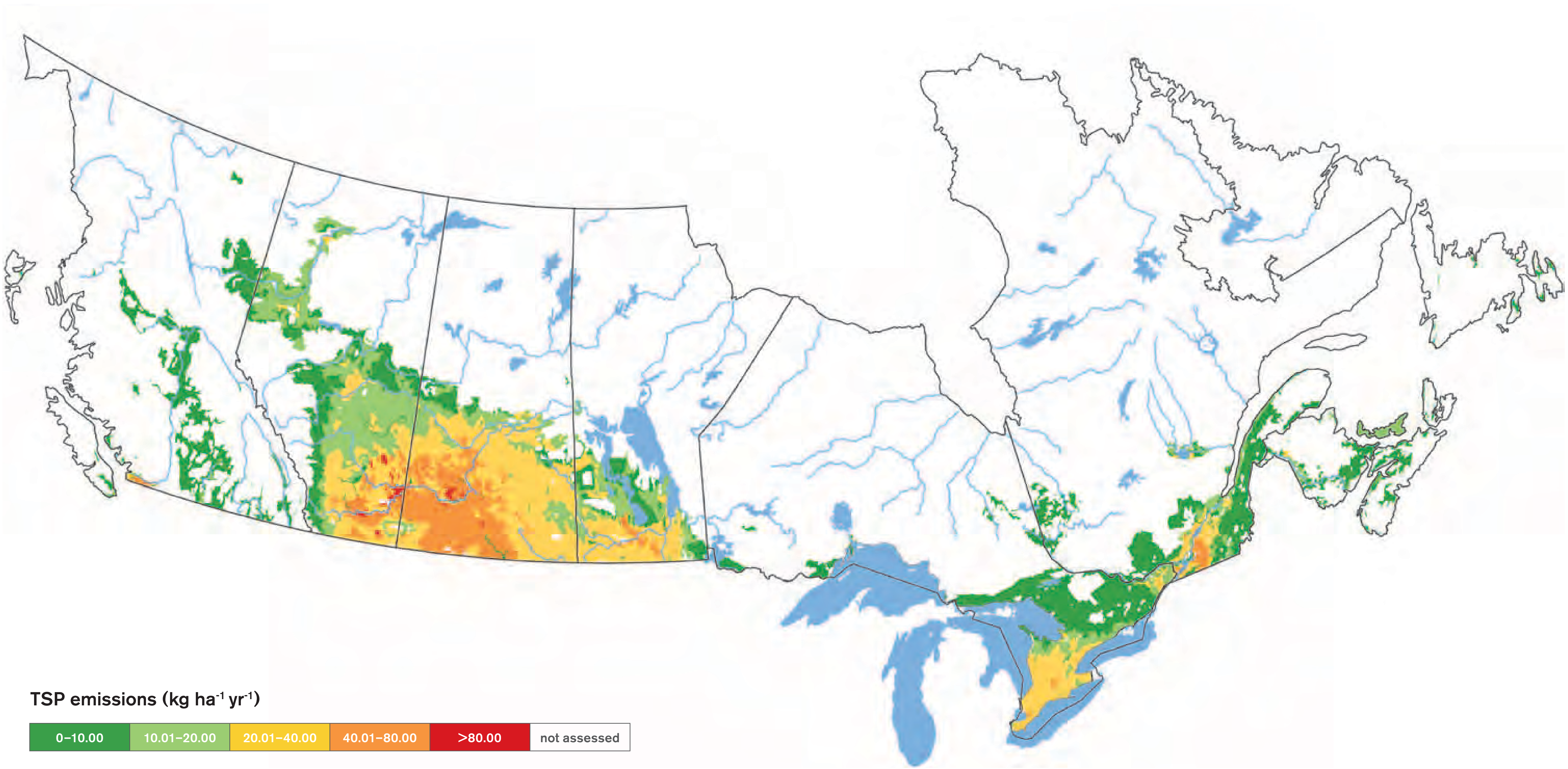


FIGURE 18-2 Agriculture primary PM emissions under 2006 management practices for TSP

TABLE 18-1 Particulate matter emissions (in kilotonnes) from Canadian agricultural operations, 1981–2006

	TSP Emissions (kt yr^{-1})						PM_{10} Emissions (kt yr^{-1})						$PM_{2.5}$ Emissions (kt yr^{-1})						% change 1981–2006*		
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	TSP	PM_{10}	$PM_{2.5}$
BC	13	13	13	13	12	13	4	4	4	4	3	4	1	1	1	1	1	1	-4	-4	-11
AB	803	735	673	615	514	431	278	269	249	234	204	179	76	73	67	62	52	43	-46	-35	-44
SK	1828	1560	1387	1248	1116	848	665	596	530	492	460	366	174	155	137	125	112	84	-54	-45	-52
MB	295	251	225	217	196	169	99	90	82	79	73	63	28	25	22	22	20	17	-43	-36	-40
ON	172	149	146	129	127	111	36	34	34	29	28	26	12	12	12	10	10	9	-36	-28	-31
QC	48	45	47	50	61	57	11	10	10	11	12	12	3	3	3	4	4	4	18	12	16
NB	4	3	3	3	3	3	1	1	1	1	1	1	0	0	0	0	0	0	-12	-6	-9
NS	3	2	4	2	2	2	1	1	1	1	1	0	0	0	0	0	0	0	-23	-28	-27
PE	5	5	5	5	5	4	2	1	1	1	1	1	1	0	0	0	0	0	-20	-16	-14
CANADA**	**3170**	**2763**	**2504**	**2283**	**2036**	**1637**	**1095**	**1005**	**911**	**852**	**783**	**653**	**296**	**270**	**243**	**223**	**198**	**158**	**-48**	**-40**	**-47**

* excluding NL ** comparison is only between emissions categories reported for all census years. The categories included are: wind erosion, tillage, crop harvest, grain handling, pollen, fertilizer application, chemical applications and animal-feeding operations.

TABLE 18-2 Percentage of agricultural farmland in each TSP emission intensity class, 1981–2006

	(0–10 kg $ha^{-1}yr^{-1}$)						(10–20 kg $ha^{-1}yr^{-1}$)						(20–40 kg $ha^{-1}yr^{-1}$)						(40–80 kg $ha^{-1}yr^{-1}$)						(>80 kg $ha^{-1}yr^{-1}$)					
	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006	1981	1986	1991	1996	2001	2006
BC	86.0	87.9	92.0	91.4	91.5	92.7	10.0	10.3	6.5	7.1	4.4	4.2	3.7	1.8	1.2	1.3	2.0	1.5	0.2	0.0	0.3	0.2	2.1	1.6	0.0	0.0	0.0	0.0	0.0	0.0
AB	9.8	10.5	11.0	12.2	16.0	17.4	10.6	11.3	11.7	13.0	27.3	44.0	25.5	30.7	34.1	41.8	42.5	30.1	44.9	42.0	38.7	29.9	12.9	7.1	9.2	5.5	4.4	3.2	1.4	1.4
SK	1.8	2.0	2.1	2.3	2.3	2.6	2.2	2.4	2.5	2.9	2.5	11.7	9.1	11.0	11.8	14.9	49.2	53.7	48.2	54.9	63.9	64.8	41.4	31.1	38.7	29.7	19.7	15.0	4.5	0.9
MB	11.4	12.5	14.3	15.0	10.9	10.5	11.1	11.6	11.1	10.5	11.1	23.6	14.6	16.9	17.2	21.9	67.5	60.6	58.8	57.5	55.6	52.1	10.5	5.3	4.1	1.5	1.7	0.6	0.0	0.0
ON	23.6	24.8	28.9	30.2	16.2	22.7	20.8	22.7	21.7	19.4	21.9	19.1	29.6	31.1	32.5	37.9	53.8	57.0	26.0	21.4	16.9	12.5	8.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0
QC	61.6	59.0	54.4	51.1	34.6	36.5	17.6	18.6	21.5	23.0	20.9	20.8	20.4	20.5	22.8	21.7	25.7	28.7	0.3	1.9	1.3	4.3	18.9	14.0	0.0	0.0	0.0	0.0	0.0	0.0
NB	83.0	82.3	83.0	83.1	65.5	65.9	17.0	17.7	17.0	16.9	27.7	31.0	0.0	0.0	0.0	0.0	6.8	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NS	88.2	89.9	88.4	91.4	87.9	89.7	7.7	7.7	8.8	5.8	7.8	6.8	4.1	2.4	2.8	2.8	3.9	3.1	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
PE	28.0	28.9	35.5	24.1	0.0	0.0	37.0	36.2	34.2	41.1	77.4	100.0	35.0	34.9	30.2	34.8	22.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CANADA	**13.2**	**13.2**	**13.7**	**14.5**	**13.5**	**15.0**	**8.4**	**8.9**	**8.9**	**9.3**	**14.0**	**24.4**	**16.8**	**19.5**	**21.1**	**25.8**	**46.6**	**43.7**	**42.4**	**44.2**	**46.5**	**43.2**	**23.6**	**16.2**	**19.2**	**14.2**	**9.8**	**7.2**	**2.3**	**0.8**

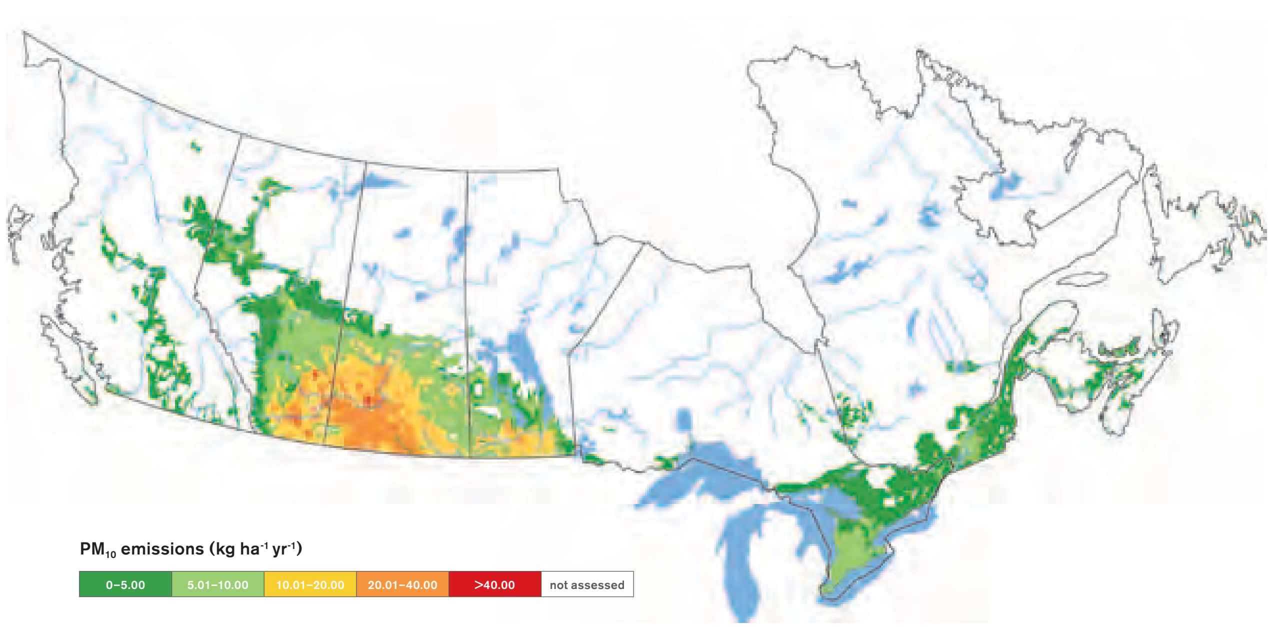


FIGURE 18-3 PM emissions distribution by province in 2006 for PM_{10}

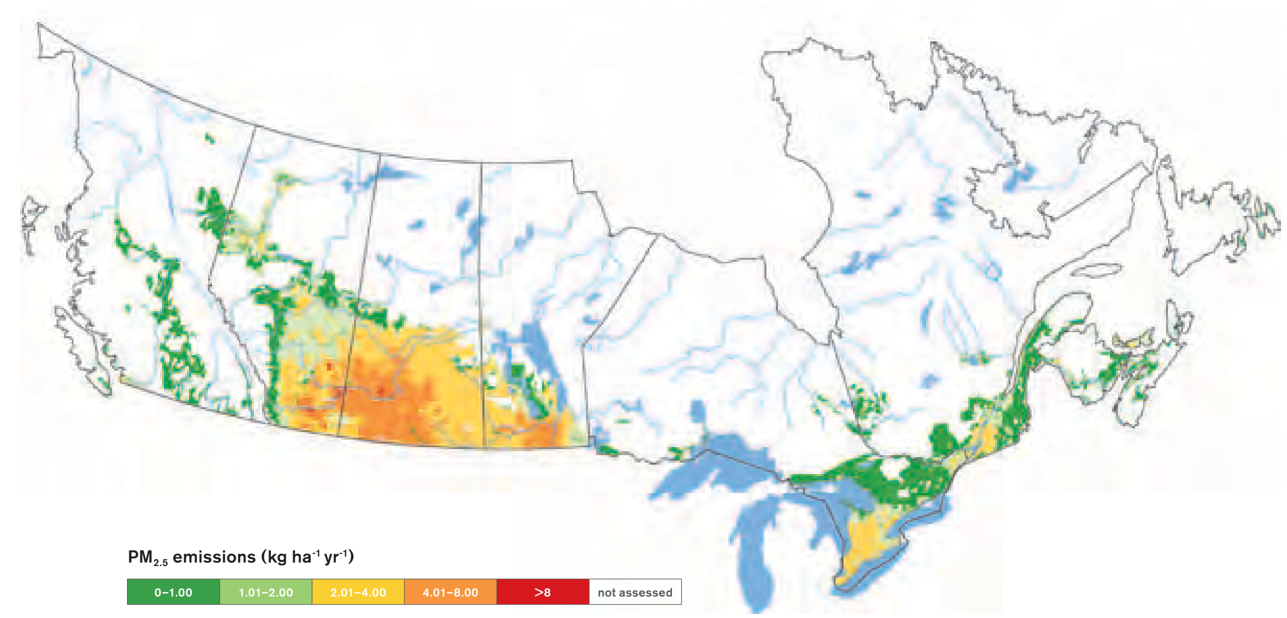


FIGURE 18-4 PM emissions distribution by agricultural sector in 2006 for $PM_{2.5}$

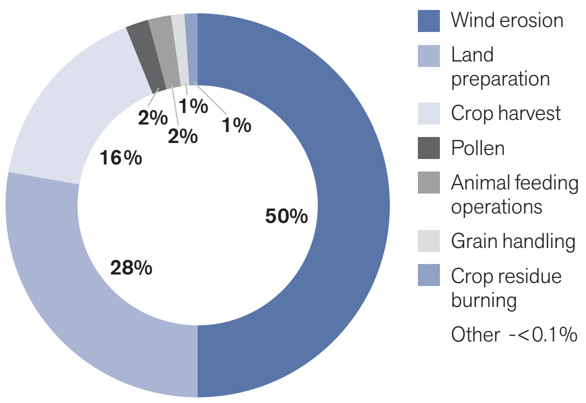


FIGURE 18-5 Contribution of agricultural operations to particulate matter emissions (TSP).

managing crop residues decreases PM emissions from vehicles traveling in fields.

PM emissions from fertilizer application are generated in windy conditions or when the soil is disturbed by land preparation. Optimum nutrient management is the best practice for controlling PM emissions from the application of fertilizer, which includes optimizing the timing of fertilizer application, fertilizer placement and matching the nutrient needs of crops.

The application of agrochemicals to croplands is a widely used practice in Canadian agricultural systems. This practice greatly improves productivity; however, the possible drift of these chemicals may contribute to TSP emissions. Although these emission estimates are currently very low compared to other agricultural sources, chemical drift may be reduced by confining application to calm and cool conditions, by selecting appropriate nozzle design, reducing sprayer speed and boom height, and leaving an unsprayed buffer zone next to uncultivated sensitive areas.

More research on agricultural PM emissions and emission factors relevant to Canadian conditions could enhance the Agricultural Particulate Matter Emissions Indicator (APMEI) and contribute to model development of PM emissions. Future enhancements could include integrating secondary PM in the APMEI, which requires additional research and should be done in collaboration with atmospheric modelling experts.

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Food and Beverage Industry

Food and Beverage Industry (FBI)

Summary

The Canadian food and beverage industry (FBI) consists of approximately 6,700 establishments across Canada involved in the transformation of raw agricultural commodities or semi-prepared food and beverage products into a variety of consumer-ready food and beverage products (Figure F-1). The FBI accounts for 2% of the national Gross Domestic Product and supplies approximately 78% of all processed food and beverage products available in Canada.

The industry uses considerable resources in the production of a broad range of highly diversified products either for the consumer or as ingredients for other FBI products. The FBI establishments and products are often tightly linked to regional agricultural production characteristics while the technologies used are highly dependent on the scale of production.

Five indicators have been developed to assess the efficiency of the FBI's use of water, energy and packaging materials per value of production sold. These indicators can be used as a proxy to assess the environmental performance of the FBI and identify gaps where improvements may be made.

To maintain consistency within food industry sectors and to make valid regional comparisons with the indicators, FBI sectors have been grouped by common characteristics such as activity sector, region and size as determined by the number of employees. Table F-1 details these characteristics.

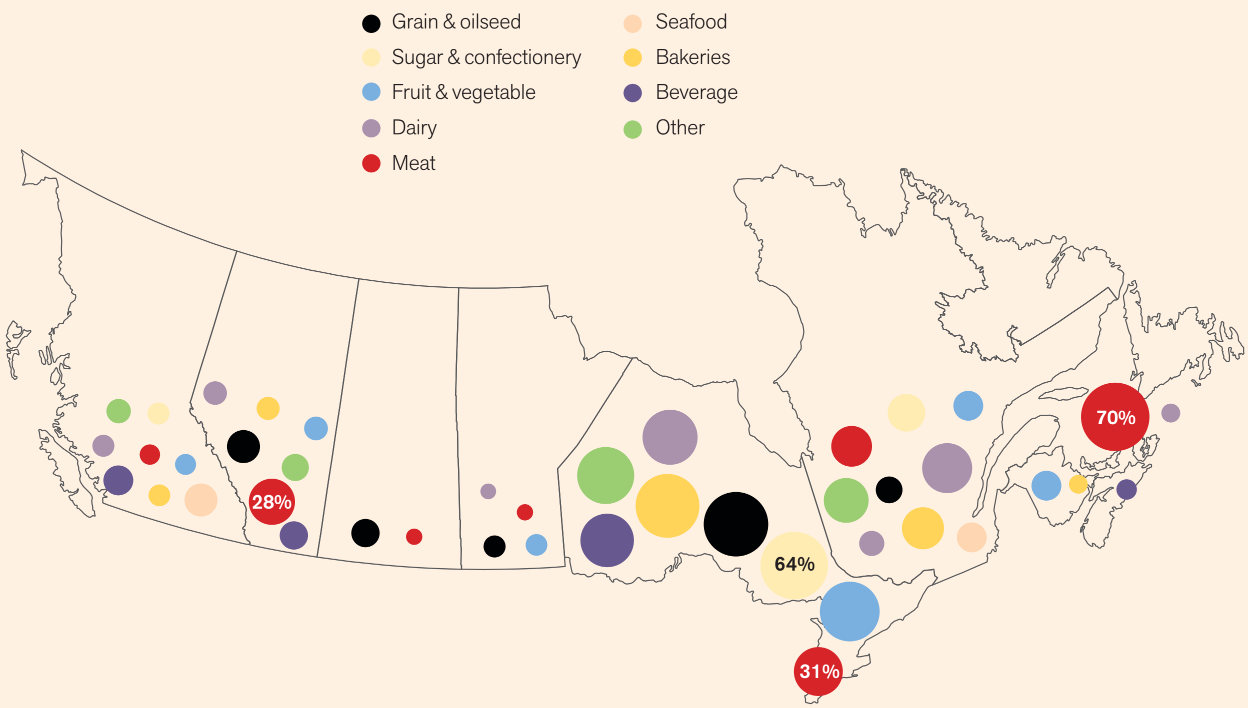

FIGURE F-1 Relative contribution by province to Canadian production by food and beverage manufacturing sectors, 2002.

To assess environmental efficiency within the food and beverage industry (FBI), five agri-environmental indicators developed:

- The Energy Consumption Intensity (ECI) Indicator measures the amount of energy used per dollar of manufactured goods produced (MJ/$) (Chapter 19).
- The Greenhouse Gas Emission Intensity (GHGEI) Indicator measures the amount of GHG emitted, expressed in CO_2 equivalent, per dollar of manufactured goods produced (kg CO_2e/$) (Chapter 19).
- The Water Intake Intensity (WII) and Water Discharge Intensity (WDI) indicators measure the total amount of water entering a plant (WII) and discharged as wastewater (WDI) per value of production sold (expressed in litres per dollar of sold products, or L/$) (Chapter 20).
- The Packaging Use Intensity (PUI) Indicator measures the annual purchases of packaging materials per dollar of production for different sectors of the FBI (Chapter 21).

At this time, the ECI Indicator, the GHGEI Indicator, and the PUI Indicator have data available for 2002 only. Similarly, WDI and WII indicators have data for only one benchmark year, 2005. Therefore, trend analysis is not possible. However, the indicators will allow for trend analysis in future years.

TABLE F-1 Plant groupings for indicators reporting

Sector and subsector short name	Activity sector and subsector definition
Grain & Oilseed	**Grain & oilseed milling, *made of***
‣ Flour	‣ Flour milling
‣ Malt	‣ Rice milling and malt manufacturing
‣ Oilseed	‣ Oilseed processing
‣ Breakfast	‣ Breakfast cereal manufacturing
Sugar & Conf.	**Sugar & confectionery product manufacturing, *made of***
‣ Sugar	‣ Sugar manufacturing
‣ Cacao conf.	‣ Chocolate and confectionery manufacturing from cacao beans
‣ Chocolate conf.	‣ Confectionery manufacturing from purchased chocolate
‣ Candy conf.	‣ Non-chocolate confectionery
F&V	**Fruit & vegetable preserving, *made of***
‣ Frozen F&V	‣ Frozen food
‣ Other F&V	‣ Fruit and vegetable canning, pickling and drying
Dairy	**Dairy product manufacturing, *made of***
‣ Milk	‣ Fluid milk
‣ Other dairy	‣ Butter, cheese and dry and condensed dairy products manufacturing
‣ Ice cream	‣ Ice cream and frozen dessert manufacturing
Meat	**Meat product manufacturing, *made of***
‣ Red meat slaughter	‣ Animal (except poultry) slaughter
‣ Red meat	‣ Rendering and meat processing from carcasses
‣ Poultry	‣ Poultry processing
Seafood	**Seafood product preparation and packaging**
Bakeries	**Bakeries & tortilla manufacturing, *made of***
‣ Retail bakeries	‣ Retail bakeries
‣ Com. bakeries	‣ Commercial bakeries and frozen bakery product manufacturing
‣ Cookies	‣ Cookie and cracker manufacturing
‣ Flour mix	‣ Flour mixes and dough manufacturing from purchased flour
‣ Pasta	‣ Dry pasta manufacturing
Beverage	**Beverage manufacturing, *made of***
‣ Soft drink	‣ Soft drink and ice manufacturing
‣ Breweries	‣ Breweries
‣ Wineries	‣ Wineries
‣ Distilleries	‣ Distilleries
Region and short name	**Region and definition**
All	**Canada**
‣ BC	‣ British Columbia
‣ PR	‣ Alberta, Saskatchewan, Manitoba
‣ ON	‣ Ontario
‣ QC	‣ Quebec
‣ AT	‣ New-Brunswick, Prince Edward Island, Nova-Scotia, Newfoundland & Labrador
Size short name	**Establishment size category**
All	**All size**
‣ Small	‣ Up to 49 employees
‣ Medium	‣ From 50 to 99 employees
‣ Large	‣ From 100 to 199 employees
‣ Very large	‣ 200 and more employees

19 Energy Use and Greenhouse Gas Emissions

AUTHORS
D. Maxime, Y. Arcand, D. Landry and M. Marcotte

INDICATOR NAME
Energy Consumption Intensity (ECI) and
Greenhouse Gas Emissions Intensity (GHGEI)

STATUS
National coverage for 2002

Summary

The food and beverage industry (FBI) requires a significant amount of energy and contributes to the emission of greenhouses gases (GHGs) when transforming agricultural raw materials into semi-prepared and consumer-ready food and beverage products. In 2002, the Canadian FBI accounted for approximately 4% of energy consumption by all Canadian manufacturing sectors. GHG emissions in the FBI come from burning fossil fuels, from hydrofluorocarbons (HFCs) found in refrigeration and freezing units, and possibly from the release of methane (CH_4) from wastewater treatment. The Energy Consumption Intensity (ECI) indicator and the Greenhouse Gas Emission Intensity (GHGEI) indicator estimate the direct amount of energy consumed and GHGs emitted per dollar of manufactured goods produced for the FBI for 2002.

The ECI reveals that the grain & oilseed milling sector, and the sugar & confectionery products manufacturing sector are among the most energy-intensive users, particularly the rice milling & malt manufacturing, oilseed processing and sugar manufacturing subsectors. The same is true of the distilleries within the beverage sector. The least energy-intensive sectors are seafood, meat, and dairy products manufacturing.

The GHGEI is generally consistent with energy consumption. However, regional differences exist in the type of energy used, which influences the amount of GHG emitted. For example, in the Atlantic provinces, the energy grid is more reliant on heavy fuel oil and other petroleum based energy which emits large quantities of GHG, whereas British Columbia's energy grid relies mostly on cleaner energy mixes such as natural gas. Lastly, the indicators showed no consistent relationship between the size of establishment and energy efficiency or GHG emissions.

The Issue

The FBI in Canada consumes a significant amount of energy in the production of semi-prepared and consumer-ready foods and beverages. The energy consumed can be direct or indirect: direct energy is generated onsite and indirect energy is produced elsewhere then converted and transported to the site, such as when an establishment uses an electric oven with electricity coming from a coal burning power plant. When this energy is fossil fuel based, such as natural gas or coal, GHGs are emitted.

As Table 19-1 shows, the Canadian FBI consumed around 100,700 terajoules (TJ, which can also be described as millions of megajoules) in 2002. This was approximately 4% of the energy consumed by all Canadian manufacturing sectors. Table 19-1 also compares the energy use of the FBI with other manufacturing industries as well as with the agriculture sector and with the total net energy supplied in Canada.

Energy accounts for a significant share of FBI production costs and typically ranks third after raw materials and labour costs. It is estimated that 40% of the value of processed food is added through energy intensive manufacturing (U.S. Environmental Protection Agency, 2007) such as process heating and cooling systems. Thus, the FBI is sensitive to rises in energy prices, especially as its profit margins are often low. Most of the energy demand is necessary to maintain food safety. Therefore, increased energy efficiency, rather than just energy reduction, is

TABLE 19-1 Energy use and GHG emissions from manufacturing industries, from agriculture and in Canada, 2002

	Energy use		GHG emissions	
	terajoules	percentage††	thousand tons CO_2 equivalent	percentage††
Food manufacturing*	88 765	3.5	3 477	3.3
Beverage manufacturing*	11 975	0.5	517	0.5
Total, food and beverage manufacturing (FBI)*	100 740	4	3 994	3.8
Pulp and paper manufacturing*	830 779	33	9 888	9.5
Total, manufacturing industries*	2 515 928	100	103 911	100
Agriculture**	205 655	–	52 000	–
Canada**, †	9 669 768	–	720 000	–

* Manufacturing data come from CIEEDAC (2008), both for energy and GHG.

** Energy use data come from Statistics Canada (2003, 2007); GHG emissions data come from Environment Canada's GHG national inventory report; GHG for Agriculture exclude combustion-related emissions, which are a few percent only of total agriculture emissions.

† Canada energy use is the total net energy supply in Canada.

†† Since data sources and accounting methods differ, precise comparisons are not recommended between manufacturing data and other data and are presented for information only. CIEEDAC data are deemed more comprehensive and include energy and GHG emissions from waste, biomass, etc., which can influence significantly total energy use for some manufacturing sectors.

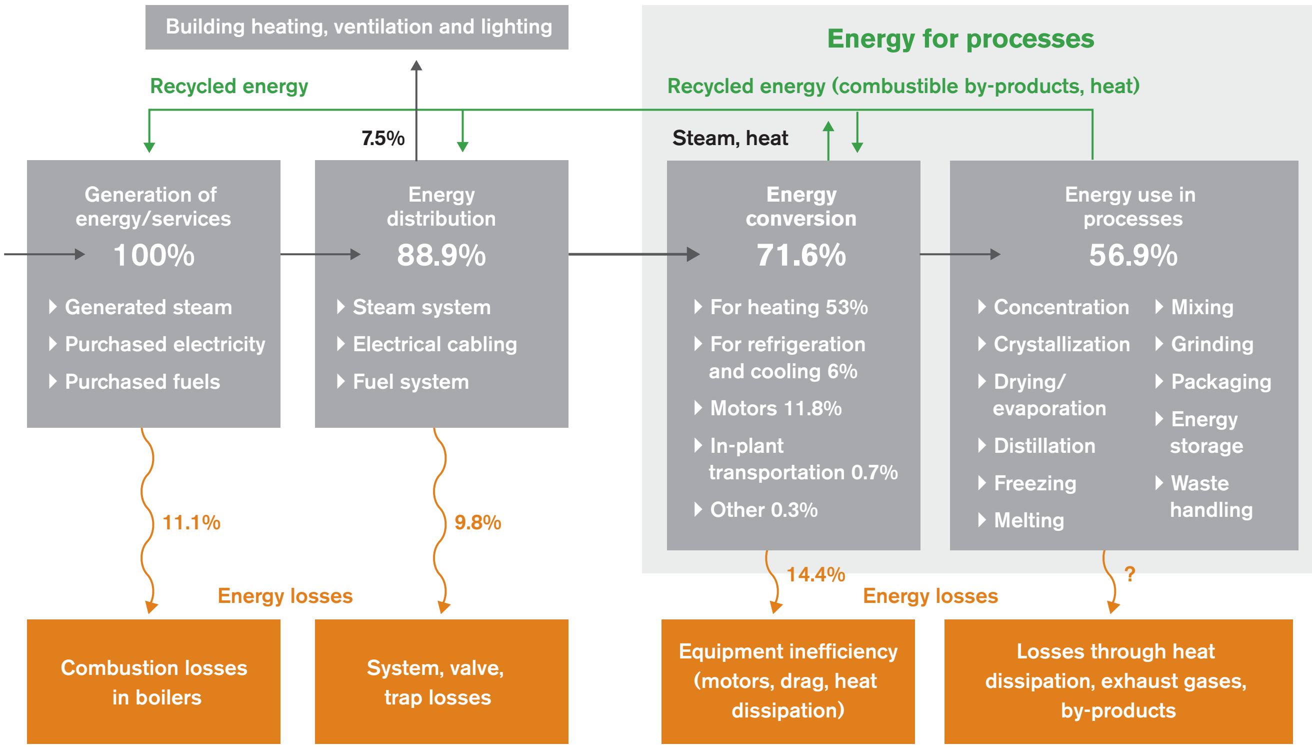

FIGURE 19-1 Diagram of typical energy flows in a food manufacturing plant

Source: adapted from U.S. Department of Energy, 2004

the main path to a more sustainable food industry. Figure 19-1 shows the typical energy uses in an FBI plant.

A variety of energy sources exist, most of which are non-renewable, such as fossil fuels or electricity produced using coal, heavy fuel or nuclear sources. In 2002, approximately two thirds of the FBI's energy needs were supplied by natural gas and more than 20% by electricity (CIEEDAC, 2008). In addition to problems associated with the increasing cost of fossil fuels and the environmental issues associated with their extraction and refining, the combustion of fossil fuels generates GHGs such as carbon dioxide (CO_2) and nitrous oxide (N_2O) that contribute to global climate change.

There are three primary sources of direct—onsite—GHG emissions in the FBI. First, fossil fuel combustion in boilers and in ovens accounts for up to 90% of total emissions in a plant relying heavily on these types of energy, and emits CO_2, N_2O and other particulates into the atmosphere. Second, hydrofluorocarbons (HFCs) are used in refrigeration and freezing units that sometimes leak during a system's lifespan. While leakage volume may be small, the global warming potential (GWP) of these ***refrigerants*** is hundreds to thousands times higher than that for CO_2, making them a noteworthy contributor to total emissions for plants that need a great deal of cold processing or storage (e.g. frozen foods, dairy products, meat, seafood). Third, a plant's wastewater treatment system using anaerobic digestion will emit CH_4 if it is not captured to fire a boiler. If it is captured, it is transformed into CO_2. Methane has a GWP of 21, which means that 1 kg of CH_4 has the same effect as 21 kg of CO_2. In addition, solid biomass such as spent grains from distilleries, breweries residues and agriculture wastes may be landfilled, composted (onsite or offsite) or burned by some FBI plants as a source of energy, all of these emitting various levels of GHG.

Emissions from refrigerants and organic wastes are still difficult to estimate accurately at the sectoral level or the FBI level, as reliable statistics are available only for fossil fuel-related GHG emissions. At FBI production sites, there were 3,994 and 4,020 kilotonnes of CO_2-equivalent GHGs produced in 2002 and 2005, respectively (CIEEDAC, 2008). That translates to 3.7% of the total Canadian industry emissions (Table 19-1).

The FBI's demand for energy is expected to grow due to increased demand for shelf-stable products, individual ready-to-serve or quick-to-prepare meals and minimally processed fresh food (e.g. baby carrots which are considered a fresh food although there is some processing). Energy is a particularly complex challenge for the FBI given that the industry must maintain high product quality and ensure product safety.

The Indicators

The ECI and GHGEI indicators assess the energy efficiency and subsequent GHG emission efficiency of the FBI. The ECI measures the amount of energy used per dollar of manufactured goods produced (MJ/$) and the GHGEI measures the amount of GHG emitted expressed in CO_2 equivalents (CO_2e) per dollar of manufactured goods produced (kg CO_2e/$). The indicators are inversely proportional to efficiency performances: the higher the intensity, the lower the efficiency and associated environmental performance.

These indicators may be used as a proxy to estimate the environmental impact of the FBI from the consumption of energy (ECI) and the emission of GHGs (GHGEI).

The amount of each type of energy consumed by each establishment onsite (such as electricity, natural gas, light fuel, diesel, bunker, wood) is calculated using regional energy prices and converted into a common unit of energy (megajoule, or MJ) using Statistics Canada's 2002 energy conversion factors (Statistics Canada, 2004). GHG emissions (CO_2, CH_4 and N_2O) in CO_2e are also calculated for each form of energy consumed onsite using Environment Canada (2004) GHG emission factors and the Intergovernmental Panel on Climate Change (1995) global warming potentials (GWP).

The ECI and GHGEI indicators are calculated for each group in two ways:

- A global indicator value for the group, using the sum of all energy used by all establishments included in the group, divided by the total sales value of the whole group. This process gives a good picture of the group as a whole. However, it does not provide information on the performance of any individual plant compared to the group.

GHGEI/ECI ratio

As a complement to the GHGEI indicator, the ratio of GHGEI/ECI was calculated to assess the amount of GHG emitted for each MJ of energy consumed for the global indicator in each sector (Table 19-2). This ratio can be influenced by how clean the energy consumed within a sector is and the technological efficiencies in place to reduce the amount of GHG released for energy consumed. Improvements can be gained through adopting more efficient processes and switching to cleaner energy types.

TABLE 19-2 Sectoral results of GHG emitted per unit of energy consumed (kg CO_2e/MJ) in Canada, 2002

	GHGEI/ECI (kg CO_2e/MJ)
Bakery	36.7
Dairy	37.6
Meat	37.7
Seafood	39.6
Grain & oilseed	40.8
Sugar & confectionary	42.5
Beverage	43.1
Fruits & Vegetables	45.0

Results show that:

- No sector is more than 10% different from the average, which is somewhat surprising considering some sectors rely heavily on electric processes such as cooling, refrigeration and freezing, which indirectly emit GHGs and are therefore not included in the indicator. However, this ratio is calculated at the sectoral level and different subsectors within each grouping may offset each other's gains. For example, the sugar & confectionary sector is dominated by the sugar refining subsector (Figure 19-3). Also, this calculation is national, and across Canada there is great variability in the energy sources used by FBI establishments (Figure 19-4). This likely influences the results. For example, Quebec, Ontario and Alberta each have approximately one third of Canada's meat sector and have similar ECI and GHGEI (Figure 19-5) despite having different energy source profiles (Figure 19-4).
- The seafood sector, while being the most GHG efficient, is not the cleanest energy user. There are marked regional discrepancies in the kind of seafood processed and the energy sources available.
- The grain & oilseed sector, while being the least GHG-efficient (as well as the least energy-efficient), is mid-ranking for the GHGEI/ECI ratio. This may be explained by the fact that a significant part of the energy consumed is by the flour milling and breakfast cereal manufacturing subsectors in the form of electricity or more efficient energy sources which emit less GHGs.
- The bakeries sector, an intensive energy user and GHG emitting sector shows the lowest GHGEI/ECI ratio of the FBI. Energy in this sector is mainly required for baking processes in well-controlled gas or combined-energy ovens, which emit lower quantities of GHG. The bakeries sector is a rather *dry* sector that uses a small amount of steam. Other energy uses in this sector are supplied by electricity, which does not directly emit GHG at the FBI site.

■ A median range indicator for the group. The indicator result is calculated for each establishment in a grouping, then ranked by increasing value. The lowest 40% are considered *better than average* the highest 40% are considered *worse than average* and the remaining establishments are considered *average*. The lowest and highest values in the average group represent the median indicator range, in which a typical, representative plant of the group scores.

Limitations

The indicators are calculated per value of product manufactured, instead of per volume of product manufactured as initially intended (Marcotte et al., 2005) due to the limited amount of volume data in the Statistics Canada Annual Survey of Manufacturer's (ASM) database. Also, at this time, trend analysis is not possible, as only the benchmark year, 2002 is available. The indicators also provide a measure of energy efficiency and GHG emission intensity but do not assess the direct impact on the environment of the FBI at this time. The GHG indicator is calculated from the energy used onsite only, which does not take into account the energy used to produce and bring these energies to the plant. Using these premises, the consumption of electricity does not produce any GHG (even if it was produced using a coal power plant) while the energy used to extract the crude oil, refine it and bring liquid fuel to the plant is also not taken into consideration. Lastly, hydrofluorocarbons (HFC's) were not included in the calculations due to limited data availability.

Results and Interpretation

NATIONAL

Energy Consumption Intensity

Figure 19-2 provides an overall picture of ECI indicator values across Canada for all sectors reported, with or without regard to the size of the establishments.

When the sizes of establishments are not considered (Figure 19-2), the median range indicator reveals that there are two distinct groupings of energy efficiency in the FBI. A typical plant in the sugar & confectionery, dairy, meat, and seafood sectors show an ECI of approximately 0.75MJ/$, while the grain & oilseed, fruits & vegetables, bakeries & tortillas and beverage sectors have an ECI of roughly 1.5 MJ/$. The higher values are largely the result of energy-intensive operations such as evaporation, concentration and drying, cooking and baking, process heating and freezing for the fruits & vegetables sector. The global indicators for each sector reveal similar general conclusions as the median range indicators.

However, the comparison between the global and median range values for these three sectors shows a global intensity significantly higher than their median range intensity, especially for sugar & confectionery (136% higher than the upper boundary of the median range) and for grain & oilseed (64% higher). This indicates that the largest establishments with respect to sales within these sectors are energy-intensive plants, and, since the median range is much lower, that only a few are influencing the performance of the whole sector. This is likely due to the fact that larger plants are more automated and therefore require more energy, or that larger plants sell a higher volume of products at lower prices. Where the global indicator is far above the median range, a potential gain in energy efficiency is possible for large establishments.

ECI, sectoral features with regard to establishments' sizes

The sizes of the establishments (determined by the number of employees, see Table F-1 in Summary), are also considered in Figure 19-2. In the fruit & vegetable sector, the median ECI is similar for small, medium and large plants but is significantly higher for the very large establishments. The global indicators for each size range are within the median values for all size categories except medium, which indicates that efficiencies can be found in some of the higher selling medium-sized establishments. As well, efficiencies can likely be found in the *very large* category to achieve an intensity similar to that of other size categories (between 1.0 and 1.6 MJ/$).

Within the meat sector, the median range does not appear to be influenced by plant size, with a value close to 0.75 MJ/$. However, all but very large establishments have the potential for energy efficiency improvements since their global values are significantly above their respective median ranges. The seafood sector's median range is also independent of the size of establishments; only the very large category shows a global range higher than the median range, indicating that similar energy efficiency performance has already been achieved for most of the sector. This is likely because similar beneficial management practices are being used. The dairy sector, as well as the grain & oilseed and the sugar & confectionery sectors, show that some plants could achieve improvements in all size categories.

ECI, subsectoral features regardless of the size of establishments

A study of the effect of subsectors on ECI was conducted and the following conclusions have surfaced:

■ The malt and the oilseed subsectors have the highest ECIs within the grain & oilseed sector,[1] about twice as high as that of the flour and the breakfast subsectors.

■ Sugar refining plants are the driver of the whole sugar & confectionery sector's energy intensity, while the cacao and the chocolate confectionery subsectors show a very low intensity (as low as a typical dairy, meat, or seafood plant).

■ There are few differences within the dairy sector and within the meat sector.

1 Data on two other subsectors of the grain & oilseed sector, that is, wet corn milling (or corn milling) and fat and oil refining and blending, cannot be published because of confidentiality.

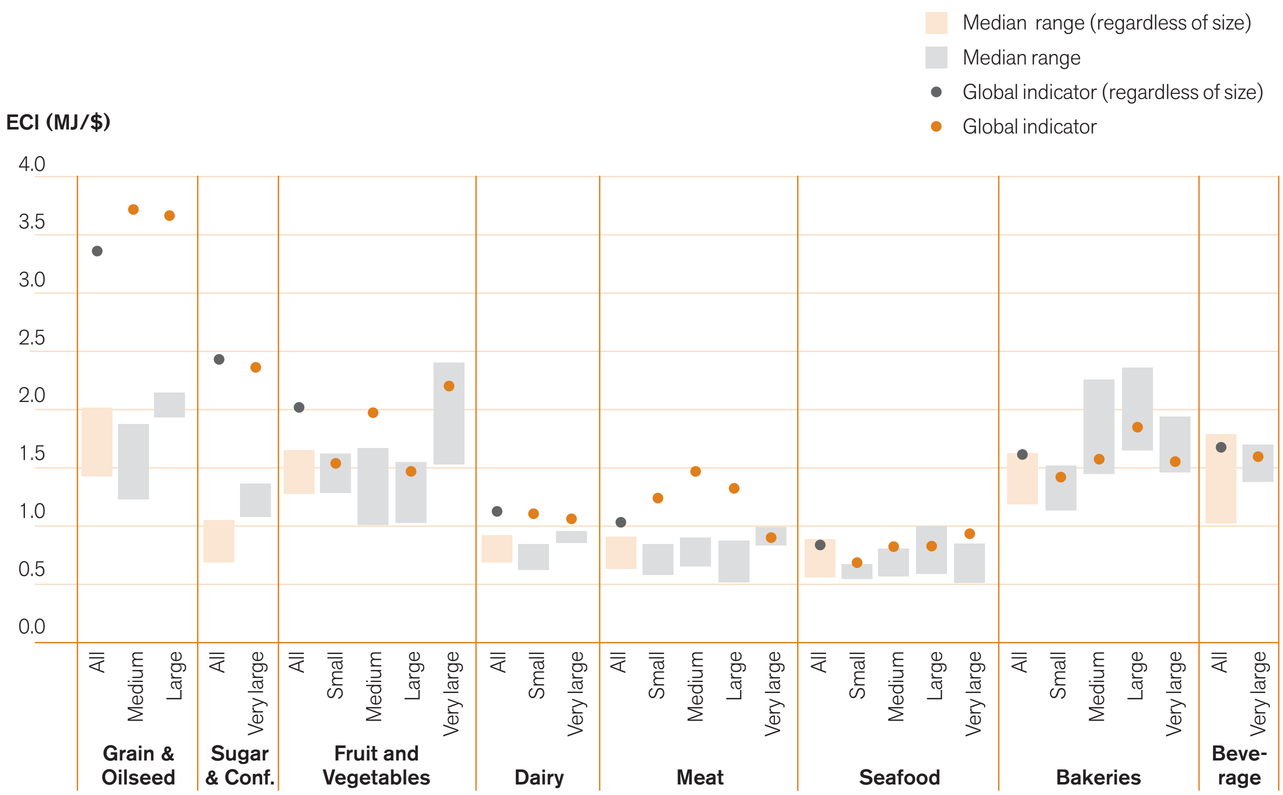

FIGURE 19-2 Energy consumption intensity (ECI) as a function of activity sector and size, Canada, 2002

- Retail and commercial bakeries are slightly more energy intensive than cookie & cracker manufacturing, the flour mix and dough manufacturing, and the dry pasta manufacturing subsectors within the bakeries sector.
- Within the beverage sector, the wineries and distilleries subsectors clearly stand out, the first being the sector's least intensive energy user, and the second posting a very large median range, which may be explained by a large spreading of single plant ECIs.

Greenhouse Gases Emission Intensity

The total amount of GHG a plant can emit depends on the quantity of energy it consumes as well as on the types of energy used. Some energy types emit less GHG than others. For example, the consumption of electricity does not emit any GHG directly from the FBI plant and is not considered in these calculations, while all fossil fuels release GHG directly from the FBI plant, some emitting less GHG than others to provide the same amount of useful energy (e.g. natural gas emits around 1.5 times less GHG than light fuel oil to provide one megajoule of steam in a boiler). For a given quantity of total energy consumed, the mix of energy types involved will influence the amount of GHG emitted onsite.

Figure 19-3 provides Canada-wide details of the GHGEI global and median range indicator at the sector level and the median range indicator at the subsector level. The national GHGEI sectoral results are consistent with the ECIs and suggest the amount of GHG produced per quantity of energy used was similar from one FBI sector to another in 2002. Similar to the ECI, where the global GHGEI indicator is far above the median range, a potential improvement of GHG emissions maybe possible for large establishments in these sectors.

PROVINCIAL

Energy Consumption Intensity (ECI)

The global ECI peak of 3.8 MJ/$ for the sugar & confectionery sector in British Columbia is twice as high as that in Ontario (Figure 19-4). The sugar refinery subsector is responsible for the high global ECI within this sector: a typical Canadian sugar refinery can display intensity as high as 4.2 MJ/$, whereas a typical confectionery plant's intensity does not exceed 1.2 MJ/$ (data not shown). The median range for a plant in the sugar & confectionery sector in British Columbia displays the lowest Canadian ECI in this sector, which indicates a few very energy-intensive plants are influencing the results.

The global ECI for the meat sector in British Columbia is also the highest in Canada. It indicates that energy efficiency improvements could be achieved by local meat plants with a large share of sales to reach values close to—or below—1 MJ/$. The provincial median range ECI for the meat sector is typical of the national values as a small number of plants are influencing the global mean. This situation is also seen for the bakeries sector and the fruit & vegetable sector when compared to provinces like Ontario and Quebec, even though the fruit & vegetable sector is performing well when compared to national values. The dairy sector and the seafood sector are both performing well in British Columbia.

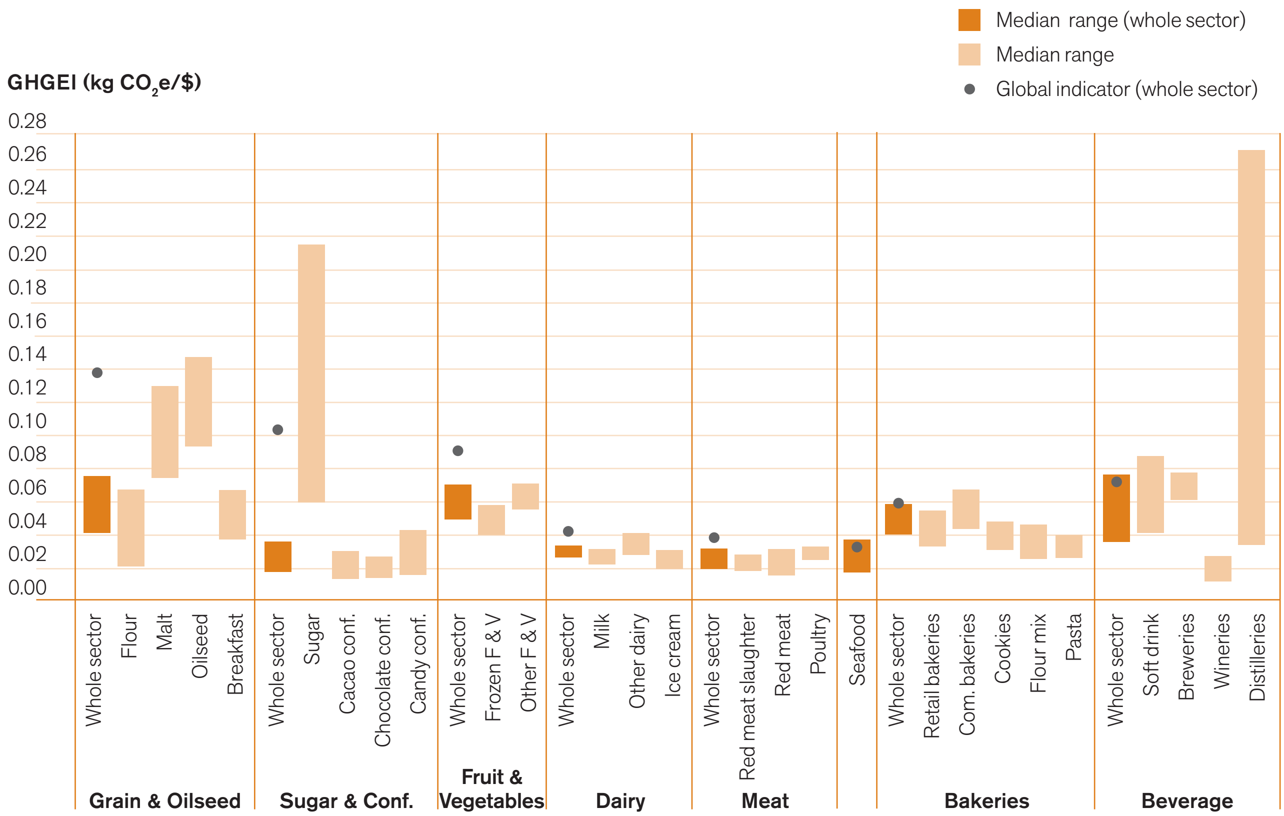

FIGURE 19-3 Greenhouse gases emission intensity (GHGEI) as a function of activity sector and subsector Canada, 2002.

