Design and development of environmental indicators with reference to Canadian agriculture / T. McRae ... [et al.]

DESIGN AND DEVELOPMENT OF ENVIRONMENTAL INDICATORS WITH REFERENCE TO CANADIAN AGRICULTURE

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The views and interpretations expressed in this paper are those of the authors and should not be interpreted as having been endorsed by either Agriculture and Agri-Food Canada or Statistics Canada.

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OUTLINE

1.0 INTRODUCTION. [5]

We live in a period of heightened awareness and concern about the sustainability of ecosystems and the issues which are fuelling concern are varied and complex. How ecosystems are used and managed by humans will affect their ability to provide social, economic and environmental benefits, such as renewable resources (as in the case of fisheries, forestry and agriculture), clean air and water, habitat for wildlife, landscape for recreation and so forth.

Managing ecosystems sustainably requires a sound understanding of what the stressors are, the linkages among them and the nature and severity of their impacts. Ultimately, human activities must be managed in a manner which respects ecological principles and limits while at the same time maximizing social and economic benefits.

The challenges of ecosystem management are increasing pressures on both the generators and users of environmental information. Generators of information include the scientific community in its broadest sense: researchers and analysts from diverse social, ecological and economic disciplines. Their challenge is to help define and increase understanding of the issues, the expected ecological consequences of human activities, and ecological limits and thresholds. Users of information include decision-makers at all levels, from ordinary citizens to senior decision-makers in government and industry. Their challenge is to take decisions and set policies that achieve an optimal balance between what are often conflicting sets of objectives as stakeholders have various objective sets and frequently desire different policy outcomes.

Complex tradeoffs are involved in many policy decisions and these have to be discussed and weighed in an open forum. In essence, policy-makers must have at their disposal information about the issues of concern and methods to discover the weights that stakeholders attach to those issues. Although the environmental policy process is becoming more broadly based, the analytical capability has not historically kept pace with the need to develop, assess and integrate environmental information into decision-making processes.

This paper reviews some basic principles of environmental indicator design and summarizes work underway in Agriculture and Agri-Food Canada (AAFC) to develop agri-environmental indicators (AEIs) for Canadian agriculture. Concepts and applications of environmental indicators are reviewed in section 2, the approach being pursued by AAFC to develop AEIs is presented in section 3 and examples of results achieved to date are identified in section 4. The paper concludes with some general points concerning the implications of the work on AEIs to ecological monitoring and assessment.

[5] A modified version of this paper was originally presented under the title "Role and Nature of Environmental Indicators in Canadian Agricultural Policy Development" at the June 1995 symposium on environmental indicators of the Resource Policy Consortium in Washington, D.C. .

2.0 INDICATOR CONCEPTS AND APPLICATIONS.

2.1 Definition and functions of environmental indicators.

The term "indicator" has achieved widespread use in many disciplines, particularly in economics, where work to develop economic indicators has been ongoing for decades. In the environment field, formal work to develop environmental indicators is much more recent.

As a result of diverse national and international initiatives in this area (see Hardi and Pinter, 1995) several definitions or terms have emerged, including environmental indicators, environmental performance indicators, ecosystem health indicators and natural resource indicators, among others. These terms are closely linked and generally express similar concepts.

Environmental indicators can be defined as measures of change in the state of the environment, or in human activities which affect the state of the environment, preferably in relation to a standard, value, objective or goal (United States Environmental Protection Agency, 1972). For agriculture, AAFC has modified this definition as follows:

> "A measure of change in the state of environmental resources used or affected by agriculture, or in farming activities which affect the state of such resources, preferably in relation to a standard, value, objective or goal".

The functions of environmental indicators have been described by several analysts and institutions (Adriaanse, 1993; OECD, 1993; Hammond et al., 1995). Indicators can be seen as succinct expressions of information or as tools to deliver information to decision-makers in a useable, understandable form. The OECD (1993) distinguishes between indicators and data by adding that their significance extends beyond the parameters that are directly measured by the indicator, thus they have a broader meaning than data alone.