Note that there is no subsector within the seafood sector

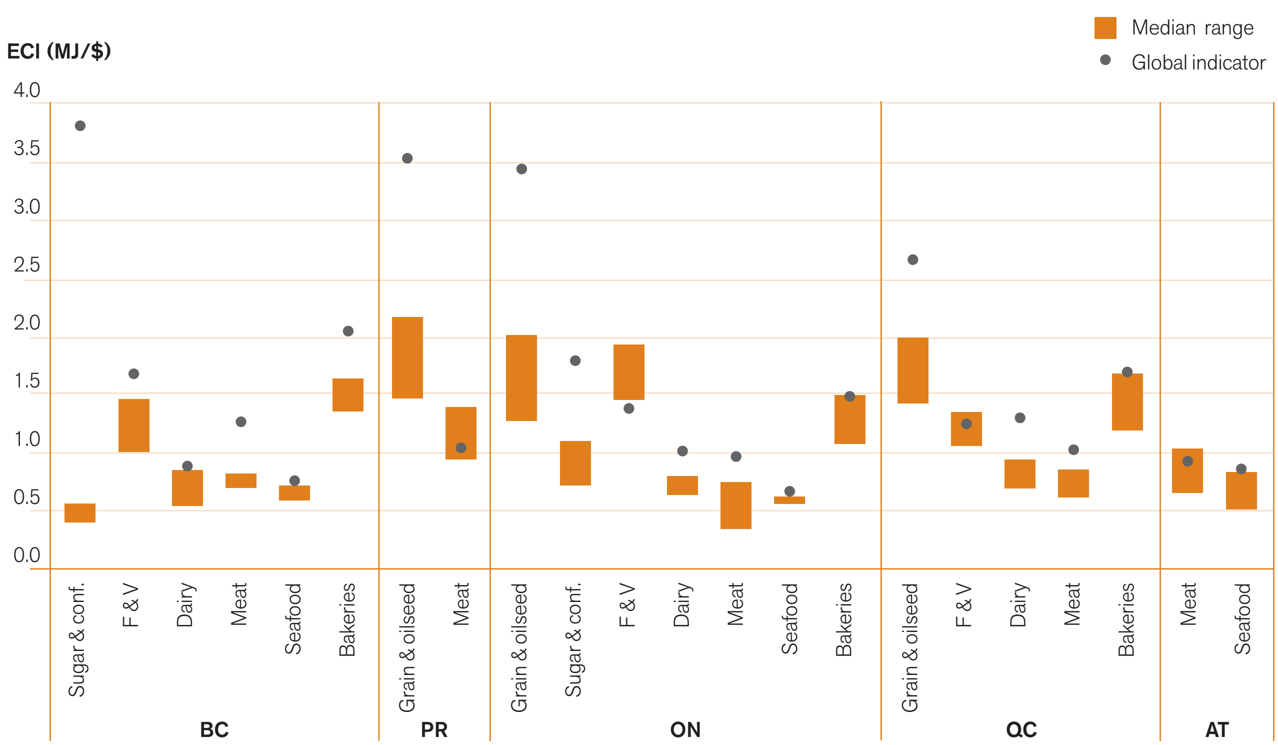

FIGURE 19-4 Energy consumption intensity (ECI) as a function of regions and activity sector, 2002.

(Note: some sectors cannot be published under the Statistics Act)

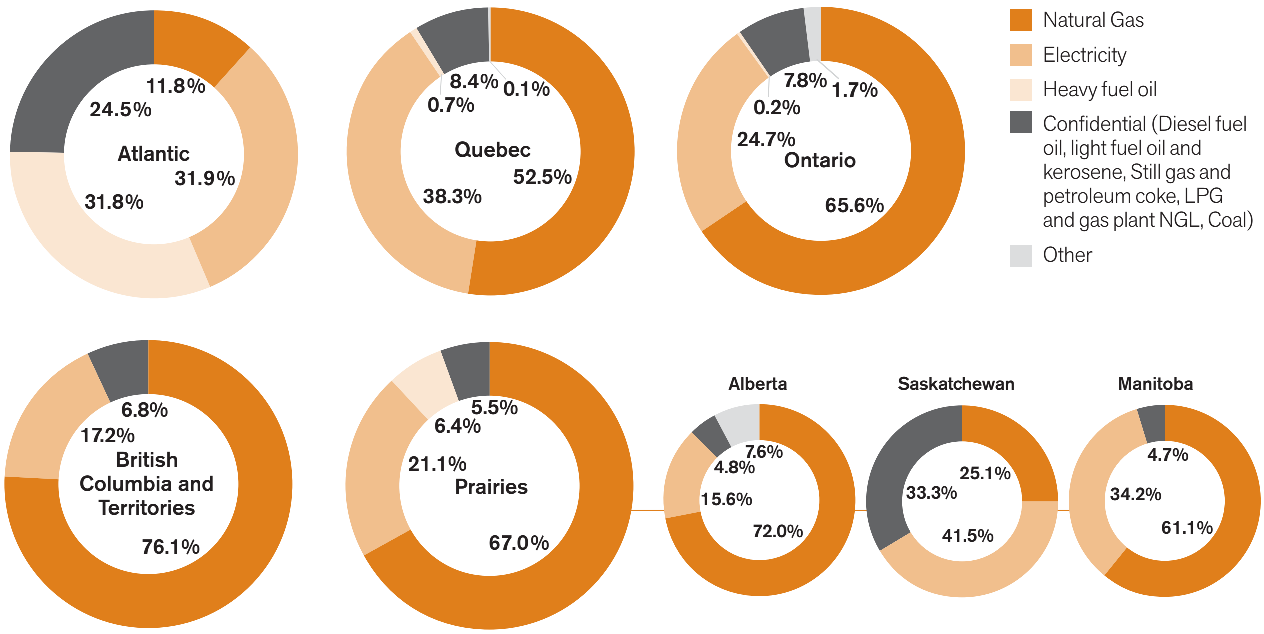

FIGURE 19-5 Share for each region and province of the energy sources used in 2002 by manufacturing industries of the category "Other manufacturing"

Source: Natural Resources Canada, 2007

Note: The "Other manufacturing" industry sector includes motor vehicle, textile, food, beverage and tobacco industries. This is the most detailed category offering provincial details.

The performance of the grain & oilseed sector in the Prairie Provinces is similar to that of Ontario, Quebec and Canada (Figures, 19-4, 19-2). The Prairies' meat sector displays the highest typical plant ECI across Canada, despite more energy efficient production by some of the largest processors (in terms of sales) as illustrated by the global ECI close to median range bottom boundary.

Ontario's sugar & confectionery sector global indicator performs well compared to British Columbia, due to a more diverse sector and a larger share of low energy-intensive activities such as confectionery manufacturing. Establishments of the fruit & vegetable sector have a higher median indicator value than other provinces. However, the global ECI of the sector is lower than the median range, indicating that a major part of fruit and vegetable processing in Ontario is performed by plants slightly more energy-efficient than a typical representative one. Lastly, the province is among the most energy efficient in the meat, seafood and bakeries sectors.

Quebec shows the lowest global ECI in Canada for both the grain & oilseed and fruit & vegetable sectors. Quebec's energy intensity in the meat sector stands at the national level, quite similar to Ontario and the Atlantic Provinces. Lastly, the dairy sector in Quebec shows the highest global ECI across Canada, significantly above the intensity achieved by a typical representative plant of the sector in the province or in Ontario, British Columbia or Canada.

The Atlantic Provinces' food industry is highly oriented towards seafood, fruits and vegetable processing, confectionery, and beverage. The median range for the meat sector is consistent with other provinces, and its global ECI is within the median range, indicating that the largest establishments are as energy efficient as a typical plant. The seafood sector is the most influential in the region and shows a global indicator only slightly higher than the median range indicator, indicating many energy efficiencies have been gained, but improvement is still possible.

Greenhouse Gases Emission Intensity

The types of energy used by establishments influence the total amount of GHG a plant will emit. Figure 19-5 shows the different energy mixes used by the provinces in 2002 for a group of manufacturing industries, including the FBI.

Figure 19-6 illustrates regional GHGEI indicator results per sector. The inserted figure shows calculations of the regional global indicators ratio GHGEI/ECI—the amount of GHG emitted for each MJ of energy consumed—in order to provide insights into how clean the energy consumed is and about the efforts made to shift to technologies or processes using electricity or low GHG-emitting energies.

The bakery and dairy sectors are well established, selling similar products across the country. Figure 19-6 shows insignificant differences between regions for their global and median range GHGEI indicators. Similarly the grain & oilseed sector shows regionally similar GHGEI median ranges even though the global indicator values differ considerably among the regions. The sugar & confectionary sector shows big differences between British Columbia and Ontario due mainly to differences in the subsectors. A very large part of British Columbia's activity in this sector

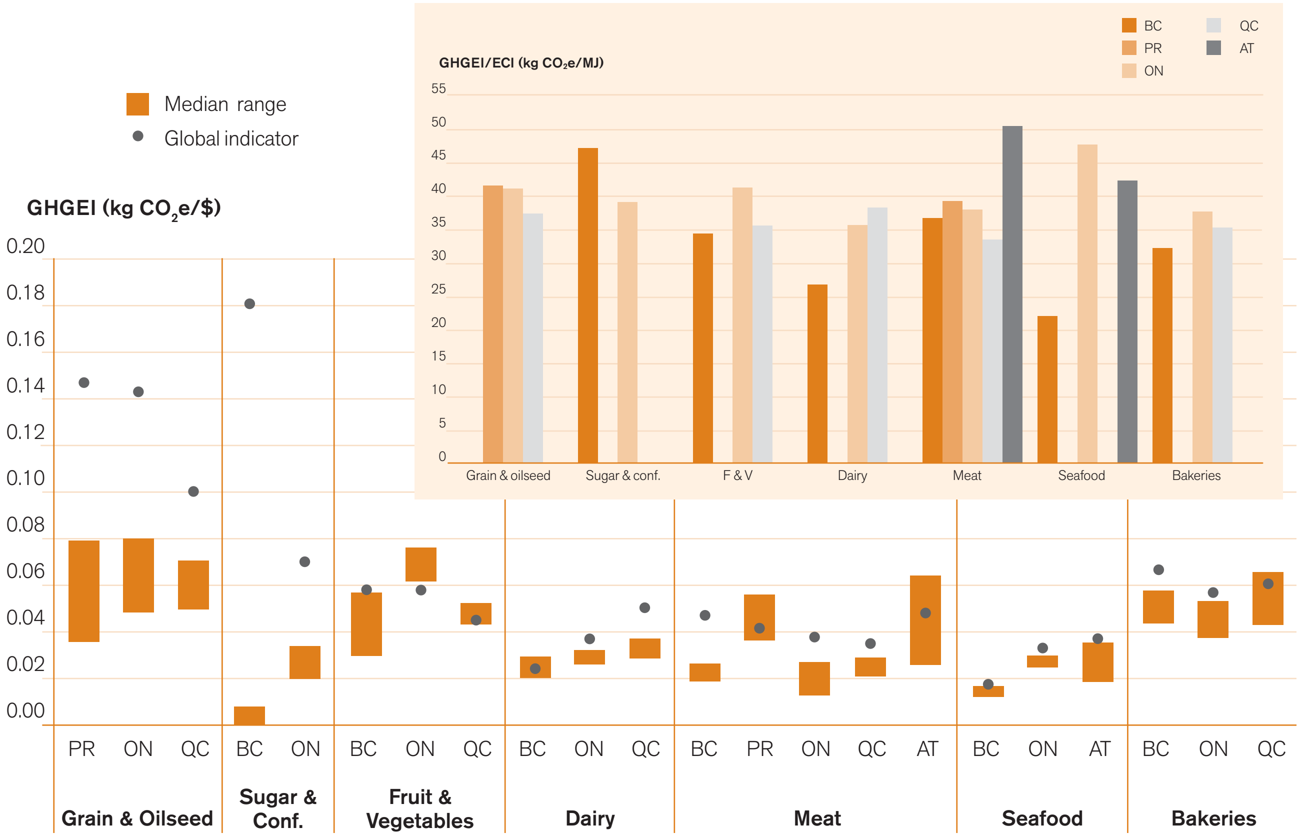

FIGURE 19-6 Greenhouse gases emission intensity (GHGEI) as a function of activity sector and region, 2002. *Boxed figure: Global indicators' ratio GHGEI/ECI (kg CO_2 equivalent of GHG emitted per MJ of energy consumed) as a function of region, 2002.*

is oriented towards sugar manufacturing, which requires extensive fossil fuel energy for processing that cannot be handled economically by electricity. A comparison of the global and median ranges of the ECI and GHGEI (Figure 19-4 and Figure 19-6) also reveals that a few large plants are responsible for these below average performances, since the median range of both ECI and GHGEI are amongst the lowest sectoral values attained in Canada. A very small part of the activity in this sector comes from other subsectors (e.g. confectionery manufacturing activities) that are very efficient users of cleaner energy sources.

Slight differences in the seafood sector are due to subsector differences and a cleaner energy grid used in British Columbia (more natural gas). The regional differences in the meat sector are attributable to the fact that the energy grid of the Atlantic Provinces and Alberta rely more on heavier fuel oils than the energy grids in Quebec, Ontario and British Columbia.

Response Options

Measures to improve energy efficiency and the onsite production of secondary energy (such as steam) will help reduce both energy consumption intensity and GHG emissions.

The challenge for the FBI is to reduce its demand for energy by improving its efficiency. It can do this by adopting beneficial management practices that do not compromise hygiene or food safety. Companies can choose from a wide range of possible measures, the costs of which vary. By measuring consumption and heat flows, and through careful management of the procedures that require the most energy, companies can react swiftly to any problems and avoid waste. Through a process integration approach, a plant's energy and water flows can be studied jointly, and the results will generally provide a series of options for optimizing the flow of heat and water in a plant.

Governments can encourage establishments to monitor energy use and GHG emissions and establish sectoral benchmarks. This will provide companies with the incentive to become more energy efficient compared to their peers while they remain competitive.

Also, the development of a more comprehensive national database with a disclosure and reporting framework would make it possible to set up reasonable benchmarks and to better monitor progress in achieving reduction targets.

The indicators could be optimized to become more robust, to better cover and represent relevant environmental issues and to facilitate response options and measures. Improvements could include physical indicators independent of financial data, an ECI indicator that weights each source of energy used by an environmental pressure factor, taking into consideration the total direct and indirect impacts of a source, and geographic location. This should highlight any shift made to more sustainable energy uses, in particular renewable ones, and an ECI indicator that could break down energy consumption according to main uses (as seen in Figure 19-1, for example). Causes of low efficiencies could then be more easily identified, and therefore eco-efficiency measures and beneficial management practices could be more straightforwardly deployed.

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20 Water Use

AUTHORS
D. Maxime, Y. Arcand, D. Landry and M. Marcotte

INDICATOR NAME
Water Intake Intensity (WII) and
Water Discharge Intensity (WDI)

STATUS
National coverage for 2005

Summary

The food and beverage industry (FBI) transforms agricultural commodities into semi-prepared and consumer-ready food and beverage products. In 2005, the FBI was responsible for nearly 20% of the water used by all Canadian manufacturing industries. Of this water intake, the FBI discharges 77% after use as wastewater. The Water Intake Intensity (WII) and Water Discharge Intensity (WDI) indicators measure the total amount of water entering a plant (WII) and discharged as wastewater (WDI) per value of production sold (expressed in litres per dollar of products sold, or L/$), respectively.

The most intense water withdrawing industry among the FBI in Canada is the seafood product preparation and packaging industry, with a national average value of 17 L of water withdrawn per dollar of product sold. It also discharges the most water (96% of its withdrawal). In contrast, the beverage manufacturing industry group is the most intensive consumer of water with discharges accounting for two thirds of the water withdrawn, the remainder being incorporated into finished products. The meat product manufacturing industry group is the least intense water withdrawing group, withdrawing six times less than the seafood product group and almost four times less than the dairy product manufacturing group per dollar of product sold. Within the meat sector, geography makes a clear difference, with the Prairie Provinces, Ontario and Quebec being more efficient (below 3 L/$) than British Columbia (7 L/$) and the Atlantic provinces (5 L/$).

The Issue

The FBI requires large amounts of high-quality water to use as both an ingredient and to carry out numerous processing operations. It is estimated that in Canada the FBI withdrew 1,500 million cubic metres of water in 2005, which is almost 20% of the total amount withdrawn by Canada's manufacturing industries (Figure 20-1) and close to 3% of total water intake in Canada (Environment Canada, 2008). In 2005, establishments obtained half their water requirements from public water suppliers and supplied the other half themselves from surface water, ground water and tidal water bodies.

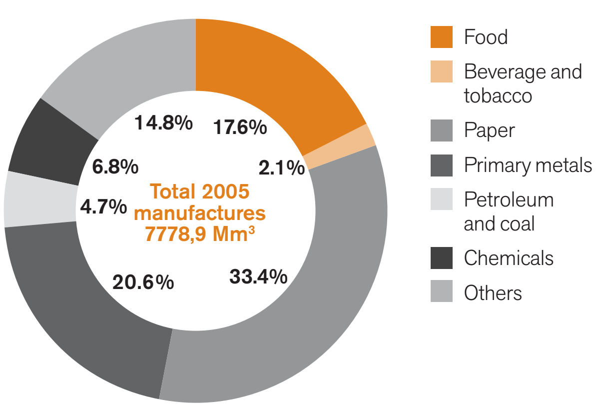

FIGURE 20-1 Share of water intake volume by the main manufacturing sectors in Canada in 2005

Source: Statistics Canada, 2008

Water flows and uses in the FBI are conceptually illustrated in Figure 20-2. Water is used at almost all stages of processing; as a heat transfer medium (e.g. hot water for blanching or steam for heating), as a carrier (e.g. for transportation of fragile products on a production line), or for washing, rinsing, cleaning and sanitizing. Water needs vary significantly in both quality and quantity depending on the products manufactured and on the process implemented to achieve the desired transformation. Good water quality is essential for meeting food hygiene and safety standards as soon as there is a chance of direct or indirect contact with food (Maxime et al., 2006).

In 2005, of the FBI's total intake volume, 4% was re-circulated or reused in process or cooling systems and 77% was discharged after use as wastewater, either to public utilities or directly back to the environment, generally after onsite treatment. The remaining 19% was incorporated into finished products, evaporated during processing operations or was part of wastewater sludges and solid wastes.

The high demand for water by FBI establishments can have direct and indirect impacts on the ecosystems and economies that depend on them. Depletion of high-quality water reserves in some parts of the country has pushed up industrial water-supply costs and placed additional pressure on public water utilities to find new supply sources (Environment Canada, 2004). The geographic concentration of FBI groups and the marked seasonality of the water withdrawals for some sectors, such as fruits & vegetables, can increase the pressure on the environment locally and seasonally. Many of the processing plants are located in rural areas where the municipal water treatment systems (i.e.,

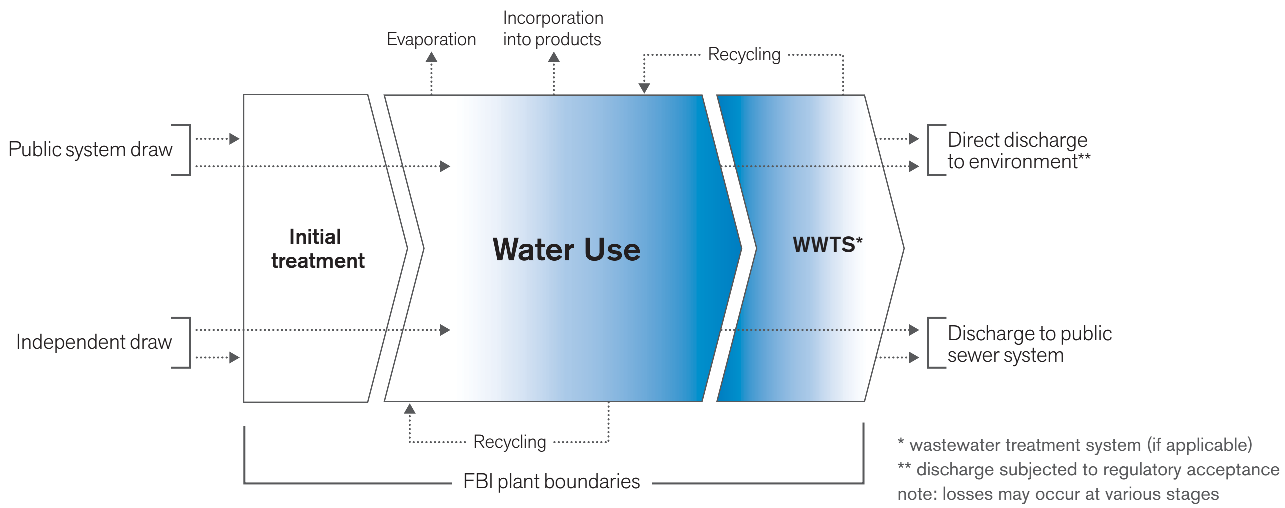

FIGURE 20-2 Primary water and wastewater flow in a food processing plant

drinking and wastewater systems) are designed to serve small populations. A medium-sized plant can have a major effect on local water supply.

The Indicators

The Water Intake Intensity Indicator (WII) and the Water Discharge Intensity indicators (WDI) assess the efficiency of the water management practices of FBI establishments. The WII indicator calculates the amount of water used by the plant per dollar of manufactured goods produced and the WDI indicator calculates the amount of water discharged per dollar of manufactured goods produced (both in L/$). These intensity indicators are inversely proportional to efficiency; the larger the indicator value, the lower the efficiency and the environmental performance. The indicators are calculated using data from Statistics Canada's 2005 Industrial Water Survey (Statistics Canada, 2008) and Annual Survey of Manufactures and Logging (Statistics Canada, 2007).

Establishments were grouped by common characteristics: same sector of activity, same region, and same size as determined by the number of employees in order to make valid regional comparisons (see Table F-1 in the section summary). Both indicators are calculated for each grouping by dividing the total of all water withdrawn (or discharged, respectively) by the sum of the sales value for the whole group. This gives a good picture of the group as a whole (like considering the group as one unique establishment) but does not provide information on the performance of any individual plant compared to the group.

Limitations

The indicators have several limitations, most of them resulting from the desire to provide indicators that report subsectoral and regional details. The indicators are calculated per value of product manufactured, instead of per amount of product manufactured due to the availability of data. Grouping establishments was necessary due to the fact that some data were confidential. As well, results from some sectors could not be published due to lack of data and confidentiality of data.

The indicators were computed for a single benchmark year, 2005, which does not allow for year-to-year comparison. The indicators do not assess the quality and pollution loads of the effluents discharged from the establishments—something that would provide a better assessment of the environmental performance of the FBI.

Results and Interpretation

NATIONAL

Figure 20-3 provides an overall picture of the WII and WDI indicator values across Canada. There is a high level of variability from one industry group to the next with respect to both intake and discharge intensities. The meat sector and the seafood sector are at the two extremes, with WII national values ranging from 3 to 17 L/$ of product sold, respectively.

The WII for seafood processing plants is 17L/$. These establishments are generally located near the coasts and use the abundance of marine water available to them for fish handling, rinsing and defrosting, and for general hygiene and washing of equipment. A large amount of water is needed by this sector for cleaning and processing, but the WDI is also high at 16.3 L/$, indicating that efficiencies can be found—for example through dry procedures and better water management during fish washing and area clean up—without compromising safety and quality standards.

The meat sector also requires large amounts of water for carcass washing and surface cleaning operations (Table 20-1). However, WII and WDI indicators are much lower for the meat sector than for the seafood sector at 2.8 and 2.5 L/$, respectively. Whereas seafood processing plants are largely located near an abundance of water, the meat sector is concentrated

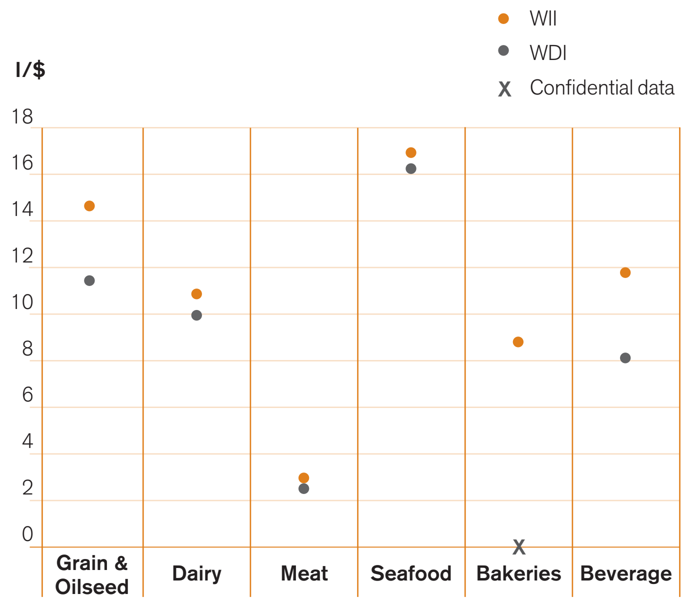

FIGURE 20-3 Water Intake Intensity (WII) and Water Discharge Intensity (WDI) as a function of FBI sectors, Canada, 2005

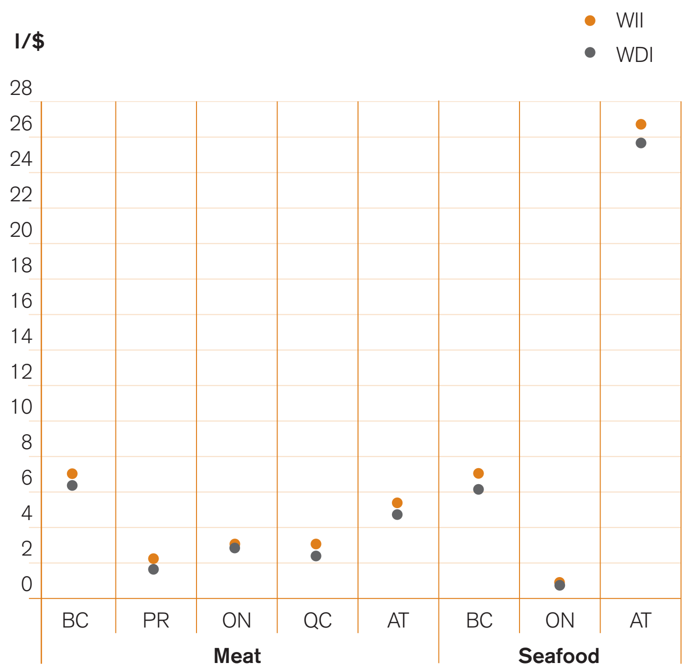

FIGURE 20-4 Water Intake Intensity (WII) and Water Discharge Intensity (WDI) as a function of region and the meat and seafood sectors, 2005

in regions where water is less abundant. This results in efficient water management practices in the meat sector (e.g. air instead of water thawing, shovel and broom clean up instead of high pressure water jet), and water recycling.

WII is also high in the grain & oilseed sector (15 L/$) as this industry uses a great deal of water and steam during its extraction processes (e.g. wet dehulling, wet milling, malt steeping, oil refining and deodorisation). The difference between WII and WDI indicates that 22% of the water withdrawn is consumed, largely through evaporation during the dehydration and drying operations of flour processing, the malting process and breakfast cereal manufacturing.

The bakeries & tortillas sector, dairy products sector and beverage sector all show intermediate WII values of 9, 11 and 12 L/$, respectively. The largest uses of water in the bakeries & tortillas sector are for making dough and for equipment cleaning. A large amount of water evaporates during baking, cooking and drying and thus is not discharged as wastewater. Discharges mainly result from cleaning operations.

The dairy sector requires large quantities of water for cleaning and disinfecting all equipment that can be in contact with milk or dairy products along process lines (Table 20-1). The WII and WDI for the dairy sector are 10.8 and 9.9 L/$, respectively, which means that most of the water withdrawn is discharged. The wastewater is highly concentrated in dissolved organic substances and minerals such as phosphorus, nitrogen and chloride, and contains residuals from cleaning agents. Dairy plants generally treat their wastewater onsite to accommodate the contaminants thresholds of public sewage systems.

Water is the main ingredient of most finished products from the beverage sector, making it different from most other sectors (Table 20-1). This explains the large difference between WII and WDI (12 versus 8 L/$, respectively); almost one third of the water withdrawn is not discharged, but consumed through incorporation into products such as bottled water, soft drinks, beer and some alcoholic beverages. Another significant use of water in this sector is for cleaning and rinsing containers and equipment.

Sector-to-sector comparisons are discouraged because different processes are often required when using different raw materials (e.g. red meat versus fresh lobsters). This is also true when comparing two plants within the same sector (e.g. canned tuna versus fresh lobsters). However, the high WII and WDI values of the seafood sector relative to other sectors means there is a far greater potential for improvement in the seafood sector than in others.

PROVINCIAL

Due to data limitations, the regional results for the WII and WDI are restricted to those presented in Figure 20-4. Missing sectors in each region does not necessarily mean that an industry is not present in the region, but rather that confidential data does not allow for reporting.

TABLE 20-1 Typical water consuming activities in food and beverage plants

Water consuming activity	Vegetable (%)	Dairy industry (%)	Meat industry (%)	Beverage industry (%)
Water into product	2	0	0	60
Plant cleaning	15	49	48	25
Cooling towers	5	6	2	2
Process operations	76 (washing, peeling, blanching)	42 (heating)	47 (slaughtering)	8
Auxiliary use	2	3	3	5

Source: Pagan and Price, 2008; Genné and Derden, 2008

The largest variability between water intake and water discharge between regions is in the seafood sector, with a factor of four between British Columbia (WII = 7 L/$) and the Atlantic Provinces (WII = 26 L/$). The difference is even larger when compared to Ontario (WII = 0.7 L/$). However, this is partly due to different processing stages between Ontario and the coastal provinces, so the two cannot be directly compared. British Columbia and the Atlantic Provinces both process significant quantities of landed fish, therefore they are comparable to some extent. The fourfold difference in their WII values can be explained by the high shellfish activity in the Atlantic Provinces. Processing shellfish involves the use of seawater (Fisheries and Oceans Canada, 2003) that can be discharged back to the sea in the Atlantic Provinces, but needs be treated in British Columbia. This explains the high discharge rate observed in the Atlantic Provinces as compared to British Columbia (97.2% vs. 89%, respectively). British Columbia's seafood product industry ranges from landing activities (initial washing of products and of equipments at the pier) to the advanced processing of seafood and focuses largely on freezing, canning and secondary processing (British Columbia Ministry of the Environment, 2007), all of which require water.

The meat sector also shows regional differences. Two groupings are apparent: British Columbia and the Atlantic provinces with WII indicators between 5 and 7 L/$, and Ontario, the Prairies and Quebec with intensity between 2 and 3 L/$. The two groups differ significantly as some regions are more industrialized than others in this sector and because of qualitative production differences. British Columbia and the Atlantic Provinces have a larger number of relatively small plants processing different products (beef, hog and poultry) than Ontario, the Prairie Provinces and Quebec, and account for only 6% and 3% of national manufacturing shipments, respectively. Most Canadian meat processing activities are performed in the Prairies, Ontario and Quebec, where the largest and most specialized facilities are located, and it is the larger-scale facilities that require more water. However, because of high costs, local water limitations and effluent regulations, these facilities focus more on energy efficient processes and therefore tend to have comparatively lower WII and WDI than other regions.

Response Options

The FBI faces the challenges of reducing its current demand for water by improving efficiency. It must do this by adopting beneficial management practices without compromising the quality of its products, hygiene or food safety. Improving the efficiency with which it uses water would result in reductions to the WII indicator. The result would be less water used and lower water utility costs. As well, such practices would reduce the volume of water discharged and its associated contaminants, which, in turn, would lead to a reduction of the WDI indicator, and of the discharge cost.

Low-cost activities such as measuring discharge and carefully managing activities that require large quantities of water would enable companies to react swiftly to problems and avoid waste. Other cost-effective activities include optimizing cleaning and disinfection procedures and cycles, particularly for sub-sectors driven by stronger food safety regulations. More advanced technologies to fill up and clean equipment would allow establishments to reduce their water requirements and volume of effluents, and may allow recovery and reuse of raw materials.

Conducting a process integration analysis can help identify ways to optimize interactions between various components of the production chain, including water and energy, rather than improve each component individually. This is particularly relevant to the FBI, where these two resources are often closely linked. Given constraints such as water and effluent quality standards, food safety and quality, process and financial options, the best strategy for water (and energy) usage, recycling and discharge within a plant can be identified through this analysis, leading to savings in resources and in production cost (Gonzalez and Poirier, 2003).

Establishing sectoral benchmarks so that each company can position its performance with regard to the quality of its equipment and environmental technologies would be a sensible approach that would provide companies with an incentive to become eco-efficient.

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21 Packaging

AUTHORS
D. Maxime, Y. Arcand, D. Landry and M. Marcotte

INDICATOR NAME
Packaging Use Intensity (PUI)

STATUS
National coverage for 2002

Summary

The food and beverage Industry (FBI) transforms agricultural raw materials into semi-prepared and consumer-ready food and beverage products. Products sold to the public must be packaged adequately to ensure they reach consumers without losing quality as well as offer adequate consumer and manufacturer information. However, packaging is being increasingly scrutinized because of the resources it consumes and the environmental impacts it causes when it is disposed of. The Packaging Use Intensity (PUI) indicator measures annual purchases of packaging materials per dollar of production for different sectors of the FBI.

In 2002, the fruit & vegetable and beverage manufacturing sectors had PUI values greater than $15 of packaging per $100 of product, which is the highest among the FBI sectors, largely because the fruit & vegetable sectors are typically large consumers of metal cans (iron and aluminium) and glass containers. Conversely, animal materials processing groups (meat, fish & seafood, and dairy products) show the lowest PUI values. This is due to the high value of the product and the relatively small amount of packaging required (e.g. unprocessed meat products, fish & seafood).

The Issue

Food packaging protects products from physical damage or spoilage during transportation, storage and handling. Packaging also conveys consumer and manufacturer information and is a marketing tool for the brand owner.

There are three types of packaging: primary, secondary and tertiary. Primary packaging is in direct contact with the food product, such as the plastic liner of a breakfast cereal box or a glass juice bottle. Secondary packaging is designed for consumer use and generally has branding information (an example of secondary packaging is a cereal box). Tertiary packaging is used for products packaged together as a lot. It facilitates transfer of the product from the manufacturing plant to the warehouse, distribution centre and retail store. Primary and secondary packaging is generally discarded by the consumer, while tertiary packaging is managed by wholesalers and retailers.

The use of packaging can generate significant environmental impacts. Packaging manufacturing uses resources such as iron, aluminium and silica (for metal and glass containers), trees (for paper and cardboard) and petroleum products (for plastics) as well as energy for the production of packaging. Management of packaging wastes became a major issue in the 1980s when it was realized that nearly 80% of the packaging used in Canada was going to disposal (CCME, 1990). In 1989 an estimated 30% (by weight) of municipal wastes going to landfill consisted of packaging (CCME, 1996). Alternative solutions were developed to divert waste from landfills, including local selective collection, deposit-refund containers, recyclable material sorting plants, waste exchange systems for recycled material, plants dedicated to specific recycled materials such as aluminium and plastics, new waste reclamation routes (particularly for plastics), and energy recovery through waste incineration.

However, challenges still exist since not all services are available uniformly across the country and packaging is made up of various materials that may need to be processed differently (Table 21-1). Despite the effort put into diversion programs, landfilled and incinerated wastes increased by 5.2% between 2002 and 2006 (Statistics Canada, 2008a), and account for 15% of materials disposed of in landfills today (Downham, 2008). As food packaging accounts for around 60% of total packaging (Dworkin, 2006), food packaging wastes would tally to 1.4 million tonnes yearly in Canada or approximately 42 kg per inhabitant.

The Indicator

The PUI indicator is a proxy for the amount of packaging used by FBI establishments and is expressed as a ratio of the value of packaging and containers purchased per dollar of manufactured goods produced ($/$). This intensity indicator is inversely proportional to efficiency performances; this means that the larger the indicator value, the lower the efficiency and environmental performance. Establishments were grouped by common characteristics: same sector of activity, same region and same size as determined by the number of employees. This was done to make valid regional comparisons (see Table F-1 in summary).

The PUI indicator, expressed either in dollars per dollar ($/$) or in dollars per one hundred dollars ($/$100), is calculated for each group using two different methods:

- A global indicator value is calculated using the total of all packaging materials purchased by all establishments included in each group divided by the total sales value for that group. This process gives a good picture of the group as a whole but does not provide information on the performance of any individual plant compared to that of the group.

TABLE 21.1 Environmental issues and cost of the main food packaging materials (Marsh and Bugusu, 2007)

Material	Environmental issues		Cost
	Advantages	Disadvantages	
Glass	Reusable Recyclable Often contains recycled content	Heavy and bulky to transport	Low cost material but somewhat costly to transport
Aluminum	Recyclable Lightweight Economic incentive to recycle	No disadvantages in rigid form Separation difficulties in laminated form	Relatively expensive but value encourages recycling
Tinplate	Recyclable Magnetic, thus easily separated	Heavier than aluminum	Less expensive than aluminum
Tin-free steel	Recyclable Magnetic, thus easily separated	Heavier than aluminum	Less expensive than tinplate
Polyolefins (e.g. polyethylene, polypropylene)	Recyclable* High energy source for incineration	Easily recycled in semi-rigid form but identification and separation more difficult for films	Low cost
Polyesters (PET, PETE, polycarbonates, and polyethylene naphthalates)	Recyclable*, **	Easily recycled in rigid form but identification and separation more difficult for films	Inexpensive but higher cost among plastics
Polyvinyl chloride (PVC)	Recyclable*	Contains chlorine Requires separating from other waste	Inexpensive
Polyvinylidene chloride	Recyclable*	Contains chlorine Requires separating from other waste	Inexpensive but higher cost among plastics
Polystyrene (PS)	Recyclable*	Requires separating from other waste	Inexpensive
Polyamide	Recyclable*	Requires separating from other waste	Inexpensive but higher cost among plastics
Ethylene vinyl alcohol (EVOH)	Recyclable*	Requires separating from other waste	Inexpensive when used as thin film
Polylactic acid (PLA)	Recyclable*, †	Requires separating from other waste	Relatively expensive
Laminates/coextrusions (plastic and plastic/or foil/or paper)	Often allows for source reduction	Layer separation is required	Relatively expensive but cost-effective for purpose
Paper & Paperboard	Made from renewable resources Recyclable**		Low cost

* All thermoplastics are technically recyclable and are recycled at the production site, which contributes to lower cost. As inexpensive materials, post-consumer recycling competes with ease of separating and cleaning the materials.
** Recycled extensively for non-food product uses.
† Can be broken down to monomer level and reprocessed.

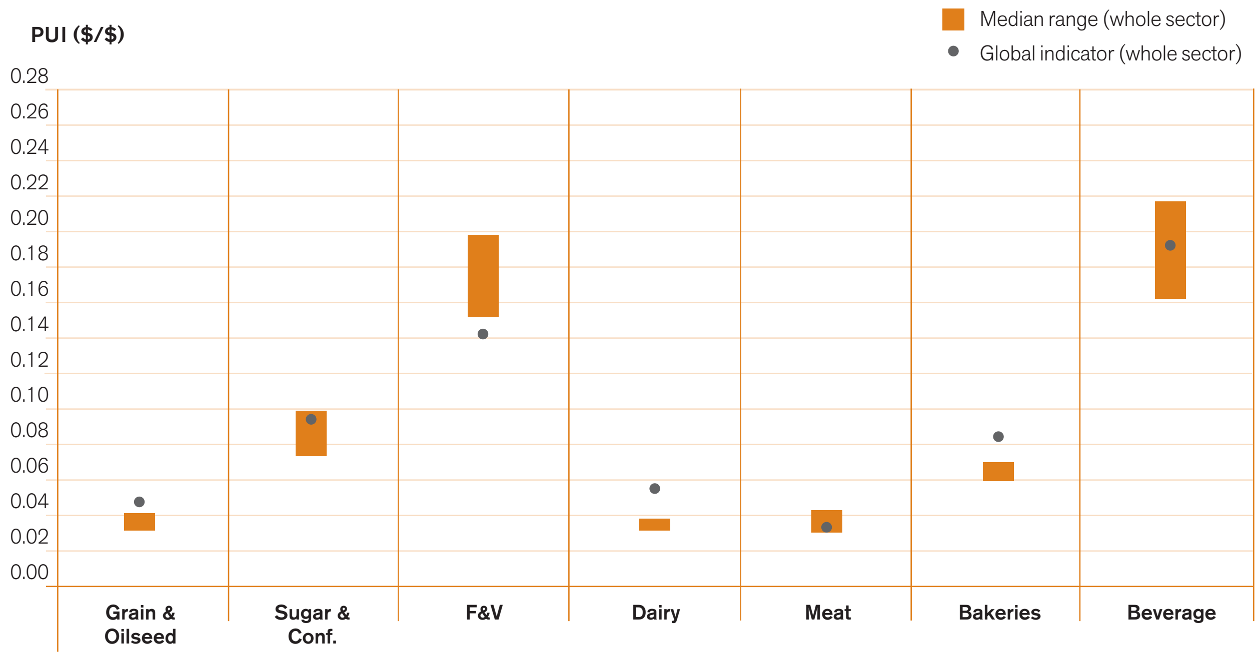

FIGURE 21-1 Packaging use intensity (PUI in $/$) as a function of activity sector and subsector, Canada, 2002

■ A median range indicator is therefore also calculated to provide a range of efficiencies within the groupings. For this, the PUI is calculated for each establishment and results are then ranked by increasing value. The lowest 40% are considered *better than average,* the highest 40% are considered *worse than average* and the remaining establishments are considered *average*. The PUI range in the average group represents the median indicator range in which a typical representative plant of the group scores.

Limitations

The indicator is calculated per *value* of product manufactured, instead of per *volume* of product manufactured, which would have been a better eco-efficiency indicator (Arcand et al., 2005) but was limited by the availability of data. Also, at this time, trend analysis is not possible and only the benchmark year (2002) is available. Finally, the PUI indicator makes assumptions only about the environmental impact of packaging products and does not explicitly calculate it based on packaging quantities or environmental impact factors.

Results and Interpretation

NATIONAL

Figure 21-1 presents PUI indicator values across Canada for all sectors and subsectors reported, without regard to the size of establishments.

The high values of the fruit & vegetable sector and the beverage sector (up to six or seven times higher than that of the least intense sectors) can be explained by the containers used in both of these groups. The fruit & vegetable sector uses metal (steel cans) or glass containers in its production of non-frozen products (approximately half of its total shipments). These are costly compared to less complex plastic packaging. Fresh juices from fruits or vegetables are often packaged in sophisticated composite packaging such as multilayered laminated cartons, including aluminium and plastic films, whose price compared to the price of the final product is higher than for plastic bottles and jugs. The global PUI is lower than the median range PUI for the fruits & vegetables sector. This means that few of the larger establishments spend less for packaging materials than typical plants in this sector.

The beverage manufacturing sector uses glass (bottles) or metal (aluminium cans, kegs) for all alcoholic beverages and for numerous other beverages that are not packaged in plastic bottles, resulting in a share of packaging cost-to-cost of production as high as almost 20 percent.

The high PUIs in the fruits & vegetable sector are largely due to fruit & vegetable canning, pickling and drying. Within the beverage industry there are large economic differences as breweries, wineries and distilleries have more expensive products than soft-drinks, largely reducing their PUI. The deposit system for reusable glass beer bottles in all provinces (Comeau, 2005) significantly reduces the cost of purchased packaging for breweries.

With a typical value of packaging expenses around 3% to 4% of finished product, the dairy sector as a whole shows a low PUI. However, it is one of the few food sectors (together with the bakeries & tortilla manufacturing sector) for which the global

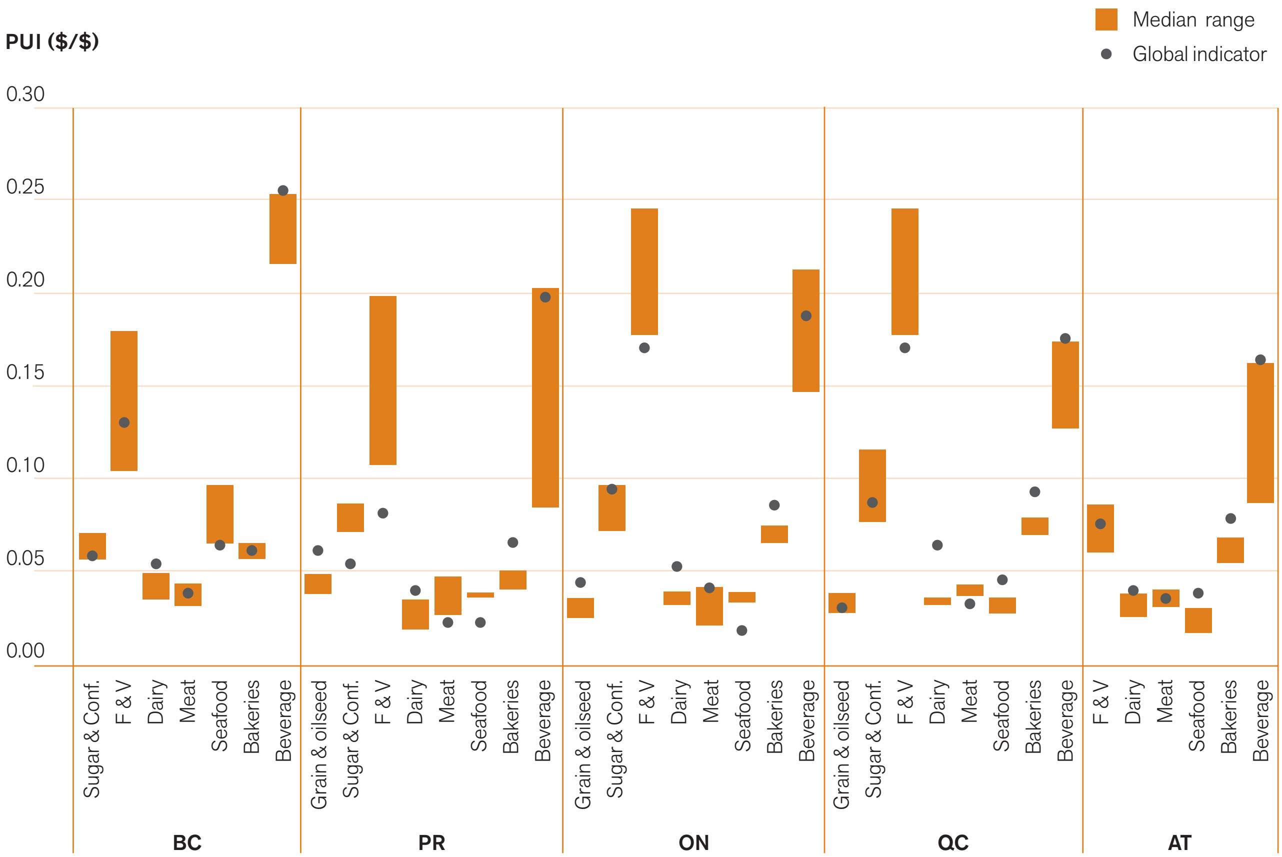

FIGURE 21-2: Packaging use intensity (PUI in $/$) as a function of activity sector and region, 2002

PUI value is significantly higher than the median range (at least +40%). This can be explained by the fact that few of the biggest players (with respect to shipment values) have higher than average PUIs. The comparison of the global and the median range PUI shows that these establishments could improve their eco-efficiency and shift their PUI to a lower level.

The bakeries sector shows an intermediate PUI level. The fact that the global intensity measures higher than the median is largely attributable to the cookie & cracker sub-sectors, which often use multiple packaging for their products—as opposed to bakery products from commercial or retail bakeries, which use more basic packaging.

PROVINCIAL

Details by region (province or group of provinces) of the PUI indicator are presented in Figure 21-2.

British Columbia

British Columbia stands among the least intense regions for the sugar & confectionery sector, which is explained by the predominance of the sugar manufacturing subsector within this industry in this province. Conversely, the province shows a significantly higher PUI than any other region in the seafood sector. The global PUI is 50% higher than in Quebec, and more than three times higher than in Ontario. Moreover, a typical plant in this sector is at least three times more intensive than a typical plant in any other region. British Columbia's seafood industry is largely oriented towards salmon canning, which means that a large amount of its packaging purchases are expensive steel or aluminium cans, whereas the seafood industries in the Atlantic provinces and Quebec are mostly focused on shellfish & seafood activities involving more basic and cheaper packaging materials, together with far higher selling prices.

In the beverage sector, British Columbia stands out as the most intensive province. This may be due to British Columbia primarily packaging beer in cans or draught kegs instead of refillable glass bottles as other regions do, thus increasing packaging cost. In 2002, bottles represented only 26.1% of the beer sold in the province, whereas it represented 47.5% in the Prairie Provinces, 76.9% in the Atlantic Provinces, 77.2% in Ontario, 85.1% in Quebec, and averaged 68.1% in Canada (Brewers Association of Canada, 2007).

Prairie Provinces

The Prairies, like British Columbia, show a low PUI in the sugar & confectionery sector. It also has the lowest intensity in the meat sector, which is one of the main economic drivers of the FBI in the Prairies. This is also true in the fruit & vegetable sector, where the region has a global PUI of $8/$100. However, this low intensity appears to be the result of a few of the larger selling plants, since, as the median range indicator shows, a typical mid-performing plant has an intensity between $11 and $20/$100. Large-scale plants may be benefiting from less expensive packaging materials in the fruit & vegetable, sugar & confectionery, the meat, and the seafood sectors. The reverse is observed in the grain & oilseed sector where the higher positioning of the global indicator may reveal that few of the largest selling plants are more intensive than other mid-performing plants.

Ontario and Quebec

Ontario is a leading province in almost all sectors of Canadian FBI, both with respect to the number of establishments and with respect to production. It is therefore not surprising to see national sectoral values presented in Figure 21-1 very similar to Ontario's values, for both the global and median range PUI. The main exception is for the seafood sector, where Ontario establishments are quite different from processing plants in coastal regions and deal mainly with imported materials for secondary processing. Other exceptions, though to a lower extent, are for the meat and for the fruit & vegetable sectors, where the dominance of Ontario is less marked because production is shared with other provinces. In the fruit & vegetable sector, Ontario and Quebec are the most intensive buyers of packaging materials. Mid-performing plants can spend up to $25 for packaging per $100 of production, which is substantial. As Figure 21-1 shows, such a high intensity level is a characteristic of the canning and pickling subsector and 75% of the Ontario fruit & vegetable industry was engaged in this in 2002 (Statistics Canada, 2008b).

Figure 21-2 confirms the effect of economic concentration in the dairy sector. In 2002, Ontario and Quebec together accounted for more than 74% of Canadian dairy product manufacturing shipments (Statistics Canada, 2006) and almost 60% of all establishments. The concentration effect is particularly marked in this sector, with three companies (or 15% of all establishments) owning 75% of the market (Agriculture and Agri-Food Canada, 2005). These are highly productive establishments that influence the global PUI as a result. The global PUI for the dairy sector is higher than the median range, mainly because big players tend to produce more specialty products sold in sophisticated packaging.

Atlantic Provinces: The Atlantic Provinces show the lowest global PUI of the country in the fruit & vegetable sector, slightly below $8/$100. However, the median range stays in line with this value, displaying a narrow range. It is thus likely that all plants in the region behave similarly in this sector with respect to packaging requirements, provided their production is qualitatively comparable. This region might also serve as a benchmark for other provinces in this sector provided production patterns are similar. Unfortunately, the lack of disaggregated data about the relative importance of both fruit & vegetable subsectors in the Atlantic Provinces does not supply sufficient information to make such inferences.

Response Options

With the main objective of decreasing the costs associated with packaging and transportation while maintaining the quality of the products sold, food processors have significantly reduced the amount of material per standard container over the last few decades (Refreshments Canada, 2008; Marsh and Bugusu, 2007). The industry can act by reducing the quantity of materials needed to pack a given quantity of finished product. However, such an approach is limited by the minimal protection required by a given product within the distribution system. This is a threshold that cannot be crossed. Another option is to reduce secondary packaging by redesigning the packaging. New designs may also offer the opportunity to choose materials with a lower environmental impact—either the same materials with a higher recycled content or those coming from cleaner processes, or new materials with a smaller ecological footprint. The industry may be influenced in this direction by market demand from distributors and consumers who, thanks to their purchasing power, can request low ecological footprints.

The reduction of FBI packaging waste is a complex issue. The management of packaging-related environmental issues cannot be limited to reducing packaging quantity only. This is because decreasing packaging can lead to food losses, thus producing an impact more negative than positive (Erlöv et al., 2000). The real challenge lies in choosing packaging materials and design with a smaller environmental impact, taking into account the manufacturing steps of each material, the minimum requirements of the (product-packaging-distribution) system, and impacts that the packaging generates once it becomes waste. The consumer is the last decision-maker when purchasing and is also the local waste generator. One of the responsibilities of governments and local authorities is to inform consumers and support public education about packaging wastes. A further step could be to guide the public about alternative consumer choices by embedding information on impacts into product packages.

A consensus is building among the policy and scientific communities that the best approach to analyzing packaging and the environmental issues associated with it is a life cycle approach. Life cycle analysis is time-consuming during the data inventory phase and thus requires a significant investment. But it becomes cost-effective afterwards and often pays off during subsequent analyses of similar products. Moreover, life cycle analysis is not limited to environmental assessments as it can also be used for cost analyses of the whole life cycle of a packaged product. This technique could be used to improve the current PUI indicator to allow for a breakdown by type of packaging. Hence, it should weight every type of packaging material put on the market by an environmental pressure factor which would take into account direct and indirect impacts of each packaging material as well as waste management scenarios of packaging.

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Linking Science to Policy

22 Using Integrated Modelling

AUTHOR
H. Morand

Summary

A firm understanding of how changes to agricultural policies and programs will impact the sector's future economic and environmental outcomes is critical to the policy development and evaluation process in Canada. To achieve such insights, science must be linked to analytical policy tools. Agriculture and Agri-Food Canada (AAFC) has used a multidisciplinary approach to develop this kind of integrated modelling capacity by linking the Canadian Regional Agriculture Model (CRAM), a policy model, to *biophysical models* such as agri-environmental indicators.

In recent years, this science-based analytical approach has proven very useful for agricultural policy analysis (for example, to assess possible greenhouse gas (GHG) mitigation strategies), to support the selection of quantitative environmental performance targets under Canada's Agricultural Policy Framework (APF) and to assess the environmental impacts of trade liberalization scenarios as part of World Trade Organization (WTO) negotiations on agriculture. While demand for this type of analysis is increasing, many issues of methodology still need to be ironed out.

Introduction

Agri-environmental indicators (AEIs) provide a historical perspective on the agriculture sector's environmental performance. However, for the sector to manage its natural resources in a manner that is environmentally, socially and economically sustainable, there is a need to understand how changes to agricultural policies and programs will affect the sector's economic and environmental outcomes and how to produce outcomes that are consistent with government goals and objectives.

Government must harness science in the policy development process. Science generates reliable quantitative information about environmental effects and supports analytical tools that allow this information to be integrated into the policy decision-making process. Currently, this involves integrating agri-environmental indicator models with policy models. Such integrated models can then be used to evaluate existing policies and programs relative to their combined economic and environmental performance, as well as to estimate or predict the economic and environmental impacts of proposed programs and policies.

Linking Science To Policy

Building an integrated modelling capacity requires multiple players, including research scientists and economists. The ongoing development of an integrated economic-environmental modelling system at AAFC links economic and biophysical models at scales ranging from global to regional and local (Figure 22-1). The process starts with economic models (red components in Figure 22-1) which estimate changes in farm resource allocation (crops and livestock) relative to a baseline level for selected scenarios and feeds this information into biophysical models (grey components in Figure 22-1) to assess the potential environmental impacts.

The main economic model used by AAFC is the Canadian Regional Agriculture Model (CRAM) (Horner et al., 1992). CRAM can estimate changes in resource allocations for various crop and livestock activities that will occur in response to changes in technology, government programs and policies or market conditions. It covers grains and oilseeds, forage, beef, hogs,

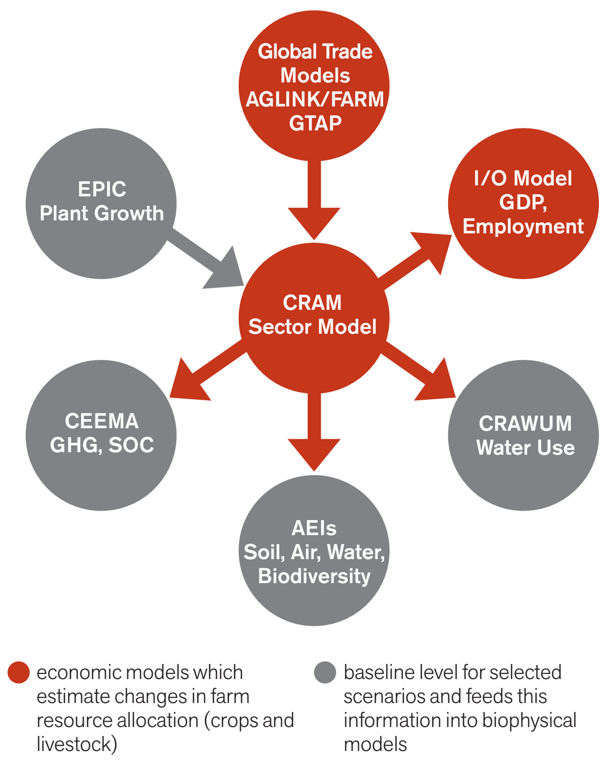

FIGURE 22-1 Components of the Integrated Economic-Environmental Modelling System

dairy and poultry. Biofuels, a value added product for grains and oilseeds, are a recent inclusion in the CRAM model.

CRAM has been linked over the years to different biophysical models, depending on the purpose for which it is being used and the issues being analyzed. The Environmental Policy Integrated Climate (EPIC) model has been used to forecast agricultural yields, which are then integrated into CRAM to assess the medium- to long-term economic impacts of climate change. Agri-environmental indicators (AEIs) are science-based models that track trends in environmental performance for the agriculture sector. They have been used to analyze the impacts on water, air, soil and biodiversity that result from shifts in production patterns due to changing technology, policies or market conditions. The Canadian Economic and Emission Model for Agriculture (CEEMA) (Kulshreshtha et al., 2002) provides a link between CRAM and a GHG emissions indicator to estimate the agriculture sector's potential contribution to climate change mitigation policies. Finally, the Canadian Regional Agriculture Water Use Model (CRAWUM) is aimed at assessing the total agricultural demand for water by sub-sectors and regions.

Applications to Integrated Modelling

The integrated economic-environmental modelling approach was first developed to enable AAFC to estimate the economic and environmental consequences of wind and water erosion on the Prairies (Bouzaher et al., 1996). AAFC subsequently enhanced the methodology and used it to undertake an environmental assessment of the Federal-Provincial Crop Insurance Program across Canada (MacGregor et al., 1998).

The emphasis shifted then to climate change. CRAM and CEEMA were used to analyze possible GHG mitigation strategies in support of the work of the Agriculture and Agri-Food Table (National Climate Change Secretariat-Agriculture and Agri-Food Table, 2000), to develop GHG mitigation programs for agriculture and support international negotiations (UNFCCC, 2000), and to help develop a national climate change plan for Canada. Results from this phase of work were instrumental in getting agricultural soil sinks accepted under the *Kyoto Protocol*.

In the early 2000s this integrated economic-environmental modelling capacity was used to identify provincial environmental goals and targets under the Environment Chapter of the Agricultural Policy Framework (APF) (Heigh et al., 2005). The analysis was limited to existing AEI models with national coverage that could be linked to CRAM (water and wind erosion, Residual Soil Nitrogen, Indicator of Risk of Water Contamination by Nitrogen, Greenhouse Gas emissions, Soil Carbon and Wildlife Habitat Availability). The study helped identify appropriate environmental goals by indicating the range of achievable outcomes based on various adoption rates for each beneficial management practice (BMP) under consideration.

More recently, AAFC used integrated modelling for a country-specific regional environmental impact analysis of two trade liberalization scenarios representing extreme cases of multilateral trade proposals to the World Trade Organization (WTO). The first scenario assumed an extension of the Uruguay Round Agreement on Agriculture (URAA), which calls for reductions of 36% to all food and agricultural tariffs in developed countries and of 24% in developing countries, reductions in domestic support of 20% in developed countries and of 14% in developing countries, and reductions in export subsidies of 36% in developed countries and of 24% in developing countries. The second scenario assumed full multilateral trade liberalization in the form of the complete elimination of all food and agriculture policy measures—tariffs, domestic support and export subsidies—in developed and developing countries.

Science generates reliable quantitative information about environmental effects and supports analytical tools that allow this information to be integrated into the policy decision-making process.

For Canada, the simulated economic impacts from these scenarios suggested that arable crop output and the use of chemicals would increase by less than 2%, while the intensity of chemical use would also increase, but by no more than 5%. With respect to environmental impacts, the analysis indicated that complete liberalization resulted in higher GHG emissions and a slight worsening of the overall nitrogen balance while soil erosion improved marginally. The effects of partial liberalization were similar but more modest (Figure 22-2).

This work was used for the mandated environmental assessment of the Doha Multilateral Trade Negotiations, and it has been incorporated as one of only two country-specific case studies in a report published by the Organization for Economic and Co-operation Development (OECD) investigating the linkages between agriculture, trade and the environment (OECD, 2005).

Limitations and Future Directions

Analytical models based on sound science have proven very useful for policy evaluation and development purposes, and the demand for this type of analysis is increasing. However, development is ongoing with issues related to resources, data, models, science and spatial aspects still to be resolved. Some of the main limitations to the current capacity to do this type of integrated modelling, as well as future directions envisaged for this work, are described below.

As a policy tool, CRAM is based on political boundaries that are dictated by the availability of economic data. Yet environmental issues are inherently local in nature, which is why AEIs are based on much smaller ecological regions (Soil Landscape of Canada, or SLC, polygons). Consequently, the output from CRAM needs to be scaled down to the SLC level so that cropping and management practice scenarios from the policy model can be assigned to specific locations within the landscape. At present, this is done by assuming a uniform distribution. Work is underway to address this issue through the development of a Land Use Allocation Model (LUAM) (Touré et al., 2007).

The scenarios and agri-environmental indicators that have been used in the analyses to date are constrained by the availability of integrated models. As a result, some important farm management options (e.g. manure management) are left out of the analyses. Similarly, researchers' ability to assess the on-farm economic impacts of environmental management scenarios is limited by a lack of relevant economic information. For many scenarios, informed assumptions about BMP adoption rates have been imposed and so the results are not driven by the underlying economics of the policy model. Finally, the existing integrated modelling system does not include any feedback linkages between the economic and environmental components in the sense that outputs from policy model scenarios are used as inputs to the AEI models to estimate the environmental impacts, but not vice versa (changes in environmental indicators could have economic consequences).

Developing an integrated modelling capacity and learning to apply models to analyze policies is an ongoing process. Improvements to CRAM will incorporate modules for cellulosic-based *ethanol* production and for water availability, as well as a higher spatial resolution of livestock activities. Since the existing AEI models are being updated and new ones developed, linkages between CRAM and the AEIs will require ongoing adjustments in combination with the development of a totally automated, computer-based interface to facilitate the use of AEIs by economic modellers. Finally, in the future, an estimate of the level of uncertainty associated with model results will be required for informed policy decision-making.

Integrated economic-environmental models provide the capacity to estimate the environmental impacts of agricultural programs and policies in physical terms (e.g. soil erosion in tonnes per hectare per year or GHG emissions in tonnes per year), as well as to quantify the economic consequences for producers. However, to permit a complete cost-benefit analysis, a monetary value must first be assigned to these environmental impacts before a trade-off analysis of the economic and environmental outcomes can be performed. This aspect of monetary valuation of biophysical changes is currently being developed within the Agri-Environmental Valuation component of the NAHARP program (see chapter 23).

There is increasing demand for this type of integrated analysis among policy makers. Ongoing and future applications of the integrated economic-environmental modelling system include the following:

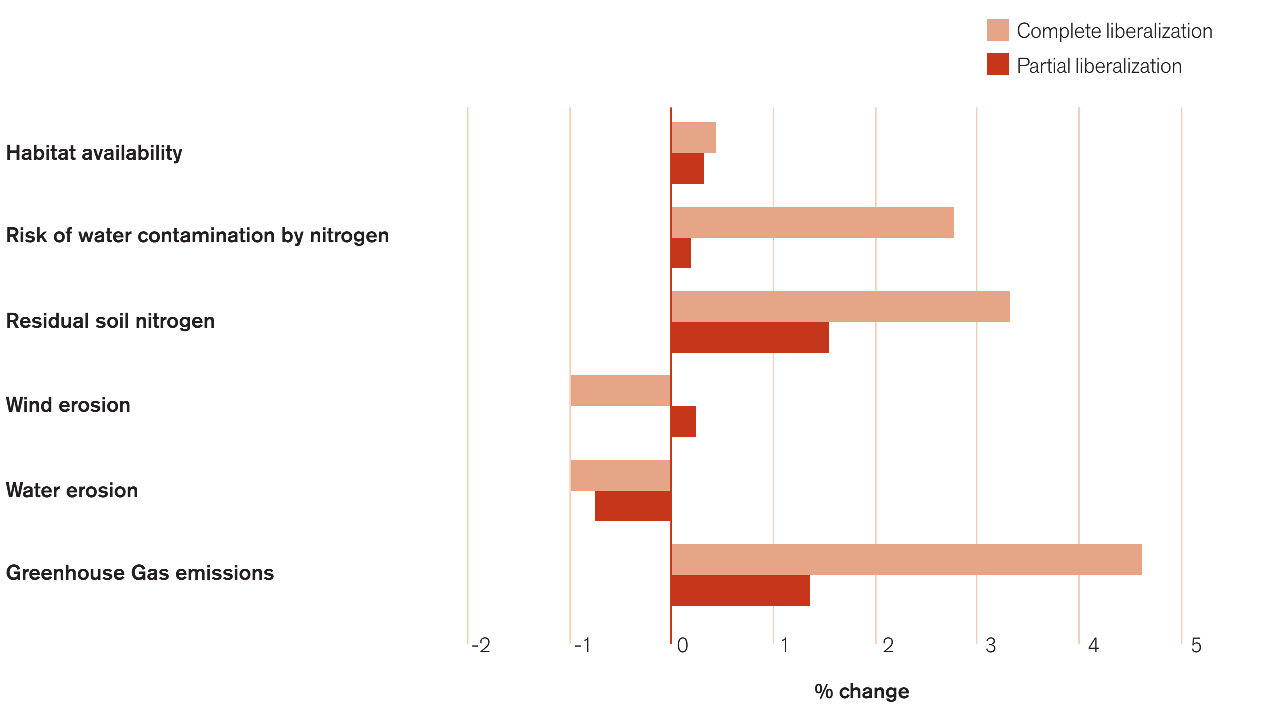

FIGURE 22-2 Environmental Effects of trade liberalization scenarios

- completing an environmental impacts assessment of APF business risk-management programs such as the Canadian Agriculture Income Stabilization (CAIS) program and the Production Insurance program;
- conducting an environmental impacts assessment of Canada's biofuels strategy, including second-generation ethanol production;
- tackling climate change by analyzing more aggressive mitigation options in the context of carbon trading and by assessing the impacts of climate change on the agricultural sector along with possible adaptation strategies;
- assessing policy options that would enhance the provision of ecosystem services from agricultural lands; and
- carrying out strategic environmental assessments of agricultural policies and programs to meet legislative obligations.

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23 Economic Valuation

AUTHOR
M. Straub

Introduction

The agri-environmental indicators (AEI) presented in this report assess and report trends on the environmental performance of the agriculture sector from changing land-use patterns and management practices. A capacity for *integrated modeling* (Chapter 22) has enhanced the value of these indicators by using them to assess eventual environmental outcomes from changing market conditions or government policies. There continues to be a gap in how the indicators are used in the policy process due to the difficulty in translating their biophysically-based measurements into a form that resonates with decision-makers. The AEIs measure environmental impacts in physical terms such as risk of soil erosion or greenhouse gas emissions, which does not allow easy comparison to economic consequences. Since policy decisions are largely based on economic tradeoffs (i.e. costs vs benefits), non-monetary factors such as environmental impacts can easily be overlooked or considered of secondary importance because they are not expressed in monetary terms. Yet it is widely acknowledged that much of Canada's national wealth and well-being stems from the goods and services provided by nature. Effectively establishing a value for these ecosystem goods and services can bridge that gap.

Agri-environmental valuation techniques can bridge natural science with policy by attaching monetary values to environmental impacts, for example by providing dollar values for changes to the biophysical measures from the agri-environmental indicators. This field of work is drawing increased attention for both its potential relevance for informing decision-making and its ties to the concept of rewarding producers for the ecological goods and services they provide to society.

Ecological Goods and Services

Increasingly, agricultural landscapes are recognized for their potential to produce goods and services, in addition to food, fibre and fuel, that provide benefits to society such as flood control, cleaner air and water, and wildlife habitat (Figure 23-1). These are often referred to as Ecological Goods and Services (EG&S) and can be interpreted as the benefits that human populations derive, directly or indirectly, from healthy functioning ecosystems (Millennium Ecosystem Assessment 2003). The concept of EG&S is useful for describing the biophysical impacts of changing ecosystems in terms of human well-being, and can provide a powerful lens through which to understand and assess resource and landscape changes for environmental policy (Brauman et al., 2007).

While often appreciated by the public, it is difficult to determine a monetary value for the intangible services provided by ecosystems such as flood control, nutrient cycling and water and air purification. As a result, their use typically goes unchecked. People do not pay for EG&S, and land managers do not gain financially from producing them on their land. As the environmental benefits and impacts of agriculture have drawn increased attention, so too has the idea that policy decision-making must account for these essential services. Being able to assign meaningful measures to EG&S across varying landscapes and circumstances is fundamental to designing policies that recognize agricultural land managers' roles in implementing (or maintaining) activities at levels that are desirable to society and the environment.

This field of work is drawing increased attention for both its potential relevance for informing decision-making and its ties to the concept of rewarding producers for the ecological goods and services they provide to society.

Environmental Valuation

The field of economics has developed techniques that can interpret changing environmental risks and impacts from and on agricultural land in dollar values. The fundamental principle in agri-environmental valuation is that this value is reflected in people's willingness-to-pay (WTP) to reduce environmental risks or impacts. Using the concept of WTP in a valuation exercise can help determine how individuals make tradeoffs between specified EG&S and other purchases with respect to their limited budget, thereby providing some indication of what the monetary value of an EG&S might be.

Each type of EG&S however, can affect human well-being in a variety of ways. For instance, establishing wildlife habitat can also provide more recreational opportunities, improved erosion control, potential timber and non-timber forest products, and improved landscape aesthetics. To capture the value of wildlife habitat, a valuation exercise would assess either all of the relevant effects with respect to human well-being, or the most significant effects as a minimum value of the EG&S. In the case of clean water, a person's willingness-to-pay for an improvement in a water body that allows for more swimming days and/

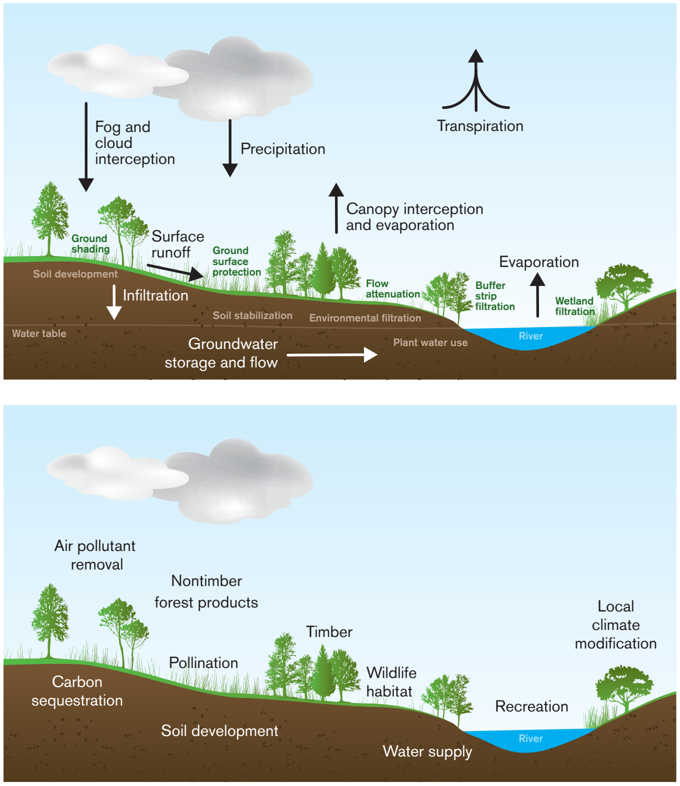

FIGURE 23-1 Water cycle-ecosystem interactions.
a) Biophysical interactions at the watershed scale.
b) Examples of a variety of EGS that a watershed produces
Source: Brauman et al. (2007)

or increases the quality of drinking water would represent the monetary value for that improvement.

The valuation exercise constructs a WTP profile for an EG&S by eliciting individuals' preferences for an improvement in the benefits and/or impacts. These profiles are then used to estimate a dollar value of an EG&S and estimate society's total value for the change in an EG&S. Such results can help set priorities for landscape management programs and can serve as a basis for incentives for EG&S in agriculture (Turner, et. al., 2004).

The main challenge for agri-environmental valuation lies in linking on-farm actions with the multiple benefits to human populations. In practice, valuation includes a number of links illustrated in Figure 23-2: 1) untangling how actions affect complex ecological functions (Behaviour-Resource link), 2) linking those functions to the EG&S they provide (Resource-Ecosystem link), and 3) determining how these EG&S affect human well-being (Ecosystem-Society link). The final step is the valuation exercise itself, which involves quantifying economic values for the contribution of the EG&S to human well-being. For example, valuing improved water quality in a watershed would involve: 1) understanding how, where, and to what extent improved on-farm actions impact the watershed, 2) determining how these impacts will affect the EG&S provided, 3) establishing how changes in these EG&S might impact relevant water users. Valuation uses this information to determine the contribution to the well-being of water users in dollar values.

Linking with the Indicators

Determining the value of EG&S by assessing the whole system requires understanding how the Behaviour-Resource link and Resource-Ecosystem link work together, which is often quite complex. The Behaviour-Resource link requires an understanding of how on-farm actions affect the environment and how conditions such as soil type, slope, and climate might affect impacts. The Resource-Ecosystem link requires an assessment of how these impacts spread across the landscape and over time, and requires that the potential trends in ecosystem services be modelled and mapped. These two links are integrated by the indicators in a simplified way which allows a valuation exercise to be conducted.

The indicators provide information about environmental effects and EG&S that can be readily understood by non-scientists, and therefore can be used in valuation exercises. For example, if the Wildlife Habitat Availability indicator can provide the relative change in species richness from improvements in bank stability or a wider buffer strip on a specific site, then it can link on-farm actions to the related EG&S for that site.

Valuation Methods and Pilot Projects

A number of methods are available to estimate consumer WTP. Valuation pilot projects were conducted at two sites in eastern Canada and used hypothetical questions about realistic situations in which EG&S would be valued in an agricultural setting. Agri-environmental indicator information was used to construct the possible scenarios for this valuation exercise.

The research used survey tools to determine society's WTP for EG&S related to surface water quality. The two valuation pilot exercises focused on changes in landscape aesthetics, commercial/consumptive use, recreational opportunities and biodiversity. Survey respondents were presented with realistic scenarios of future states of an ecosystem and asked to select their preference among varying prices and policy options. Results allow estimation of individual willingness-to-pay for changes between the status quo and various alternative scenarios, and the results provide estimates for the value of ecosystem services associated with improvements in surface water quality at two specific sites.

One pilot study was conducted along the Thomas Brook and throughout the Cornwallis River watershed in Kings County, Nova Scotia. Using economic models and a mail survey, the study estimated the value that residents place on changes in water quality arising from implementation of on-farm Beneficial Management Practices (BMPs). Some respondents indicated

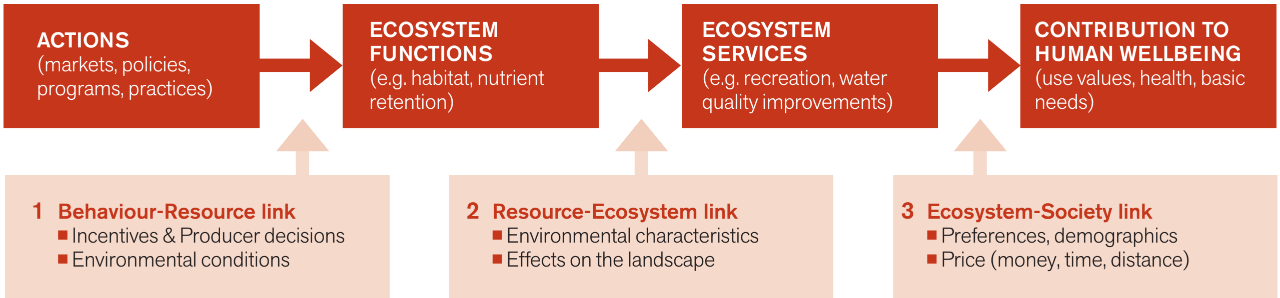

FIGURE 23-2 Linking Ecosystems to Human Well-Being: A simple general framework for valuation Source: adapted from Turner et al. (2004); Turner and Daily (2008); IISD (2008)

strong willingness to pay for environmental improvements while others did not. The study found that residents, including some who participated in many recreational activities in the watershed and others who obtained little recreational benefit from it, were willing to pay between $1.56 and $291.13 per household per year for an increase from 'fair' to 'good' water quality (CCME, 2008). The study also estimated how home values in the community would change with improvements from 'moderate' to 'good' levels for water quality, the establishment of riparian habitat, and continued agricultural water use, using the models. On a per-household basis, the models suggested that, should water quality in the Cornwallis River watershed be substantially improved, the improvements are worth between $3,000 and $8,000 in added value to each household. Further study is required to determine the accuracy of these estimates.

A second pilot study used models and an online survey to determine the value that residents place on specific improvements to habitats in a number of St. Lawrence River tributaries in Quebec. Three scenarios were presented. They ranged from minimal to major environmental improvement, representing the impact of progressive integration of all environmental regulations for agricultural producers in order to achieve 'good' to 'excellent' rankings for water quality, landscape diversity and aesthetic value, and bird and fish habitat. (Quebec Ministry of Sustainable Development, Environment and Parks, 2008). Fifty-two percent of respondents indicated that they were willing to pay between $67 and $213 for a five-year program to improve the environment. This study also showed that respondents were least willing to pay for improvements to fish diversity, which would cost $53 per person per year. For water quality improvements, respondents would be willing to pay up to $59 per person per year. Respondents were willing to pay the highest amounts for improvements related to landscape diversity and aesthetic value ($79 per person per year).

Benefits Transfer

Benefits transfer (BT) is a separate category of valuation designed to transfer calculated values from existing studies to new locations, and to scale values up for policy. Benefits transfer results are based on the collective input of individual valuation studies, so the robustness of the final estimates are directly dependent on the quality of the studies that feed into them.

A study was conducted that synthesized data from existing North American valuation work, reconciled water quality measures across different sites and produced some average values to represent changes in water quality over the broad landscape.

Using existing measures of water quality, the BT study developed an empirical model that forecasted WTP values across a wide range of scenarios and that is sensitive to characteristics of the landscape and policy context. The model estimated an annual WTP of $6.81 per household for a one-unit increase in the water quality index used. The model assessed that the WTP for an improvement of water quality from being only boatable to also include fishing was $57 per household/year, and from fishable to being fit for swimming an additional $44 per household/year (Thomassin and Johnston, 2008). The accuracy of any measure of such descriptive outcomes is clearly subject to scrutiny, and the methods require further refinement, but it illustrates how results could be useful for policy assessment.

Limitations and Building a Framework

A number of challenges remain before the full-scale development of work on agri-environmental valuation will bear fruit. The assignment of values to ecosystem structure and functions must consider:

- the spatial and temporal scale of ecological processes,
- the structure, complexity and diversity that underlie ecosystem functions,
- the dynamic (in space and time) nature of ecosystems, and
- that all ecosystem processes are not fully understood.

For these reasons, the development of a solid framework is crucial for strategic valuation work in an agricultural context. Some frameworks, such as the Millennium Ecosystem Assessment (MA), have attempted to enumerate discrete EG&S and categorize them in a useful way, but most have proven difficult to incorporate into valuation exercises. Without a widely accepted and applicable framework, many studies are inconsistent in their application methods of valuation techniques which hinders their utilisation.

Work has been ongoing with partners and stakeholders, drawing upon the experiences of other countries and various organizations to develop a uniform approach to agri-environmental valuation across different landscapes that will allow results to be fed into a regional and national analysis. While current valuation work is exploratory, approaches to valuation continue to be tested and refined. Hydrological modelers, for example, can help determine the fate and transport of nutrients and pathogens from field to watershed, landscape ecologists may offer guidance in resolving spatial issues and agriculture's interactions with other aspects of the landscape, and the evolution of indicators and the contribution of indicator experts to this work will likely provide better ways to identify and measure EG&S. The ultimate goal is to build the agri-environmental indicators into this approach in a systematic way, and to develop a protocol to estimate values for changes in EG&S on agricultural landscapes in Canada.

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Provincial Results

24.1 British Columbia

Summary

Agriculture makes up approximately 3% of British Columbia's land area, 62% of which is pasture, and 22% of which is cultivated (Table 24.1-1). Floriculture and nursery, dairy, poultry and vegetables make up the largest grossing outputs in BC. The province's agri-environmental performance shows an improvement in land management and soil quality, with land use change, erosion, soil cover and soil carbon indicators showing improvement over the 1981 to 2006 period. Air quality indicators showed decreases in ammonia and particulate matter emissions, however there was no change in net greenhouse gas emissions. There was also no change in the risk to water contamination by pesticides, coliforms or nitrogen between 1981 and 2006. There was an increase in risk of water contamination by phosphorus, an increase of risk of soil contamination by trace elements, and a reduction of wildlife habitat capacity on agricultural lands from 1981–2006.

TABLE 24.1-1 Summary of agricultural statistics in British Columbia, 2006

Land Statistics (hectares (ha))	
Total area	94.5 million ha
Total land area	92.5 million ha
Total farm area	2.8 million ha
Cultivated land	22%
Pastureland	62%
Other land	16%
Average farm area	143 ha
Farm Characteristics	
Total # of farms	19,844
Total # of families	16,000
Total # of operators	29,870
Average age of operators	54
Major Agricultural Outputs	
Floriculture & nursery	$402 million
Dairy	$395 million
Poultry & eggs	$360 million
Vegetables	$353 million
Cattle & calves	$263 million
Livestock Population (number of animals)	
Poultry	18.3 million
Cattle and calves	801,000
Pigs	136,000
Dairy cows	73,000
Farm Income	
Total net cash income	$0.2 billion
Total cash receipts	$2.3 billion
Total operating expenses	$2.1 billion
Distribution of farms by revenue class	
Less than $10,000	48%
$10,000 to $49,000	26%
$50,000 to $100,000	8%
More than $100,000	18%
Food and Beverage Industry	
Total # of establishments	455
Total value of shipments	$6.6 billion
Food Processing	$5.6 billion
Meat products	25%
Dairy products	21%
Seafood products	10%
Animal food products	9%
Other food	35%
Beverages	$1.0 billion
International Trade Statistics	
Trade balance	$-1.7 billion
Exports	
Total agricultural exports	$1.5 billion
Bulk	4%
Intermediate	21%
Consumer-oriented	75%
Major export markets	
United States	$1.1 billion
Japan	$116 million
Korea, South	$70 million
Taiwan	$26 million
Hong Kong	$18 million
Imports	
Total agricultural imports	$3.2 billion
Bulk	9%
Intermediate	11%
Consumer-oriented	81%

Farm Land Management

AGRICULTURAL LAND USE (Chapter 4)

The total amount of farmland in British Columbia increased by 30% to 2.8 million hectares between 1981 and 2006 (Figure 24.1-1). The proportion of cropland to farmland declined over this period (Table 4-1), despite an increase of 21,000 ha in the area of cropland. Summerfallow virtually disappeared, while pasture and other land increased as a proportion of farmland from 1981-2006. The area devoted to cereals declined, shifting to forages (Table 4-2). There was a consistent shift away from the use of conventional tillage on cropland in favour of conservation tillage and no-till (Table 4-3). Cattle, poultry and horse numbers increased, while the pig population dropped (Table 4-4).

FIGURE 24.1-1 Proportion of agricultural land in British Columbia, 2006.

FARM ENVIRONMENTAL MANAGEMENT (Chapter 5)

In 2006, 11% of producers in British Columbia had completed Environmental Farm Plans (EFP) and another 9% had plans under development (Statistics Canada, 2007). Despite the low adoption of EFPs in the province in 2006, BC producers were adopting a wide range of BMPs such as 57% of producers using a certified pesticide operator for all pesticide applications, and 62% calibrating pesticide sprayers at the beginning of each season. Some improvements can be made however, as only 14% of permanent wetlands and 33% of waterways had an established riparian buffer along the edge.

SOIL COVER (Chapter 6)

In 2006, 42% of British Columbia farmland fell in the high and very high soil cover classes and 35% was in the moderate class (Table 6-2). The lowest levels of soil cover occur in the lower Fraser Valley where snow cover is minimal, much of the cropland is under low-cover crops such as vegetables and nurseries, and most of the residues from the small amount of cereal grains grown is baled and removed from the field. Average annual soil cover days (SCD) in British Columbia increased by 3% from 1981–2006, with most of the increase occurring between 1981 and 1986 (Table 6-1). There was considerable variation in soil cover within the province, with the lower mainland showing a 13% increase in SCD, the Peace River district a 6% increase and the interior a 3% increase in SCD values. The increases in soil cover days are the result of a virtual elimination of summerfallow and increased use of reduced and no-till practices on what little remained, and increases in perennial crops, as well as the use of reduced and no-till practices on cropland. Factors countering these positive effects included a reduction in the area of cereal grains and expansion of the area under low–residue crops (berries, grapes and nursery crops).

WILDLIFE HABITAT (Chapter 7)

In British Columbia, 442 species of birds, mammals, reptiles and amphibians were reported on agricultural land, 92 of which have been identified as at risk, may be at risk or sensitive species (Figure 7-1). In 2006, habitat capacity for breeding/ feeding (HC_{bf}) on the majority of agricultural land was very low or low and only 1% was high or very high (Table 7-1). From 1986 to 2006 provincial HC_{bf} significantly declined, as 51% of farmland showed decreases and 39% remained constant (Table 7-2).

Although there was an overall increase in farmland between 1986 and 2006, a reduction of the all other lands category (which supported the breeding and feeding requirements of close to 90% of species) was the major contributor to declining HC_{bf}. This land category decline was mainly a result of deforestation on agricultural land. Unimproved pasture increased its share of farmland over these twenty years and as the second most valuable cover type (providing breeding and feeding habitat needs for 25% of species), strongly influenced HC_{bf} on vast areas of agricultural land in British Columbia.

In 2006, the majority (57%) of farmland fell into the moderate category for habitat capacity for wintering (HC_w) as valuable unimproved pasture comprised a major share of farmland in the province. No land was in the very low category (Table 7-3).

Soil Health

SOIL EROSION (Chapter 8)

British Columbia maintained the lowest levels of soil erosion risk between 1981 and 2006, with 76% of cropland in the very low risk class at the start of that period and 88% by the end (Figure 24.1-2, Table 8-1). The reduction in overall risk can be attributed to reductions in water and tillage erosion. The share of cropland with very low water erosion risk increased from 90% in 1981 to 94% in 2006 while the share in each of the other risk classes decreased by about half within this period (Table 8-2). There was a steady decrease in tillage erosivity and tillage erosion risk between 1981 and 2006 due to changes in tillage practices. The proportion of cropland in the very low tillage erosion risk class increased from 90% in 1981 to 95% in 2006 (Table 8-4). In the Peace River Region wind erosion risk is extremely low and has not changed greatly over time. This area has relatively little cropland requiring intensive tillage, and there has been conversion from crops requiring intensive tillage to crops requiring very little tillage. Cropping changes were dominated by the reduction in the share of cropland in cereals, and an increase in alfalfa and hay.

FIGURE 24.1-2 Risk of Soil Erosion on cultivated land in British Columbia under 2006 management practices.

SOIL ORGANIC MATTER (Chapter 9)

In British Columbia in 1981, about one third of agricultural land was losing soil organic carbon (SOC). This had been reduced to only 14% in 2006 (Figure 24.1-3, Table 9-1). The amount of land with increasing SOC was 15% in 2006, up from 1% in 1981. The turnaround in SOC change can be related to an increased proportion of perennial crops. There has been relatively little cumulative SOC change from 1981 to 2006. There are still areas of concern as 4% of the land with very low and low relative organic carbon (ROC) also have decreasing SOC, representing a soil health concern (Table 9-4). Many of these areas are where tillage is intensive for horticultural crops that produce limited crop residues.

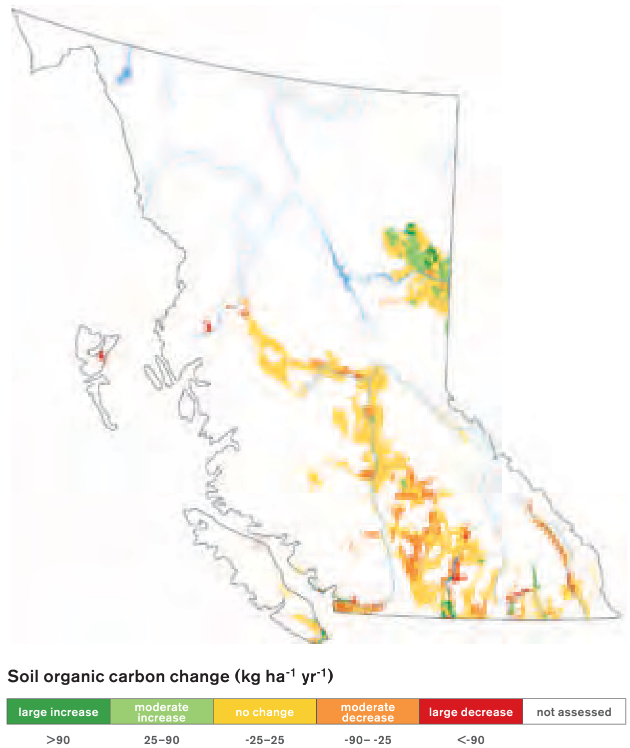


FIGURE 24.1-3 Indicator of soil organic carbon change (kg $ha^{-1}yr^{-1}$) for British Columbia, 2006.

TRACE ELEMENTS (Chapter 10)

About 16% of British Columbia's agricultural area could be at very high risk of contamination by trace elements in 100 years if 2006 management practices continue (Table 10-1). This is a 6% increase in area from that under 1981 populations and crop areas. There was little change between 1981 and 2006 in the areas in the moderate and high risk classes.

Twenty-seven percent of agricultural land in BC is expected to have an increase in TE of at least 30% above present background levels under 2006 populations and crop areas (Table 10-2). The change in populations and crop areas from 1981 to 2006 has resulted in an increase of 11% in the share of land expected to increase TE by 30 to 50% above background levels. Over this time period the rate of human population increase in BC has been one of the largest in Canada. There has also been a large increase in number of broiler chickens (Table 10-5). Because there is relatively little agricultural land in BC, especially in lower BC, the increases in broiler and human populations are concentrated on a small land area and will have a more distinct effect on TE accumulation than they might in other Provinces where the livestock farms are more widely spaced.

Water Quality

NITROGEN (Chapter 12)

12.1 Residual Soil Nitrogen (RSN)
In 2006, the majority of agricultural land in BC was in the very low and low classes and 12% was in the high and very high classes for RSN (Table 12.1-1). Southern and coastal agricultural areas of BC were in a high RSN class, whereas central BC tended to be in a low RSN class. The share of land in the high and very high RSN classes has remained fairly constant over the 1981 to 2006 period, while there has been some shift from the very low to the low and moderate classes. The exception to this was in 2001 when only 44% of land was in the very low and low classes and 31% was in the higher classes (Table 12.1-1). This was a common trend in 2001 across Canada when drought conditions reduced N outputs.

The RSN level averaged 18.9 kg N ha^{-1} from 1981 to 1996, spiked in 2001 to 28.1 kg N ha^{-1} before decreasing again in 2006 (Table 12.1-2). The changes in N inputs over the 1996 to 2001 period were primarily due to increases in both fertilizer rates and the amount of N fixed by legume crops. These rates declined again in 2006.

12.2 Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N)
Close to 90% of farmland in British Columbia was in the very low and low risk classes from 1981 to 2006 (Figure 24.1-4). The remaining 10% was spread equally among the moderate, high and very high risk classes (Table 12.2-2). Over the six census years, there was a slight shift of land from the very low to higher risk classes, mainly caused by year-to-year changes in RSN levels. The over-winter weather conditions remained fairly constant. The geographical distribution of the estimated very high risk classes on the mainland of southwestern British Columbia (Figure 12.2-1) corresponds closely to the Abbotsford-Sumas aquifer, where nitrate concentrations exceeding the Canadian drinking water guideline of 10 mg N L^{-1} have been measured (Carmichael et al., 1995, Mitchell et al., 2003).

PHOSPHORUS (Chapter 13)

Indicator of the Risk of Water Contamination by Phosphorus (IROWC-P)
IROWC-P in the thirteen watersheds of British Columbia have mostly low and very low risk values, except for two watersheds in the Lower Fraser Valley region that are in the very high risk class (Figure 24.1-5, Table13-1). This represents an increased risk in these two watersheds from 1981 (Figure 13-2). Soil P balance showed no clear variation from 1981 to 2006 (Figure 13-4). While most of BC farmland is at very low P-source levels, 10% of the farmland, mostly located in the Lower Fraser Valley, shows high and very high levels of P-source (Table 13-2). The Lower Fraser Valley region is characterised by an average input of 30 kg P ha^{-1} higher than the provincial mean (~ 10 kg P ha^{-1}),

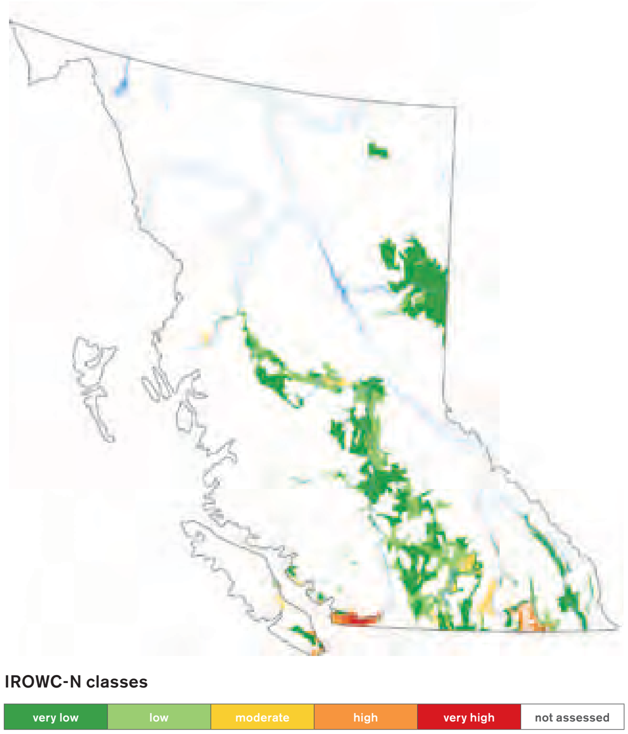


FIGURE 24.1-4 Risk of water contamination by nitrogen in British Columbia under 2006 management practices.

FIGURE 24.1-5 Risk of water contamination by phosphorus in agricultural watersheds in British Columbia under 2006 management practices.

mainly due to the high concentration of poultry operations. This high level of input has contributed to the progressive P enrichment of soils. The Lower Fraser Valley region also receives the highest annual amount of rain on agricultural land in the country (2000mm per year), which means that there is a very high risk of water contamination by phosphorus in the area and special attention to implementing practices to mitigate this risk is encouraged.

COLIFORMS (Chapter 14)

Indicator of the Risk of Water Contamination by Coliforms (IROWC-Coliform)

In 2006 the IROWC-Coliform estimated 98% of farmland at very low to low risk in British Columbia watersheds (Figure 14-2). Only one watershed (3% of farmland) was classed at high risk (Table 14-1). This is comparable to the risks observed from 1981 to 2001. The source of active populations of coliforms in the Lower Fraser Valley region remained relatively low in 2006 (Figures 14-5 and 14-6). Overall, active populations of coliforms in British Columbia have generally diminished by one to two classes (Figure 14-7). The regions of exception are the northeast area where relatively small SLC polygons have shown one to two class increases in the active population of coliforms, and the southern part of Vancouver Island. However, IROWC-Coliform risk changes are not yet detectable at the watershed scale. The risk of contamination of water by coliforms at the watershed level in the Abbotsford region in particular was highly dependent on climatic conditions. The risk varies from a low value during a dry year, to a moderate value during a humid year.