Desirable characteristics of indicators include policy relevance, scientific rigor and replicability, regional sensitivity (particularly in a country as large and diverse as Canada) and feasibility (in terms of cost and access to required data). Adriaanse (1993) also distinguishes between retrospective and prospective indicators. Retrospective indicators measure historical change to the present while prospective indicators report the predicted direction of change based on assumptions about future policy and market scenarios. Retrospective indicators provide a base on which to develop prospective indicators thus both types of indicators are similar; conceptually, it is the historical and predictive focus which distinguishes them.

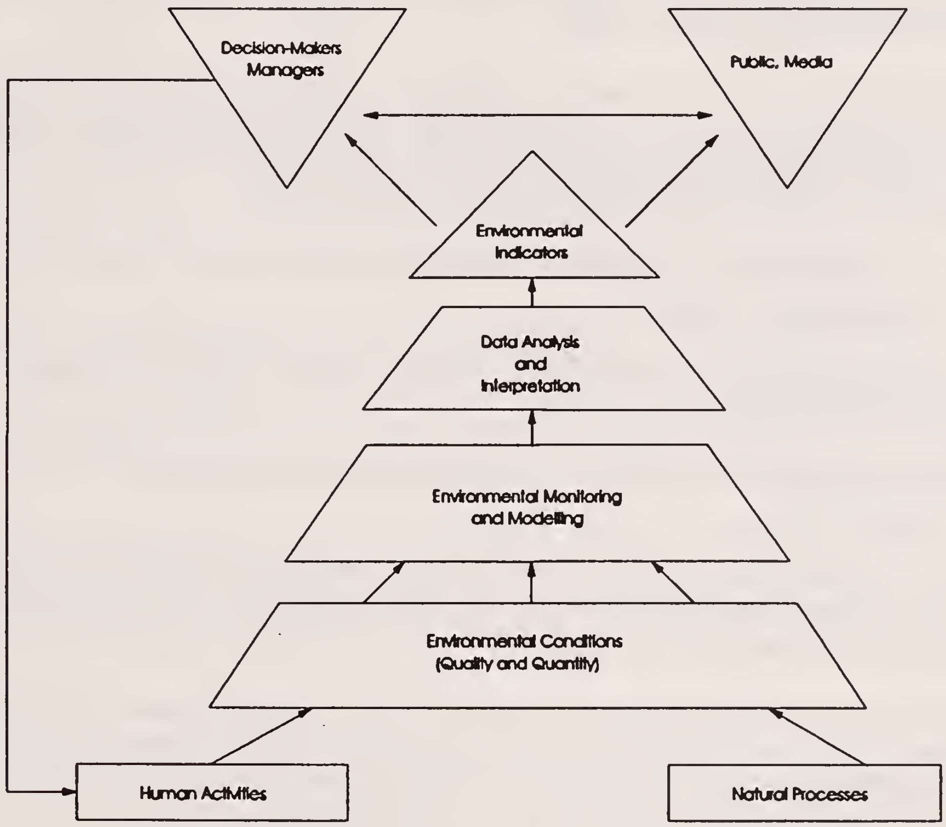
If environmental indicators are useful to policy-makers and stakeholders, they must:

- -- assess to what degree key agri-environmental issues are being addressed and objectives met;
- -- help to identify areas and resources at risk;
- -- help to design and target strategies and actions to ensure all costs are appropriately internalized; and
- -- facilitate communication among stakeholders, and between stakeholders and policy makers, on setting appropriate policy responses, especially when it comes to evaluating tradeoffs that might have to be made.

The recognized need to develop environmental indicators does not derive from a naive view that these will allow a consensus to be achieved or that in the past environmental considerations were not factored into decisions that were made. They will allow better measurements of whether priority issues have been adequately addressed, how stakeholders view the tradeoffs that might be involved, where inconsistencies exist, and where information is lacking.

2.2 Linkages between indicators, environmental monitoring and assessment.

As illustrated in Figure 1, indicators are a key link in the information development and delivery cycle. To develop indicators, methods of collecting and interpreting relevant data must be available, hence both monitoring and assessment methods are key inputs to the indicator development process.



Source: Modified from Kerr, 1990

Figure 1:The Relationship Between Environmental Information and Decision-Making.

Environmental monitoring can be defined as the repetitive observing of one or more environmentally-related parameters according to pre-arranged schedules in space and time using comparable methodologies for data collection. Design criteria to consider for maximizing the utility and value-added of environmental monitoring have been reviewed by Philips and Segar (1986), Shalski (1990), Wolfe (1987) and the National Research Council (1990), among others. Data obtained from monitoring are essential to indicator development, but it must be recognized that raw or excessively detailed data are meaningless to decision-makers and the public until summarized and interpreted. Methods of presenting, interpreting and aggregating data over time and space are needed.

An ecological approach to the spatial aggregation of data is outlined in section 3.2. Regarding interpretation, many practitioners stress that indicators derived from monitoring data should be linked to measurable objectives and reference thresholds. Reference thresholds associate closely with objectives and aid with interpretation of data.

Environmental quality as a concept is strongly influenced by human values. Environmental objectives articulate these values while reference thresholds quantify them by identifying ranges of desirable or undesirable conditions or activities (eg., normal, problem, critical and irreversible (Gelinas and Slaats, 1989). As used here, a reference threshold can be any of the following:

- -- an environmental quality guideline, objective or standard, such as water quality guidelines for contaminants in water;
- -- a human activity target or goal, such as a goal to increase use of conservation tillage on erosion-prone soils;
- -- an ecological threshold, such as a minimum population size required for a given species in a specific area.

Environmental indicators juxtapose monitoring data against threshold levels of environmental quality and, in so doing, provide information on whether objectives are being met and whether conditions and trends are acceptable, improving or deteriorating.

Another consideration is whether monitoring should focus on ecological change, on human activities (i.e. on behaviour) or on both. Monitoring of ecological change directly reveals conditions and trends in the environment, eliminating any uncertainty about the nature and severity of environmental impacts. A major disadvantage, however, is the cost and complexity of such monitoring. Another approach is to monitor human activities and to infer from behavioral information what may or is likely to be happening in the environment or in ecosystems. A major advantage of this approach is that established statistical and other agencies already collect information on human activities of environmental significance. However, this "risk-based" approach requires a solid understanding of the linkages between human activities and environmental impacts. In order to present decision-makers with a good understanding of cause and effect linkages, it is likely that, in many cases, both approaches and information sets will be required for a comprehensive monitoring and indicator program.

3.0 ENVIRONMENTAL INDICATORS FOR CANADIAN AGRICULTURE.

3.1 Conceptual Framework.

When developing indicators, a framework is required to structure analysis and to encapsulate broad linkages between activities and effects. For agroecosystems, the conceptual framework used must reflect the nature and key attributes of agroecosystems as well as the linkages between these attributes.