PESTICIDES (Chapter 15)

Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest)

From 1981 to 2006, most of the cropland in British Columbia was in the very low and low risk classes for water contamination (Table 15-2). However, from year to year, there was consistently a small percentage of cropland in the moderate to very high risk classes. This corresponds to those areas where the predominant crop type shifts from forages to fruits and vegetables, such as in the southwest corner of the province.

Air Quality and Greenhouse Gases

GREENHOUSE GASES (Chapter 16)

Net greenhouse gas emissions for British Columbia in 2006 are presented in Figure 24.1-6. Net GHG emissions in British Columbia were relatively constant at 2.3 Mt CO_2e between 1981 and 2006 (Table 16-1). However, during this time an increasing animal population has led to a 17% increase in CH_4 emissions from 1.2 to 1.4 Mt CO_2e and a corresponding increase in manure nitrogen. Despite the increase in manure nitrogen, N_2O emissions in British Columbia have been relatively constant at 0.9 Mt CO_2e between 1981 and 2006. The relatively stable N_2O emissions are the result of a decrease in nitrogen input from synthetic fertilizers and crop residues in 2006, both of which are due to a general decline in the cultivation of cereal crops in British Columbia. Agricultural soils in British Columbia have gone from being a small source of CO_2 in 1981 to being approximately neutral in 2006.

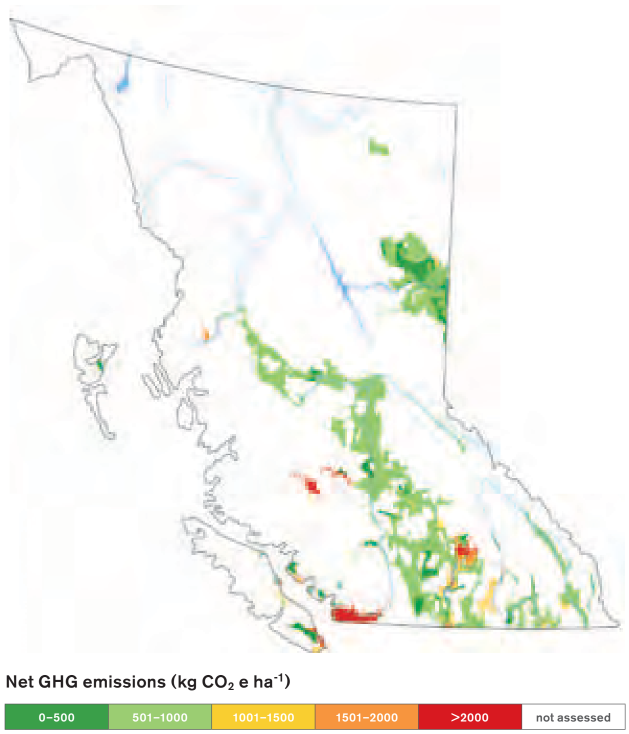


FIGURE 24.1-6 Agricultural net greenhouse gas emissions for British Columbia, 2006.

AMMONIA (Chapter 17)

Ammonia emissions in British Columbia account for approximately 4% of national emissions from agriculture (Figure 24.1-7, Table 17-2). The beef and dairy sectors combined are responsible the majority of these emissions followed by poultry. There was a small (6%) decrease in the amount of agricultural NH_3 emissions in British Columbia between 2001 and 2006 due to a decrease in livestock numbers. The share of land in the high and very high emissions-intensity classes decreased from 12% in 2001 to 9% in 2006 (Table 17-1).

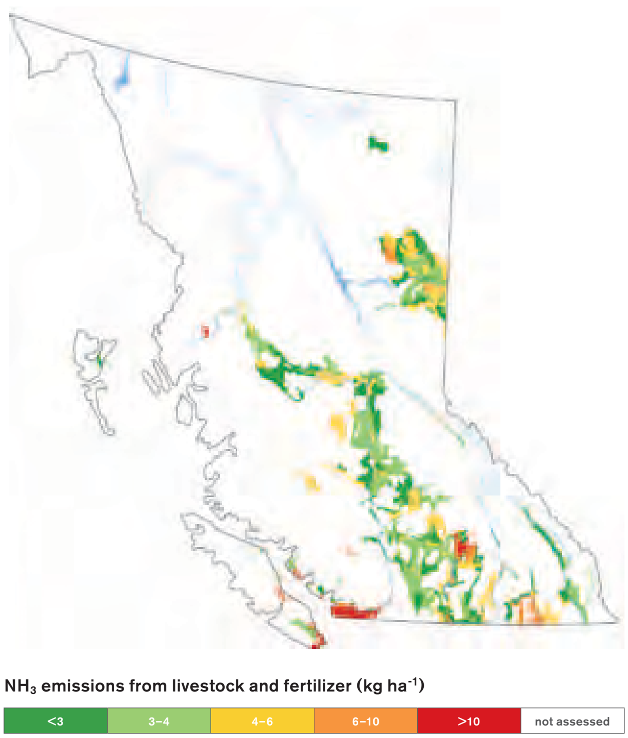


FIGURE 24.1-7 Total ammonia emissions per hectare of agricultural land in British Columbia in 2006 from major livestock sectors and fertilizer.

PARTICULATE MATTER (Chapter 18)

Despite an increase in PM emissions from animal-feeding operations, a combination of reduced tillage and decreased summerfallow contributed to a decline in the overall PM emissions in British Columbia. PM emissions decreased by 4% for both TSP and PM_{10}, and 11% for $PM_{2.5}$ between 1981 and 2006 (Table 18-1). In this province, the contributions of PM emissions from wind erosion and land preparation account for 17% of total TSP, 53% of PM_{10} and 62% of $PM_{2.5}$, which are the lowest rate among all the provinces in Canada.

24.2 Alberta

Summary

Agriculture makes up approximately 33% of Alberta's land area, half of which is cultivated land, almost half is pasture, and 7% falls into the All Other Land category. (Table 24.2-1). The highest grossing outputs in Alberta are cattle and calves, followed by canola, then wheat. Alberta's agri-environmental performance shows an improvement in land management and soil quality, with land use change, erosion, soil cover, soil carbon and salinization indicators showing improvement over the 1981 to 2006 period. Improvements can be made with water quality however, as risk of water contamination by nitrogen, phosphorus, and coliforms has increased. Ammonia and greenhouse gas emissions also increased despite the increase in carbon sequestration by soils. Wildlife habitat capacity and soil contamination by trace elements both showed no change between 1981 and 2006.

TABLE 24.2-1 Summary of agricultural statistics in Alberta, 2006

Land Statistics (hectares (ha))	
Total area	66.2 million ha
Total land area	64.2 million ha
Total farm area	21.1 million ha
Cultivated land	50%
Pastureland	43%
Other land	7%
Average farm area	427 ha
Farm Characteristics	
Total # of farms	49,431
Total # of families	38,000
Total # of operators	71,660
Average age of operators	52
Major Agricultural Outputs	
Cattle and calves	$2.9 billion
Canola	$990 million
Wheat	$616 million
Hogs	$496 million
Dairy	$382 million
Livestock Population (number of animals)	
Poultry	11.8 million
Cattle and calves	6.4 million
Pigs	2 million
Dairy cows	79,000
Farm Income	
Total net cash income	$1.1 billion
Total cash receipts	$7.8 billion
Total operating expenses	$6.7 billion
Distribution of farms by revenue class	
Less than $10,000	20%
$10,000 to $49,000	32%
$50,000 to $100,000	15%
More than $100,000	33%
Food and Beverage Industry	
Total # of establishments	266
Total value of shipments	$9.6 billion
Food Processing	$8.8 billion
Meat products	53%
Dairy products	14%
Grain and oilseed milling	11%
Animal food products	7%
Other food	15%
Beverages	$800 million
International Trade Statistics	
Trade balance	$4.4 billion
Exports	
Total agricultural exports	$5.8 billion
Bulk	36%
Intermediate	32%
Consumer-oriented	32%
Major export markets	
United States	$2.6 billion
Japan	$776 million
Mexico	$396 million
China	$231 million
Korea, South	$123 million
Imports	
Total agricultural imports	$1.4 billion
Bulk	3%
Intermediate	12%
Consumer-oriented	85%

Farm Land Management

AGRICULTURAL LAND USE (Chapter 4)

Alberta, with 21 million hectares of farmland in 2006 (up from 19 million hectares in 1981), had the second largest area of farmland in Canada, accounting for approximately 31% of the national total (Figure 24.2-1). Over the 25 year period, summerfallow area decreased to only 4% of farmland in 2006, and cropped land expanded by about the same amount (Table 4-1). The main area of increase in proportion of cropland to farmland was in the Lethbridge to Edmonton corridor (Figure 4-1). Producers diversified their production, reducing the proportion of cropland in cereals and increasing the area of oilseeds, pulses and forages (Table 4-2). The use of conventional tillage practices decreased dramatically, from 1991 to 2006, while conservation tillage and no-till increased (Table 4-3). Management of summerfallow showed a similar trend of reduced intensive tillage and increased no-till (Table 4-3), but the practice of controlling weeds through a combination of tillage and chemicals declined. The area of pasture and forages increased, coinciding with the expansion of the livestock industry. The numbers of all livestock types increased in Alberta over this period, particularly the numbers of cattle and swine which increased by 52% and 71% respectively (Table 4-4).

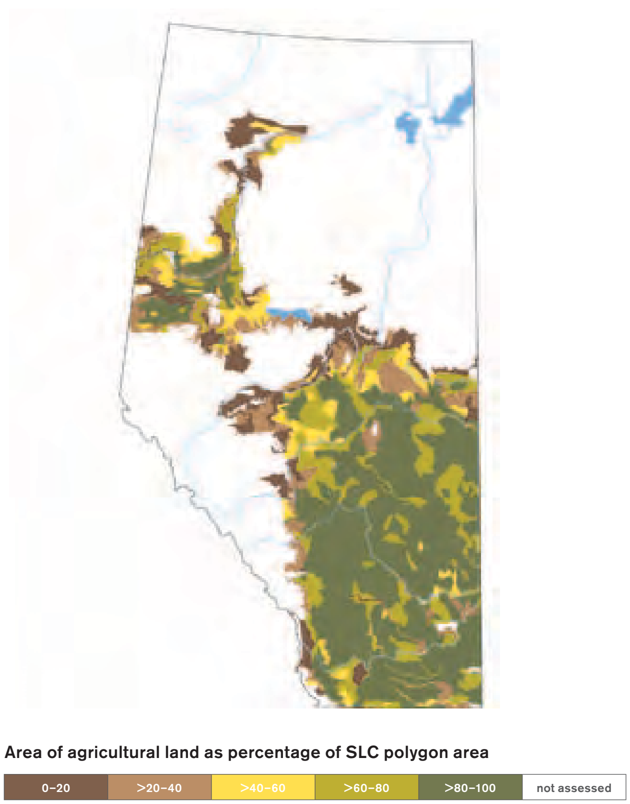


FIGURE 24.2-1 Proportion of agricultural land in Alberta, 2006.

FARM ENVIRONMENTAL MANAGEMENT (Chapter 5)

Environmental Farm Plan (EFP) programs are relatively new to the Prairies, so participation in Alberta is understandably low. In 2006 approximately 13% of producers in Alberta had a completed EFP, with another 11% having a partially completed one (Statistics Canada, 2007). Despite the low adoption of EFPs, producers were still implementing Beneficial Management Practices (BMP), with 77% reducing fertilizer application to offset the nutrients added to the soil by manure, and 65% using the optimal practice of incorporating solid manure after broadcasting it. Improvements can be made however, as only 4% of solid manure was stored on an impermeable pad.

SOIL COVER (Chapter 6)

Overall, Alberta showed a 6% increase in soil cover days between 1981 and 2006, with a fairly consistent rate of change over the study period (Table 6-1). Soil cover increased by 6% in the southern part of the province, by 10% in the central area and by 5% in the more northern and Peace River areas. Throughout the province, soil cover improved due to a reduction in summerfallow area, an increase in perennial crops and an increase of cropland under reduced and no-till. Gains in soil cover were offset by a reduction in cereal grain acreage, and increase in oilseeds, potato area and a large increase in peas, beans and lentils, all of which reduce soil cover relative to perennial crops. The largest proportion of Alberta cropland (58%) in 2006 was in the high soil cover class, while no areas were in the very high or very low classes. The area with low soil cover days was all in the extreme south-east portion of the province, where moisture deficit conditions limit crop vegetative growth.

WILDLIFE HABITAT (Chapter 7)

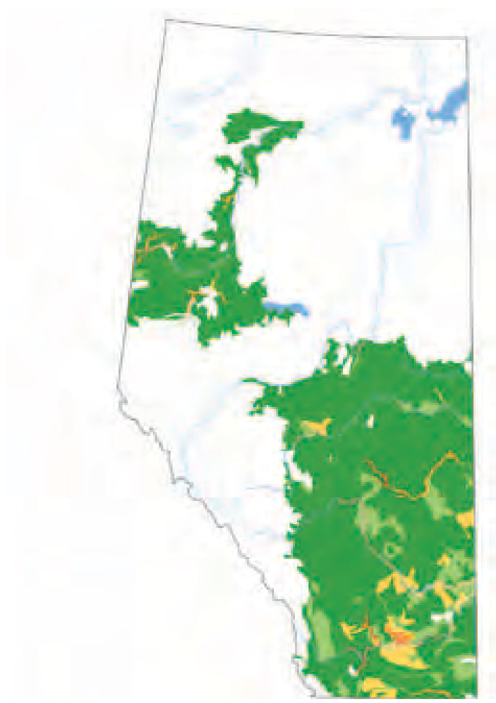
There were 419 identified terrestrial vertebrates using agricultural habitats in Alberta in 2006 including 76 sensitive species (Figure 7-1). In 2006, habitat capacity for breeding and feeding (HC_{bf}) on the majority of agricultural land (60%) was low with 25% very low and 14% moderate (Table 7-1). From 1986 to 2006, there was no significant change at the provincial scale as HC_{bf} was constant on 82% of farmland (Table 7-2).

The general stability of HC_{bf} resulted from little change in the share of the two most valuable wildlife cover types. Unimproved pasture declined very slightly while all other land was constant. However, the relatively small share of natural and semi-natural land in a landscape dominated by cultivated land, on which only 4% of species on the Prairies can obtain entire breeding and feeding requirements, resulted in the majority of farmland having low or very low HC_{bf}. It must be noted that localized loss of all other land / unimproved pasture not detected at the provincial scale occurred during this time period with potential negative impacts on wildlife habitat capacity. For example, wetland area declined by 6% in Alberta between 1985 and 2001 (Watmough and Schmoll 2007).

In 2006, the largest share of farmland (55%) fell in the low habitat capacity for wintering (HC_w) category, an additional 5% was high and no land was in the very high category (Table 7-3). Low HC_w was mainly attributable to the small share of the agricultural landscape represented by all other lands combined with the moderating effect of 31% of farmland as unimproved pasture.

Soil Health

SOIL EROSION (Chapter 8)



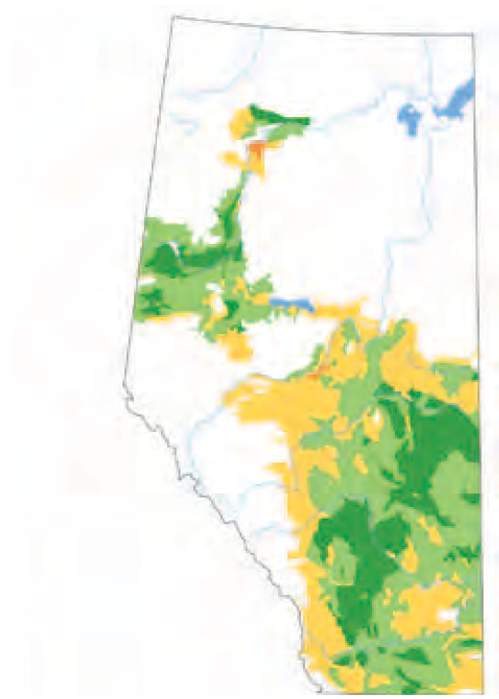
Soil erosion risk

very low	low	moderate	high	very high	not assessed

FIGURE 24.2-2 Risk of Soil Erosion on cultivated land in Alberta under 2006 management practices.

Alberta had considerable reductions in soil erosion risk between 1981 and 2006, with cropland in the very low risk class increasing from 61% to 87% (Figure 24.2-2, Table 8-1). Much of the improvement in erosion risk in Alberta is from reductions in wind erosion risk. Land with very low wind erosion risk increased from 85% in 1981 to 97% in 2006 while the amount of land with moderate to very high wind erosion risk dropped from 4% to 1% (Table 8-3). Intensely cultivated sandy soils throughout the province have moderate to high wind erosion risk. Since most cropland in Alberta has loam and clay surface textures, the majority of the land area with moderate to high wind erosion risk in Alberta occurs where cropland with those textures is managed with intensive tillage in southern Alberta. The high erosion risk in southern Alberta is due to it being the windiest and driest part of the province. Wind erosion risk is consistently high on the tilled irrigated soils in southern Alberta following potato or sugar beet crops. For tillage erosion, there were modest increases in cropland in the very low risk class (Table 8-4). Water erosion is not generally a major concern in Alberta, largely due to its climate and topography. In 2006, 95 to 98% of cropland was classed as having very low risk of water erosion (Table 8-2). However, water erosion risk needs to be managed on longer, steeper slopes such as cultivated soils on the Hand Hills in Alberta. The decrease in soil erosion is attributable in part to the reduction in land under summer fallow between 1981 and 2006. The increased adoption of direct-seeding is largely responsible for the decrease in tillage intensity and soil erosion on cropped land.

SOIL ORGANIC MATTER (Chapter 9)



Soil organic carbon change (kg ha^{-1} yr^{-1})

large increase	moderate increase	no change	moderate decrease	large decrease	not assessed
>90	25–90	-25–25	-90– -25	<-90	

FIGURE 24.2-3 Indicator of soil organic carbon change (kg ha^{-1}yr^{-1}) for Alberta, 2006.

Soil organic carbon (SOC) was increasing on 73% of cropland in 2006 as opposed to only 27% of cropland in 1981 (Figure 24.2-3, Table 9-1). Only 1 to 2% of cropland has been losing SOC from 1981 to 2006. The relative organic carbon (ROC) was generally less than 1 (mean value is 0.79) in 2006 with highest values typically in the central part of the province and lowest values in north western Alberta (Table 9-2, Figure 9-4). About one-quarter of the land falls into the low and very low ROC and, of this, 80% had increasing SOC (Table 9-4). Cumulative increases in SOC due to a reduction in the area of summerfallow and increased conservation tillage occur throughout the province and the largest increases due to annual to perennial crop conversion occurred in north western Alberta (Figures 9-2, 9-3).

TRACE ELEMENTS (Chapter 10)

The share of land in the various risk classes in Alberta did not change from 1981 to 2006 (Table 10-1). Less than 1% of Alberta's agricultural land could be in the very high risk class in 100 years if 2006 management practices continue (Figure 10-2).

The increase in soil TE concentrations relative to background showed some improvement under 2006 practices from 1981 (Table 10-2). The share of land expected to have TE increases of 30 to 50% above background levels decreased by 3% during this period. Ninety percent of agricultural land in Alberta is expected to have 10 to 30% increased TE under 2006 practices. During this time Alberta has seen an increase in the numbers of people, and livestock (Table 10-5). Because of the large agricultural land area in Alberta these increased animal and human populations are resulting in relatively small increases in TE concentration over time.

SOIL SALINITY (Chapter 11)

The majority of land (89%) in 2006 was in the very low risk of salinization class, an increase of 8% from 1981 (Table 11-1). The very high risk class was unchanged at 1%. The decreased risk was mainly due to a reduction in summerfallow with increased permanent cover also contributing. Province-wide, summerfallow showed a decrease in each census period (Figure 11-4). Permanent cover showed an initial decline but has increased since 1986.

Of the SLC polygons that changed risk classes between 1981 and 2006, the majority improved by one risk class and a few improved by two risk classes. A few areas showed a one-class increase in risk resulting from local increases in area of summerfallow and decreases in permanent cover (Figure 11-3).

Water Quality

NITROGEN (Chapter 12)

12.1 Residual Soil Nitrogen (RSN)
In 2006, 62% of Alberta's land was in the very low and low categories, 27% was in the moderate and 10% was in the high and very high RSN classes (Table 12.1-1). This represented a shift of land to higher RSN classes as, in 1981, 93% of agricultural land in Alberta was in the very low or low RSN categories and 7% of the land was in the moderate RSN category. The very low and low RSN classes were primarily located in eastern Alberta, whereas the moderate, high and very high RSN classes were generally found in central Alberta.

The RSN increased gradually from 1981 to 1996 and then sharply to 2001 before decreasing markedly by 2006 (Table 12.1-2). The increase in N inputs from 1981 to 2001 was due to increased N fixation by legume crops, increased fertilizer use and increased manure application. The decrease in RSN from 2001 to 2006 was primarily due to higher yields and N outputs in 2006 than in 2001 as N inputs were similar between 2001 and 2006.

12.2 Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N)
During each of the census years, all farmland in Alberta remained in the very low and low risk classes (Figure 24.2-4), but over the 25 years there was a 7% shift from the very low to the low risk class category.

Over-winter N losses and N concentrations in the drainage water (Figure 12.2-4 and 12.2-5) were very small in Alberta because the over-winter drainage, although highly variable, was very small (average: 4 mm, see Table 12.2-3). The mean over-winter precipitation of only 155 mm (Table 12.2-3) and consequent mean spring soil water content of 261 mm is still well below field capacity or the amount of water the soil can hold before significant deep drainage. In other words, the increasing RSN estimates over time were not at a high risk of being lost to leaching due to the overall dry climate.

FIGURE 24.2-4 Risk of water contamination by nitrogen in Alberta under 2006 management practices.

PHOSPHORUS (Chapter 13)

Indicator of the Risk of Water Contamination by Phosphorus (IROWC-P)

In 2006 twenty one out of seventy three watersheds were in moderate to very high IROWC-P classes and 41 watersheds moved to a higher risk class from 1981 to 2006 (Figure 24.2-5, 13-2). The watersheds with moderate and high IROWC-P values were primarily found in a corridor located between Lethbridge and Edmonton. Only two watersheds near the Lethbridge region, characterized by a large livestock population, showed a very high risk value. Overall, levels of P-source remained relatively low in the province with more than 90% of the farmland in the very low and low classes of P-source (Table 13-2). However, there was a general increasing trend in the soil P balance values over the last 25 years (Figure 13-4) caused by the rapid expansion of the swine and cattle sectors. The increased livestock population has created more manure-P (Figure 13-8) than is taken up and exported by harvested crops, thus increasing the soil P balance. The total amount of cultivated land also increased during this time, but at a slower rate, while the fertilizer sales remained constant.

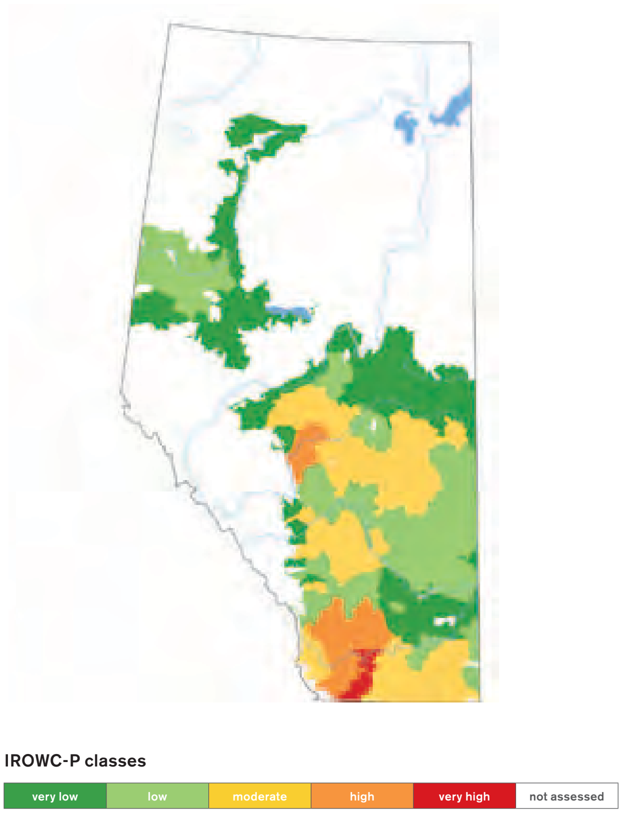


FIGURE 24.2-5 Risk of water contamination by phosphorus in agricultural watersheds in Alberta under 2006 management practices.

Very high risk of water contamination by phosphorus was estimated in two watersheds, and attention may be required in the near future to prevent the gradual shift to higher risk of watersheds located within the Lethbridge–Edmonton corridor.

COLIFORMS (Chapter 14)

Indicator of the Risk of Water Contamination by Coliforms (IROWC-Coliform)

The IROWC-Coliform assessment in Alberta watersheds estimated 61% of farmland at very low to low risk in 2006 (Figure 14-2). Higher risks are mostly due to the pasture-deposited manure which has increased the active coliform population between 1981 and 2006 (Figure 14-5). This is observed in the central Pembina, Wabamun, and Blindman watersheds (Figure 14-7). The spread manure active coliform population has also contributed considerably to the IROWC-Coliform high values observed in the Oldman River watershed (Figure 14-7) and to a lesser extent in the rest of the province. Although agricultural land increased in Alberta between 1981 and 2006, the cattle and swine population densities also increased resulting in additional manure and coliform sources.

PESTICIDES (Chapter 15)

Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest)

From 1981 to 2006, all cropland in Alberta was at a very low to low risk to contaminate water by pesticides (Table 15-2). Of all the provinces, Alberta showed the least risk of water contamination by pesticides with only 1% of the land in the moderate class for a single year (1996). Despite the application of the second-highest amount of pesticides in the country (Figure 15-3), the relatively dry climate results in few days with enough rainfall to cause runoff (Table 15-3), thereby, reducing the risk of water contamination.

Air Quality and Greenhouse Gases

GREENHOUSE GASES (Chapter 16)

Alberta has the largest provincial beef cattle population, representing 43% of the national herd and is second only to Saskatchewan in terms of crop production and nitrogen fertilizer consumption. As a result, Alberta has the highest net agricultural GHG emissions of any province at 13.8 Mt CO_2e in 2006 (Figure 24.2-6, Table 16-1). Between 1981 and 2006, CH_4 emissions increased by 62% and N_2O emissions increased by 38%. The increase in CH_4 and N_2O emissions has been largely due to a growing livestock herd, especially beef cattle and increased use of nitrogen fertilizers. Despite the increase in CH_4 and N_2O emissions, the widespread adoption of no-till, reduced frequency of summerfallow and the conversion of annual crops to perennial crops has significantly changed CO_2 emissions from agricultural soils, which were a small sink (0.7 Mt CO_2) of CO_2 in 1981, and became a large sink (4.1 Mt CO_2) in 2006. As a result, most of the increase in CH_4 and N_2O emissions has been offset by the decrease in CO_2 emissions and net emissions have increased by 24% between 1981 and 2006.

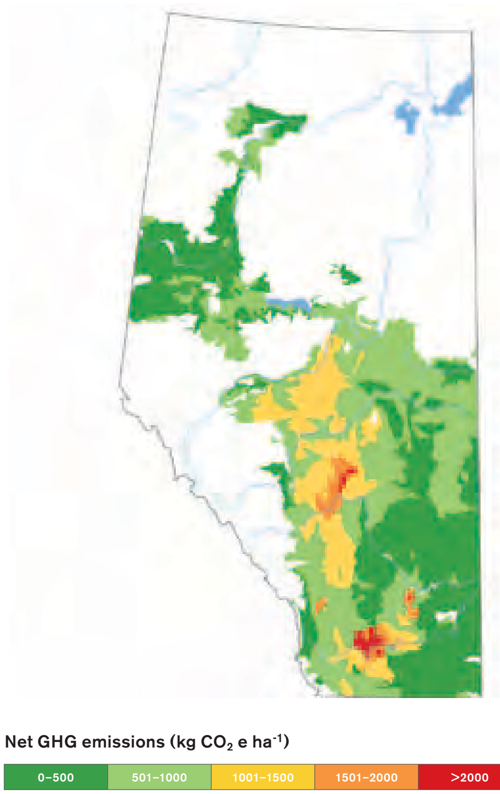


FIGURE 24.2-6 Agricultural net greenhouse gas emissions for Alberta, 2006.

AMMONIA (Chapter 17)

Alberta has the largest emission of NH_3 of all the provinces, responsible for 27% of national agricultural emissions (Table 17-2). The beef sector alone dominates NH_3 emissions in Alberta, representing 70% of emissions. There was no noticeable change in emissions between 2001 and 2006 as livestock numbers remained relatively stable. The share of land in the low and moderate emissions classes increased by 7% as a result of a shift out of the very low emissions class (Figure 24.2-7, Table 17-1).

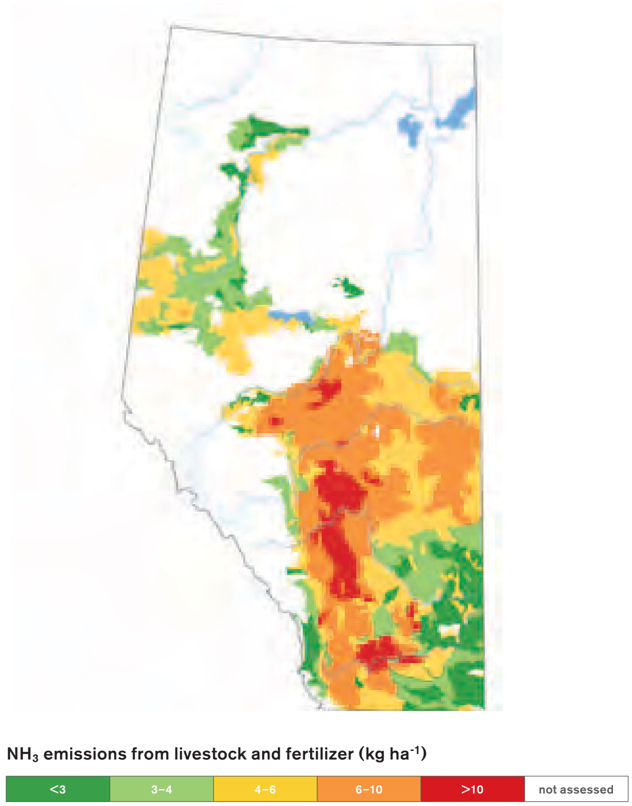


FIGURE 24.2-7 Total ammonia emissions per hectare of agricultural land in Alberta in 2006 from major livestock sectors and fertilizer.

PARTICULATE MATTER (Chapter 18)

Particulate matter (PM) emissions from agricultural operations in this province decreased substantially between 1981 and 2006. These reductions were 46% for TSP, 35% for PM_{10}, and 44% for $PM_{2.5}$ (Table 18-1). PM emissions from land preparation and wind erosion decreased between 1981 and 2006 due to reduced tillage activity and a decrease in the area of summerfallow. Although there was a net reduction in PM emissions, PM emissions from animal-feeding operations, crop harvest and fertilizer application increased. The largest increase of PM emissions was from animal-feeding operations, due to a significant increase in animal population between 1981 and 2006.

24.3 Saskatchewan

Summary

Agriculture makes up approximately 44% of Saskatchewan's land area, 67% of which is cultivated land, 27% of which is pasture, and 6% falls into the all other land category (Table 24.3-1). The highest grossing outputs in Saskatchewan are canola, cattle and calves, and wheat. Saskatchewan's agri-environmental performance showed improvements in soil cover, risk of erosion, soil carbon levels and risk of salinization between 1981 and 2006. There was also a decrease in greenhouse gas and particulate matter emissions during this time. No change was seen in the wildlife habitat capacity of Saskatchewan's agricultural land, soil contamination by trace elements or risk of water contamination by nitrogen. There was a small increase in risk of water contamination by phosphorus, coliforms and pesticides over this period.

TABLE 24.3-1 Summary of agricultural statistic in Saskatchewan, 2006

Land Statistics (hectares (ha))	
Total area	65.1 million ha
Total land area	59.2 million ha
Total farm area	26 million ha
Cultivated land	67%
Pastureland	27%
Other land	6%
Average farm area	587 ha
Farm Characteristics	
Total # of farms	44,329
Total # of families	33,000
Total # of operators	59,185
Average age of operators	53
Major Agricultural Outputs	
Canola	$1.1 billion
Cattle & calves	$1.1 billion
Wheat	$988 million
Hogs	$313 million
Dry peas	$237 million
Livestock Population (number of animals)	
Poultry	4.8 million
Cattle and calves	3.4 million
Pigs	1.4 million
Dairy cows	28,000
Farm Income	
Total net cash income	$1.2 billion
Total cash receipts	$6.6 billion
Total operating expenses	$5.4 billion
Distribution of farms by revenue class	
Less than $10,000	12%
$10,000 to $49,000	30%
$50,000 to $100,000	19%
More than $100,000	39%
Food and Beverage Industry	
Total # of establishments	130
Total value of shipments	$2.3 billion
Food Processing	$2.2 billion
Grain and oilseed milling	40%
Meat products	32%
Animal food products	5%
Other food	23%
Beverages	$36 million
International Trade Statistics	
Trade balance	$4.2 billion
Exports	
Total agricultural exports	$4.5 billion
Bulk	66%
Intermediate	31%
Consumer-oriented	3%
Major export markets	
United States	$1.1 billion
Japan	$457 million
Mexico	$293 million
India	$261 million
China	$201 million
Imports	
Total agricultural imports	$253 million
Bulk	5%
Intermediate	19%
Consumer-oriented	76%

Farm Land Management

AGRICULTURAL LAND USE (Chapter 4)

Saskatchewan accounted for approximately 38% of Canadian farmland, or about 26 million hectares in 2006 (Figure 24.3-1). Over the 25-year period under review, the amount of farmland changed very little. A significant decline in area under summerfallow translated into an increase of cropped land, a 64,000 hectare increase in pasture (although this remained at 27% of farmland in 2006) and an increase in other land (Table 4-1). Large increases in cropland as a proportion of farmland occurred primarily in central Saskatchewan (Figure 4-1). Cropping patterns diversified, with a reduction of cropland in cereal grains and increases in oilseeds, pulse crops and forages (Table 4-2). The use of conventional tillage and conservation tillage on cropland decreased from 1991 to 2006, while no-till increased to 60% of cropland (Table 4-3). Weed control on summerfallow showed a decline in tillage-only and tillage-plus-chemicals practices while chemical-only management increased from 4% of summerfallow in 1991 to 38% in 2006 (Table 4-3). Livestock numbers increased for all categories between 1981 and 2006, but the most dramatic change in Saskatchewan was the 142% increase in hog numbers (Table 4-4).

FIGURE 24.3-1 Proportion of agricultural land in Saskatchewan, 2006.

FARM ENVIRONMENTAL MANAGEMENT (Chapter 5)

The Environmental Farm Plan (EFP) program is relatively new in the Prairies which likely explains why only 11% of producers in Saskatchewan had a completed plan, and another 14% had an EFP under development in 2006 (Statistics Canada, 2007). Despite these low numbers, producers in Saskatchewan are implementing beneficial management practices to reduce environmental risk and increase environmental performance. Nineteen percent of producers in Saskatchewan have established a riparian buffer strip along waterways, and 18% have established a buffer around permanent wetlands. 16% of producers maintain a setback distance along waterways and the same percentage maintain setbacks around permanent wetlands. 21% of producers soil test on an annual basis, and 32% test every 2-3 years. For livestock, 13% of producers provide only limited access to surface water, 59% provide grazing livestock unlimited seasonal access to surface water and 26% provide unlimited year-round access to surface water, which indicates that improvements in grazing management can be made.

SOIL COVER (Chapter 6)

The highest provincial average increase in soil cover between 1981 and 2006 occurred in Saskatchewan, with an increase of 10%, the greatest increase occurring between 1986 and 1991. Regional increases ranged from 8% in northern agricultural areas to 10% in the south. The high increase in average soil cover was the result of a reduction in summerfallow area, an increase in perennial crops and the increased adoption of conservation and no-till on cropland and summerfallow. The improvement was attained despite a decline in cereal grains and increases in the area of oilseeds and pulse crops. In 2006, none of Saskatchewan's farmland was in the very high or the very low classes, but 36% fell in the high class and 36% in the low class (Table 6-2). As in Alberta, low soil cover conditions occur almost exclusively in the south-west portion of the province, where a lack of moisture limits crop growth.

WILDLIFE HABITAT (Chapter 7)

Agricultural land in Saskatchewan is used for breeding, feeding or wintering by 370 species (Figure 7-1). In 2006, habitat capacity for breeding and feeding (HC_{bf}) on the majority of agricultural land was very low and no land was in the high and very high classes (Table 7-1). From 1986 to 2006 provincial HC_{bf} did not change significantly as 88% of farmland remained constant with small decreases on 4% and small increases on 8% (Table 7-2).

The overall stability of HC_{bf} at the provincial level, as with the other Prairie Provinces, resulted from only minor shifts in the share of all other land and unimproved pasture (<1% respectively). The most valuable wildlife cover types, all other land and unimproved pasture, comprised only 6 and 20% of farmland, respectively, leaving cultivated land as the dominant land cover in Saskatchewan. The relatively small representation of natural and semi-natural habitat was the primary reason for the majority of farmland having very low HC_{bf}. On cultivated land, declines in the share of cereals and summerfallow and increases in tame hay potentially benefited wildlife while increases in oilseeds and pulses reduced HC_{bf}.

In 2006, provincial HC_w was low as the majority of land fell into the low (54%) and very low (37%) categories with only 1% of land in the high and very high categories (Table 7-3). The low HC_w resulted from all other lands and unimproved pasture comprising relatively small components of the provincial farmlands.

Soil Health

SOIL EROSION (Chapter 8)

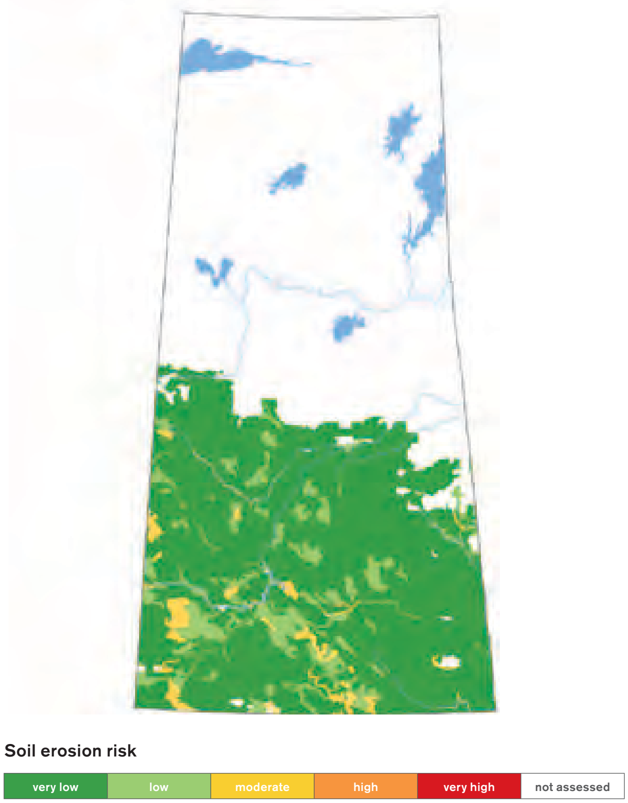


FIGURE 24.3-2 Risk of Soil Erosion on cultivated land in Saskatchewan under 2006 management practices.

Saskatchewan increased its share of cropland in the very low risk class from 40% to 87% between 1981 and 2006 (Figure 24.3-2, Table 8-1). Much of the improvement in erosion risk is from reductions in wind erosion risk (Table 8-3). Intensely cultivated sandy soils throughout the province have moderate to high wind erosion risk. Since most cropland in Saskatchewan has loam and clay surface textures, the majority of the land area with moderate to high wind erosion risk occurs on land with those textures under intensive tillage in southern, especially southwest, Saskatchewan.

The higher erosion risk in southern Saskatchewan is due to it being the windiest and driest part of the province. For tillage erosion, there were modest increases in cropland in the very low risk class, from 72% in 1981 to 97% in 2006 (Table 8-4). Owing to climate and topography, water erosion risk is generally not a major concern in Saskatchewan, with 96 to 98% of land with very low water erosion risk (Table 8-2). The decrease in soil erosion is attributable in part to the reduction in land under summerfallow and increased adoption of direct-seeding.

SOIL ORGANIC MATTER (Chapter 9)

In 2006, 93% of agricultural land was increasing in soil organic carbon (Figure 24.3-3, Table 9-1) compared to only 1% in 1981. Negligible to small changes in SOC occurred on the majority of cropland in 1981 while only 6% of cropland in 2006 was in this class. The relative organic carbon (ROC) is 0.7 and greater in northern and eastern Saskatchewan and 0.7 and lower in southern and western Saskatchewan (Figure 9-4). This pattern likely reflects the historical predominance of mixed grain-livestock farming in the north and east and historical predominance of grain farming with frequent summerfallow in the south and west of the province. SOC increase from reduction of summerfallow and tillage is widespread throughout the province. Virtually all land with low or very low ROC also has increasing SOC, indicating improving soil health conditions (Table 9-4).

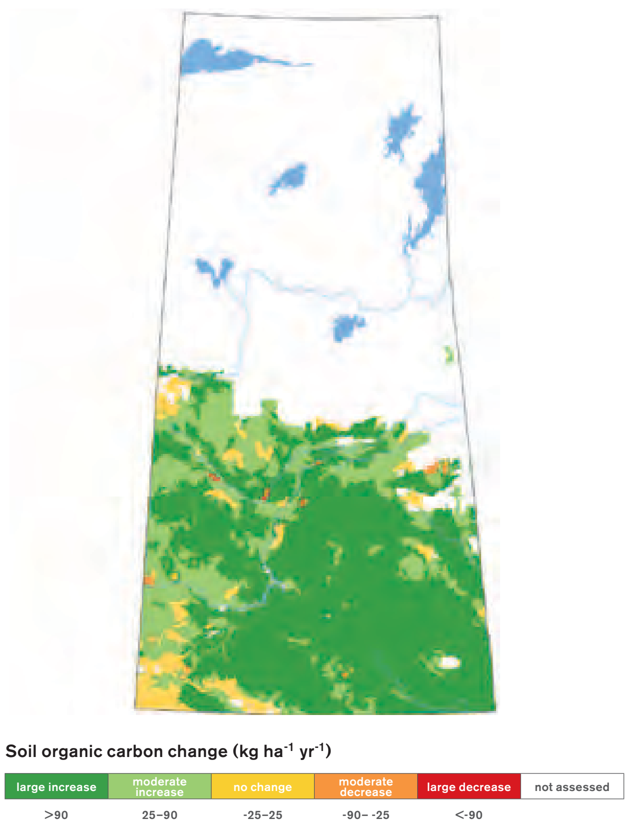


FIGURE 24.3-3 Indicator of soil organic carbon change (kg $ha^{-1}yr^{-1}$) for Saskatchewan, 2006.

TRACE ELEMENTS (Chapter 10)

The share of land in the various risk classes in Saskatchewan did not change appreciably from 1981 to 2006. Less than 1% of Saskatchewan's agricultural land could be in the very high risk class in 100 years if 2006 management practices continue (Table 10-1).

About 96% of the land in Saskatchewan is expected to have TE increases of 10 to 30% above background levels (Table 10-2). Since 1981 in Saskatchewan there has been an increase in the numbers of people and livestock (Table 10-5). Because of the large agricultural land area in Saskatchewan these increased animal and human populations are resulting in relatively small increases in TE concentration over time.

SOIL SALINITY (Chapter 11)

Land in the very low risk of salinization class increased from 65% to 72% of land area between 1981 and 2006 (Table 11-1). The high risk class was reduced to 0%. The reduced risk was mainly due to a reduction in summerfallow with increased permanent cover also contributing.

Of the SLC polygons that changed risk classes between 1981 and 2006, the majority improved by one risk class and several improved by two risk classes. A few areas showed a one-class increase in risk largely as a result of reduced permanent cover locally (Figure 11-3).

Water Quality

NITROGEN (Chapter 12)

12.1 Residual Soil Nitrogen (RSN)

Saskatchewan had the lowest RSN average (8.6 kg N ha^{-1}) compared to all other provinces in 2006 (Table 12.1-2). In 2006, Saskatchewan had 96% of land in the very low and low categories, which was a small decrease from 1981 when 100% of the farmland was in these classes (Table 12.1-1). The amount of land in the moderate category remained very low (from 0% to a maximum of 14%) over the 25-year period.

The RSN increased gradually from 1981 to 1996 and then sharply to 2001 before decreasing markedly by 2006 (Table 12.1-2). The N inputs in Saskatchewan increased from 18.2 kg N ha^{-1} in 1981 to 46.3 kg N ha^{-1} in 2006. Increased fertilizer application and increased N fixation by legume crops were responsible for most of this rise. The decrease in RSN from 2001 to 2006 was primarily due to the increased N outputs that resulted from higher yields in 2006.

12.2 Indicator of Risk of Water Contamination by Nitrogen (IROWC-N)

Virtually all farmland in Saskatchewan remained in the very low risk class throughout the 25-year period. Only in 2001 and 2006 was any farmland estimated to be at low risk, accounting for 1% and 2%, respectively, of farmland in Saskatchewan (Figure 24.3-4).

Estimated over-winter N losses and N concentrations in the drainage water were very small in Saskatchewan (Figure 12.2-4 &12.2-5), because the overall dry climate, as in Alberta, resulted in most soils remaining below field capacity in the spring. The increasing RSN estimates over time were not at high risk of being lost to leaching because of the dry climatic conditions. Long-term field experiments by Campbell et al. (2006) in southwestern Saskatchewan confirm estimates that there is little or no N leaching with good farm-management practices.

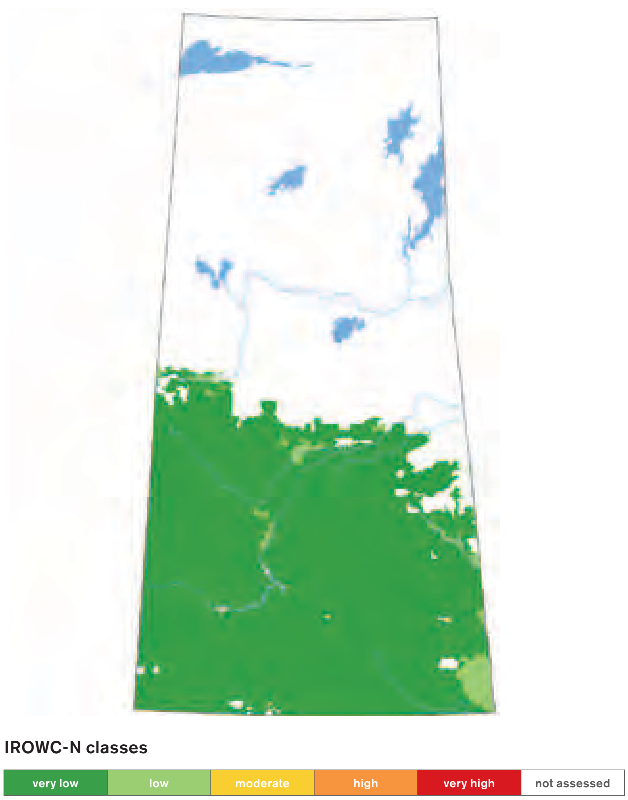


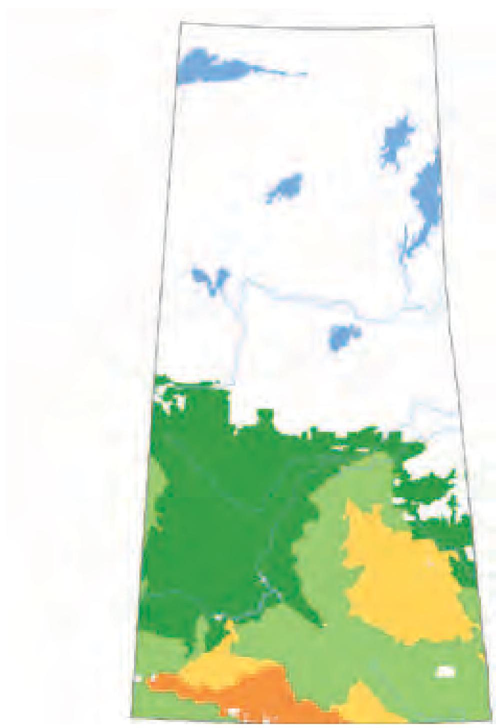
FIGURE 24.3-4 Risk of water contamination by nitrogen in Saskatchewan under 2006 management practices.

PHOSPHORUS (Chapter 13)

Indicator of Risk of Water Contamination by Phosphorus (IROWC-P)

Two regions in Saskatchewan showed watersheds with moderate and high IROWC-P values in 2006; the Swift Current region and the broader southeast area (Figure 24.3-5). Thirteen out of sixty-one watersheds were in the moderate to high risk classes and 32 watersheds moved to higher risk classes from 1981 to 2006 (Figure 13-2). In 2006, Saskatchewan presented the lowest level of P-source with more than 99% of the cultivated land in the low and very low classes (Table 13-2). The 25-year trend of mineral P fertilizer use in the province showed a gradual increase for the first 15 years but a slight downward trend for the last 10 years even though the total agricultural area has increased. The province also showed the lowest animal density in the country in 2006 despite increases in the cattle and swine populations. The increases in manure and mineral P fertilizers resulted in an overall positive soil P balance from both manure P inputs and fertilizer P inputs during the 1981-2006 period (Figure 13-8).

Even with a low risk attributed to the level of P-source, some agricultural watersheds show increased IROWC-P values in 2006 relative to 1981. This is mainly related to the greater amount of rainfall and snowmelt experienced in 2006 (Figure13-5).



IROWC-P classes

very low	low	moderate	high	very high	not assessed

FIGURE 24.3-5 Risk of water contamination by phosphorus in agricultural watersheds in Saskatchewan under 2006 management practices.

COLIFORMS (Chapter 14)

Indicator of Risk of Water Contamination by Coliforms (IROWC-Coliform)

The IROWC-Coliform assessment in Saskatchewan watersheds showed mostly very low to low risk values in 2006 corresponding to 90% of farmland with the exception of a cluster of watersheds in the south eastern region that showed moderate risk (Figure 14-2). This cluster of watersheds is related to the Assiniboine, Qu'Appelle and Souris Rivers regions which were characterized by moderate to high classes of pasture-deposited active coliform populations (Figure 14-5). Only the years 1996 and 2006 have shown moderate to high risk (Table 14-1) corresponding to 10% of farmland in 2006. Despite increases in cattle and swine populations from 1981 to 2006, in 2006, Saskatchewan had the lowest animal density in the country.

PESTICIDES (Chapter 15)

Indicator of Risk of Water Contamination by Pesticides (IROWC-Pest)

From 1981 to 2006, most of the cropland in Saskatchewan was at a very low or low risk of water contamination by pesticides (Table 15-2). Despite having the largest amount of pesticides applied in the country (Figure 15-3) (about 17 million kg in 2006), this province has a relatively dry climate, resulting in a low number of days with enough rainfall to result in a runoff event (Table 15-3) that could carry pesticides off the treated fields.

Air Quality and Greenhouse Gases

GREENHOUSE GASES (Chapter 16)

Net GHG emissions were 1.8 Mt CO_2e in Saskatchewan in 2006, representing a decrease of 73% since 1981 (Figure

Net GHG emissions (kg CO_2 e ha^{-1})

0–500	501–1000	1001–1500	1501–2000	>2000	not assessed

FIGURE 24.3-6 Agricultural net greenhouse gas emissions for Saskatchewan, 2006.

24.3-6, Table 16-1). During the 1981 to 2006 period, soils went from being a sink of 0.3 Mt CO_2 to a sink of 9.1 Mt CO_2. However, CH_4 emissions increased by 60% and N_2O emissions increased by 59% due to intensification of agriculture in Saskatchewan during this time period. The use of nitrogen fertilizers doubled as farmers increased the rate of fertilizer application to wheat crops and shifted to more nitrogen demanding crops such as canola. There was also an increase in the livestock population, particularly that of beef cattle. The decrease in net emission is attributable to a significant increase in practices that conserve soil carbon, such as decreased frequency summerfallow and increased use of no-till.

AMMONIA (Chapter 17)

Saskatchewan has the second-largest emission of NH_3 of all the provinces, responsible for 21% of national agricultural emissions (Table 17-2). The beef sector is responsible for 51% of these emissions followed by emissions from the use of fertilizers at 39%. There was a slight increase (3.2%) in emissions between 2001 and 2006 due to increased livestock numbers. This also resulted in a decrease in the share of land in the very low emissions-intensity class from 51% in 2001 to 36% in 2006 (Figure 24.3-7, Table 17-1). This land shifted to the low and moderate classes.

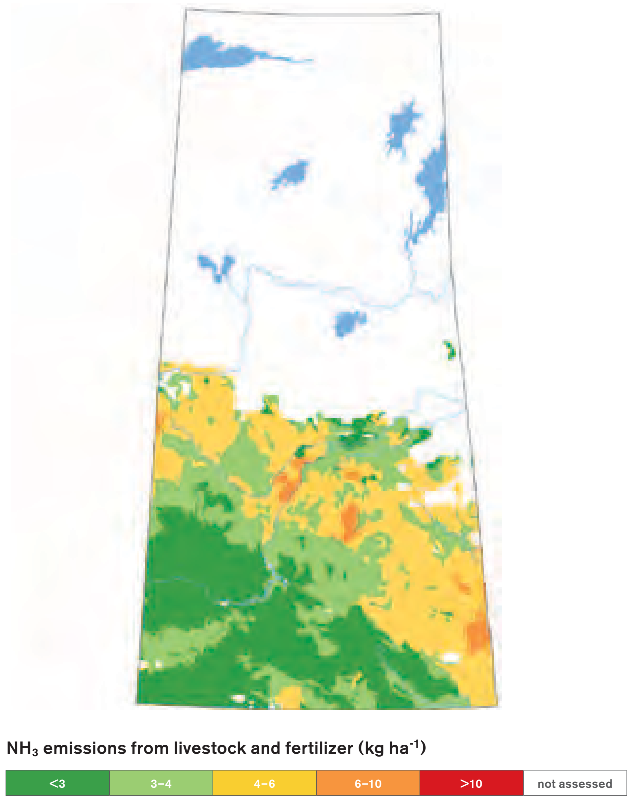


FIGURE 24.3-7 Total ammonia emissions per hectare of agricultural land in Saskatchewan in 2006 from major livestock sectors and fertilizer.

PARTICULATE MATTER (Chapter 18)

Saskatchewan, having the largest proportion of agricultural land in Canada, had the greatest PM emissions from agricultural operations, accounting for more than half of the total agricultural PM emissions in Canada (Figure 18-2). Most PM emissions are due to wind erosion, land preparation and crop harvest. However, this province also demonstrated the largest decrease in PM emissions between 1981 and 2006 (Table 18-1).

The combination of large cropland area and a susceptibility to wind erosion due to the dominant soil types and semi-arid conditions in the area were the key factors that contributed to the large PM emissions. The reduction in PM emissions between 1981 and 2006 in Saskatchewan was largely due to the combination of a large increase in conservation tillage and no-till practices, and a decrease in the area of summerfallow.

24.4 Manitoba

Summary

Agriculture makes up approximately 14% of Manitoba's land area, with the major crops being canola and wheat. The largest grossing outputs in Manitoba are hogs, followed by cattle and calves (Table 24.4-1). Since 1981, the livestock population in Manitoba, particularly hogs and cattle, has seen a large increase. The agri-environmental indicators show an improvement in soil cover, soil erosion (especially from tillage and water), soil carbon and risk of salinization. No change was seen in wildlife habitat availability, or soil contamination by trace elements between 1981–2006. Overall risk to water contamination by nitrogen, phosphorus, coliforms and pesticides is low, however since 1981 much of the agricultural land in Manitoba has shifted from very low risk to low and moderate risk, indicating that environmental performance may be declining under current practices. Air quality in Manitoba also shows a declining trend, with increases in greenhouse gas and ammonia emissions since 1981, largely due to the increased livestock population. Overall particulate matter emissions have declined due to improved cropping practices, however emissions from livestock operations have increased.

TABLE 24.4-1 Summary of agricultural statistics in Manitoba, 2006

Land Statistics (hectares (ha))	
Total area	64.8 million ha
Total land area	55.4 million ha
Total farm area	7.7 million ha
Cultivated land	63%
Pastureland	27%
Other land	10%
Average farm area	405 ha
Farm Characteristics	
Total # of farms	19,054
Total # of families	15,000
Total # of operators	26,625
Average age of operators	51
Major Agricultural Outputs	
Hogs	$829 million
Cattle & calves	$536 million
Canola	$384 million
Wheat	$274 million
Dairy	$189 million
Livestock Population (number of animals)	
Poultry	7.9 million
Cattle and calves	1.6 million
Pigs	2.9 million
Dairy cows	44,000
Farm Income	
Total net cash income	$0.5 billion
Total cash receipts	$3.7 billion
Total operating expenses	$3.2 billion
Distribution of farms by revenue class	
Less than $10,000	18%
$10,000 to $49,000	28%
$50,000 to $100,000	15%
More than $100,000	39%

Food and Beverage Industry	
Total # of establishments	146
Total value of shipments	$4 billion
Food Processing	$3.7 billion
Meat products	41%
Animal food products	16%
Grain and oilseed milling	9%
Other food	34%
Beverages	$297 million
International Trade Statistics	
Trade balance	$2.3 billion
Exports	
Total agricultural exports	$3.1 billion
Bulk	43%
Intermediate	33%
Consumer-oriented	24%
Major export markets	
United States	$1.6 billion
Japan	$435 million
Mexico	$195 million
China	$67 million
Indonesia	$60 million
Imports	
Total agricultural imports	$764 million
Bulk	14%
Intermediate	26%
Consumer-oriented	60%

Farm Land Management

AGRICULTURAL LAND USE (Chapter 4)

At 7.7 million hectares in 2006, the area of farmland in Manitoba varied little over the 25 year period (Figure 24.4-1). Cropland increased by 3% of farmland and all other land increased by 6% of farmland (Table 4-1). As throughout the west, summerfallow declined, but unlike Alberta and Saskatchewan, pasture also declined. Producers diversified their cropping practices, reducing cereal area and increasing oilseeds and pulses (Table 4-2). An increase in forage crops more than compensated for the decrease in pasture and supported a modest growth in cattle production. The use of conventional tillage practices on cropped land decreased from 1991 to 2006, while conservation tillage and no-till increased (Table 4-3). Summerfallow management showed a trend toward less tillage similar to Alberta and Saskatchewan, with tillage-only declining and chemical-only increasing, but unlike further west, tillage-plus-chemical weed control increased (Table 4-3). The most significant livestock change in Manitoba was a large increase in pig numbers between 1981 and 2006. The populations of other livestock (sheep and goats, cattle, poultry and horses also increased (Table 4-4).

Area of agricultural land as percentage of SLC polygon area

0–20	>20–40	>40–60	>60–80	>80–100	not assessed

FIGURE 24.4-1 Proportion of agricultural land in Manitoba, 2006.

FARM ENVIRONMENTAL MANAGEMENT (Chapter 5)

In 2006, 15% of producers in Manitoba had completed Environmental Farm Plans (EFP) and another 16% had EFPs under development (Statistics Canada, 2007). The EFP program was relatively new in the prairies, which explains the low adoption rate in 2006, however producers in Manitoba were still implementing beneficial management practices (BMPs) on their operations to reduce environmental risk. 76% of producers reduced the amount of fertilizer they apply to offset nutrient inputs by manure. 44% of producers who apply liquid manure inject it directly into the soil, and another 37% broadcast and incorporate into the soil. Some improvements can be made however, with only 36% of producers who store liquid manure covering it, and only 15% of producers with grazing livestock limiting access to surface water. 63% of grazing livestock have unlimited seasonal access to surface water, and 18% have unlimited year-round access to surface water.

SOIL COVER (Chapter 6)

Soil cover in Manitoba increased by 9% from 1981 to 297 SCD in 2006 (Table 6-1). The southwestern portion of the province showed an increase of 11%, the Red River valley region 5% and the Interlake area 7%. Soil cover in the province increased as a result of a reduction in summerfallow area, an increase in perennial crop acreage and an increase in the proportion of cropland and summerfallow under reduced and no-till. Decreases in the area of higher-residue crops such as cereal grains and increases in lower-residue crops such as oilseeds, potatoes and pulse crops had a negative effect on soil cover between 1981 and 2006. The distribution of farmland by soil cover class in Manitoba was very similar to that in Alberta and Saskatchewan, with no land in the very high or very low classes. However, the majority of farmland (60%) was in the high class in 2006 (Table 6-2). All of the land in the low soil cover class occurs in the southern portion of the province, where oilseeds and pulses are dominant and hay and pasture are relatively scarce. It is also estimated that 25% of crop residue is removed by baling and burning in this area.

WILDLIFE HABITAT (Chapter 7)

In 2006, habitat capacity for breeding and feeding (HC_{bf}) on the majority of agricultural land was in the low (45%) and very low (41%) categories with the remaining 14% moderate (Table 7-1). From 1986 to 2006, average provincial HC_{bf} was constant as no change was reported from 82% of farmland (Table 7-2).

Provincial wildlife HC_{bf} follows the general trend for the Prairies with the most valuable wildlife habitat cover types showing only slight shifts in their share of farmland. At the provincial scale, all other land and unimproved pasture make up 11 and 20% of farmland, respectively. This relatively low share of natural and semi-natural land cover in the agricultural landscape was the main reason for the majority of farmland having low or very low

HC$_{bf}$. Potentially beneficial shifts in crop cover included reductions in cereals and summerfallow and increases in tame hay while increases in oilseed, corn and soybean production lowered HC$_{bf}$.

In 2006, provincial habitat capacity for wintering (HC$_w$) was low with the majority of land falling into the low (49%) and very low (29%) categories (Table 7-3). The low HC$_w$ resulted from a relatively small share of natural and semi-natural land and unimproved pasture.

Soil Health

SOIL EROSION (Chapter 8)

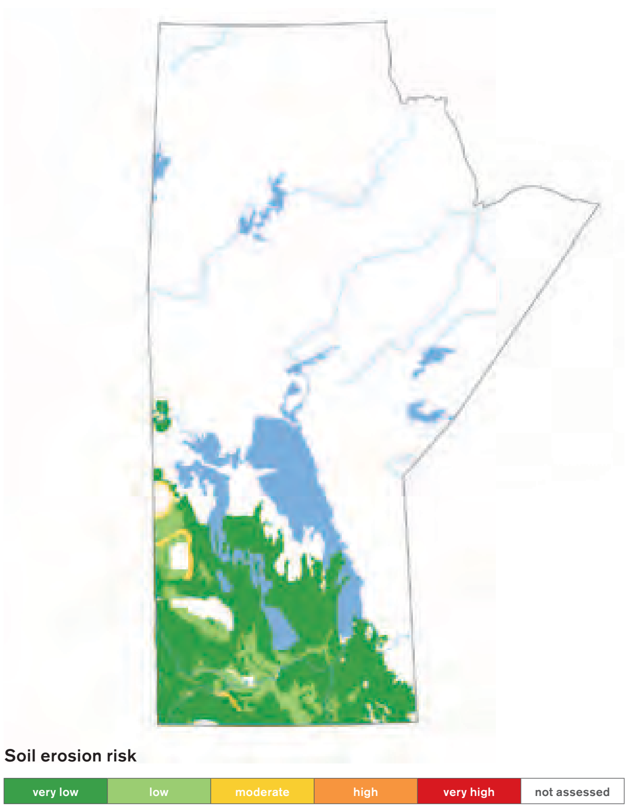


FIGURE 24.4-2 Risk of Soil Erosion on cultivated land in Manitoba under 2006 management practices.

Manitoba had reduced risk of soil erosion between 1981 and 2006, changing from 52% to 79% in the very low risk class (Figure 24.4-2, Table 8-1). Although Manitoba had relatively high risk of wind erosion on cultivated sandy soils (over half the land with moderate to very high wind erosion risk have loamy sand or sand surface textures), it has the lowest risk of water and tillage erosion of the three Prairie Provinces. For tillage erosion there was increased cropland in the very low risk class, going from 92% in 1981 to 98% in 2006 (Table 8-4). While this was a modest improvement, much of the cropland in this province (70%) is classified as having very low landscape erodibility and therefore the risk of tillage erosion is low on this land even with intensive tillage. Owing to climate and topography, water erosion risk is generally not a major concern in Manitoba, with 98 to 99% of land with very low water erosion risk (Table 8-2). However, water erosion risk is important on longer, steeper slopes such as cultivated soil on the Manitoba Escarpment. The decrease in soil erosion is attributable in part to the reduction in land under summerfallow and increased adoption of direct-seeding.

SOIL ORGANIC MATTER (Chapter 9)

Manitoba is unique among provinces in that it has had primarily increasing SOC continually from 1981 to 2006 (Table 9-2). Soil organic carbon increased on 83% of agricultural land in 2006, which compares to increasing SOC for 69% of agricultural land in 1981 (Figure 24.4-3, Table 9-1). The relative organic carbon in Manitoba is high compared to other Prairie Provinces (Table 9-2), which likely reflects the historical predominance of grain-livestock farms, relatively productive climate and limited summerfallow. The cumulative SOC increase can be related both to summerfallow and tillage reduction as well as annual to perennial crop conversion (Figure 9-2 and 9-3). Increases in SOC have been greatest for western Manitoba. SOC and ROC indicate improving soil health in Manitoba, with much of the farmland with high to very high ROC and, of this, 85% with increasing SOC in 2006 (Table 9-4).

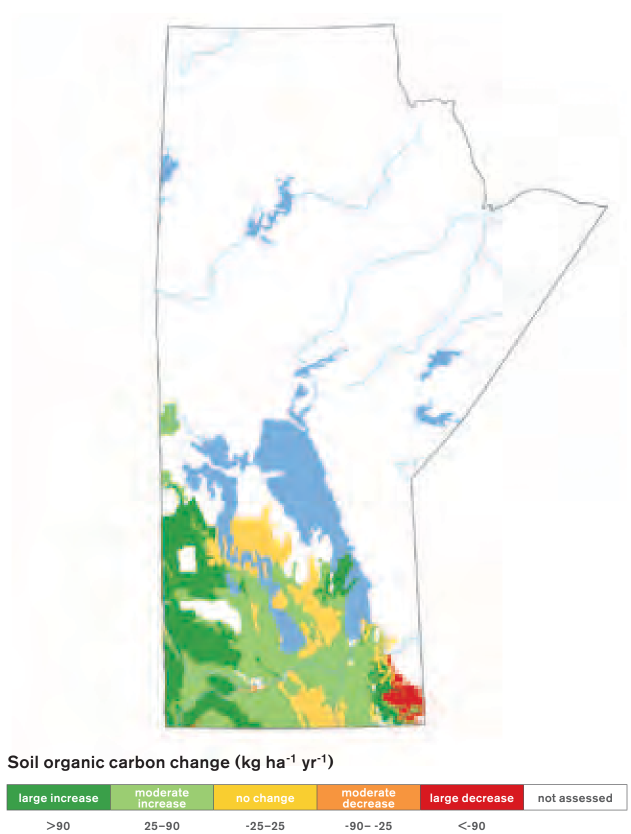


FIGURE 24.4-3 Indicator of soil organic carbon change (kg $ha^{-1}yr^{-1}$) for Manitoba, 2006.

TRACE ELEMENTS (Chapter 10)

The share of land in the various risk classes in Manitoba did not change from 1981 to 2006. The high risk class accounted for 23% of agricultural land, while only about 2% of Manitoba's agricultural land could be in the very high risk class in 100 years if 2006 management practices continue (Table 10-1). The very high risk areas (Figure 10-2) are associated with crop production on sandy soils and the area around Winnipeg because of the urban center and animal production.

The large majority of land (82%) is expected to have TE increases of less than 30% above background levels (Table 10-2). Most of the remaining land (17%) is expected to have TE increases of less than 50% above background levels.

SOIL SALINITY (Chapter 11)

Land at moderate to very high risk of salinization has shown a large decline (from 19% to 10% of the area) between 1981 and 2006 (Table 11-1) with most of the increase in land area in the very low risk class. The decrease in risk of soil salinization was mainly due to a reduction in summerfallow. Increased permanent cover or a combination of reduced summerfallow and increased permanent cover also contributed to a reduced risk in particular areas.

Of the SLC polygons that changed risk class between 1981 and 2006, the majority improved by one risk class and several improved by two risk classes, while a few showed a one-class increase in risk (Figure 11-3).

Water Quality

NITROGEN (Chapter 12)

12.1 Residual Soil Nitrogen (RSN)
Manitoba was predominately in a moderate RSN class in the central regions of the province, and in a high RSN class in many southern agricultural regions (Figure 12.1-2). There were also some noticeable hot spots in Manitoba that were in the very high RSN class. In 2006 only 14% of the land in Manitoba was in the very low and low RSN classes, a dramatic decrease from 1981 when 97% was in these classes (Table 12.1-1). There was a 39% and 40% increase in the amount of land in the moderate and high RSN categories, respectively, in Manitoba between 1981 and 2006, reflecting an almost doubling of the rate of N input over this period.

The RSN increased steadily from 1981 to 2001 and then decreased by 2006 (Table 12.1-2). The N inputs in Manitoba increased from 45.3 kg N ha^{-1} in 1981 to 83.1 kg N ha^{-1} in 2006, with 56% of this increase due to increased fertilizer application and 34% of this increase due to increased fixation by legume crops. The decrease in RSN from 2001 to 2006 was primarily due to increased yields and N outputs (from 46.8 to 55.3 kg N ha^{-1}) as N inputs were fairly similar between 2001 and 2006.

12.2 Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N)
With the exception of 2001 and 2006, all farmland in Manitoba was in the very low and low risk classes (Figure 24.4-4). However, there was a considerable shift from farmland in the very low risk class to the low risk class. For example, while in 1981 98% of the land fell into the very low class, in 2006 only 36% was in this class, whereas the low risk class increased from 2% in 1981 to 64% in 2006 (Table 12.2-2).

Manitoba received on average over the five census years 67 mm more over-winter precipitation than Alberta and Saskatchewan (Table 12.2-3), which resulted in increased cumulative over-winter drainage (7 mm) and higher spring soil water contents (306 mm). Consequently the N_{lost} estimates in Manitoba were higher than in the other two Prairie Provinces, but still among the lowest in Canada (Figure 12.2-4). Nevertheless, in 2001 and 2006 the estimated Manitoba N_{conc} values of 10.4 and 11.6 mg N L^{-1} respectively, slightly exceeded the Canadian drinking water guideline of 10 mg NO_3-N L^{-1} (Figure 12.2-5). A 1992–1993 survey in southern Manitoba found elevated levels of nitrate in the subsoil of fields that were heavily fertilized and/or manured (Henry and Meneley, 1993).

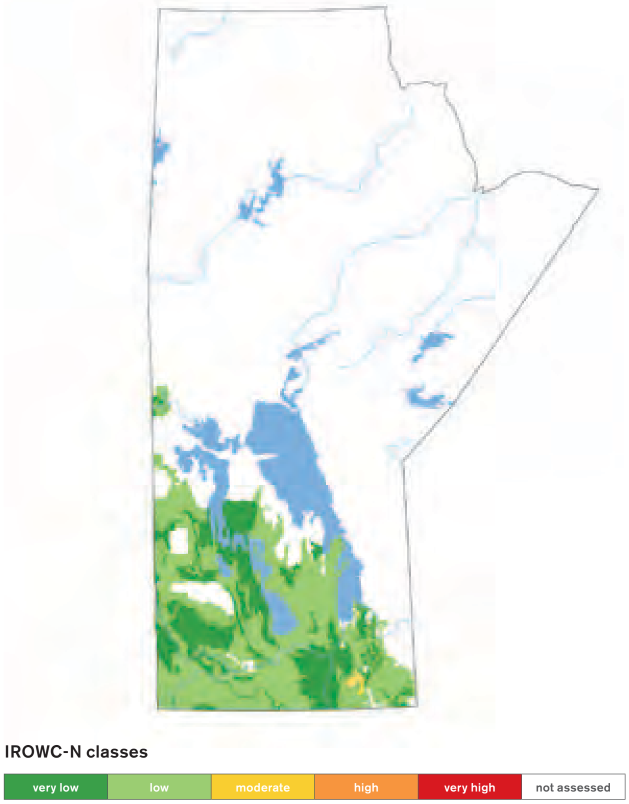
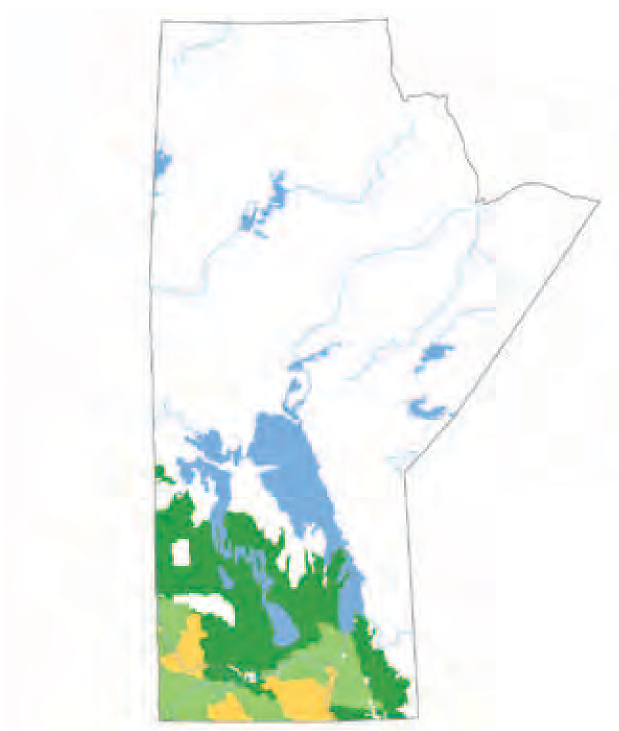


FIGURE 24.4-4 Risk of water contamination by nitrogen in Manitoba under 2006 management practices.

PHOSPHORUS (Chapter 13)

Indicator of the Risk of Water Contamination by Phosphorus (IROWC-P)

In 2006, four of the thirty agricultural watersheds in Manitoba were at moderate risk, and the rest were classified as very low to low risk (Figure 24.4-5). However, from 1981 to 2006 13 watersheds moved to a higher risk class (Figure 13-2). IROWC-P moderate risk classes are in the Central Assiniboine, Upper Pembina, Upper Red and Morris watersheds. In 2006, 3% of the farmland was in the moderate P-source class (Table 13-2). Since 1981, swine and cattle populations have increased, which explains the general rise in P inputs on agricultural land in the province. This augmented livestock population created more manure-P than was exported in harvested crops, thus increasing the soil P balance (Figure 13-4 and 13-8). This situation particularly affected the Red River and the Assiniboine River basins. Mineral P fertilizers contributed to only 9% of the increase in P inputs while manure P contributed the remainder (Figure 13-8).



IROWC-P classes

very low	low	moderate	high	very high	not assessed

FIGURE 24.4-5 Risk of water contamination by phosphorus in agricultural watersheds in Manitoba under 2006 management practices.

COLIFORMS (Chapter 14)

INDICATOR OF THE RISK OF WATER CONTAMINATION BY COLIFORMS (IROWC-Coliform)

The IROWC-Coliform assessment in Manitoba watersheds showed very low to low risk values in 2006 (Figure 14-2) and this has been relatively stable since 1981. Only during the relatively wet year of 1996, did the Central Souris-Antler watershed (9% of farmland) show an IROWC-Coliform moderate risk value. Nevertheless, the coliform source value has increased significantly across the province during the past 25 years and the increase was especially important in the Seine River region situated south of Winnipeg (Figure 14-7). Overall, cattle, swine and poultry population densities increased by 38%, 227% and 23%, respectively.

PESTICIDES (Chapter 15)

INDICATOR OF THE RISK OF WATER CONTAMINATION BY PESTICIDES (IROWC-Pest)

Although 73% of the cropland was at a very low risk of water contamination by pesticides in 1981, less than 6% was at very low risk from 1986 to 2006, with a corresponding increase in the percentage of land in the low and moderate classes. There was a notable increase in the risk of water contamination in 2001, where 35% of cropland was in the high and very high risk classes of water contamination (Table 15-2). However, by 2006 the risk decreased with only 1% of farmland in the high and very high risk classes. The increase in risk after 1981 is driven by a greater proportion of agricultural land receiving higher rates of pesticides (Table 15-4).

Air Quality and Greenhouse Gases

GREENHOUSE GASES (Chapter 16)

In Manitoba, net GHG emissions have increased more rapidly than in any other province, growing by 59% between 1981 and 2006 from 3.0 to 4.8 Mt CO_2e (Figure 24.4-6, Table 16-1). This is largely the result of a more than doubling in the swine population and a 54% increase in the beef cattle population. As a result, CH_4 emissions have increased by 67% to 2.8 Mt CO_2e. Nitrogen fertilizer use has also increased due to a general increase in the rate of nitrogen fertilizer application for wheat crops and an increase in area of canola. The increase in fertilizer use has significantly contributed to the 55% increase in N_2O emissions to 3.8 Mt CO_2e. As in other parts of the Prairie Provinces, the adoption of BMPs has led to an increase in soil carbon sequestration, which has increased by 70% from a sink of 1.0 to a sink of 1.7 Mt CO_2e.

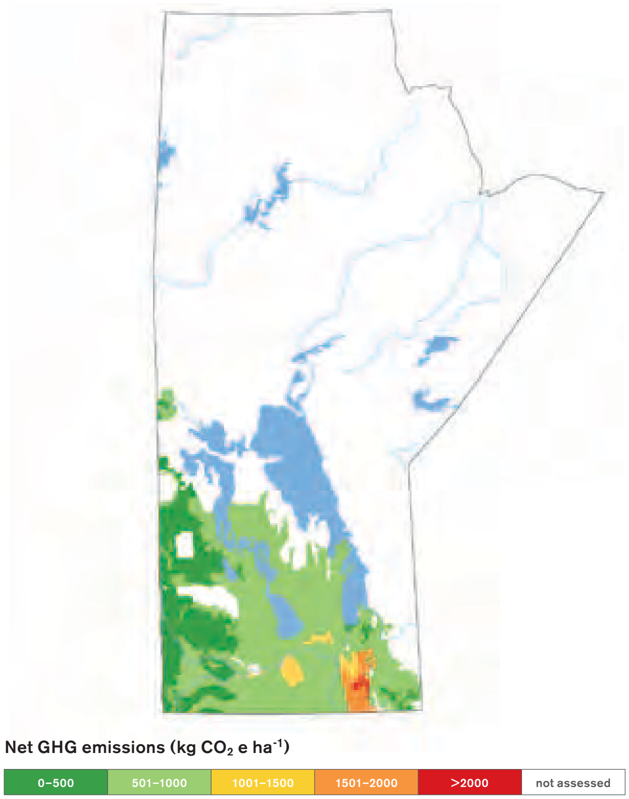


FIGURE 24.4-6 Agricultural net greenhouse gas emissions for Manitoba, 2006.

AMMONIA (Chapter 17)

Manitoba is responsible for 11% of national agricultural NH_3 emissions. The beef sector contributes the most emissions at 44% of the province's total, followed by emissions from fertilizer and swine at 26 and 22% respectively (Table 17-2). Of all the provinces, Manitoba had the largest increase (8.7%) in emissions between 2001 and 2006 due to increased livestock numbers. The share of land in the high and very high classes combined increased from 46% in 2001 to 58% in 2006 (Figure 24.4-7, Table 17-1).

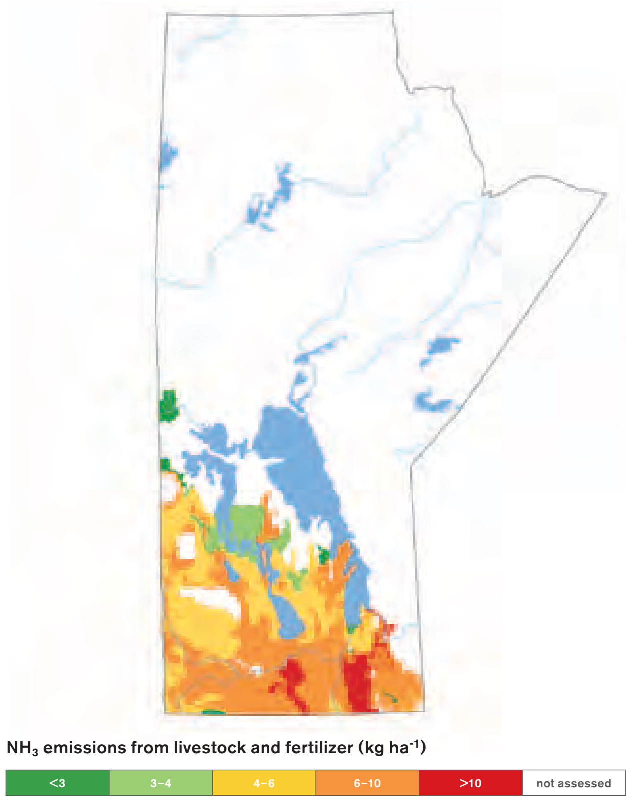


FIGURE 24.4-7 Total ammonia emissions per hectare of agricultural land in Manitoba in 2006 from major livestock sectors and fertilizer.

PARTICULATE MATTER (Chapter 18)

This province provides the lowest contribution of agricultural PM emissions of the Prairie Provinces because of its smaller cultivated area and more humid conditions that make it less prone to wind erosion. Between 1981 and 2006 PM emissions from Manitoba decreased 43% for TSP, 36% for PM_{10} and 40% for $PM_{2.5}$ (Table 18-1). The decreased trend is the result of the adoption of reduced tillage and decreasing summerfallow. Although the net PM emissions decreased, there was a 65% (1.4 kt TSP) increase in PM emissions from animal feeding operations over the same time period.

24.5 Ontario

Summary

Agriculture makes up only 6% of Ontario's land area, 68% of which is cultivated land, 14% of which is pasture, and almost all of which is found in southern Ontario (Table 24.5-1). The province's highest grossing agricultural outputs are dairy, floriculture and nursery, and cattle and calves. Ontario's agri-environmental performance shows improvements from 1981 to 2006 in soil cover and risk of soil erosion, as well as a reduction of net greenhouse gas and particulate matter emissions. A small reduction in the risk of water contamination by coliforms was also seen. Little or no change was seen in the risk of soil contamination by trace elements or the risk of water contamination by phosphorus during this time. Between 1981 and 2006 agricultural land use intensified, however conventional tillage was reduced and conservation tillage increased, which was positive. Despite the improvements, soil carbon and wildlife habitat capacity decreased, risk of water contamination by nitrogen and pesticides increased, and there was an increase in agricultural ammonia emissions.

TABLE 24.5-1 Summary of agricultural statistics in Ontario, 2006

Land Statistics (hectares (ha))	
Total area	107.6 million ha
Total land area	91.8 million ha
Total farm area	5.4 million ha
Cultivated land	68%
Pastureland	14%
Other land	18%
Average farm area	94 ha
Farm Characteristics	
Total # of farms	57,211
Total # of families	46,000
Total # of operators	82,410
Average age of operators	53
Major Agricultural Outputs	
Dairy	$1.6 billion
Floriculture & nursery	$987 million
Cattle & calves	$924 million
Poultry & eggs	$856 million
Hogs	$847 million
Livestock Population (number of animals)	
Poultry	44.1 million
Cattle and calves	2.0 million
Pigs	3.9 million
Dairy cows	330,000
Farm Income	
Total net cash income	$1.2 billion
Total cash receipts	$8.9 billion
Total operating expenses	$7.7 billion
Distribution of farms by revenue class	
Less than $10,000	25%
$10,000 to $49,000	32%
$50,000 to $100,000	11%
More than $100,000	32%
Food and Beverage Industry	
Total # of establishments	1091
Total value of shipments	N/A
Food Processing	$27.4 billion
Meat products	22%
Dairy products	20%
Bakeries & tortilla products	14%
Fruits & vegetables	11%
Other food	34%
Beverages	N/A
International Trade Statistics	
Trade balance	$-4.3 billion
Exports	
Total agricultural exports	$8.5 billion
Bulk	7%
Intermediate	19%
Consumer-oriented	74%
Major export markets	
United States	$6.8 billion
Hong Kong	$245 million
Japan	$171 million
Mexico	$162 million
Netherlands	$100 million
Imports	
Total agricultural imports	$12.8 billion
Bulk	9%
Intermediate	14%
Consumer-oriented	77%

Farm Land Management

AGRICULTURAL LAND USE (Chapter 4)

Ontario's farmland area declined by 0.7 million hectares between 1981 and 2006 (Figure 24.5-1). Agricultural production was intensified on the remaining farmland as cropland area increased its share of farmland while the share of land in pasture decreased during this period (Table 4-1, Figure 4-1). All other land increased by 3% of farmland, while summerfallow all but disappeared. Cropping practices in Ontario changed, as decreases in the share of cropland in cereal grains, corn, and other crops were replaced by an increase in pulse crops (mainly soybeans) (Table 4-2). The use of conventional tillage on cropped land decreased from 1991 to 2006, while conservation tillage and no-till increased (Table 4-3). There was a shift out of the cattle industry in Ontario as numbers declined between 1981 and 2006. The numbers of other livestock types increased (Table 4-4).

FIGURE 24.5-1 Proportion of agricultural land in Ontario, 2006.

FARM ENVIRONMENTAL MANAGEMENT (Chapter 5)

Thirty five percent of Ontario producers had a completed Environmental Farm Plan (EFP) in 2006 and another 6% had EFPs under development (Statistics Canada, 2007). Although this is less than half the producers in Ontario, in 2006 many were implementing beneficial management practices (BMP) on their operations. 63% of producers that spread solid manure in Ontario broadcast and incorporate it, 19% of those incorporate it the same day and 45% incorporate in 1-2 days. 57% of producers that spread liquid or semi-solid manure broadcast and incorporate it, and 8% inject it directly into the soil. Ontario producers soil test 7% of the cropland every year and approximately 60% of the total cropland every 2-3 years. To protect water quality, 41% of producers establish a riparian buffer along waterways, and 13% establish them around permanent wetlands.

SOIL COVER (Chapter 6)

Average soil cover in Ontario increased 6% between 1981 and 2006 with the largest improvement occurring between 1991 and 1996 (Table 6-1). The greatest rate of change between 1981 and 2006 (11%) occurred in southwestern Ontario, while the central portion of the province increased by 5%, and the eastern portion by 3%. The only significant crop change that had a positive effect on soil cover in Ontario was a decline in corn for silage, while increased areas in oilseeds, soybeans, and nursery crops, and declines in the area of cereal grains, perennial crops and grain corn all had a downward influence on soil cover. However, the increased adoption of reduced tillage and no-till on cropland produced a positive trend in the indicator. In 2006 Ontario had only 5% of farmland in the in very high soil cover class and only 2% in the very low class, while 45% was in the moderate soil cover class (Table 6-2). The very low and low soil cover areas are primarily in southwestern Ontario and the Niagara region, where pulse crops, field vegetables and nursery crops are common and perennial crops are less prevalent.

WILDLIFE HABITAT (Chapter 7)

In 2006, habitat capacity for breeding and feeding (HC_{bf}) on the majority of agricultural land was low (45%) and very low (46%) (Table 7-1). Between 1986 and 2006, HC_{bf} remained constant on 37% of agricultural land, decreased on 51% and increased on 12% (Table 7-2). The net result of these changes was a major reduction in wildlife habitat capacity as the share of land having moderate HC_{bf} declined from 18 to 9%.

Significant decreases to HC_{bf} in Ontario are attributed to declines in the agricultural land occupied by high habitat value cover types of all other lands, unimproved pasture and improved pasture. The share of land under corn and soybean production represents a major proportion of the landscape under intensive agricultural production with low habitat value. This trend towards intensification and the corresponding decreases in natural and semi-natural land cover was the main driver behind HC_{bf} decline. In many regions of southern Ontario, agriculture was the dominant land use. Pressure on wildlife is greatest in agricultural areas with declining all other lands and unimproved pasture.

In 2006, provincial habitat capacity for wintering (HC_w) was moderate with the majority of farmland falling into the moderate (52%) and low (38%) categories (Table 7-3). The moderate HC_w was provided by the two most valuable wintering habitats, all other lands and unimproved pasture.

Soil Health

SOIL EROSION (Chapter 8)

Ontario had reduced risk of soil erosion with 18% of cropland in the very low risk class in 1981 and 29% in 2006 (Figure 24.5-2, Table 8-1). However this province has the highest percentage of cropland in the high and very high classes of soil erosion risk in Canada. During the 1981 to 2006 period, the area with moderate erosion risk remained relatively stable, that with high erosion risk increased from 13 to 24% and that with very high erosion risk decreased from 33% to 17%. Among provinces, Ontario has the second greatest proportions of cropland in the unsustainable risk classes (57% in 2006). This can be explained by the high proportion of intensively tilled row crops (e.g., corn and soybeans) grown here. Although the area of these crops increased, the intensity of tillage used to grow them decreased as conservation tillage practices were implemented, causing important decreases in soil erosion risk overall. Water erosion is the greatest contributor to overall risk. The amount of land with very high water erosion risk dropped from 32% in 1981 to 17% in 2006 while that with very low water erosion risk increased from 21 to 32% (Table 8-2). Considerable changes occurred in the area of cropland in most of the tillage erosion risk classes. Cropland area in the high risk class and the low risk classes decreased while the moderate class increased slightly (Table 8-4). These improvements also produced an increase in very low tillage erosion risk class from 51% to 88%.

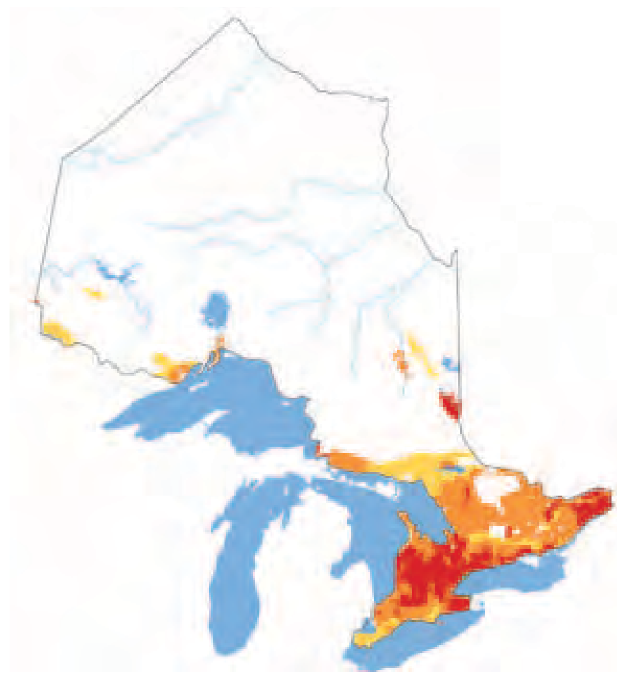
Soil erosion risk

very low	low	moderate	high	very high	not assessed

FIGURE 24.5-2 Risk of Soil Erosion on cultivated land in Ontario under 2006 management practices.

SOIL ORGANIC MATTER (Chapter 9)

Soil organic carbon has been decreasing on the majority of agricultural land in Ontario from 1981 to 2006. In 1981, 95% of land had decreasing SOC, which dropped to 82% of land by 2006 (Figure 24.5-3, Table 9-1). South western Ontario has generally low relative organic carbon (ROC), often very low, whereas the rest of agricultural land had moderate ROC (Figure 9-4 , Table 9-3). The low ROC likely reflects historically high rates of soil erosion, especially under row crops on sloping land. Southern Ontario shows some gain from reduction in tillage but this is more than compensated by the larger loss in SOC from perennial to annual crop conversions (Figure 9-2 and 9-3). The low ROC in south western Ontario combined with continuing SOC loss indicates an area where soil health is being compromised. In total 72% of Ontario farmland has low ROC and declining SOC and this province has the greatest indicated risk of soil health deterioration due to low SOC (Table 9-4).



Soil organic carbon change (kg ha^{-1} yr^{-1})

large increase	moderate increase	no change	moderate decrease	large decrease	not assessed
>90	25–90	-25–25	-90– -25	<-90	

FIGURE 24.5-3 Indicator of soil organic carbon change (kg $ha^{-1}yr^{-1}$) for Ontario, 2006.

TRACE ELEMENTS (Chapter 10)

The share of land in the various risk classes in Ontario did not change from 1981 to 2006. Three percent of Ontario's agricultural land could be in the very high risk class in 100 years if 2006 management practices continue (Table 10-1).

Sixty-seven percent of agricultural land in Ontario is expected to have an increase in TE of at least 30% above present background levels given 2006 populations, crop areas and practices (Table 10-2). Most of this area lies in the Windsor to Quebec corridor (Figure 10-3). From 1981–2006 there has been an increase in the numbers of people and livestock (Table 10-5) contributing to higher TE inputs.

Water Quality

NITROGEN (Chapter 12)

12.1 Residual Soil Nitrogen (RSN)
Central Ontario had a high RSN level in 2006; northern agricultural regions in Ontario were in a moderate RSN class, whereas some of the southern regions were in low and very low RSN classes (Figure 12.1-2). There was a slight improvement in RSN over the 1981 to 2006 period as areas shifted into lower risk classes (Table 12.1-1). However, improvement is evident compared with 2001 when the high and very high classes combined accounted for 97% of Ontario's farmland. This improvement in RSN was a result of increased N uptake in Ontario in 2006. The uptake was likely due to very high crop yields as a result of near optimal precipitation that year. This is compared to 2001 when yields were particularly low (Drury et al. 2007).

In 2006, the RSN levels in Ontario averaged 40 kg N ha^{-1}, reflecting high rates of N inputs (Table 12.1-2). There was no clear temporal pattern in RSN levels in Ontario over the six census years, 2001 being the year with the highest RSN levels as a result of increased N input and decreased N output. The amount of fertilizer and manure remained fairly constant over the 25-year period. In contrast, N fixation by legume crops increased by 62.7% from 1981 to 2006.

12.2 Indicator of Risk of Water Contamination by Nitrogen (IROWC-N)
A relatively small proportion (less than 25%) of Ontario farmland was in the very low and low risk classes between 1981 and 2006 (Figure 24.5-4, Table 12.2-2). During this 25-year period there was a slight increase in the overall risk of water contamination by N, with the share of land in the moderate risk class declining from 43% in 1981 to 34% in 2006 and the share in the high and very high classes increasing from 32% to 43%. Despite a considerably higher RSN estimate in 2001, the N_{lost} and N_{conc} estimates in 2001 (14.4 kg N ha^{-1} and 9.6 mg N L^{-1}, *respectively*) remained fairly close to the mean of the six census years, likely due to smaller amounts of drainage. The increased area in the moderate to very high risk class compared to the Prairie Provinces is the result of both higher RSN levels and more precipitation in the over-winter period (Table 12.2-3).

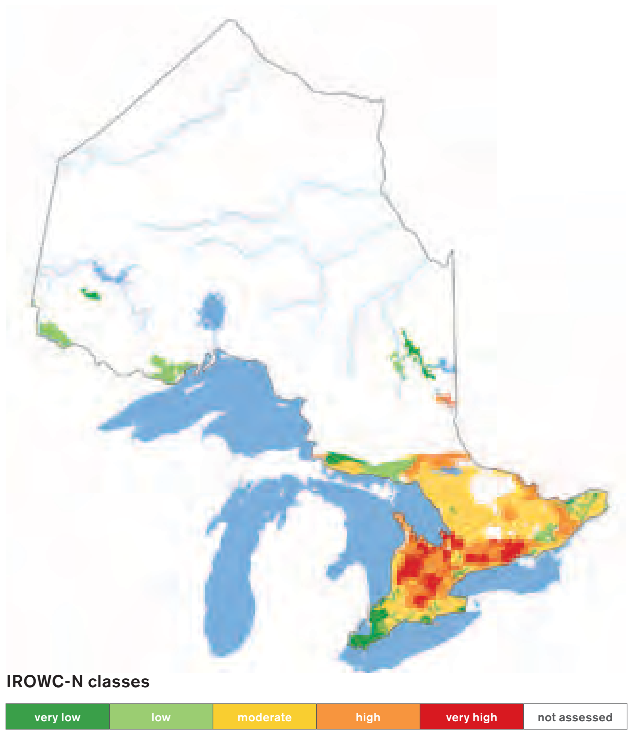


FIGURE 24.5-4 Risk of water contamination by nitrogen in Ontario under 2006 management practices.

PHOSPHORUS (Chapter 13)

Indicator of Risk of Water Contamination by Phosphorus (IROWC-P)
Ontario has only one watershed with a high IROWC-P value, located in the Niagara peninsula (Figure 24.5-5, 13-1). Four watersheds transferred to a higher risk class from 1981 to 2006 while another four bordering Lake Erie transferred to a lower risk class during the same period (Figure 13-2). Due to the long history of intensive agriculture in Ontario along with the use of repeated manure-P and mineral P fertilizers, higher soil P balance levels were found in 1981 and 1986 but trends showed a net decrease after 1991 with the exception of 2001 (Figure 13-4). The year 2001 was an exceptionally dry year where crop yields were seriously affected, reducing the crop uptake and export of P to less than expected, which likely explains the relatively high soil P-balance. These weather conditions contributed to soil P enrichment, especially in areas where animal densities are the greatest and where the soil textures are coarser. The animal density in Ontario has been slowly dropping over the last 25 years mainly due to the decline in the cattle sector. Fertilizer use showed an important 60% decrease, bringing the provincial soil P balance close to equilibrium. Thirty-five percent of the

farmland, mainly found in the southern part of the province, had slightly negative soil P balances in 2006.

IROWC-P classes

very low	low	moderate	high	very high	not assessed

FIGURE 24.5-5 Risk of water contamination by phosphorus in agricultural watersheds in Ontario under 2006 management practices.

COLIFORMS (Chapter 14)

Indicator of Risk of Water Contamination by Coliforms (IROWC-Coliform)

In 2006, 28% of farmland was in watersheds that had high to very high IROWC-Coliform risk (Table 14-1, Figure 14-2). The intensive agricultural area of Ontario including the Maitland, Upper Grand, Ausable, Saugeen, and Penetangorehas Rivers have historically been characterized by very high and high risk values (Figure 14-2, Figure 14-4). Although generally high throughout the past 25 years, there has been a slight decrease in the high coliform source from spread manure in this intensive agricultural area (Figure 14-6). The high soil erodibility enhanced the coliform transportation risk from upland to the surface water bodies. During the last 25-year period, the total area of pasture land, dairy cow and the cattle populations have declined as did the total agricultural area. In contrast, swine and poultry population densities increased. The timing between field manure application and surface runoff events has been a crucial determinant of risk, especially during spring and fall applications in Ontario.