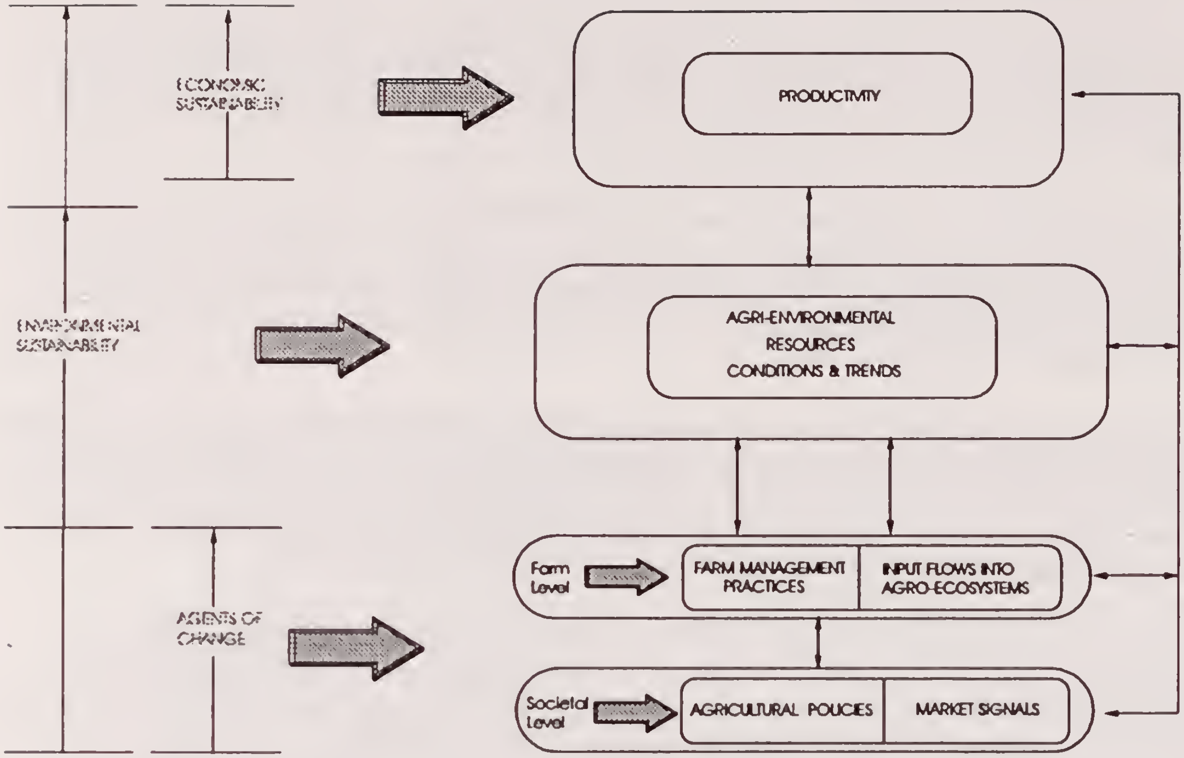
Various definitions of the term agroecosystem have been formulated. For example, the Federal-Provincial Agriculture Committee on Environmental Sustainability (1990) defined an agroecosystem as "communities of living species together with the living resources that sustain them, that interact directly or indirectly through the environment and that have established a balanced or stable equilibrium under an agricultural regime".

Agroecosystems are ecological systems that are distinct from "natural" ecosystems in several important ways. The most fundamental distinction is that agroecosystems are managed ecosystems designed primarily for the production of food and fibre. They are usually skewed to favour one or more dominant species of plant or animal but they also provide other benefits, such as the provision of habitat for wildlife, recycling of nutrients and storage of elements such as carbon.

Agroecosystems vary tremendously by production type and much of this variability stems from variability in the environment itself, for example, among soil types, land topography and climate. They encompass environmental resources such as soil, water and biodiversity and are intimately linked with other environmental media, such as the atmosphere. How agroecosystems are managed has implications for the health of environmental resources both within and adjacent (or external) to them.

After considering various frameworks, AAFC is using the framework illustrated in Figure 2 to guide its work on agri-environmental indicators. This framework is based on a framework originally proposed by researchers in Australia (Hamblin, 1991). Like similar frameworks such as the OECD Pressure-State-Response framework (OECD, 1993), it is based on a concept of causality. The framework is cyclical and its rationale is as follows:

- The management decisions and practices employed at the farm level, such as land use, input use, land management practices and types of crops grown, are fundamental to sustainability and are influenced by the economic and policy signals received by producers from the marketplace and from governments. Other factors, such as the availability of technology, cultural preferences and local resource conditions also influence these decisions and practices.
- The farm-level decisions and practices adopted can have both beneficial as well as adverse environmental impacts, both on on-farm and off-farm environmental resources.
- The state or condition of the resource base used by agriculture (e.g. soil, water, biodiversity), in combination with other factors such as improved genetics and climate, will affect farm productivity and competitiveness.
- Changes in the productivity of agriculture and in the condition of the resource base may trigger societal responses in the form of policy decisions and farm-level actions.