PESTICIDES (Chapter 15)

Indicator of Risk of Water Contamination by Pesticides (IROWC-Pest)

The risk of water contamination by pesticides generally increased from 1981, when 86% of cropland was in the very low and low risk classes, and 2006 when 25% was in these classes (Table 15-2). This increase in risk was likely due to a greater proportion of agricultural land base receiving pesticides in 2006 than 1981 (Table 15-4). In 2006, the risk was highest in southwestern Ontario and lowest in the southeastern part of the province (Figure 15-2).

Air Quality and Greenhouse Gases

GREENHOUSE GASES (Chapter 16)

Net GHG emissions (kg CO_2 e ha^{-1})

0–500	501–1000	1001–1500	1501–2000	>2000	not assessed

FIGURE 24.5-6 Agricultural net greenhouse gas emissions for Ontario, 2006.

Ontario is the only province in eastern Canada with a declining net GHG budget. Net emissions declined by 10% from 1981 to 2006 (Figure 24.5-6, Table 16-1). CH_4 emissions declined from 5.4 to 4.8 Mt CO_2e while N_2O emissions declined from 5.7 Mt CO_2e during the 1980s and 1990s to a low of 4.9 Mt CO_2e before increasing again in 2006 to 5.8 Mt CO_2e. Soil CO_2 emissions have declined by 32% primarily because of an increase in the cropland under no-till. Emissions of CH_4 and N_2O have declined due to changes in animal populations and crop production. The dairy cow and beef cattle populations have declined while, over the same period, swine and poultry populations have increased slightly. In addition to declining cattle populations, nitrogen fertilizer use in Ontario has declined by 12% between 1981 and 2006. Nitrogen input from crop residue has increased in Ontario, more than offsetting decreases in nitrogen fertilizers and nitrogen in animal manure. The increase in crop residue nitrogen, despite a decrease in fertilizer nitrogen, is the result of a four fold increase in the area for soybean production. Soybeans fix nitrogen from the atmosphere and rarely require additional nitrogen fertilization.

AMMONIA (Chapter 17)

Ammonia emissions in Ontario account for approximately 18% of the national emissions from agriculture. The beef and dairy sectors combined are responsible for 54% of these emissions, followed by swine at 23% (Table 17-2). There was a small (1%) decrease in the amount of agricultural NH_3 emission in Ontario between 2001 and 2006 despite a small increase in the number of pigs. Although there was little change in the share of land in each emissions-intensity class, due to the concentration of agriculture in Ontario, 93% of farmland was estimated to be in the high and very high classes (Figure 24.5-7, Table 17-1).

PARTICULATE MATTER (Chapter 18)

Agricultural PM emissions from Ontario decreased between 1981 and 2006 by 36% for TSP, 28% for PM_{10} and 31% for $PM_{2.5}$ (Table 18-1). PM emissions from land preparation and wind erosion decreased 42% and 35% respectively, with little change for other agricultural operations. Reduction of PM emissions in this province resulted from a decrease in conventional tillage and the area of summerfallow.

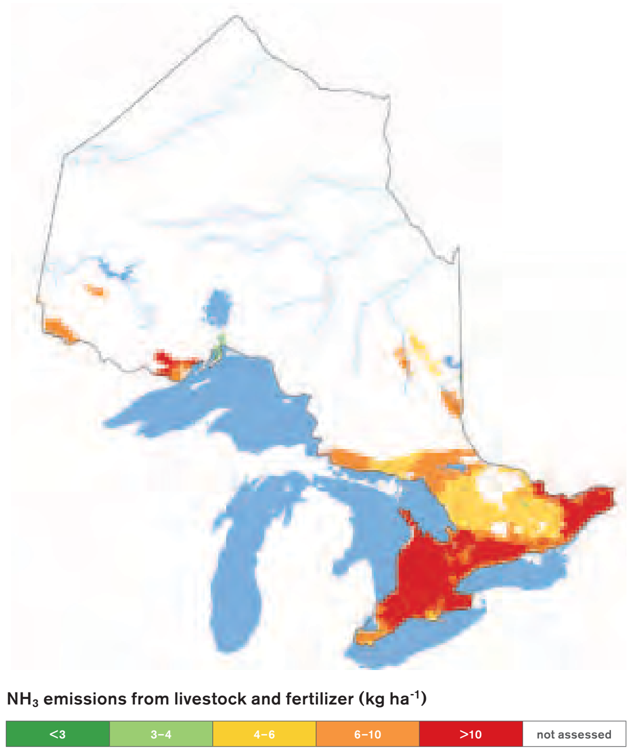


FIGURE 24.5-7 Total ammonia emissions per hectare of agricultural land in Ontario in 2006 from major livestock sectors and fertilizer.

24.6 Quebec

Summary

Agriculture makes up approximately 3% of Quebec's land area, over half of which is cultivated land, 9% is pasture, and 35% falls into the all other land category (Table 24.6-1). The highest grossing outputs in Quebec in 2006 were dairy and hogs, then poultry and eggs, cattle and calves, and corn. Quebec's agri-environmental performance showed improvement in soil cover between 1981 and 2006, and no change in contamination of soil by trace elements or risk of soil erosion. Over this time agricultural land use intensified and both soil carbon and wildlife habitat capacity decreased. Water quality was an issue in Quebec in 2006 with increased risk of water contamination by nitrogen, phosphorus, coliforms and pesticides. Greenhouse gas emissions, ammonia emissions and particulate matter emissions also increased over this 25 year period.

TABLE 24.6-1 Summary of agricultural statistics in Quebec, 2006

Land Statistics (hectares (ha))	
Total area	154.2 million ha
Total land area	136.5 million ha
Total farm area	3.5 million ha
Cultivated land	56%
Pastureland	9%
Other land	35%
Average farm area	113 ha
Farm Characteristics	
Total # of farms	30,675
Total # of families	22,000
Total # of operators	45,470
Average age of operators	49
Major Agricultural Outputs	
Dairy	$1.8 billion
Hogs	$849 million
Poultry & eggs	$573 million
Cattle & calves	$506 million
Corn	$281 million
Livestock Population (number of animals)	
Poultry	28.9 million
Cattle and calves	1.4 million
Pigs	4.3 million
Dairy cows	382,000
Farm Income	
Total net cash income	$1 billion
Total cash receipts	$6.2 billion
Total operating expenses	$5.2 billion
Distribution of farms by revenue class	
Less than $10,000	15%
$10,000 to $49,000	26%
$50,000 to $100,000	13%
More than $100,000	46%
Food and Beverage Industry	
Total # of establishments	795
Total value of shipments	N/A
Food Processing	$14.7 billion
Meat products	26%
Grain & oilseed milling	25%
Bakeries & tortilla products	11%
Animal food products	10%
Other food	28%
Beverages	N/A
INTERNATIONAL TRADE STATISTICS	
Trade balance	$53 million
Exports	
Total agricultural exports	$3.6 billion
Bulk	6%
Intermediate	11%
Consumer-oriented	83%
Major export markets	
United States	$2.2 billion
Japan	$395 million
Russia	$101 million
Korea, South	$96 million
Iran	$72 million
Imports	
Total agricultural imports	$3.6 billion
Bulk	20%
Intermediate	13%
Consumer-oriented	67%

Farm Land Management

AGRICULTURAL LAND USE (Chapter 4)

The total area of farmland in Quebec decreased from 3.8 million hectares in 1981 to 3.5 million hectares in 2006 (Figure 24.6-1), whereas the amount of cropped land, as a percentage of farmland, increased from 1981 to 2006 (Table 4-1, Figure 4-1). Pasture area declined to 9% of farmland over the 25-year period, and summerfallow effectively disappeared. The proportion of cropland in cereal grains and forages declined, whereas corn and soybean area increased as producers intensified production of higher valued crops. Other crops increased by 36,000 hectares (Table 4-2). The use of conventional tillage declined while conservation tillage and no-till increased between 1991 and 2006 (Table 4-3). Cattle numbers declined, while pig and poultry numbers increased. Sheep and goat numbers increased and the horse population in Quebec increased only marginally (Table 4-4).

FIGURE 24.6-1 Proportion of agricultural land in Quebec, 2006.

FARM ENVIRONMENTAL MANAGEMENT (Chapter 5)

Quebec producers had the highest rate of adoption of Environmental Farm Plans in Canada in 2006, with 73% having a completed environmental farm plan, and another 4% with plans under development (Statistics Canada, 2007). In Quebec, 57% of producers maintained a setback distance along waterways, but only 6% maintained a setback distance around permanent wetlands. 52% of producers applied fertilizer to land that has had manure spread on it, however almost all producers reduced the amount of fertilizer they applied to offset the nutrients added by manure. When spreading liquid manure, 46% applied it below the crop canopy and 16% broadcast and incorporated it. When storing liquid manure, 17% of producers covered the manure.

SOIL COVER (Chapter 6)

Average soil cover in Quebec was higher than in Ontario and the western provinces in all Census years studied, but the indicator has not shown the consistent upward trend of the other provinces. Average soil cover in Quebec has increased by 1% over the 25-year study period (Table 6-1). Regionally, only the St. Lawrence River valley showed an increase in soil cover (2%), while the Gaspé Peninsula remained constant and the more northern regions declined by about 1%. Land use changes which contributed to an improvement in soil cover in Quebec included a decline in silage corn area and an increase in grain corn. The increased area of soybeans, berries and nursery crops, a decline in perennial crops and a decrease in cereal grain area put downward pressure on soil cover days. As in almost all cases, improvements in soil cover came as a result of the adoption of reduced tillage and no-till, and in Quebec the proportion of cropland under these tillage practices increased between 1991 and 2006. In 2006, 66% of farmland was in the very high and high soil cover classes (Table 6-2). All of the land rated as low soil cover in Quebec occurs in the St Lawrence Lowlands, where annual crops are prevalent over perennial crops, soybeans are common and a high percentage of cereal straw is baled and removed from the field.

WILDLIFE HABITAT (Chapter 7)

In 2006, average provincial habitat capacity for breeding and feeding (HC_{bf}) was moderate with 35% of farmland in the moderate capacity class, 47% in very low and low classes, and 17% in the high and very high classes (Table 7-1). From 1986 to 2006, HC_{bf} decreased significantly on 51% of agricultural land (Table 7-2) and resulted in a deteriorating shift in the share of land from high to moderate and from moderate to low.

Intensification of agriculture was the primary driver of HC_{bf} decline in certain regions of Quebec as the share of farmland under intensive corn and soybean production expanded while unimproved pasture, improved pasture and all other land declined. Significant deforestation contributed to HC_{bf} decline in regions of Quebec where there was large-scale hog production as land was cleared to create a greater area to spread liquid manure. In these areas, the loss of all other land (woodland specifically) was the major driver associated with HC_{bf} decline.

In 2006, provincial habitat capacity for wintering (HC_w) was high with no agricultural land in the very low category and 56% of land in high and very high (Table 7-3). High HC_w resulted from the considerable all other lands component of farmland.

Soil Health

SOIL EROSION (Chapter 8)

Quebec had 72% of cropland area in the very low risk class in 2006 (Figure 24.6-2, Table 8-1). However, the risk of soil erosion has remained virtually unchanged since 1981. The risk of water erosion remains the most important contributor to overall erosion risk. Water erosion risk is low on the nearly level soils of the St. Lawrence Lowlands. Tillage erosion has remained relatively constant with 97 to 98% of cropland in the very low tillage erosion risk class (Table 8-4), despite the fact that tillage erosivity has increased due to increases in the area seeded to corn and soybeans. This increase in tillage erosivitiy has not resulted in increased tillage erosion because these crops are generally grown within the nearly level St. Lawrence Lowlands and because there has been a modest increase in conservation tillage.

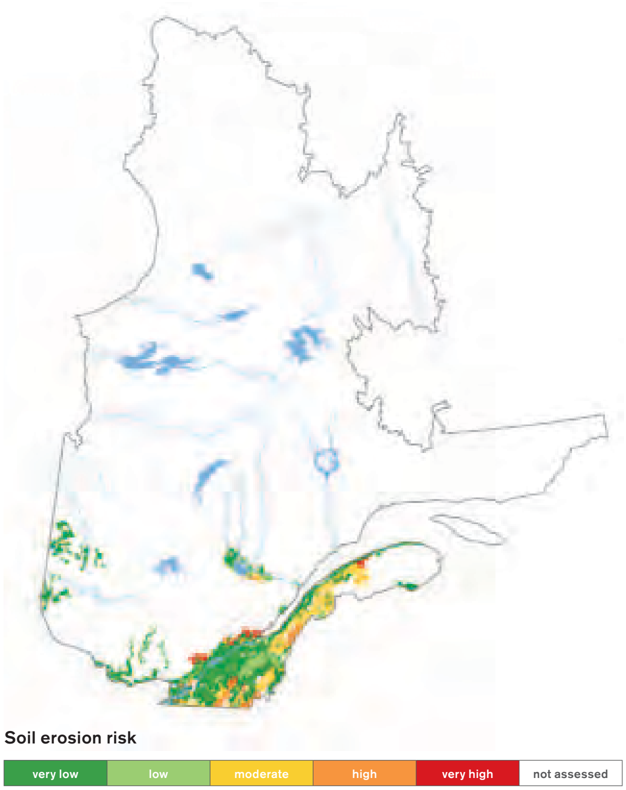


FIGURE 24.6-2 Risk of Soil Erosion on cultivated land in Quebec under 2006 management practices.

SOIL ORGANIC CARBON (Chapter 9)

The soil organic carbon (SOC) loss in Quebec intensified from an average rate of -69 kg ha^{-1} yr^{-1} in 1981 to -152 kg ha^{-1} yr^{-1} in 2006. SOC was decreasing on 98% of agricultural land in 2006 (Figure 24.6-3), which was an increase in proportion of land from 1981 when 86% of agricultural land had decreasing SOC (Table 9-1). In contrast to neighbouring provinces, Quebec has relatively high relative organic carbon (ROC) (average = 0.91) (Table 9-2). Very high ROC in much of south eastern Quebec (Figure 9-4) indicates areas where land has historically been managed with frequent forages and with regular manure applications. In these areas, the declining SOC is not an immediate concern with regard to soil health because the SOC is already high. Nevertheless, many of the soils in the St. Lawrence have a combination of very low or low ROC and declining SOC. Over the entire province, 30% of the land has low to very low ROC combined with decreasing SOC (Table 9-4). In these areas, declining SOC is a concern for soil health. Cumulative carbon change is dominated by losses from land use change (e.g. conversion of forest to agriculture) and perennial to annual crop conversions (Figure 9-2). Almost one-half (49%) of the farmland has high to very high ROC and declining SOC. These areas are not an immediate soil health concern but do represent large emissions of CO_2 into the atmosphere.

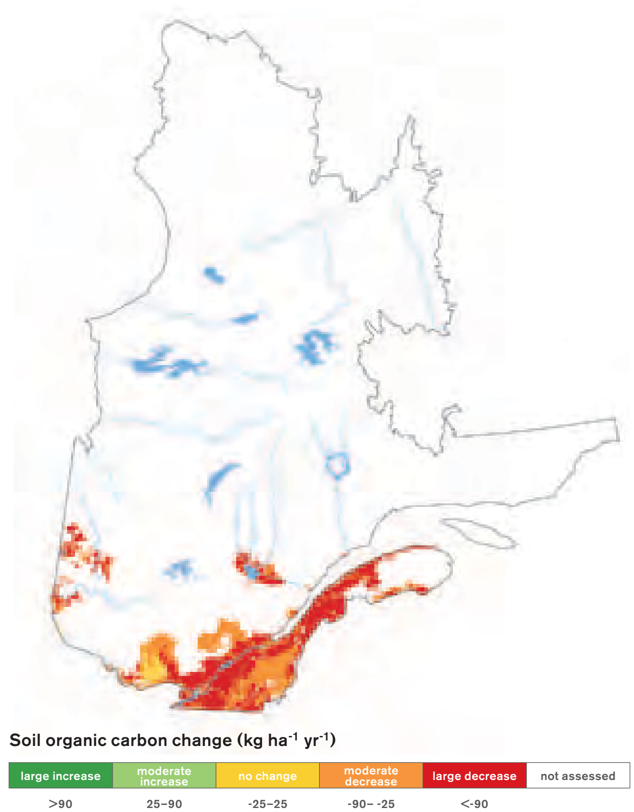


FIGURE 24.6-3 Indicator of soil organic carbon change (kg $ha^{-1}yr^{-1}$) for Quebec, 2006.

TRACE ELEMENTS (Chapter 10)

The share of land in the various risk classes in Quebec did not change appreciably from 1981 to 2006. Almost all of the agricultural land in Quebec was in the moderate risk class under both 1981 and 2006 management populations, crop areas and practices at 99% and 98% respectively (Table 10-1).

Soil trace element (TE) concentrations relative to background showed an increasing rate under 2006 practices as opposed to 1981 (Table 10-2). The area that is expected to have increases of 50% to 100% over background concentrations, largely in the Montreal to Quebec area (Figure 10-3), more than doubled from 10% in 1981 to 24% under 2006 management practices. Over this time period in Quebec there has been an increase in the numbers of people and livestock (Table 10-5) contributing to higher TE inputs.

Water Quality

NITROGEN (Chapter 12)

12.1 Residual Soil Nitrogen (RSN)

In 2006, 12% of farmland in Quebec was in the very low and low RSN classes, an increase from 1981. However there was a decrease in both the moderate and high RSN classes from 1981 to 2006, with a corresponding increase in the proportion of agricultural land in the very high RSN class over this period (Table 12.1-1).

The RSN levels in Quebec averaged 47 kg N ha^{-1}, which places the province in the very high class and reflects high rates of N inputs (Table 12.1-2). The RSN levels in Quebec gradually increased from 1981 to 2001, then decreased in 2006. The spike in RSN levels in 2001 was the result of a combination of increased N inputs and decreased N outputs, the latter caused by drought conditions. In Quebec, fertilizer N inputs increased from 23.6 kg N ha^{-1} in 1981 to 43.9 kg N ha^{-1} in 2001 and then decreased to 33.6 kg N ha^{-1} in 2006. Nitrogen fixation by legume crops also increased in Quebec, whereas manure N inputs remained fairly constant.

12.2 Indicator of Risk of Water Contamination by Nitrogen (IROWC-N)

The proportion of Quebec farmland area in the very low, low and moderate risk class decreased from 75% in 1981 to 35% in 2006, while the proportion in the two highest risk classes increased from 19 to 61% (Figure 24.6-4, Table 12.2-2). This was the result of higher RSN as N inputs from fertilizer use, manure production and fixation by leguminous crops rising faster than N outputs via crop removal. Over-winter precipitation and drainage in Quebec were high (averaging 558 mm and 202 mm, respectively) with relatively low variability. Therefore, the N_{lost} estimates increased steadily from 1981 to 2006 (Figure 12.2-4). The N_{conc} estimates increased from 1981 to 2001 period, and then decreased in 2006 (Figure 12.2-5).

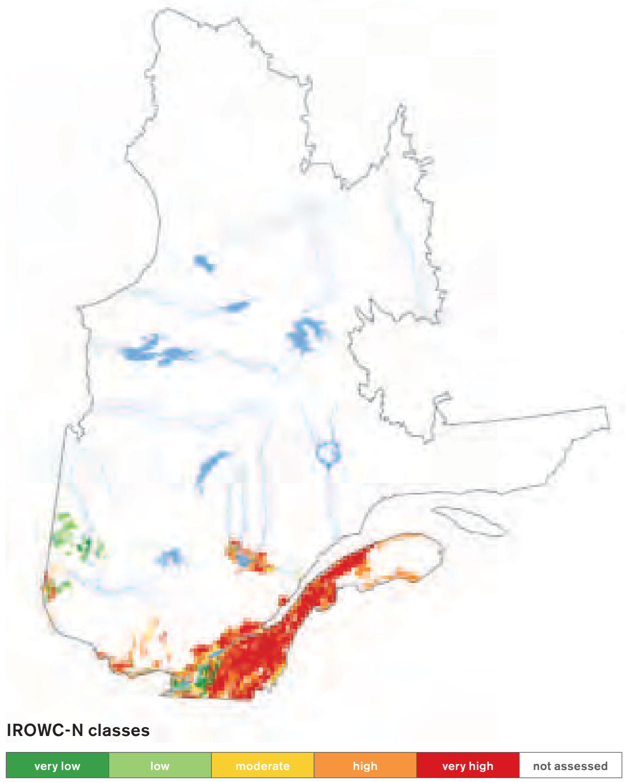


FIGURE 24.6-4 Risk of water contamination by nitrogen in Quebec under 2006 management practices.

PHOSPHORUS (Chapter 13)

Indicator of Risk of Water Contamination by Phosphorus (IROWC-P)

Moderate and high IROWC-P values were observed in watersheds of the St-Lawrence Lowlands, a region characterized by intensive agriculture, located between Montreal and Québec City (Figure 24.6-5). Five out of twenty-five watersheds were in moderate to high classes of risk, and 12 watersheds transferred to a higher risk class from 1981 to 2006 (Figure 13-2). Similar to the findings in Ontario, high P surpluses in 1981 through 1991 contributed to soil P enrichment in the St-Lawrence Valley, where 40% of farmland was in the high and very high classes of P-source in 2006 (Table 13-2). Soil P-balance showed a net decrease after 1991 (Figure 13-4) coinciding with the implementation of efficient fertilizing regulations and use of phytase in pig and poultry feeding. The introduction of mandatory nutrient management plans in Quebec helped decrease P inputs by reducing the amount of P fertilizer used by 40% over the last 10 years. Changes in feeding regimes, additions of enzymes to animal feed to reduce P in manure and an increase in areas seeded with high P uptake crops such as corn were implemented in the province in efforts to reduce the soil P levels. Nevertheless, 72 % of total P inputs still come from manure and areas with very high animal densities such as the Yamaska, Assomption and

Chaudière watersheds still had soil P balances greater than 10 kg P ha^{-1} in 2006.

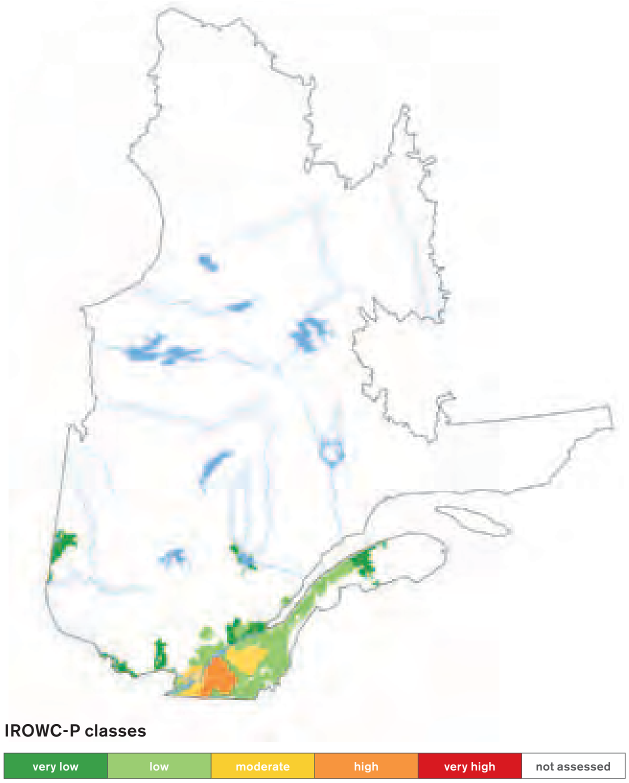


FIGURE 24.6-5 Risk of water contamination by phosphorus in agricultural watersheds in Quebec under 2006 management practices.

COLIFORMS (Chapter 14)

Indicator of Risk of Water Contamination by Coliforms (IROWC-Coliform)

The IROWC-Coliform assessment in Quebec watersheds gave mostly very low to low risk values in 2006 corresponding to 87% of farmland (Table 14-1, Figure 14-2) with the exception of two watersheds that showed a moderate risk: the Nicolet River watershed and the Bécancour River watershed. Nevertheless, during the past 25 years the coliform pressure has increased substantially over the province's farmland (Figure 14-7), mainly from spread manure coliforms (Figure 14-6). A considerable area of agricultural land within the Nicolet River and Bécancour River watersheds showed a shift of up to two or more higher classes of coliform source in 2006 (Figure 14-7). From 1981 to 2006 pasture land declined significantly (61%), the cattle population decreased and swine and poultry populations increased. In the same period, the total agricultural land decreased by 11%, resulting in the remaining agricultural land receiving more manure applications. Provincial regulations on manure spreading period and on animal access to surface water have partially limited the risk of coliforms reaching surface water. Manure spreading in spring has remained a key driver of risk because of the relatively large volume of manure applied during this time, and the wet soil conditions. The timing of storm events that trigger soil erosion occurrences combined with the increasing trend of manure applications was a key component of Quebec's increased risk. If the coliform pressure persists in the future, this timing can easily shift watersheds to higher IROWC-Coliform risk classes.

PESTICIDES (Chapter 15)

Indicator of Risk of Water Contamination by Pesticides (IROWC-Pest)

There was a general shift of land into higher risk classes between 1981 and 2006. In 1981, more than 99% of cropland was in the very low risk class (Table 15-2). By 2001, a significant shift to the low (40%), moderate (34%) and high (20%) risk classes had occurred. By 2006, the share in these higher risk classes had declined slightly. The shift to the moderate and high risk classes occurred mainly in the Eastern Townships and was likely due to the high proportion of fruits and vegetables grown there, which require several pesticide applications.

Air Quality and Greenhouse Gases

GREENHOUSE GASES (Chapter 16)

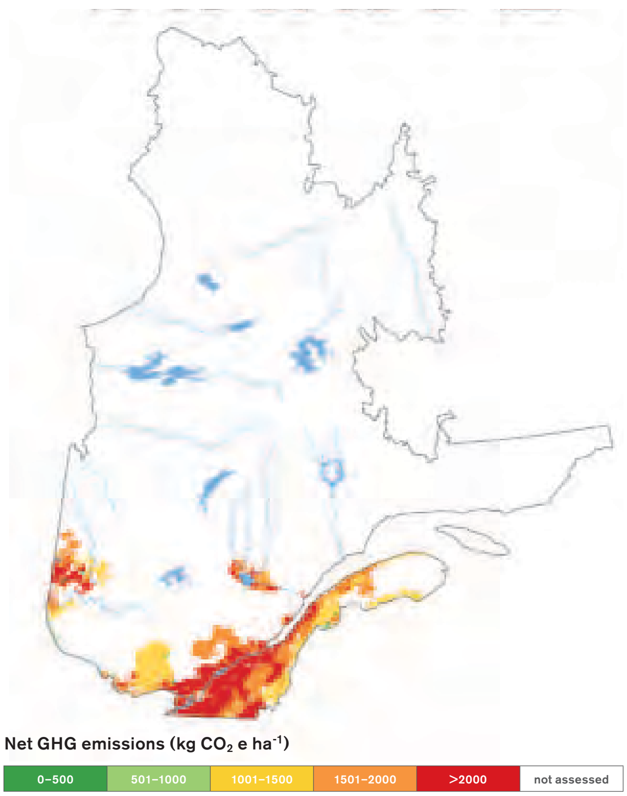


FIGURE 24.6-6 Agricultural net greenhouse gas emissions for Quebec, 2006.

Net GHG emissions in Québec have increased by 12% to 8.5 Mt CO_2e between 1981 and 2006 (Figure 24.6-6, Table 16-1). CH_4 emissions from Quebec were nearly unchanged between 1981 and 2006 at 3.7 Mt CO_2e, while N_2O emissions increased slightly from 3.2 to 3.4 Mt CO_2e. Reduced GHG emissions from the dairy herd in Quebec which declined between 1981 and 2006 were offset by increases in other animal populations and by an increase in nitrogen fertilizer use. CO_2 emissions in Quebec increased from 0.6 to 1.4 Mt CO_2 between 1981 and 2006, largely because of a 200,000-hectare decrease in the area of perennial crops, especially for soybean and corn production.

AMMONIA (Chapter 17)

Ammonia emissions in Quebec increased by 3% between 2001 and 2006 and represented approximately 15% of national agricultural emissions. Emissions from swine contributed the largest amount to provincial emissions (35%) followed by dairy (28%) and beef at 18% of provincial agricultural emissions (Table 17-2). As in Ontario, the concentration of agriculture led to 96% of the farmland in Quebec being in the high and very high emissions intensity classes (Figure 24.6-7, Table 17-1).

PARTICULATE MATTER (Chapter 18)

Quebec was the only province to experience an increase of PM emissions between 1981 and 2006. Agricultural PM emissions in this province increased by 18%, 12% and 16% for TSP, PM_{10} and $PM_{2.5}$, respectively (Table 18-1). PM emissions from land preparation and crop harvesting increased by 24% and 20%, respectively due to an increase in the area of grain corn. In addition, emissions from animal-feeding operations increased by 5% due to increases in animal population, particularly within the poultry and swine industries. However, a slight increase in conservation tillage and no-till practices and a drop in summerfallow area partially offset the PM increase caused by the increases of grain corn and animal production.

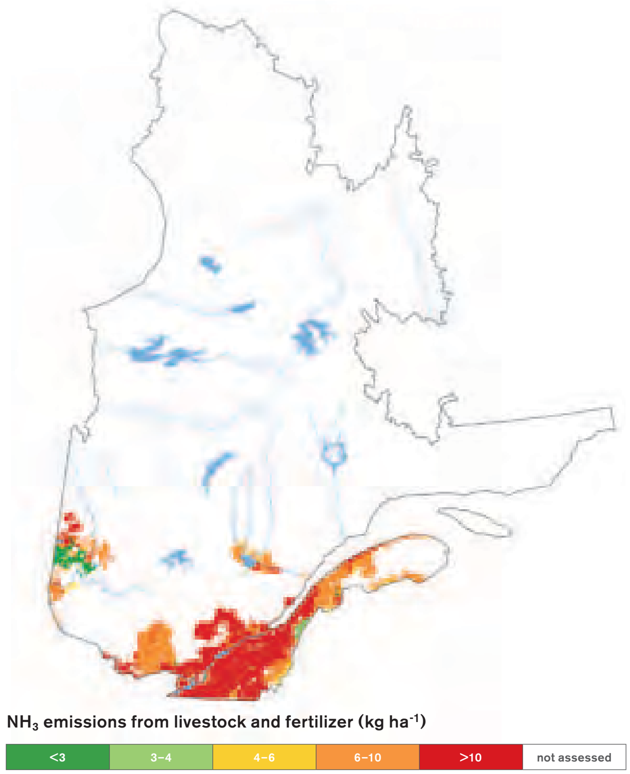


FIGURE 24.6-7 Total ammonia emissions per hectare of agricultural land in Quebec in 2006 from major livestock sectors and fertilizer.

24.7 New Brunswick

Summary

Agriculture makes up approximately 6% of New Brunswick's land area, 39% of which is cultivated and 11% of which is pasture (Table 24.7-1). The major agricultural outputs in New Brunswick include potatoes, dairy, poultry and eggs. New Brunswick showed an improvement in soil cover and particulate matter emissions in 2006, and a small reduction in ammonia emissions since 1981. There is little change in the risk of soil erosion, soil contamination by trace elements and the risk of water contamination by phosphorus. Wildlife habitat capacity on agricultural land in New Brunswick is high for wintering, however has deteriorated for breeding and feeding since 1981. Over this 25 year period land use intensity has increased as the area of cropland has risen and pasture has decreased. Soil carbon levels have also decreased during this time. The risk to water quality by nitrogen and pesticides has increased, largely due to the wet climate. Greenhouse gas emissions were calculated for the entire Atlantic region and have increased slightly from 1981 to 2006.

TABLE 24.7-1 Summary of agricultural statistics in New Brunswick, 2006

Land Statistics (hectares (ha))	
Total area	7.3 million ha
Total land area	7.1 million ha
Total farm area	396,000 ha
Cultivated land	39%
Pastureland	11%
Other land	50%
Average farm area	143 ha
Farm Characteristics	
Total # of farms	2,776
Total # of families	2,140
Total # of operators	3,695
Average age of operators	53
Major Agricultural Outputs	
Potatoes	$113 million
Dairy	$84 million
Poultry & eggs	$64 million
Floriculture & nursery	$50 million
Cattle & calves	$23 million
Livestock Population (number of animals)	
Poultry	3.2 million
Cattle and calves	89,000
Pigs	107,000
Dairy cows	19,000
Farm Income	
Total net cash income	$61 million
Total cash receipts	$452 million
Total operating expenses	$391 million
Distribution of farms by revenue class	
Less than $10,000	36%
$10,000 to $49,000	29%
$50,000 to $100,000	8%
More than $100,000	27%
Food and Beverage Industry	
Total # of establishments	177
Total value of shipments	$2 billion
Food Processing	$1.7 billion
Seafood products	47%
Dairy products	11%
Animal food products	11%
Bakeries & tortilla products	3%
Other food	28%
Beverages	$293 million
International Trade Statistics	
Trade balance	$113 million
Exports	
Total agricultural exports	$325 million
Bulk	0%
Intermediate	7%
Consumer-oriented	93%
Major export markets	
United States	$248 million
Venezula	$11 million
Mexico	$8 million
Guatemala	$8 million
Costa Rica	$6 million
Imports	
Total agricultural imports	$212 million
Bulk	15%
Intermediate	11%
Consumer-oriented	74%

Farm Land Management

AGRICULTURAL LAND USE (Chapter 4)

In New Brunswick there was a decrease in total farmland from 0.44 million hectares in 1981 to approximately 0.40 million hectares in 2006 (Figure 24.7-1). Production intensity increased, with the proportion of cropland to farmland expanding and that of pasture declining over this 25-year period (Table 4-1, Figure 4-1). Land in the all other land classification decreased by 17,000 hectares although it increased as a proportion of farmland. Although the area of cereal grain increased, the proportion of cropland in cereal grains dropped (Table 4-2). The area of corn doubled, increasing its proportion of cropland to 3%. The area in potatoes expanded, but its proportion of cropland dropped to 16%. Similarly, forage area increased by 11,000 hectares, but its proportion of cropped land dropped to 54% in 2006. New Brunswick's decline in the use of conventional tillage practices on cropland was 8%, with small corresponding increases in the uptake of conservation tillage and no-till (Table 4-3). As for livestock, numbers of cattle, sheep and goats in New Brunswick dropped between 1981 and 2006. Pig and poultry numbers increased, while the horse population remained stable (Table 4-4).

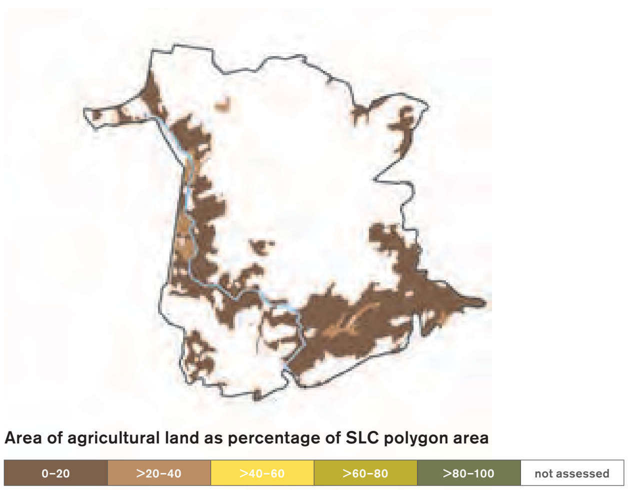


FIGURE 24.7-1 Proportion of agricultural land in New Brunswick, 2006.

FARM ENVIRONMENTAL MANAGEMENT (Chapter 5)

In 2006, soil testing was conducted every year by 23% of New Brunswick producers, and 39% soil tested every 2–3 years, which indicated active management of nutrients (Statistics Canada, 2007). Only 12% did not soil test. Data on Environmental Farm Plans (EFP) was only available for the Atlantic region in 2006, where 40% of producers had a completed EFP and another 10% had a plan under development. In the Atlantic provinces, 21% of producers established a riparian buffer around permanent wetlands in 2006 and 45% established buffers around waterways. 23% did not allow grazing livestock access to surface water, and 24% only allow limited access.

SOIL COVER (Chapter 6)

Soil cover values in New Brunswick were quite high in 2006 and showed a 1% increase between 1981 and 2006 (Figure 6-2, Table 6-1). Improvements in soil cover values came primarily from the northern agricultural areas (4% increase) and the small area of agriculture along the Fundy coast (10% increase). Land use changes which contributed to improved soil cover include increased areas in cereal grains and grain corn and a decline in vegetables. Negative factors included increased areas in potatoes and decrease in perennial crops. Conservation and no-till were practiced on 14% of cropland in 1991 and on 22% in 2006. In New Brunswick in 2006, 93% of farmland was in the high and very high soil cover classes, with none in the low or very low classes. While the area of lowest soil cover in New Brunswick occurs in the potato region of the Saint John River Valley, the generally high soil cover values reflect the reliance on perennial crops and cereal grains in the crop rotations in this province.

WILDLIFE HABITAT (Chapter 7)

In 2006, average provincial habitat capacity for breeding and feeding (HC_{bf}) was moderate (Table 7-1) and 272 species were reported using agricultural land (Figure 7-1). HC_{bf} on 57% of agricultural land rated high with an additional 3% ranked as very high (Table 7-1). From 1986 to 2006, overall provincial HC_{bf} showed a significant decrease, with 67% of farmland with a decreasing HC_{bf} (Table 7-2). Decrease in HC_{bf} resulted from decreased amounts of all other land and unimproved pasture. The net impact of HC_{bf} changes was a drop in the proportion of farmland with very high HC_{bf} from 12 to 3% and an increase of the share of land in the low category from 1 to 7%.

As with many other regions of the Maritimes, farmland occupied a relatively small percentage of the broader landscape and HC_{bf} in New Brunswick ranked high primarily due to the considerable natural and semi-natural land components of farmland.

In 2006, average provincial habitat capacity for wintering (HC_w) was very high with the majority of farmland in the very high category (67%) and the remainder classified as high (26%) and moderate (7%) (Table 7-3). The relatively high share of all other lands in agricultural areas was the primary factor contributing to very high HC_w.

Soil Health

SOIL EROSION (Chapter 8)

New Brunswick had virtually no change in the risk of soil erosion between 1981 and 2006 with the share of cropland in the very low risk class remaining at about 40% (Figure 24.7-2, Table 8-1). Both water and tillage erosion are important and relatively high in this province. Between 1981 and 2006, there was very little change in the area of potato crops, alfalfa and hay or cereals. This very small change in crops, accompanied by a very small reduction in tillage intensity, resulted in no net change in soil erosion. New Brunswick saw essentially no change in cropland area in the very low tillage erosion risk class (77% in 1981 to 78% in 2006) (Table 8-4) and slight decreases in the higher risk classes, with about 15% of the area in the moderate to high risk classes. However, water erosion risk in New Brunswick remained almost unchanged with about 43% in very low erosion risk class and 30% in the moderate to very high risk classes (Table 8-2).

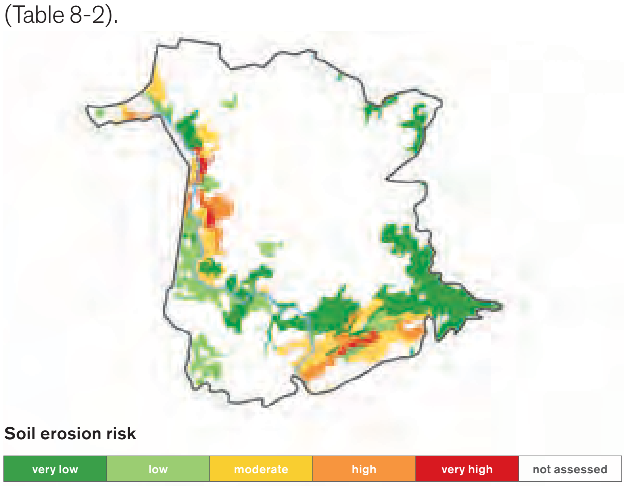


FIGURE 24.7-2 Risk of Soil Erosion on cultivated land in New Brunswick under 2006 management practices.

SOIL ORGANIC MATTER (Chapter 9)

Soil organic carbon has moved from a situation of predominantly neutral change in 1981 (82%) to 79% decreasing SOC by 2006 (Figure 24.7-3, Table 9-1). Relative organic carbon is largely in the low to moderate range (average 0.72 in 2006 down from 0.75 in 1981). However, there are many soils in New Brunswick with low to very low ROC (Figure 9-4). Of these soils, 70% are showing a loss in SOC and thereby indicating a situation where general soil health is being reduced. These changes, primarily decreases in SOC, are driven by perennial to annual crop conversion with some forest clearing.

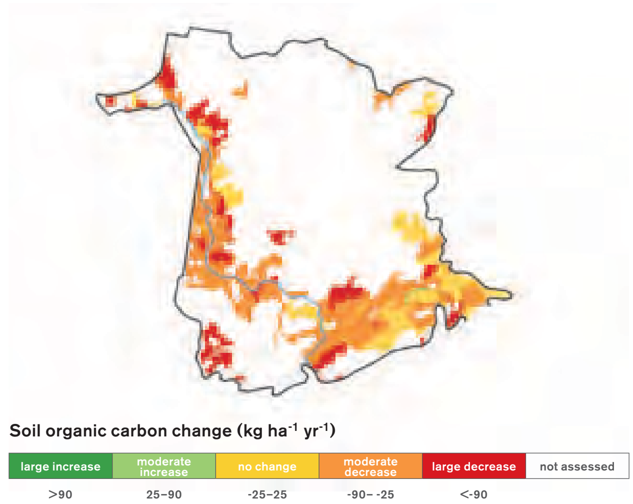


FIGURE 24.7-3 Indicator of soil organic carbon change (kg $ha^{-1}yr^{-1}$) for New Brunswick, 2006.

TRACE ELEMENTS (Chapter 10)

The share of land in the various risk classes in New Brunswick did not change appreciably from 1981 to 2006. The low, moderate and high risk classes accounted for 69%, 21% and 10% respectively of its agricultural area. None of New Brunswick's agricultural land was expected to be in the very low or very high risk classes (Table 10-1).

Almost ninety percent of the agricultural land in New Brunswick is expected to have an increase in TE of at least 30% above present background concentrations based on 2006 data. However the area that is expected to have increases of 50% to 100% over background concentrations increased from 17% in 1981 to 30% under 2006 management practices (Table 10-2). This increased rate of TE accumulation is mainly due to use of phosphate fertilizers in potato production on sandy textured soils.

Water Quality

NITROGEN (Chapter 12)

12.1 Residual Soil Nitrogen (RSN)

In 2006, there was no agricultural land in New Brunswick in the very low RSN class and only 1% in the low class (Table 12.1-1). From 1981 to 2006 there was a general shift of land to the very high RSN category which increased from 2% to 89% over this 25-year period.

In New Brunswick, N inputs increased from 83.5 kg N ha^{-1} in 1981 to 128 kg N ha^{-1} in 2006 (Table 12.1-2). These increases were primarily due to increases in the amount of fertilizer applied as well as increases in N fixation by legume crops.

12.2 Indicator of Risk of Water Contamination by Nitrogen (IROWC-N)

In New Brunswick the risk of water contamination by N increased markedly between 1981 and 2006 (Table 12.2-2, Figure 12.2-2, 12.2-3). The proportion of farmland area in the very low and low risk classes in New Brunswick decreased from 61% to 0%, the moderate class decreased from 36% to 5%, while the proportion in the high and very high risk classes increased from 2% to 96% (Figure 24.7-4).

The Atlantic Provinces are among the wettest in Canada, receiving on average 600 to 800mm over-winter precipitation, leading to high and variable over-winter drainage estimates and spring soil water contents close to field capacity. In New Brunswick, the more than doubling of the over-winter N losses (Figure 12.2-4) and the sharply increased N concentrations (from 5.0 to 14.2 mg N L^{-1}, Figure 12.2-5) was mainly in response to the doubling of the RSN values (from 23.8 to 57.3 kg N ha^{-1}), which, in turn, was caused by increased N inputs from fertilizer and N fixation by legumes. Reynolds et al. (1995) reported that nitrate levels in tile drainage water from potato fields in New Brunswick often exceed 10 mg N L^{-1}.

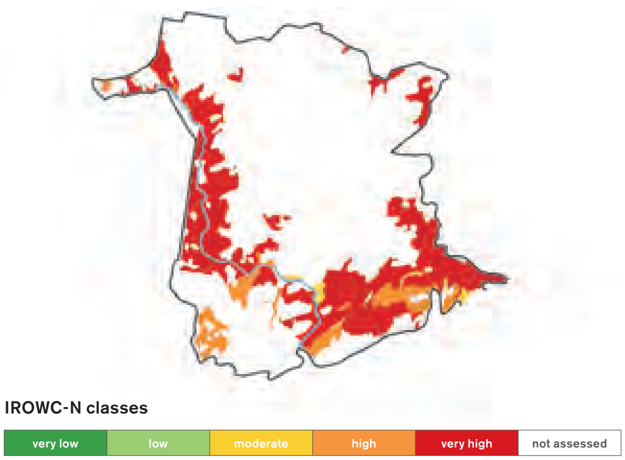


FIGURE 24.7-4 Risk of water contamination by nitrogen in New Brunswick under 2006 management practices.

PHOSPHORUS (Chapter 13)

Indicator of Risk of Water Contamination by Phosphorus (IROWC-P)

All 14 watersheds in New Brunswick were classified in the very low and low risk classes (Figure 24.7-5). During the 1981-2006 period however, four watersheds at very low risk were reassigned as low risk (Figure 13-2). One watershed located in the potato cultivation area in the western part of the province showed the highest P-Source pressure due to the use of mineral P fertilizers (Figure 13-7). The shift of the three other watersheds to a higher risk class in the south eastern part of the province may be due to the increased area of large row crops amplifying the surface runoff and soil erosion. As shown in Table 13-2, 35% of farmland is now classed as high to very high for P-Source, likely due to an 11% increase in mineral P fertilizers between 1981-2006.

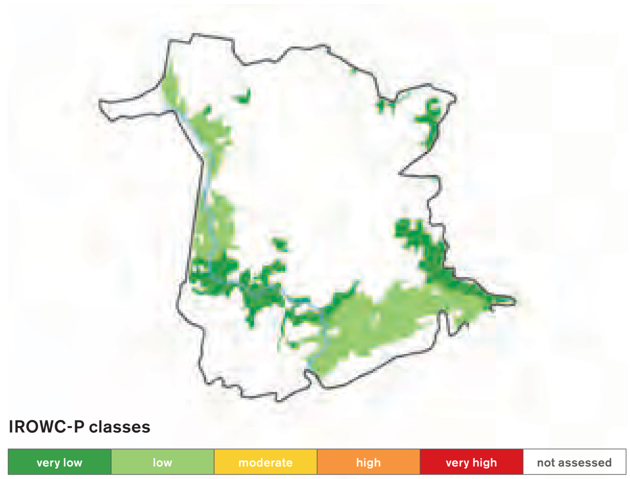


FIGURE 24.7-5 Risk of water contamination by phosphorus in agricultural watersheds in New Brunswick under 2006 management practices.

COLIFORMS (Chapter 14)

Indicator of Risk of Water Contamination by Coliforms (IROWC-Coliform)

The IROWC-Coliform assessment in New Brunswick demonstrated that the majority of the fourteen watersheds, representing 76% of the farmland had very low and low risk values in 2006 with the exception of the Central Saint John-Becaguimec watershed (Figure 14-2). During the 25-year period of 1981 to 2006, two watersheds, the Central Saint John-Becaguimec River and Petitcodiac River, were frequently classed at either moderate or high IROWC-Coliform risk and together accounted for 34% of farmland. In terms of coliform source pressure during the last 25 years, pasture land declined significantly, the cattle population decreased and swine and poultry populations increased.

PESTICIDES (Chapter 15)

Indicator of Risk of Water Contamination by Pesticides (IROWC-Pest)

In 2006, 52% of the cropland in New Brunswick was at very low and low risk of contamination of water by pesticides, which represents a decrease from 1981, when 85% was in these classes (Table 15-2). There has been a significant, though variable, proportion of cropland in the moderate risk class over the 25-year period and a generally increasing amount in the high and very high risk classes. The low to moderate risk over this 25-year period correlates well with the average number of days per year when surface runoff occurred. In 2006, 16% of cropland experienced 21 to 28 runoff events (Table 15-3) such that 14% and 12% of cropland were at high and very high risk, respectively, to contaminate water with pesticides (Table 15-2). This high risk is most likely due to the increased application rates of pesticides evident in the very high mass-applied class in 2001 and 2006 (Table 15-4).

Air Quality and Greenhouse Gases

GREENHOUSE GASES (Chapter 16)

Compared to other provinces, agricultural production in each of the Atlantic Provinces is small. Therefore, Newfoundland and Labrador, Prince Edward Island, Nova Scotia and New Brunswick have been grouped together and their agricultural GHG emissions are presented as a single region. Net GHG emissions in the Atlantic Provinces have increased slightly from 1.4 to 1.6 Mt CO_2e between 1981 and 2006 (Figure 24.7-6, Table 16-1). A reduction in the population of dairy cows and beef cattle has resulted in a small decrease in CH_4 emissions from 0.7 to 0.6 Mt CO_2e. Although manure nitrogen has declined as well, increases in nitrogen fertilizer and crop residue nitrogen have resulted in nearly constant N_2O emissions at 0.7 Mt CO_2e. Similar to Quebec, conversion of perennial cropping systems to annual cropping systems in the Atlantic Provinces have resulted in an increase in CO_2 emissions from 0.1 to 0.2 Mt CO_2.

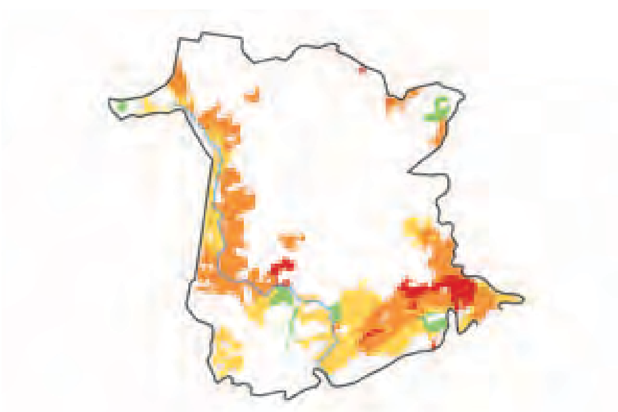


FIGURE 24.7-6 Agricultural net greenhouse gas emissions in New Brunswick, 2006.

AMMONIA (Chapter 17)

Ammonia emissions in New Brunswick account for less than 1% of national emissions from agriculture. The beef and dairy sectors combined are responsible for 53% of these emissions while the remaining emissions contributed almost equally from poultry, swine and fertilizers (Table 17-2). There was a small (6.9%) decrease in the amount of agricultural NH_3 emissions in New Brunswick between 2001 and 2006. The share of land in the high and very high emissions-intensity classes remained relatively constant at about 80% in both 2001 and 2006 (Figure 24.7-7, Table 17-1).

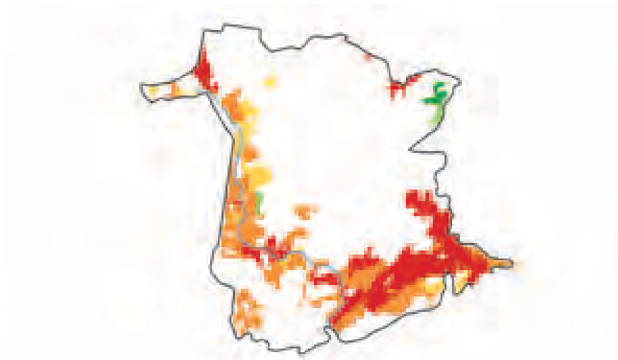


FIGURE 24.7-7 Total ammonia emissions per hectare of agricultural land in New Brunswick in 2006 from major livestock sectors and fertilizer.

PARTICULATE MATTER (Chapter 18)

In New Brunswick, total agricultural particulate matter (PM) emissions showed decreases of 12% for TSP, 6% for PM_{10} and 9% for $PM_{2.5}$ (Table 18-1). PM emissions from land preparation and wind erosion decreased approximately 30%, while PM emissions from all other agricultural operations increased between 1981 and 2006. The increased PM emissions from animal-feeding operations and crop harvest are mainly due to increased cropland area and animal populations in this province. The major factor resulting in the decreasing trend in PM emissions observed between 1981 and 2006 is a combination of a reduction in conventional tillage and and elimination of summerfallow.

24.8 Nova Scotia

Summary

Agriculture makes up approximately 8% of Nova Scotia's land area, 29% of which is cultivated land, 14% of which is pasture, and 57% in the all other land category (Table 24.8-1). The two primary outputs in Nova Scotia are dairy, and poultry and eggs. The agri-environmental indicators for Nova Scotia showed that from 1981 to 2006 agricultural land use intensified, although conventional tillage declined and conservation and no till increased. Soil cover increased and risk of soil erosion decreased over this time. There was no change in the risk of contamination by trace elements, and soil carbon decreased. There was also no change in the wildlife habitat capacity of Nova Scotia's agricultural land. Risk to water quality by nitrogen, phosphorus, coliforms and pesticides all increased over this time, indicating more management may be necessary. Nova Scotia showed decreases in emissions of ammonia and particulate matter between 1981 and 2006, however the Atlantic provinces had a small increase in greenhouse gas emissions over this period.

TABLE 24.8-1 Summary of agricultural statistics in Nova Scotia, 2006

Land Statistics (hectares (ha))	
Total area	5.5 million ha
Total land area	5.3 million ha
Total farm area	403,000 ha
Cultivated land	29%
Pastureland	14%
Other land	57%
Average farm area	106 ha
Farm Characteristics	
Total # of farms	3,795
Total # of families	3,055
Total # of operators	5,100
Average age of operators	53
Major Agricultural Outputs	
Dairy	$108 million
Poultry & eggs	$85 million
Floriculture & nursery	$37 million
Cattle & calves	$23 million
Hogs	$23 million
Livestock Population (number of animals)	
Poultry	4.2 million
Cattle and calves	104,000
Pigs	95,000
Dairy cows	22,000
Farm Income	
Total net cash income	$46 million
Total cash receipts	$447 million
Total operating expenses	$401 million
Distribution of farms by revenue class	
Less than $10,000	36%
$10,000 to $49,000	33%
$50,000 to $100,000	8%
More than $100,000	23%

Food and Beverage Industry	
Total # of establishments	173
Total value of shipments	N/A
Food Processing	$2.1 billion
Seafood products	45%
Meat products	17%
Dairy products	11%
Animal food products	5%
Other food	22%
Beverages	N/A
International Trade Statistics	
Trade balance	$13 million
Exports	
Total agricultural exports	$257 million
Bulk	0%
Intermediate	7%
Consumer-oriented	93%
Major export markets	
United States	$176 million
Japan	$16 million
Germany	$10 million
United Kingdom	$10 million
China	$8 million
Imports	
Total agricultural imports	$244 million
Bulk	65%
Intermediate	5%
Consumer-oriented	30%

Farm Land Management

AGRICULTURAL LAND USE (Chapter 4)

The total area of farmland in Nova Scotia decreased from 466,000 hectares in 1981 to 403,000 hectares in 2006 (Figure 24.8-1). The area of pasture declined, summerfallow virtually disappeared and area of all other land declined, although its share of farmland remained at 55%. Production intensified, with cropland increasing to 31% of farmland (Table 4-1, Figure 4-1). The proportion of cropland devoted to cereal grains decreased, while that for corn increased. The proportion of cropland devoted to forage declined although it underwent an increase of approximately 1000 hectares. The other crops category increased to 26% of cropland (Table 4-2). The use of conventional tillage on cropped land declined from 1991 to 2006 and there was a corresponding increase in the area under conservation tillage and no-till (Table 4-3). As in other Atlantic Provinces, cattle numbers in Nova Scotia decreased and poultry numbers increased, but Nova Scotia was one of only 3 provinces in which pig numbers declined (32%) between 1981 and 2006. Sheep and goat numbers also decreased and horses increased.

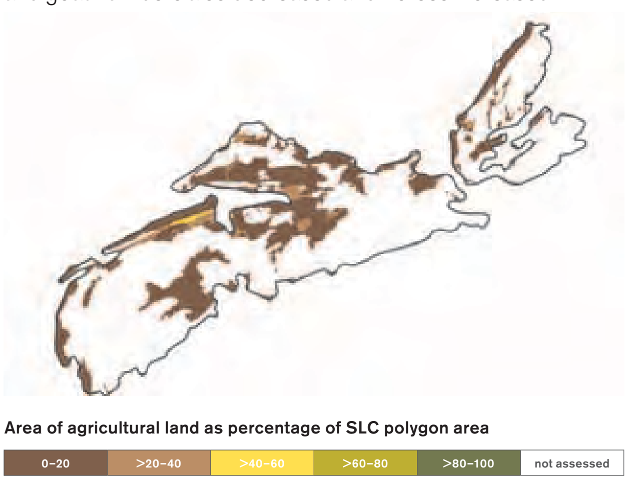


FIGURE 24.8-1 Proportion of agricultural land in Nova Scotia, 2006.

FARM ENVIRONMENTAL MANAGEMENT (Chapter 5)

40% of producers in the Atlantic Provinces had a completed Environmental Farm Plan (EFP) and another 10% had plans under development in 2006 (Statistics Canada, 2007). Many producers in the Atlantic region implemented beneficial management practices on their operations to reduce risk to the environment and improve environmental performance. 45% of producers established a riparian buffer along waterways in the Atlantic provinces and 43% established a setback distance. 23% of producers restricted grazing livestock from surface waters, and 24% only allowed limited access to surface waters. 4% of producers injected liquid manure directly into the soil, and 43% broadcast and incorporated it into the soil. 48% did not incorporate liquid manure into the soil, which indicates that improvements can be made.

SOIL COVER (Chapter 6)

Soil cover in Nova Scotia is the highest in Canada, and has shown a gradual increase over the past 25 years, with the exception of the 1996 – 2001 period, in which it declined slightly (Table 6-1). Overall improvement amounted to just over 1%, with the largest increase of 4% along the Gulf coast. The improvements in soil cover came as a result of an increase in grain corn, a drop in potato acreage and the adoption of conservation and no-till on cropland. Changes which negatively affected the amount of soil cover included increased areas in silage corn, soybeans and nursery crops, and declines in perennial crop and cereal grain areas. In 2006, 82% of farmland was in the very high soil cover class and 14% was in the high class (Table 6-2). All of the land in the moderate class (4%) is found in the Annapolis Valley, where the majority of annual crops in the province are grown, and where much of the cereal grain straw is removed from the field.

WILDLIFE HABITAT (Chapter 7)

In 2006, habitat capacity for breeding and feeding (HC_{bf}) on the majority of farmland was rated as high (58%) with an additional 18% and 23% ranked as very high and moderate, respectively (Table 7-1). Over 20 years, HC_{bf} was constant as significant decreases were offset by increases (Table 7-2) at the provincial scale.

The relatively high percentages of natural and semi-natural land associated with farmland in Nova Scotia were the main contributors to the high HC_{bf}. Over twenty years, constant HC_{bf} resulted from generally stable representation of important cover types within the agricultural landscape like: all other land, unimproved pasture, improved pasture and tame hay. Improvements in HC_{bf} were associated with a shift to crop types that supported more wildlife whereas declines generally resulted from the loss of all other land. Farmland in Nova Scotia made up a relatively small component of the broader landscape, therefore, the majority of areas that experienced decline still maintained high and very high HC_{bf} due to the high all other land component.

In 2006, average provincial habitat capacity for wintering (HC_w) was very high. The majority of farmland fell into the very high category (82%) with the remainder of land as high (17%) and moderate (1%) (Table 7-3). The very high HC_w resulted from the most important wintering land cover (all other lands) making up a major proportion of the agricultural landscape.

Soil Health

SOIL EROSION (Chapter 8)

Nova Scotia showed increases in the cropland area in the very low risk class, from 36% in 1981 to 67% in 2006 (Figure 24.8-2,

Table 8-1). There were also modest improvements in tillage and water erosion risk for Nova Scotia during this time. The area in the very low risk class for tillage erosion increased from 93% to 99% (Table 8-4) and from 52% to 72% for the very low risk class for water erosion during this time period (Table 8-2). The area with moderate to very high water erosion risk decreased from 19 to 7%, while the area in the moderate to very high tillage erosion risk classes was very small at less than 1% throughout this period.

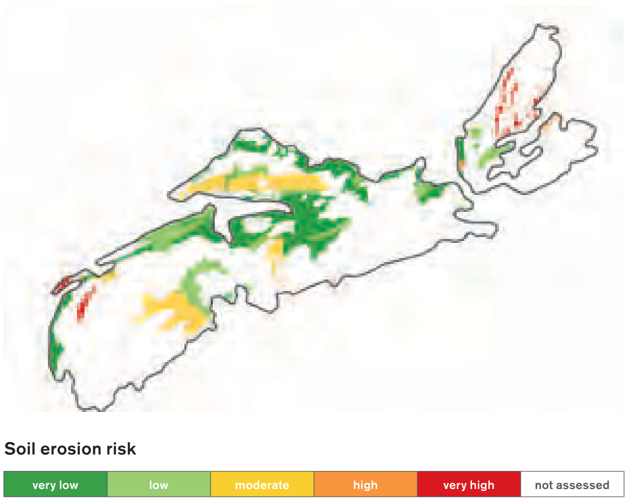


FIGURE 24.8-2 Risk of Soil Erosion on cultivated land in Nova Scotia under 2006 management practices.

SOIL ORGANIC MATTER (Chapter 9)

In Nova Scotia, 83% of land had decreasing soil organic carbon (SOC) in 1981 (Figure 24.8-3, Table 9-1). This provincial average SOC loss was at its lowest value in 1996 at -41 kg ha^{-1} yr^{-1} but had risen to -64 kg ha^{-1} yr^{-1} by 2006. The amount of land

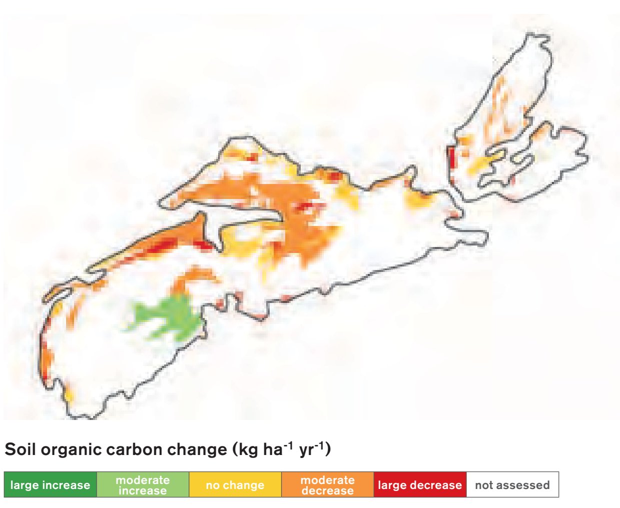


FIGURE 24.8-3 Indicator of soil organic carbon change (kg $ha^{-1}yr^{-1}$) for Nova Scotia, 2006.

with increasing SOC was also largest in 1996 at 5% and has declined slightly to 4% in 2006. The relative organic carbon (ROC) value was frequently in the very low class (provincial average is 0.58). With 56% of its farmland having low to very low ROC and decreasing SOC, low SOC is a soil quality concern (Table 9-4). Land use change, such as conversion of forest to agriculture and perennial to annual crop conversions, dominate SOC decline since 1981 (Figure 9-2).

TRACE ELEMENTS (Chapter 10)

The share of land in the various risk classes in Nova Scotia did not change appreciably from 1981 to 2006. The very low, low, moderate and high risk classes accounted for 0%, 27%, 41% and 31% respectively of its agricultural area. Approximately 1% of Nova Scotia's agricultural land could be in the very high risk class in 100 years if 2006 management practices continue (Table 10-1).

Almost 70% agricultural land in Nova Scotia is expected to have an increase in TE of at least 30% above present background concentrations under both 1981 and 2006 populations, crop areas and practices (Table 10-2). There was some shift of land to higher rates of increase as the share of expected to have TE increases in the 50% to 100% range went from 21% to 25%. Over this time period in Nova Scotia there has been an increase in human and livestock populations contributing to higher TE inputs (Table 10-5).

Water Quality

NITROGEN (Chapter 12)

12.1 Residual Soil Nitrogen (RSN)

In 2006 there was no agricultural land in Nova Scotia in the very low RSN class (Table 12.1-1). From 1981 to 2006 the share of farmland in the low RSN class decreased from 10% to 1% and the share of farmland in the very high RSN category increased from 12% to 83% .

The N inputs in Nova Scotia increased from 92.7 kg N ha^{-1} in 1981 to 124 kg N ha^{-1} in 2006, primarily due to increased fertilizer application and to increased N fixation by legume crops. Manure N inputs and N outputs remained fairly constant over this 25-year period. However, a noticeable spike in yields and N outputs occurred in 1996 (Table 12.1-2).

12.2 Indicator of Risk of Water Contamination by Nitrogen (IROWC-N)

The risk of water contamination by N in Nova Scotia increased markedly between 1981 and 2006 (Table 12.2-2, Figure 12.2-2& 12.2-3). The proportion of farmland area in the very low and low risk classes in Nova Scotia decreased from 59% to 4%, the moderate class decreased from 15% to 3%, while the proportion in the high and very high risk classes increased from 26% to 94% (Figure 24.8-4).

In Nova Scotia, over-winter N losses doubled (from 18 kg N ha^{-1} in 1981 to 40 kg N ha^{-1} in 2006) and the N concentrations sharply increased (Figure 12.2-4, 12.2-5), mainly in response to the doubling of the RSN values, which, in turn, was caused by increased N inputs from fertilizer use and fixation by legumes.

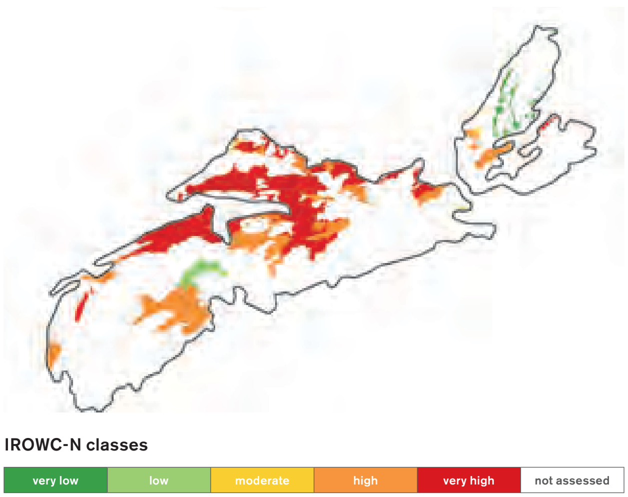


FIGURE 24.8-4 Risk of water contamination by nitrogen in Nova Scotia under 2006 management practices.

PHOSPHORUS (Chapter 13)

Indicator of Risk of Water Contamination by Phosphorus (IROWC-P)

Of the 19 watersheds in Nova Scotia, in 2006 the Annapolis watershed was at moderate risk, the Gaspereau watershed at high risk, and the remaining 17 watersheds were at very low and low risk (Figure 24.8-5). These two watersheds comprise 34% (Table 13-1) of the provincial farmland with high and very high P-Source pressure (Figure 13-6). Despite a 15% decrease in the total agricultural area during the past 25 years, the area in large row crops has increased by approximately 20%. During the same period, 11 watersheds shifted to a higher risk level (Figure 13-2). Almost half of the farmland (46%) shows high and very high P-Source classes (Table 13-2).

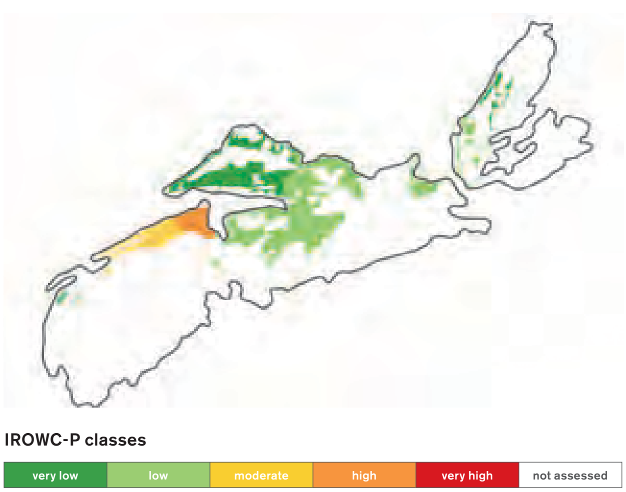


FIGURE 24.8-5 Risk of water contamination by phosphorus in agricultural watersheds in Nova Scotia under 2006 management practices.

COLIFORMS (Chapter 14)

Indicator of Risk of Water Contamination by Coliforms (IROWC-Coliform)

The 2006 IROWC-Coliform assessment in Nova Scotia gave essentially very low and low risk value for the nineteen watersheds (Figure 14-2). During the 1981 to 1996 period, the Gaspereau River watershed has frequently ranked at either moderate or high IROWC-Coliform risk accounting for 18% of farmland but not since 2001 (Table 14-1). In terms of coliform source pressure during the last 25 years, pasture land declined significantly, the cattle and swine populations decreased, and the poultry population increased.

PESTICIDES (Chapter 15)

Indicator of Risk of Water Contamination by Pesticides (IROWC-Pest)

In 2006, 90% of the cropland in Nova Scotia was at very low to low risk of contaminating water by pesticides. This represents a small decrease from 1981 when 99% was in these classes. Only 7% of the cropland was at moderate to very high risk of contaminating water with pesticides in 2006 (Table 15-2). The proportion of land in these risk classes corresponds to the variable amount of herbicides applied and is also influenced by the number of runoff days. Years with greater proportions of land in the very high risk class (Table 15-2) correspond to years that have higher amounts of pesticides applied per hectare (Table 15-4).

Air Quality and Greenhouse Gases

GREENHOUSE GASES (Chapter 16)

Compared to other provinces, agricultural production in each of the Atlantic Provinces is small. Therefore, Newfoundland and Labrador, Prince Edward Island, Nova Scotia and New Brunswick have been grouped together and their agricultural GHG emissions are presented as a single region. Net GHG emissions in the Atlantic Provinces have increased slightly from 1.4 to 1.6 Mt CO_2e between 1981 and 2006 (Figure 24.8-6, Table 16-1). A reduction in the population of dairy cows and beef cattle has resulted in a small decrease in CH_4 emissions from 0.7 to 0.6 Mt CO_2e. Although manure nitrogen has declined as well, increases in nitrogen fertilizer and crop residue nitrogen have resulted in nearly constant N_2O emissions at 0.7 Mt CO_2e. Similar to Quebec, conversion of perennial cropping systems to annual cropping systems in the Atlantic Provinces have resulted in an increase in CO_2 emissions from 0.1 to 0.2 Mt CO_2.

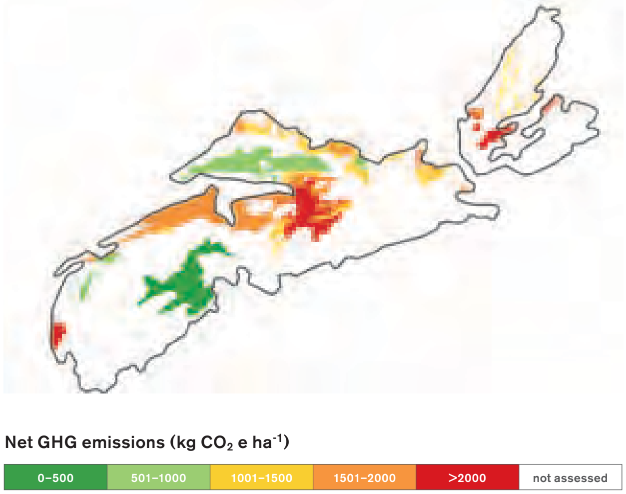


FIGURE 24.8-6 Agricultural net greenhouse gas emissions in Nova Scotia, 2006.

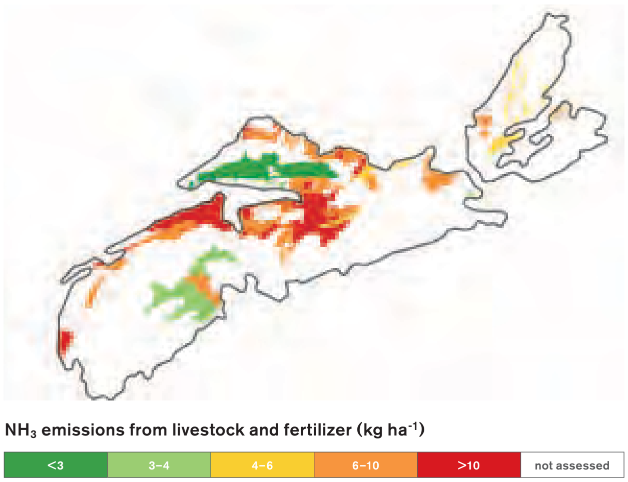


FIGURE 24.8-7 Total ammonia emissions per hectare of agricultural land in Nova Scotia in 2006 from major livestock sectors and fertilizer.

AMMONIA (Chapter 17)

Less than 1% of national agricultural NH_3 emissions originate from Nova Scotia. The beef and dairy sectors combined are responsible for over 57% of emissions, with poultry contributing almost 20% (Table 17-2). Emissions decreased slightly (6%) between 2001 and 2006 due to a decrease in the number of livestock—primarily a decrease in the number of pigs. The decrease in numbers of livestock resulted in a decrease of farmland in the high and very high classes, from 80% in 2001 to 76% in 2006 (Figure 24.8-7, Table 17-1).

PARTICULATE MATTER (Chapter 18)

Agricultural PM emissions in Nova Scotia decreased by 23% for TSP, 28% for PM_{10} and 27% for $PM_{2.5}$ between 1981 and 2006 (Table 18-1). PM emissions from land preparation and wind erosion decreased greatly due to an increase of conservation tillage and no-till practices and a decrease of summerfallow.

24.9 Prince Edward Island

Summary

Agriculture makes up approximately 44% of Prince Edward Island's land area, with the major agricultural outputs being potatoes and dairy (Table 24.9-1). Prince Edward Island showed improvements in soil cover, soil erosion and particulate matter emissions in 2006, and no change in the risk of soil contamination by trace elements, the risk of water contamination by coliforms or ammonia emissions. The land use intensity has increased in Prince Edward Island from 1981 to 2006 however, and the wildlife habitat capacity has declined. Soil carbon decreased from 1981 to 2006 and there was increased risk of water contamination by nitrogen, phosphorus and pesticides. There was a slight increase in greenhouse gases for the Atlantic provinces between 1981 and 2006.

TABLE 24.9-1 Summary of agricultural statistics in Prince Edward Island, 2006

Land Statistics (hectares (ha))	
Total area	566,000 ha
Total land area	566,000 ha
Total farm area	251,000 ha
Cultivated land	68%
Pastureland	9%
Other land	23%
Average farm area	148 ha
Farm Characteristics	
Total # of farms	1,700
Total # of families	1,335
Total # of operators	2,330
Average age of operators	51
Major Agricultural Outputs	
Potatoes	$203 million
Dairy	$63 million
Hogs	$24 million
Cattle & calves	$21 million
Vegetables	$10 million
Livestock Population (number of animals)	
Poultry	447,000
Cattle and calves	86,000
Pigs	123,000
Dairy cows	13,000
Farm Income	
Total net cash income	$31 million
Total cash receipts	$376 million
Total operating expenses	$345 million
Distribution of farms by revenue class	
Less than $10,000	24%
$10,000 to $49,000	26%
$50,000 to $100,000	13%
More than $100,000	37%

Food and Beverage Industry	
Total # of establishments	51
Total value of shipments	N/A
Food Processing	$880 million
Seafood products	40%
Other food	60%
Beverages	N/A
International Trade Statistics	
Trade balance	$324 million
Exports	
Total agricultural exports	$327 million
Bulk	0%
Intermediate	7%
Consumer-oriented	93%
Major export markets	
United States	$288 million
Trinidad-Tobago	$5 million
Japan	$4 million
Bahamas	$4 million
Venezula	$3 million
Imports	
Total agricultural imports	$4 million
Bulk	0%
Intermediate	4%
Consumer-oriented	96%

Farm Land Management

AGRICULTURAL LAND USE (Chapter 4)

Between 1981 and 2006, the total amount of farmland in Prince Edward Island dropped from 283,000 to 251,000 hectares (Figure 24.9-1), pasture area decreased, summerfallow was essentially eliminated and all other land declined. However, cropland increased by 13,000 hectares and by 2006 constituted 68% of farmland (Table 4-1, Figure 4-1). The distribution of crop types changed significantly, with a decline in cereal grain area, and increases in potatoes, pulse crops, forages and other crops. The area of corn remained constant at 2700 hectares and the area of oilseeds remained at less than 1% (Table 4-2). The use of conventional tillage decreased from 1991 to 2006, while the area under conservation tillage and no-till increased (Table 4-3). The livestock industry in Prince Edward Island also changed during the 1981 to 2006 period, with declines in number of cattle, horses and sheep and goats and increases in pigs and poultry (Table 4-4).

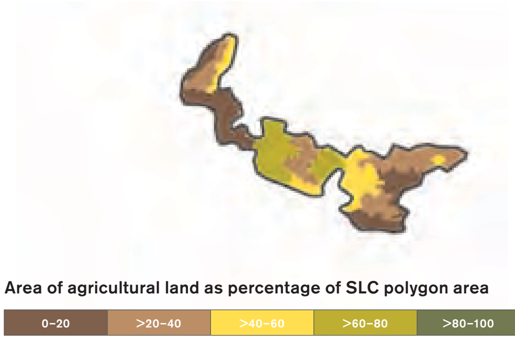


FIGURE 24.9-1 Proportion of agricultural land in Prince Edward Island, 2006.

FARM ENVIRONMENTAL MANAGEMENT (Chapter 5)

40% of producers in the Atlantic Provinces had a completed Environmental Farm Plan (EFP) and another 10% had plans under development in 2006 (Statistics Canada, 2007). Many producers in the Atlantic region were implementing beneficial management practices on their operations to reduce risk to the environment and improve environmental performance. 45% of producers established a riparian buffer along waterways in the Atlantic provinces, and 43% established a setback distance. 23% of producers restricted grazing livestock from surface waters, and 24% only allowed limited access to surface waters. 4% of producers injected liquid manure directly into the soil, and 43% broadcast and incorporated into the soil. 48% did not incorporate liquid manure into the soil, which indicates that improvements can be made.

SOIL COVER (Chapter 6)

Provincial average soil cover increased by 2% between 1981 and 2006, with the greatest increase occurring between 1981 and 1986. A number of cropping system changes that influence soil cover occurred in Prince Edward Island over the 25 years of study, but the mix of positive and negative effects essentially counteracted each other to keep the change in values minimal. Positive effects included the adoption of reduced and no-till on cropland, a decrease in silage corn and vegetables and the virtual elimination of tobacco, as well as an increase in grain corn area. Changes which negatively affected the amount of soil cover included increases in potatoes and soybeans and decreases in perennial crops and cereal grains. Prince Edward Island farmland is concentrated in the high (28%) and moderate (72%) soil cover day classes (Table 6-2). The high levels of soil cover are due to frequent use of perennial crops and cereal grains in the crop rotations, as well as relatively high proportions of winter cereals.

WILDLIFE HABITAT (Chapter 7)

In 2006, average provincial habitat capacity for breeding and feeding (HC_{bf}) was low as the majority of farmland was low (75%) or very low (24%) with only 1% rated as moderate (Table 7-1). From 1986 to 2006 HC_{bf} decreased significantly in Prince Edward Island. HC_{bf} declines occurred on 47% of farmland, increases occurred on 10% and HC_{bf} was constant on 42% (Table 7-2). These changes, over 20 years, resulted in a major HC_{bf} shift from moderate to low and very low and from low to very low classes.

HC_{bf} decrease resulted from the combined effects of declines in the share of land in the three most valuable cover types for wildlife: all other land, unimproved pasture and improved pasture, respectively. Concurrently, the share of cover types that support comparatively less wildlife such as potato and tame hay expanded. Low HC_{bf} was a result of a large proportion of the agricultural landscape being under production (77.6%), leaving a relatively small share of natural or semi-natural habitat available for the 235 terrestrial vertebrate species reported on farmland in Prince Edward Island. The greatest pressure from agriculture on wildlife habitat capacity is in areas where the all other land component of farmland is declining, and where farmland makes up a relatively high percentage of the total landscape.

In 2006, average provincial habitat capacity for wintering (HC_w) was moderate with 76% of farmland in this category and the remainder classified as high (24%) (Table 7-3). The share of all other land in the agricultural landscape was the primary reason for the moderate classification.

Soil Health

SOIL EROSION (Chapter 8)

Prince Edward Island had increases in cropland area in the very low risk class, from 18% in 1981 to 25% in 2006 (Figure 24.9-2, Table 8-1). Prince Edward Island posted an 8% increase in the area of potato crops, a 7% increase in alfalfa and hay and a 13% decrease in cereals. Increases in the areas of potatoes, alfalfa and hay accompanied by a reduction in cereals and a small reduction in tillage intensity resulted in a small decrease in soil erosion risk. The most positive change was the shift of the area in the high erosion risk class from 10 to 0% and a corresponding shift to the moderate erosion risk which increased from 0 to 10%. Changes in soil erosion risk in the higher classes were due solely to reduced risk of water erosion. Prince Edward Island posted the largest increase in the area of cropland in the very low risk class for water erosion, changing from 67% to 90% between 1981 and 2006 (Table 8-2). Tillage erosion was negligible in the moderate to very high risk classes. The change for tillage erosion in the very low risk class was from 34% to 41% (Table 8-4). The cropland in low risk class showed a decrease of 23% to 1% for water erosion, which moved to the very low risk class, and 66% to 59% for tillage erosion. The large share of area in the low risk class for tillage erosion was the largest of any province.

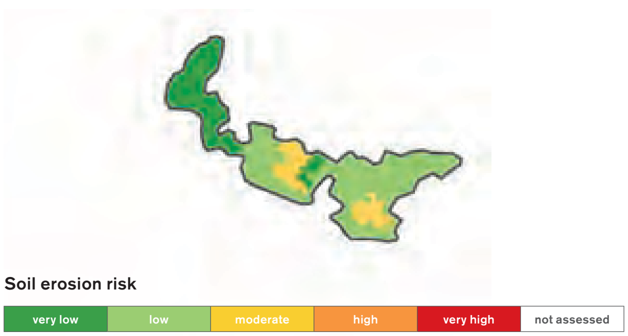


FIGURE 24.9-2 Risk of Soil Erosion on cultivated land in Prince Edward Island under 2006 management practices.

SOIL ORGANIC MATTER (Chapter 9)

From 1981 to 2006 all land had decreasing soil organic carbon (SOC) (Figure 24.9-3). The average rate of loss had decreased from -79 kg ha^{-1} yr^{-1} in 1981 to -67 kg ha^{-1} yr^{-1} in 2006 (Table 9-2). During this period, 27% of land had large SOC decreases (Table 9-1). The relative organic carbon (ROC) was generally in the low to moderate range (average 0.70). One-third of the land has relatively low ROC with continuing loss of SOC and this represents an important soil quality concern (Table 9-4). Perennial to annual crop conversions and land conversions dominate SOC decline.

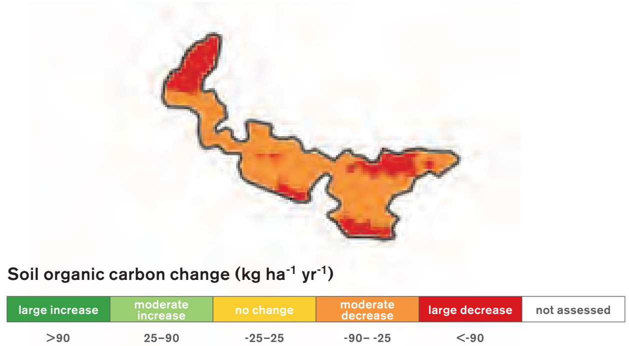


FIGURE 24.9-3 Indicator of soil organic carbon change (kg ha^{-1}yr^{-1}) for Prince Edward Island, 2006.

TRACE ELEMENTS (Chapter 10)

The share of land in the various risk classes in Prince Edward Island did not change appreciably from 1981 to 2006. The majority of land was in the moderate risk class at 86%, with 5% in the low risk class and 9% in the high risk class under 2006 management practices (Table 10-1).

All agricultural land in Prince Edward Island is expected to have an increase in TE of at least 30% above present background concentrations under 2006 populations, crop areas and practices (Table 10-2). There was a shift of land to higher rates of increase as the share expected to have increases in the 50 to 100% changed from 5 to 24% of agricultural land from 1981 to 2006. This increased rate of TE accumulation is mainly due to use of phosphate fertilizers in potato production on sandy textured soils. Over this time period in Prince Edward Island there has also been increase in human and broiler chicken populations contributing to higher TE inputs (Table 10-5).

Water Quality

NITROGEN (Chapter 12)

12.1 Residual Soil Nitrogen (RSN)
In 2006 all the agricultural land in Prince Edward Island was in the very high RSN class (Table 12.1-1). This represents a shift from the low and moderate classes, which together accounted for 100% of farmland in 1981.

The increase in N inputs in PEI from 88.3 kg N ha^{-1} in 1981 to 145 kg N ha^{-1} in 2006 was due to a near doubling of both fertilizer inputs and inputs from N fixation by legume crops. The rate of N output, however, did not keep pace with N inputs. Over the 25-year period, N outputs increased from 64.1 kg N ha^{-1} in 1981 to 79.6 kg N ha^{-1} in 2006 (Table 12.1-2).

12.2 Indicator of Risk of Water Contamination by Nitrogen (IROWC-N)
Similar to the other Atlantic Provinces, the risk of water contamination by N in Prince Edward Island increased very sharply between 1981 and 2006 (Table 12.2-2, Figure 12.2-2 and

12.2-3). The proportion of farmland area in the very low and low risk classes decreased from 96% to 0%. The moderate class changed from 4% in 1981 to a high of 69% in 1986 to 0% in 2001 and 2006, while the proportion of land in the high and very high risk classes increased from 0% to 100% (Figure 24.9-4).

The wet over-winter climate of Prince Edward Island (average over-winter precipitation: 753 mm, Table 12.2-3) results in high and variable over-winter drainage estimates (average: 333 mm, Table 12.2-3). The doubling of the over-winter N losses (from 11 kg N ha^{-1} in 1981 to 38.5 kg N ha^{-1} in 2006) and the sharply increased N concentrations (Figure 12.2-5) were mainly in response to the more than doubling of the RSN estimates.

While the Prince Edward Island estimates have not been verified by direct measurements, there is evidence to suggest that nitrate levels are continuing to rise in both groundwater and surface water (Somers et al., 1999; Young et al., 2002). Well-water nitrate concentrations measured between 2000 and 2005 varied mostly from 3 to 10 mg N L^{-1}. Similarly, Reynolds et al. (1995) report that nitrate levels in tile drainage water from potato fields in Prince Edward Island often exceed 10 mg N L^{-1}.

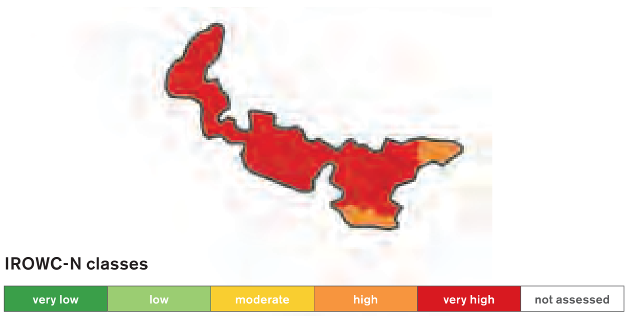


FIGURE 24.9-4 Risk of water contamination by nitrogen in Prince Edward Island under 2006 management practices.

PHOSPHORUS (Chapter 13)

Indicator of Risk of Water Contamination by Phosphorus (IROWC-P)

Out of the five watersheds in Prince Edward Island, only the Wilmot watershed (38% of PEI farmland) is at moderate risk (Figure 24.9-5). The Wilmot watershed is mainly cropped with intensive potato cultivation where the P-Source pressure is high (Figure 13-7). Additionally, there is a relatively high quantity of mineral P fertilizer (~25 kg P ha^{-1}) used in comparison to the Eastern Canada average of ~7 kg P ha^{-1}. In 2006, 46% of the total farmland was in the high P-Source class (Table 13-2) and during the past 25 years, 3 of the 5 watersheds moved to a higher P-source level.

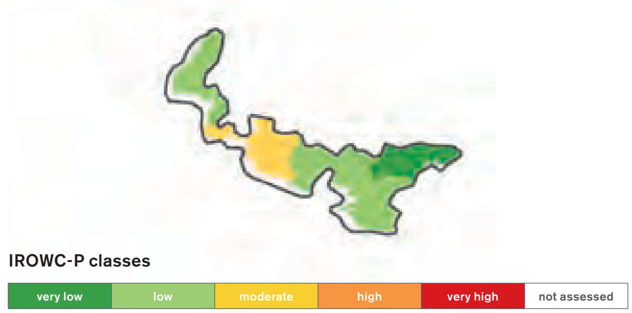


FIGURE 24.9-5 Risk of water contamination by phosphorus in agricultural watersheds in Prince Edward Island under 2006 management practices.

COLIFORMS (Chapter 14)

Indicator of Risk of Water Contamination by Coliforms (IROWC-Coliform)

The 2006 IROWC-Coliform assessment in Prince Edward Island showed essentially very low and low risk values for the five watersheds (Figure 14-2) and this was constant from 1981 to 2006 (Table 14-1). During the 25-year period, pasture declined significantly, the cattle population declined, and swine and poultry populations increased.

PESTICIDES (Chapter 15)

Indicator of Risk of Water Contamination by Pesticides (IROWC-Pest)

In 2006, most cropland was at low (27%) to moderate (60%) risk of contaminating waters with pesticides (Table 15-2; Figure 15-2). This represents an increased risk from 1981 when 96% of cropland was in the very low to low risk class. Although the most significant driver of this increased risk is the increased amount of pesticides applied, it is also influenced by the number of runoff events. In 2006, even though a large proportion of land received high pesticide application (Table 15-4), no cropland was at high or very high risk of contaminating water with pesticides (Table 15-2) because of the generally low number of runoff events (Table 15-3).

Air Quality and Greenhouse Gases

GREENHOUSE GASES (Chapter 16)

Compared to other provinces, agricultural production in each of the Atlantic Provinces is small. Therefore, Newfoundland and Labrador, Prince Edward Island, Nova Scotia and New Brunswick have been grouped together and their agricultural GHG emissions are presented as a single region. Net GHG emissions in the Atlantic Provinces have increased slightly from 1.4 to 1.6 Mt CO_2e between 1981 and 2006 (Figure 24.9-6, Table 16-1). A reduction in the population of dairy cows and beef cattle has resulted in a small decrease in CH_4 emissions from 0.7 to 0.6 Mt CO_2e. Although manure nitrogen has declined as well, increases in nitrogen fertilizer and crop residue nitrogen have resulted in nearly constant N_2O emissions at 0.7 Mt CO_2e. Similar to Quebec, conversion of perennial cropping systems to annual cropping systems in the Atlantic Provinces have resulted in an increase in CO_2 emissions from 0.1 to 0.2 Mt CO_2.

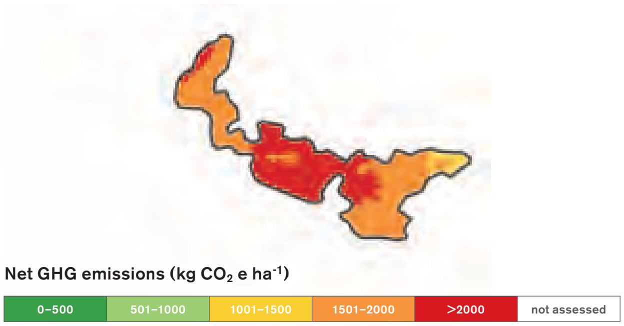


FIGURE 24.9-6 Agricultural net greenhouse gas emissions in Prince Edward Island, 2006.

AMMONIA (Chapter 17)

Ammonia emissions in Prince Edward Island account for less than 1% of national emissions from agriculture. The beef sector contributes the largest amount at 32% of provincial emissions with the remaining emissions contributed almost equally from dairy, swine and fertilizers (Table 17-2). Emissions from poultry contributed only 2%. There was no estimated change in emissions between 2001 and 2006. The share of land in the high and very high classes was stable at 95% in 2001 and 2006 (Figure 24.9-7, Table 17-1).

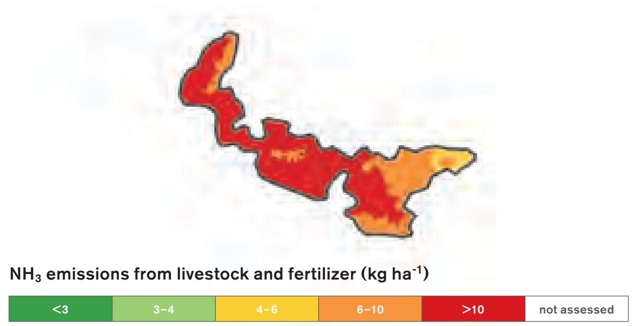


FIGURE 24.9-7 Total ammonia emissions per hectare of agricultural land in Prince Edward Island in 2006 from major livestock sectors and fertilizer.

PARTICULATE MATTER (Chapter 18)

Agricultural PM emissions decreased by 20% for TSP, 16% for PM_{10} and 14% for $PM_{2.5}$ over the 1981 to 2006 period (Table 18-1). PM emissions from land preparation contributed approximately 73% for TSP, 54% for PM_{10} and 66% for $PM_{2.5}$ of the total agricultural PM emissions. Reduced emissions were the result of an increase in conservation tillage and no-till practices and a decrease in the area of summerfallow. Nonetheless, there was a slight increase in PM emissions from animal-feeding operations over the last 25 years. Prince Edward Island has shown improvements in PM emission intensity over the 25 year period.

24.10 Newfoundland and Labrador

Summary

Agriculture makes up only 0.1% of Newfoundland and Labrador's land area, 26% of which is cultivated land, 35% of which is pasture and the rest is considered all other land (Table 24.10-1). The primary agricultural output in Newfoundland and Labrador is dairy, followed by poultry and eggs. Newfoundland and Labrador has had an increase in farmland since 1981, as well as an increase in conventional tillage which indicates an increase in intensity. The increased intensity may explain the increase in risk of erosion, and the reduction of soil carbon. Soil cover has increased between 1981 and 2006, and the risk of soil contamination by trace elements is low, indicating an improving condition on agricultural land. The risk to water quality by pesticides is improving, however the risk of water contamination by nitrogen, phosphorus and coliforms has increased since 1981. The low livestock population in Newfoundland and Labrador has resulted in reduced emissions of ammonia from agriculture, however agricultural greenhouse gas emissions for the Atlantic provinces has increased between 1981 and 2006.

TABLE 24.10-1 Summary of agricultural statistics in Newfoundland and Labrador, 2006

Land Statistics (hectares (ha))	
Total area	40.5 million ha
Total land area	37.4 million ha
Total farm area	36,000 ha
Cultivated land	26%
Pastureland	35%
Other land	39%
Average farm area	65 ha
Farm Characteristics	
Total # of farms	588
Total # of families	360
Total # of operators	710
Average age of operators	52
Major Agricultural Outputs	
Dairy	$39 million
Poultry & eggs	$12 million
Floriculture & nursery	$8 million
Vegetables	$3 million
Cattle & calves	$2 million
Livestock Population (number of animals)	
Poultry	1.6 million
Cattle and calves	12,000
Pigs	2,000
Dairy cows	6,000
Farm Income	
Total net cash income	$4 million
Total cash receipts	$95 million
Total operating expenses	$91 million
Distribution of farms by revenue class	
Less than $10,000	37%
$10,000 to $49,000	30%
$50,000 to $100,000	9%
More than $100,000	24%
Food and Beverage Industry	
Total # of establishments	117
Total value of shipments	N/A
Food Processing	$734 million
Seafood products	70%
Other food	30%
Beverages	N/A
International Trade Statistics	
Trade balance	$-13 million
Exports	
Total agricultural exports	$4 million
Bulk	0%
Intermediate	41%
Consumer-oriented	59%
Major export markets	
United States	$1,792,000
Denmark	$583,000
France	$314,000
St-Pierre-Miquelon	$291,000
Germany	$231,000
Imports	
Total agricultural imports	$16 million
Bulk	0%
Intermediate	1%
Consumer-oriented	99%

Farm Land Management

AGRICULTURAL LAND USE (Chapter 4)

Total farmland increased by 3,000 hectares between 1981 and 2006 (Figure 24.10-1). Cropland area doubled, pasture area declined and all other land area increased (Table 4-1). Forages were the dominant crop throughout the period. Cereal grains, oilseeds and pulse crops constituted 1% or less of cropland throughout the 25 years, while corn increased, potato area declined and other crops increased (Table 4-2). Newfoundland and Labrador was the only province in which the proportion of cropland under conventional tillage increased, while conservation tillage and no-till each declined (Table 4-3). The cattle population in Newfoundland and Labrador expanded, pigs almost disappeared, poultry numbers increased, sheep and goats and horses declined (Table 4-4).

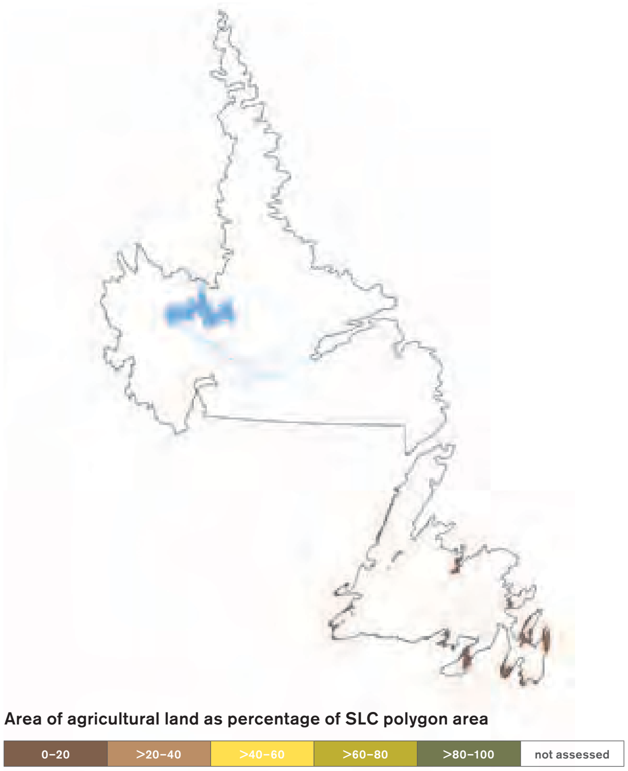


FIGURE 24.10-1 Proportion of agricultural land in Newfoundland and Labrador, 2006.

FARM ENVIRONMENTAL MANAGEMENT (Chapter 5)

Environmental Farm Plans (EFP) had been completed for 40% of producers in the Atlantic provinces, with another 10% with EFPs under development in 2006 (Statistics Canada, 2007). In the Atlantic region, 43% of producers maintained a setback distance from waterways and 20% maintained a setback around permanent wetlands. In the Atlantic provinces, 4% of producers that applied liquid manure applied it by direct injection, and 43% broadcast and incorporated it. 48% broadcasted but did not incorporate liquid manure, indicating improvements can be made. 23% of grazing livestock had no access to surface water in the Atlantic provinces in 2006, and 24% had only limited access, which is a good practice to reduce risk of water contamination by nutrients and coliforms.

SOIL COVER (Chapter 6)

Newfoundland and Labrador had an overall 8% increase in soil cover days between 1981 and 2006; however, changes between Census-years were erratic (Table 6-1). Driving forces of change in soil cover in Newfoundland and Labrador are difficult to assess due to the relatively small number of farms and amount of farmland, as well as fluctuations in areas reported in the Census of Agriculture. For example, total farmland area increased from 1981 to 1991 and has been declining since then, whereas cropland in the province has been increasing steadily since 1981. The proportion of cropland under conservation and no-till fell from 1991 to 1996, rose in 2001 and then fell again in 2006. However, an increase in silage corn and an increase in nursery crops between 1981 and 2006 have influenced soil cover rates to fall, while decreases in potato and vegetable areas, as well as increases in perennial crops and cereal grains have led to an increase in soil cover days. In 2006 Newfoundland and Labrador had a relatively low percentage of farmland in the very high soil cover class (23%), but 63% was in the high soil cover class (Table 6-2). The moderate and low soil cover areas occur in the Avalon Peninsula, where some corn silage and cereal grains are grown.

WILDLIFE HABITAT (Chapter 7)

In 2006, average provincial habitat capacity for breeding and feeding (HC_{bf}) was moderate with 64% of farmland in the moderate HC_{bf} category (Table 7-1). Over 20 years, HC_{bf} decreased significantly with declines on 64% of farmland (Table 7-2). These changes were reflected in a major shift of land rated as high or very high to moderate changing the overall provincial HC_{bf} rating from high to moderate from 1986 to 2006.

Agricultural land occupies a relatively small percentage of total land area in Newfoundland and Labrador and its influence on wildlife should be interpreted as a minor component of the overall landscape. On farmland, the most significant contributing factor to a decrease in HC_{bf} was a shift in the share of agriculture land from natural and semi-natural habitat to cover types of less value to wildlife, most notably tame hay which increased its share of farmland from 1981 to 2006.

In 2006, provincial habitat capacity for wintering (HC_w) was high with 88% of farmland in the high and very high categories and no land in the low or very low categories (Table 7-3). The relatively high percentage of all other lands and unimproved pasture were the main contributors to high HC_w in Newfoundland and Labrador.

Soil Health

SOIL EROSION (Chapter 8)

Newfoundland and Labrador trends in soil erosion are difficult to interpret owing to its small area of cropland. The amount of land with very low erosion risk in this province decreased from 46% to 40% between 1981 and 2006 with a considerable share of cropland area in the higher risk classes (Figure 24.10-2, Table 8-1).

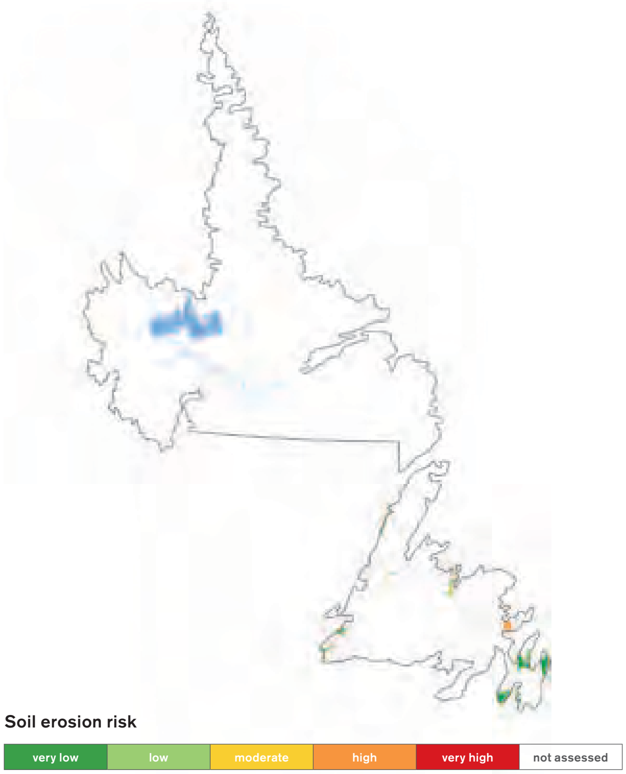


FIGURE 24.10-2 Risk of Soil Erosion on cultivated land in Newfoundland and Labrador under 2006 management practices.

SOIL ORGANIC MATTER (Chapter 9)

Soil organic carbon (SOC) has been mostly decreasing from 1981 to 2006 (Figure 24.10-3, Table 9-1). Consistent with the average, rates of decrease have gone from -90 kg ha^{-1} yr^{-1} in 1981 to -161 kg ha^{-1} yr^{-1} in 2006 (Table 9-2). Much of the decrease has been due to forest clearing. However, likely because many of the soils are relatively recently broken from forest, the relative organic carbon (ROC) is relatively high (mean value in 2006 of 0.86). Hence, these relatively high rates of SOC decline are less of a concern generally than they would be elsewhere in Atlantic Canada where ROC is often much lower. Nevertheless, there needs to be concern about the loss of SOC, especially on soils on sloping land that are also subject to erosion. In total, 17% of the soils have the combination of low and very low ROC and declining SOC (Table 9-4).

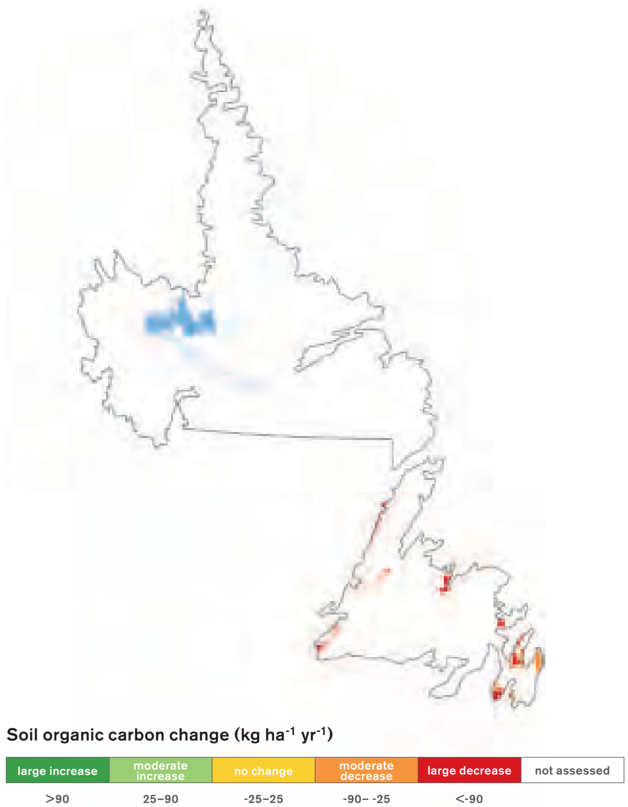


FIGURE 24.10-3 Indicator of soil organic carbon change (kg $ha^{-1}yr^{-1}$) for Newfoundland and Labrador, 2006.

TRACE ELEMENTS (Chapter 10)

There appeared to be some improvement in the risk of TE contamination in Newfoundland and Labrador from 1981 to 2006. The low risk class increased from 56% to 67% while the high risk classes decreased from 12 to 5% and the very high risk class decreased from 11 to 6% (Table 10-1).

Fifty-seven percent of agricultural land in Newfoundland and Labrador is expected to have an increase in TE of at least 30% above present background concentrations for 2006 populations, crop areas and practices (Table 10-2). There was a shift of land to lower rates of increase as the share expected to have TE increases of 30 to 50 % changed from 57 to 47% and the share expected to have increases in the 50 to 100% changed from 25 to 9% of agricultural land from 1981 to 2006. Over this time period in Newfoundland and Labrador there has been an increase in human population, a decrease in beef cattle (but increase in dairy), a decrease in swine and a decrease in broiler chickens (Table 10-5).

Water Quality

NITROGEN (Chapter 12)

12.1 Residual Soil Nitrogen (RSN)

In 2006 Newfoundland and Labrador had 14% of its agricultural land in the very low RSN category and 53% was in the very high RSN class (Table 12.1-1). This represents a significant shift to the higher RSN classes from 1981, when 42% was in the very low RSN class and 17% was in the very high RSN class.

In Newfoundland and Labrador, N inputs doubled over 25 years, from 50.7 kg N ha^{-1} in 1981 to 100.7 kg N ha^{-1} in 2006. This was due to increased fertilizer application and increased manure application, as well as a 2.7-fold increase in N fixation by legume crops (Table 12.1-2).

12.2 Indicator of Risk of Water Contamination by Nitrogen (IROWC-N)

Overall, the risk of water contamination by nitrogen has increased between 1981 and 2006. The amount of farmland in the high and very high risk classes increased from 27% in 1981, peaking at 87% in 2001, and declining to 75% in 2006 (Figure 24.10-4, Table 12.2-2).

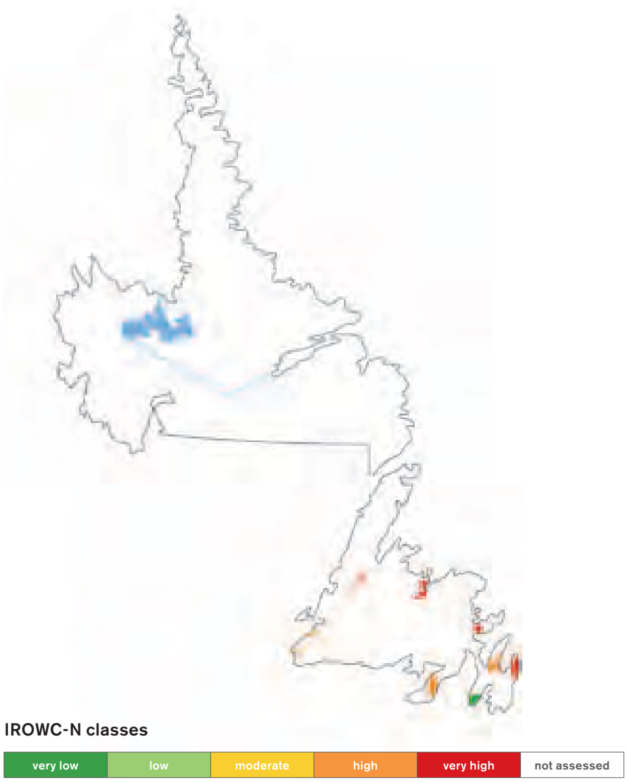


FIGURE 24.10-4 Risk of water contamination by nitrogen in Newfoundland and Labrador under 2006 management practices.

In Newfoundland and Labrador the mean over-winter drainage was 414 mm (Table 12.2-3) and spring soil water contents were always close to field capacity. The increase of the over-winter N losses (Figure 12.2-4) and the increased N concentrations (from 4.0 to 7.8 mg N L^{-1}) was mainly in response to the more than doubling of the RSN values.

PHOSPHORUS (Chapter 13)

Indicator of Risk of Water Contamination by Phosphorus (IROWC-P)

The province of Newfoundland and Labrador is characterized by the absence of agricultural watersheds with more than 5% farmland (Figure 13-1). Still, 74% of the farmland showed very high P-Source class (Figure 13-6) primarily due to the relatively high amount of manure P application (~20 kg P ha^{-1}). Notably, the manure P and the mineral P fertilizer have both decreased by 22 % since 1996

COLIFORMS (Chapter 14)

Indicator of Risk of Water Contamination by Coliforms (IROWC-Coliform)

The province of Newfoundland and Labrador is characterized by the absence of agricultural watersheds with more than 5% farmland (Figure 14-2). Nevertheless, the coliform source risk within the relatively small agricultural land has increased by two classes (Figure14-7). This is a result of a pasture land decrease and a doubled dairy cattle herd during the 25-year period (1981–2006).

PESTICIDES (Chapter 15)

Indicator of Risk of Water Contamination by Pesticides (IROWC-Pest)

Newfoundland has the smallest agricultural land base in Canada and the lowest mass of pesticide applied (Figure 15-3). From 1981 to 2006, risk of contaminating water has generally decreased with most cropland in the very low risk class. In 2006, only 1% of cropland was in the high risk category (Table 15-2). Newfoundland has had minimal movement among the risk classes and some areas have moved to a lower risk class (Figure 15-5).

Air Quality and Greenhouse Gases

GREENHOUSE GASES (Chapter 16)

Compared to other provinces, agricultural production in each of the Atlantic Provinces is small. Therefore, Newfoundland and Labrador, Prince Edward Island, Nova Scotia and New Brunswick have been grouped together and their agricultural GHG emissions are presented as a single region. Net GHG emissions in the Atlantic Provinces have increased slightly from 1.4 to 1.6 Mt CO_2e between 1981 and 2006 (Figure 24.10-5, Table 16-1). A reduction in the population of dairy cows and beef cattle has resulted in a small decrease in CH_4 emissions from 0.7 to 0.6 Mt CO_2e. Although manure nitrogen has declined as well, increases in nitrogen fertilizer and crop residue nitrogen have resulted in nearly constant N_2O emissions at 0.7 Mt CO_2e. Similar to Quebec, conversion of perennial cropping systems to annual cropping systems in the Atlantic Provinces have resulted in an increase in CO_2 emissions from 0.1 to 0.2 Mt CO_2.

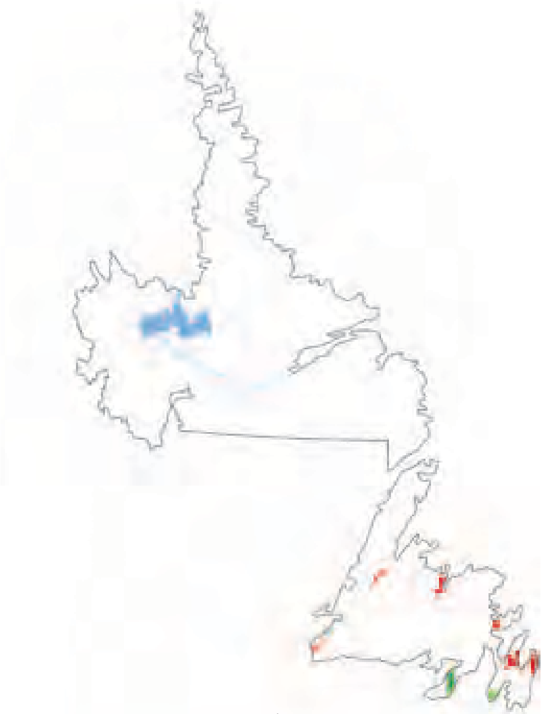


FIGURE 24.10-5 Agricultural net greenhouse gas emissions in Newfoundland and Labrador, 2006.

AMMONIA (Chapter 17)

Ammonia emissions for Newfoundland and Labrador are very small in relation to the rest of Canada. Emissions are mainly the result of dairy (62%), poultry (17%) and beef (11%) (Table 17-2). Emissions are estimated to have declined by almost 19% from 2001 to 2006; however, due to the limited extent of agriculture in Newfoundland and Labrador these estimates are prone to error (Figure 24.10-6, Table 17-1).

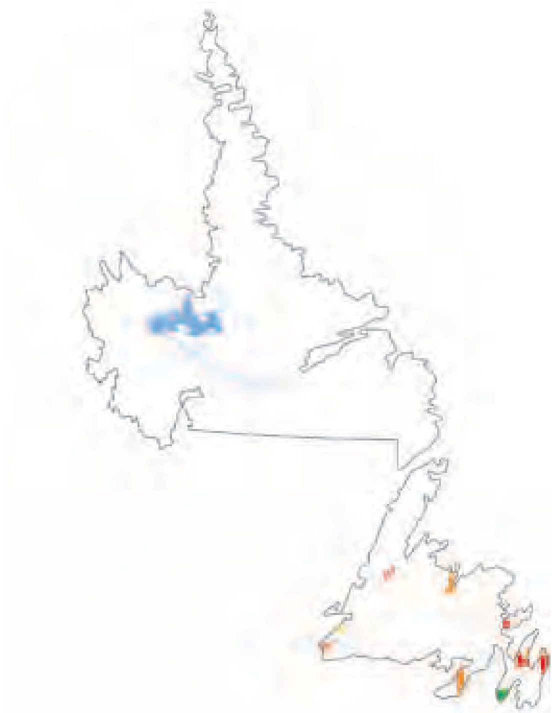


FIGURE 24.10-6 Total ammonia emissions per hectare of agricultural land in Newfoundland and Labrador in 2006 from major livestock sectors and fertilizer.

25 Glossary

Abatement: A lessening or reduction.

Agricultural Policy Framework (APF): An agreement between Government of Canada and the provincial and territorial governments on a policy framework composed of five elements: food safety and food quality, environment, science and innovation, renewal and business risk management. The policy was in effect from 2003 to 2008.

Agri-environmental indicator: A measure of a key environmental condition, risk or change resulting from agriculture; or a measure of management practices used by producers.

Agroecosystem: Species and ecosystems under agricultural management; an open, dynamic system connected to other ecosystems through the flow of energy and the transfer of material such as crops, pastures, livestock, other flora and fauna, air, soil and water.

Algal blooms: A rapid growth of algae in an aquatic system often resulting from excessive nutrient levels.

All other land: *Census of Agriculture* category of agricultural land use denoting land occupied by farm buildings, barnyards, gardens, greenhouses, mushroom houses, idle land, woodlots, sugar bushes, tree windbreaks, bogs, marshes, sloughs, etc.

Ammonia: A compound of nitrogen and hydrogen (NH_3) formed naturally when bacteria decompose nitrogen-containing compounds, especially urea and uric acid, in manures. Emissions of ammonia can be a problem in enclosed livestock facilities and can react with other compounds to produce fine particulate matter in the ambient air. Ammonia is a component of some fertilizers and an important plant nutrient. It can also be used as a refrigerant in the Food and Beverage Industry.

Anaerobic: Characterized by the absence of oxygen.

Anaerobic digester: The facility or containment system in which micro-organisms break down biodegradable material in the absence of oxygen. Often used to treat waste water, reduce emissions of GHG to the atmosphere and capture methane to be used as a source of energy.

Anthropogenic: Involving the impact of humans on nature; induced or altered by the presence or activities of humans.

Arable land: Land that can be cultivated.

Banding liquid fertilizer: An application of liquid fertilizer in strips, usually to a bed or seed row.

Bare soil: Soil not covered by a crop canopy or crop residue and exposed to the elements.

Beneficial management practices: Methods, measures or practices designed to minimize or prevent environmental risks and negative effects (including pollution) on the environment.

Biodiversity: The variety of life forms on earth and the natural processes that link and maintain them. Biodiversity has three components: ecosystem diversity, species diversity and genetic diversity. Also called biological diversity.

Biofuel: A gaseous, liquid or solid fuel derived from a biological source, such as methane, ethanol, rapeseed oil or fish liver oil.

Biofilters: A filter composed of biological material used to capture and biologically degrade pollutants.

Biogas: A gas produced by the biological breakdown of organic matter in the absence of oxygen. Often captured and used as an energy source.

Biomass: Total mass of a species or group of species per unit area; or the total mass of all the species in a community.

Biophysical models: Models that represent the interaction of biological systems with their physical environment.

Bioplastics: Biodegradable plastics made from natural resources such as starch, cellulose and proteins.

Bioremediation: Process of restoring a natural area through the use of living organisms (e.g. plants or bacteria).

Biosolid: The soil-like residues of materials that are removed from sewage during treatment processes. During treatment, bacteria and other organisms break sewage down into simpler forms of organic matter which, combined with bacterial cell masses, settle to form biosolids.

Biota: All the living organisms of a particular place or time.

Biotechnology: In agriculture, refers to the science and methods of genetic engineering used to produce new varieties of crops or livestock that have superior traits.

Black soil: Grassland soil type occurring on the Canadian Prairies, characterized by a very dark coloured surface layer. These soils are associated with cool, relatively moist climatic conditions.

Bovine spongiform encephalopathy: Commonly known as "mad cow disease," bovine spongiform encephalopathy (BSE) is a progressive, incurable disease that affects the central nervous system of cattle.

Brown soil: Grassland soil type occurring on the semi-arid Canadian Prairies, characterized by a brown coloured surface layer. These soils are associated with the dry climatic conditions of the southern prairies.

Carbon (C): Element present in all materials of biological origin.

Carbon dioxide (CO_2): Major greenhouse gas produced through the decomposition of organic matter in soils under oxidizing conditions; also produced by the burning of fossil fuels.

Carbon dioxide equivalent (CO_2e): Expression of the effectiveness of a gas to produce a greenhouse effect in the atmosphere in terms that compare it with that of carbon dioxide.

Carbon sequestration: Biochemical process by which carbon is transferred from the atmosphere by living organisms, including plants and micro-organisms to another carbon pool such as soils or forests with the potential to reduce atmospheric carbon dioxide levels.

Carbon sink: A system that accumulates and stores carbon removed from the atmosphere for an indefinite period. Soil organic matter is regarded as a carbon sink.

Census of Agriculture: National agricultural Census undertaken every five years to compile information on farm structure and economics, crops and land use as well as livestock.

Clay soil: Soil material that contains 40% or more clay, less than 45% sand and less than 40% silt.

Composting: The controlled biological decomposition of a mixture of organic residues often comprising soil, which is kept in piles and periodically moistened.

Connectivity factors: Values used in the IROWC-P and IROWC-Coliforms calculation that represent pathways for P and Coliforms to move across the land into water bodies.

Conservation tillage: Any tillage sequence designed to minimize or reduce the loss of soil and water; operationally, a tillage or tillage and planting system that leaves 30% or more crop residue cover on the soil surface.

Continuous cropping: Practice of growing crops every growing season with no fallow years or growing the same crop on the same land year after year.

Contour cultivation: Cultivation on the contour of the land, rather than up and down slope, to reduce soil erosion, protect soil fertility and use water more efficiently.

Conventional tillage: Primary and secondary tillage operations normally performed in preparing a seedbed, usually resulting in less than 30% crop residue cover on the soil surface.

Cover crop: Secondary crop grown after a primary crop or between rows of the primary crop to provide a protective soil cover that will minimize soil erosion and leaching of nutrients.

Crop residue: Plant material remaining after harvesting, including leaves, stalks and roots.

Crop rotation: Agricultural practice that consists of growing two or more crops or crop types on the same land in consecutive years in a repetitive pattern. Rotation is usually done to increase soil fertility, reduce pest populations and sustain agricultural production in future years.

Cropland: *Census of Agriculture* category of agricultural land use denoting the total area on which field crops, fruits, vegetables, nursery crops and sod are grown.

Cultivated land: Land tilled and used to grow crops; includes land left fallow.

Cyanobacteria: Also known as blue-green algae, these are bacteria that are often associated with algal blooms in aquatic environments.

Dark brown soil: Grassland soil type occurring on the Canadian Prairies, characterized by a dark brown coloured surface layer. These soils are associated with climatic conditions intermediate between those for the Brown and Black soils of the prairies.

Decomposition: Breakdown of complex organic matter into simpler materials by micro-organisms.

Denitrification: A chemical process in which nitrates in the soil are reduced to molecular nitrogen, which is released to the atmosphere.

Drainage: Procedure carried out to improve the productivity of agricultural land by enhancing the removal of excess water from the soil by means such as ditches, drainage wells and subsurface drainage tiles.

Dryland: Type of farming that depends exclusively on natural precipitation and soil moisture to supply water to crops (i.e. non-irrigated). Sometimes called “rainfed”.

Ecodistrict: A subdivision of an ecoregion characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies and fauna. See ecoregion.

Eco-efficiency: A process designed to produce more or higher-value products or services while using fewer inputs such as material and energy, in turn minimizing environmental impacts.

Ecological or ecosystem services: Services provided by natural systems that result in a benefit for society. Examples of ecological services include nutrient cycling, air and water purification, crop pollination and climate control.

Ecoregion: Mapping unit in Canada’s ecological classification system. A subdivision of a larger ecological classification unit characterized by distinctive regional ecological factors, including climate, physical geography, vegetation, soil, water and fauna.

Ecosystem: A unit of land or water comprising populations of organisms considered together with their physical environment and the processes linking them.

Ecozone: Largest mapping unit in Canada's ecological classification system. An ecozone is an area of the earth's surface representing large and very generalized ecological units characterized by interactive and adjusting abiotic and biotic factors. Agriculture is carried out in seven of Canada's 15 ecozones.

Effluent: Any liquid or gaseous waste material that is discharged from a system into the environment or into a collecting system (e.g. sewage).

Emission factor: An estimate or statistical average of the rate at which a contaminant is released to the atmosphere through some activity (e.g. farming, burning of fuel), divided by the level of that activity. Given an emission factor and a known activity level, a simple multiplication yields an estimate of the actual emission.

Energy input: Non-renewable energy (not including sunlight) that is used in agricultural systems, for example, to power vehicles and farm machinery, to manufacture equipment and chemicals (fertilizer, pesticides) and to manage a farmhouse.

Energy output: Energy embodied in the products of agriculture that are used or consumed by humans.

Enteric bacteria: Group of bacteria that live in the intestinal tracts of humans and other animals.

Environmental farm management: Managing a farm with a view to environmental sustainability. See beneficial management practices.

Environmental farm plan: Plan outlining the environmental concerns related to a given farm and the steps required to address them. This type of plan is prepared and implemented by farmers on a voluntary basis.

Environmental sustainability: Management approach that seeks to protect natural resources and ensure they are available for future generations. This approach stresses the importance of ecological integrity in maintaining earth's life-support systems.

Erodibility: The susceptibility of a soil to erosion.

Erosivity: Measure of the predictable capacity of water, wind, tillage or other agents to cause erosion.

Ethanol: Liquid that is produced chemically from ethylene or biologically from the fermentation of various sugars found in agricultural crops and cellulose residues from crops or wood. Depending on how it is produced, it can be used as a substitute for fossil fuels and thus reduce greenhouse gas emissions. Also known as ethyl alcohol or grain alcohol.

Eutrophication: The process by which a body of water acquires a high concentration of plant nutrients, especially nitrates and phosphates. This nutrient enrichment promotes the excessive growth of algae, which can lead to depletion of dissolved oxygen and kill aquatic organisms such as fish.

Evapotranspiration: Movement of water into the atmosphere by evaporation from the soil and transpiration from plants.

Fermentation: A biochemical reaction that breaks down complex organic substances, especially carbohydrates, into simpler materials (ethanol, carbon dioxide, and water), usually occurring in the absence of oxygen.

Fertilizer: Any organic or inorganic material, either natural or synthetic, used to supply elements (such as nitrogen, phosphorus and potassium) essential for plant growth.

Fertilizer injection: Placement of fertilizer below the surface of the soil to minimize nutrient loss through volatilization and runoff.

Forage: Grass or legume crop grown to provide livestock feed; may be stored dry as hay or under moist conditions as silage, ploughed into the soil as green manure, or grazed.

Fossil fuel: Carbon-based remains of organic matter that has been geologically transformed into coal, oil or natural gas. Combustion of these substances releases large amounts of energy. Fossil fuels are used to supply a large proportion of human energy needs.

Fumigant: Any pest control substance that is a vapour or gas, or forms a vapour or gas on application.

Global Warming Potential (GWP): Measure of the ability of a greenhouse gas to trap radiation and thus contribute to global warming (rise in global temperatures).

Grassed waterways: Natural or constructed channel, usually broad and shallow, covered with erosion-resistant grasses, used to convey surface water from or across cropland along natural depressions.

Greenhouse gas: Greenhouse gases absorb and trap heat in the atmosphere and cause a warming effect on earth. Some occur naturally in the atmosphere, while others result from human activities. Greenhouse gases include carbon dioxide, water vapour, methane, nitrous oxide, ozone, chlorofluorocarbons, hydrofluorocarbons and perfluorocarbons.

Greenhouse gas offset payment: A payment or credit for verified greenhouse gas emissions reductions or removals by eligible projects.

Ground water: Portion of water below the soil surface that has the water table as its upper boundary. This water supplies wells and springs.

Habitat quality: Fitness of a habitat to provide for the needs of a species.

Humid region: Pertaining to a climate in which the lower limit of annual precipitation is 50 cm in cool regions and the upper limit is 150 cm in hot regions.

Inorganic: Pertaining to a compound that is not organic, usually of mineral origin.

Integrated modeling: An interdisciplinary approach that combines science based models of agricultural response with economic models in order to provide economic and environmental analysis for policy development and evaluation.

Integrated pest management: Decision-making process that uses all the necessary techniques to suppress pests effectively, economically and in an environmentally sound manner. Integrated pest management, or IPM, is an ecologically based strategy that relies on natural mortality factors such as natural enemies, weather and crop management, and applies control measures that disrupt these factors as little as possible.

Invasive alien species: Alien (non-native) species (plant, animal or micro-organism) whose introduction causes or is likely to cause economic or environmental harm or harm to human health.

Invasiveness: Ability of a plant to spread beyond its introduction site and become established in new locations where it may adversely affect other organisms.

Irrigation: Artificial watering of crops by various methods.

Kyoto Protocol: An international agreement linked to the United Nations Framework Convention on Climate Change that sets targets for reducing greenhouse gas (GHG) emissions .

Leaching: Process by which soluble substances are dissolved and transported through the soil by percolating water.

Life cycle assessment: Technique to assess the environmental aspects and potential impacts associated with a product, process or service by: compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential environmental impacts associated with all identified inputs and releases; and interpreting the results to aid in making a more informed decision.

Loamy sand soil: Soil material containing a mixture of sand, clay and silt in which sand particles are predominant, followed by clay particles. For example, a soil sample consisting of 90% sand and 10% clay falls into the loamy sand soil category. Note that this soil contains less clay than a sandy loam soil (see below).

Methane (CH_4): Gas produced through anaerobic decomposition of waste in landfills, animal digestion, decomposition of manure, production and distribution of natural gas and oil, coal production and incomplete fuel combustion. It is one of the three main agricultural greenhouse gas (with CO_2 and N_2O).

Microclimate: The climate of a small area resulting from modification of the general climate by local differences in elevation or exposure.

Minimum tillage: Minimum use of tillage necessary to meet crop production requirements under existing soil and climatic conditions, usually resulting in fewer tillage operations than for conventional tillage.

Moldboard plough: Tillage implement used to break up soil with partial to complete inversion of soil.

Native species: Species known to have existed on a site prior to the influence of humans, possibly including long-established exotic species.

Nitrogen (N): Chemical element in most natural organic substances. Also a key crop nutrient and water pollutant in soluble forms such as nitrate; also forms nitrous oxide.

Nitrous oxide (N_2O): Potent, naturally occurring greenhouse gas whose emissions are enhanced by anthropogenic activities such as nitrogen fertilization, crop residue decomposition and farming of organic soils as well as the deposition, storage and application of manure to agricultural land. It is one of the three main agricultural greenhouse gases (with CO_2 and CH_4).

No-till : Procedure by which a crop is planted directly into the soil using a special planter, with no primary or secondary tillage after harvest of the previous crop.

Nutraceutical: Conventional food product that has been modified (potentially by genetic engineering) to provide improved nutritional characteristics and/or pharmaceutical properties.

Nutrient: Substance required by a living organism for proper growth and development. Nitrogen, phosphorus and potassium are key crop nutrients.

Offset payment: A payment or credit for verified greenhouse gas emissions reductions or removals by eligible projects.

Ozone: Naturally occurring gas, formed from normal oxygen. In higher atmosphere, ozone protects the earth by filtering out ultraviolet radiation from the sun.

Particulate matter: Air pollutants composed of minuscule liquid or solid particles temporarily suspended in the atmosphere (e.g. dust, pollen, spores, smoke, organic compounds)

Pathogen: A disease-causing agent.

Pathogens: A biological agent that can cause disease or illness to its host.

Perennial forage: Grasses and legumes that re-grow each spring from the rootstock of plants from the previous growing season.

Permanent cover: Perennial crop that provides vegetative protection to the soil throughout the year. Can be achieved by successive annual or biennial crops in some cases.

Pest: Organism (plant or animal) that is directly or indirectly detrimental to agricultural production.

Pest resistance: A situation in which exposed pests are not affected by a particular recommended application rate of pesticide.

Pesticide: A substance, usually a chemical, that is used to kill or control pests. Pesticides include herbicides, insecticides, fungicides, nematocides, rodenticides and miticides.

pH: An expression of the intensity of the basic or acidic condition of a liquid or of soil generally expressed on a scale ranging from 0 to 14, where values below 7 are acidic, 7 is neutral and values above 7 are considered alkaline.

Phosphorus (P): Chemical element essential for all living organism and a key crop nutrient. Phosphorus can be the cause of eutrophication above a threshold concentration in fresh water .

Photosynthesis: Process by which plants transform carbon dioxide and water into carbohydrates and other compounds using energy from the sun captured by the plants' chlorophyll.

Phytase: An enzyme common in malt that is widely used in the animal feed industry to increase absorption of organic phosphorus from feed and reduce phosphorus releases to the environment.

Polygon: Irregularly shaped, closed delineation on a map; used in the context of mapping units in the *Soil Landscapes of Canada* map series and superimposed on *Census of Agriculture* maps to align soil and landscape data with information on agricultural management practices.

Preferential flow: Process whereby water, soluble substances and compounds such as particulate phosphorus and fecal coliforms move through soil macropores to tile drains and water tables.

Pulse crop: Legume that provides edible seeds, such as beans, peas and lentils.

Redeposition: The addition of a material to the soil after it has been moved from one location to another, usually through natural processes.

Reduced tillage: Tillage operations that involve less soil disturbance than conventional tillage, either through the use of fewer passes or special equipment. Includes minimum tillage.

Refrigerant: The fluid in a refrigeration system that produces cold by changing from a liquid to a vapour and back to a liquid state.

Riparian: Relating to the area at the interface of land and a stream.

Riparian area: Land bordering a stream or other body of water.

Riparian buffer strip: Narrow strip of vegetated land along a watercourse designed to reduce erosion, intercept pollutants, provide habitat for wildlife and address other environmental concerns.

Row cropping: A production system involving crops that are grown in widely spaced rows and that may involve tilling between the rows for weed control, hilling the rows for root protection, or both. Typical row-crops include potatoes, tobacco, vegetables, beans, sugar beets and corn. Usually involves a high level of production per unit area.

Run-off: The portion of precipitation and snowmelt that flows over the land into surface water (e.g. streams, marshes, lakes).

Salinization: Process by which the content of soluble salts increases at the soil surface or within the root zone.

Sandy loam soil: Soil material containing sand, clay and silt, with sand particles being predominant, followed by clay particles. For example, a sample consisting of 70% sand and 10% clay falls into the sandy loam soil category.

Sandy soil: Soil material in which sand particles are very abundant.

Sequestered: Stored separately away. Carbon that is removed from the atmosphere and stored in soil in the form of soil organic matter is said to be sequestered carbon.

Shelterbelt: A barrier of trees, shrubs or other perennial vegetation designed to reduce wind erosion. Also called a windbreak.

Side-banding: Application of fertilizer in the seed row adjacent to but not in direct contact with the seed.

Side-dressing: Fertilizer or other material added to the soil around a growing crop.

Sink: In soils, the capacity to assimilate substances and retain them or subsequently provide them as a source for above- and below-ground vegetative growth.

Sludge: The accumulated settled solids separated from various types of water or wastewater as a result of natural or artificial processes.

Smog: Unhealthy air caused by smoke, chemical fumes or dust formed in the atmosphere.

Soil Landscapes of Canada: National series of broad-scale (1:1 million) soil maps containing information about soil properties and landforms.

Soil organic matter: Carbon-containing material in the soil that derives from living organisms.

Soil structure: Physical properties of a soil relating to the arrangements and stability of soil particles, aggregates and pores.

Soil texture: Relative proportion of the different sizes of mineral particles of less than 2 mm (sand, silt and clay) in soil.

Solid residues: All the material inputs to a process that are not turned into products or by-products. This material is either recycled or becomes waste.

Understanding Mass Units Used to Express GHG Emissions

GRAM	1 gram
KILOGRAM (kg)	1,000 grams
MEGAGRAM (Mg) other name: *Tonne* (t)	1,000,000 grams
GIGAGRAM (Gg) other name: *Thousand tonnes* (kt)	1,000,000,000 grams
TERAGRAM (Tg) other name: *Million tonnes* (Mt)	1,000,000,000,000 grams
PETAGRAM (Pg) other name: *Gigatonne or billion tonnes* (Pt)	1,000,000,000,000,000 grams

Sterilization: The process (mainly by heating) to kill pathogens in food that may be harmful to humans, such as bacteria, viruses, protozoa, molds and heat-resistant bacterial spores.

Strip cropping: Erosion control method consisting of growing crops that require different types of tillage, such as row crops and permanent grass or annual crops and fallow in alternate strips along contours.

Summerfallow: *Census of Agriculture* category of agricultural land use and general term denoting cropland that is not cropped for at least one year, primarily for the purpose of conserving soil moisture, but is managed by cultivating or spraying to control weeds

Suspended particulates: Small particles of solid pollutants in sewage that contribute to turbidity.

Sustainable agriculture: An integrated farming system that will, over the long term, satisfy food and fibre needs, enhance environmental quality, make the most efficient use of resources, sustain the economic viability of farm operations and enhance the quality of life.

Tame pasture: *Census of Agriculture* category of agricultural land use denoting pasture that has been improved by management such as cultivation, drainage, irrigation, fertilization, seeding or spraying. Also referred to as "improved pasture" and "seeded pasture".

Taxonomic relationship: Information about classifying organisms based on how closely related they are.

Temporal scale: A duration or period of time.

Terracing: A soil and water conservation technique consisting of a raised level space supported on one or more sides by a wall or a bank.

Trace element: A chemical substance essential to plant or animal life, but required in very small amounts, e.g. less than 1 ppm in plants.

Volatilization: The conversion of a solid or liquid into a gas.

Watershed: The area of land from which a water body receives water. An area of land that drains water, organic matter, dissolved nutrients and sediments into a lake or stream; the topographic boundary is usually a height of land that marks the dividing line from which surface streams flow in two different directions.

Wetland: Area of land inundated by surface water or groundwater. Under the Canadian Wetland Classification System, wetlands are divided into five classes: bogs, fens, marshes, swamps and shallow waters.

Wildlife: All undomesticated organisms living in the wild, especially animals.

Wildlife habitat: Parts of the natural environment on which an organism depends to carry out its life processes.

Windbreak: A barrier that provides shelter from the wind. Also called a shelterbelt.

Winter cover crop: Crop planted in the fall in order to provide cover and thus curb soil erosion during winter and spring.

26 Contributing Authors

A

Suzanne Allaire
Sciences de l'agriculture et de l'alimentation, Université Laval
Ville de Québec, Québec
Email: suzanne.allaire@fsaa.ulaval.ca

Yves Arcand
AAFC, Food Research and Development Centre
Saint-Hyacinthe, Québec
Email: yves.arcand@agr.gc.ca

B

Murray J. Bentham
AAFC, Saskatoon Research Centre
Saskatoon, Saskatchewan
Email: murray.bentham@agr.gc.ca

Shabtai Bittmam
AAFC, Pacific Agri-Food Research Centre
Agassiz, British Columbia
Email: shabtai.bittman@.agr.gc.ca

Malcolm Black
AAFC (Retired)
Halifax, Nova Scotia
Email: Malcolmw.black@gmail.com

Patrice Bouchard
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: patrice.bouchard@agr.gc.ca

J.A. (Tony) Brierley
AAFC, Lacombe Research Centre
Edmonton, Alberta
Email: tony.brierley@agr.gc.ca

C

Carolyn Callaghan
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: carolyn.callaghan@agr.gc.ca

Con A. Campbell
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: con.campbell@agr.gc.ca

Darrel Cerkowniak
Soil Sciences, University of Saskatchewan
Saskatoon, Saskatchewan
Email: darrel.cerkowniak@usask.ca

Allan J. Cessna
AAFC, Lethbridge Research Centre
Lethbridge, Alberta
Email: allan.cessna@agr.gc.ca

Dick Coote
Consultant
Stittsville, Ontario
Email: dcoote@compmore.net

Michel Cournoyer
Groupe Conseil UDA inc.
Saint-Charles-sur-Richelieu, Québec
Email: mcournoyer@udainc.com

D

Reinder De Jong
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: reinder.dejong@agr.gc.ca

Farida Dechmi
AAFC, Soils and Crops Research and Development Centre
Sainte-Foy, Québec
Email: farida.dechmi@agr.gc.ca

Jean-Thomas Denault
AAFC, Soils and Crops Research and Development Centre
Sainte-Foy, Québec
Email: jean-thomas.denault@agr.gc.ca

Raymond Desjardins
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: ray.desjardins@agr.gc.ca

Craig F. Drury
AAFC, Greenhouse and Processing Crops Research Centre
Harrow, Ontario
Email: craig.drury@.agr.gc.ca

Gail Dyck
AAFC, Agri-Environment Services Branch
Outlook, Saskatchewan
Email: gail.dyck@.agr.gc.ca

J.A. Dyer
Private Consultant
Email: go_my_way@hotmail.com

E

Warren D. Eilers
AAFC, Agri-Environment Services Branch
Saskatoon, Saskatchewan
Email: warren.eilers@agr.gc.ca

F

Annemieke Farenhorst
University of Manitoba
Winnipeg, Manitoba
Email: farenhor@ms.umanitoba.ca

Robert G. Foottit
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: robert.foottit@agr.gc.ca

Catherine A. Fox
AAFC, Greenhouse and Processing Crops Research Centre
Harrow, Ontario
Email: catherine.fox@agr.gc.ca

G

Ravinderpal Gill
AAFC, Strategic Policy Branch
Ottawa, Ontario
Email: raivinderpal.gill@agr.gc.ca

François Granger
Commission de la santé et de la sécurité du travail
Ville de Québec, Québec
Email: francois.granger@csst.qc.ca

Cynthia Grant
AAFC, Brandon Research Centre
Brandon, Manitoba
Email: cynthia.grant@agr.gc.ca

Matt C. Grant
AAFC, Atlantic Food and Horticulture Research Centre
Kentville, Nova Scotia
Email: matt.grant@agr.gc.ca

H

John Harrington
AAFC, Agri-Environment Services Branch
Outlook, Saskatchewan
Email: john.harrington@.agr.gc.ca

Jamie Hewitt
AAFC, Agri-Environment Services Branch
Winnipeg, Manitoba
Email: jamie.hewitt@agr.gc.ca

Edward (Ted) Huffman
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: ted.huffman@agr.gc.ca

J

Steve K. Javorek
AAFC, Atlantic Food and Horticulture Research Centre
Kentville, Nova Scotia
Email: steve.javorek@agr.gc.ca

Jill Jensen
AAFC, Agri-Environment Services Branch
Ottawa, Ontario
Email: jill.jensen@agr.gc.ca

L

Denyse Landry
AAFC, Market and Industry Services Branch
Ottawa, Ontario
Email: denyse.landry@agr.gc.ca

Alexandre Lefebvre
AAFC, Agri-Environment Services Branch
Ottawa, Ontario
Email : alexandre.lefebvre@agr.gc.ca

J. Philip Lemieux
AAFC, Pacific Agri-Food Research Centre
Kamloops, British Columbia
Email: jeffrey.lemieux@agr.gc.ca

Sheng Li
Soil Science, University of Manitoba
Winnipeg, Manitoba
Email: umlis2@yahoo.ca

Lavona Liggins
AAFC, Agri-Environment Services Branch
Kamloops, British Columbia
Email: lavona.liggins@agr.gc.ca

David Lobb
Soil Science, University of Manitoba
Winnipeg, Manitoba
Email: lobbda@ms.umanitoba.ca

M

Robin MacKay
AAFC, Agri-Environment Services Branch
Ottawa, Ontario
Email: robin.mackay@agr.gc.ca

Michèle Marcotte
AAFC, Food Research and Development Centre
Sainte-Hyacinthe, Québec
Email: michele.marcotte@agr.gc.ca

Peter G. Mason
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: peter.mason@agr.gc.ca

Daniel Massé
AAFC, Dairy and Swine Research and Development Centre
Sherbrooke, Québec
Email: daniel.masse@agr.gc.ca

Dominique Maxime
AAFC, Food Research and Development Centre
Saint-Hyacinthe, Québec
Email: dominique.maxime@agr.gc.ca

Brian G. McConkey
AAFC, Semiarid Prairie Agricultural Research Centre
Swift Current, Saskatchewan
Email: brian.mcconkey@agr.gc.ca

D.A.R. (Ross) McQueen
University of Manitoba
Winnipeg, Manitoba
Email: mcqueen@ms.umanitoba.ca

Hugues Morand
AAFC, Agri-Environment Services Branch
Ottawa, Ontario
Email: hugues.morand@agr.gc.ca

N

A. Narjoux
Project Manager at Odotech
Montréal, Québec
Email: anarjoux@odotech.com

O

Owen Olfert
AAFC, Saskatoon Research Centre
Saskatoon, Saskatchewan
Email: owen.olfert@agr.gc.ca

P

Thierry Pagé
Odotech inc.
Montréal, Québec
Email: tpage@odotech.com

Elizabeth Pattey
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: elizabeth.pattey@agr.gc.ca

Q

Guowang Qiu
AAFC, Eastern Cereal and Oilseed
Research Centre
Ottawa, Ontario
Email: guowang.qiu@ontario.ca

R

Keith Reid
Ontario Ministry of Agriculture and Food
Stratford, Ontario
Email: keith.reid@omaf.gov.on.ca

Alain N. Rousseau
Institut National de la Recherche
Scientifique, Université du Québec
Ville de Québec, Québec
Email: alain.rousseau@ete.inrs.ca

S

Claudia Sheedy
AAFC, Lethbridge Research Centre
Lethbridge, Alberta
Email: claudia.sheedy@agr.gc.ca

Steve C. Sheppard
Consultant
Pinawa, Manitoba
Email: sheppards@ecomatters.com

Ward N. Smith
AAFC, Eastern Cereal and Oilseed
Research Centre
Ottawa, Ontario
Email: ward.smith@agr.gc.ca

Matt Straub
Canadian International Development
Agency
Gatineau, Québec
Email: matthew.straub@acdi-cida.gc.ca

T

Georges Thériault
AAFC, Soils and Crops Research and
Development Centre
Sainte-Foy, Québec
Email: georges.theriault@agr.gc.ca

Don Thompson
AAFC,Pacific Agri-Food Research
Centre
Kamloops, British Columbia
Email: don.thompson@agr.gc.ca

Laurie C. Tollefson
AAFC, Agri-Environment Services
Branch
Outlook, Saskatchewan
Email: laurie.tollefson@agr.gc.ca

Ed Topp
AAFC, Southern Crop Protection and
Food Research Centre
London, Ontario
Email: ed.topp@agr.gc.ca

V

Eric van Bochove
AAFC, Soils and Crops Research and
Development Centre
Sainte-Foy, Québec
Email: eric.vanbochove@agr.gc.ca

Ronald van Haarlem
AAFC, Eastern Cereal and Oilseed
Research Centre
Ottawa, Ontario
Email: ronald.vanhaarlem@agr.gc.ca

Xavier Vergé
AAFC, Eastern Cereal and Oilseed
Research Centre
Ottawa, Ontario
Email: xavier.verge@agr.gc.ca

W

Suzanne I. Warwick
AAFC, Eastern Cereal and Oilseed
Research Centre
Ottawa, Ontario
Email: suzanne.warwick@agr.gc.ca

Ted Weins (retired)
AAFC, Prairie Farm Rehabilitation
Administration
Regina, Saskatchewan

Brian H. Wiebe
Manitoba Water Stewardship
Winnipeg, Manitoba
Email: brian.wiebe2@gov.mb.ca

Devon E. Worth
AAFC, Eastern Cereal and Oilseed
Research Centre
Ottawa, Ontario
Email: devon.worth@agr.gc.ca

Y

Jingyi Y. Yang
AAFC, Greenhouse and Processing
Crops Research Centre
Harrow, Ontario
Email: jingyi.yang@.agr.gc.ca

Xueming M. Yang
AAFC, Greenhouse and Processing
Crops Research Centre
Harrow, Ontario
Email: xueming.yang@agr.gc.ca

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Inbox: Water Use Efficiency

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Inbox Wildlife Damage

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CHAPTER 8: Soil Erosion

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CHAPTER 9: Soil Organic Matter

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CHAPTER 12: Nitrogen

12.1 RESIDUAL SOIL NITROGEN

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12.2 INDICATOR OF THE RISK OF WATER CONTAMINATION BY NITROGEN

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CHAPTER 13: Phosphorus

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