Source: Modified from Hamblin, 1991

Figure 2: Conceptual Framework for Agri-Environmental Indicators.

In developing AEIs, particular emphasis is being placed on indicators which track farm-level resource management and the relationship between management and changes in the condition of the resource base used or shared by agriculture. Modelling initiatives are also being pursued to link management actions and their environmental impacts with policy and economic signals, thus closing the conceptual loop between agents of change in agroecosystems and their potential environmental effects.

3.2 Spatial Considerations.

The issue of spatial scale presents a significant challenge in indicator development. A hierarchy of spatial scales exists, ranging from the "lower levels", such as the plot or field scale, to "higher levels", such as a major ecological zone or political jurisdiction. It is theoretically possible to collect data and report indicators at a range of scales, but in practice constraints related to data availability and the ability to extrapolate data often limit the choice of scales at which any given indicator can be calculated and reported. In addition, at various levels in a given system different characteristics and processes may predominate and those that are important at one level, such as herbicide dynamics at the soil-root interface (lower level), may be irrelevant at the regional (higher) level (MacDonald and Spaling, 1995a).

Selection of an appropriate scale for reporting AEIs is intimately linked to the intended uses (and anticipated users) of the information: different users require information at different scales for different uses. Producers, for example, manage primarily at the farm and field levels but are also concerned about policy and market developments at regional, national and international levels. Farm leaders and government policy-makers manage primarily at the national, sub-national, farm-sector and even international scales but are also concerned with developments at the farm level. Scientists have traditionally pursued a reductionist approach to investigating problems and processes, often to a micro-scale, such as the research plot.

Ideally then, a capability to develop and report indicators at a range of spatial scales is required. However, tradeoffs occur when moving among scales: gains in coverage when reporting at higher spatial scales come with a price; less information is imparted about processes and interactions occurring at lower scales. Conversely, a focus on site-specific detail can obscure the larger picture and make it impossible to track cumulative effects or large-scale or sector-wide trends and impacts. It is therefore important to identify the users of the indicators and the scale(s) at which they require information.

Environmental and economic data on the Canadian environment (including on Canadian agriculture) are captured by numerous agencies and at different scales and spatial units, but have not traditionally been ecologically-based. However, over the past 15 years a number of national-scale ecological maps have been published in Canada that have had application to environmental reporting issues (Wiken 1986, Ecoregions Working Group 1989, Wiken et al. 1993). To meet the challenges put forward to take an ecosystem approach to monitoring and reporting on agricultural sustainability, it was recognized that the concepts and levels of generalization as developed previously were sound but the spatial units defined within the national terrestrial ecosystems framework needed revision, particularly with respect to the agricultural regions of the country.

In 1991, a collaborative project to revise and complete the terrestrial component of the national ecosystems framework was undertaken with a wide range of federal, provincial and territorial stakeholders. The resulting spatial framework consists of multiple, nested levels of ecological generalization with the ability to link to other federal and provincial scientific databases (Ecological Stratification Working Group, 1995). With respect to agriculture, the principles of agro-ecological mapping and development of associated integrated databases in Canada has been summarized by Dumanski et al. (1993). The concept of nested databases serving a range of map scales (or levels of generalization) was used when constructing the design of the relational database for the present national terrestrial ecological framework for Canada.

The broadest level of generalization is the ecozone (Figure 3). Fifteen ecozones have been defined for Canada; agriculture is practised in eight of these. Macroclimate, major vegetation zones and subcontinental scale physiographic formations constitute the definitive components of these major ecosystems. The ecozones are comprised of approximately 200 ecoregions which are based on the properties of regional physiography, surficial geology, climate and vegetation. The ecozone and ecoregion levels of the framework have been depicted on national map coverage at 1:7.5M scale.

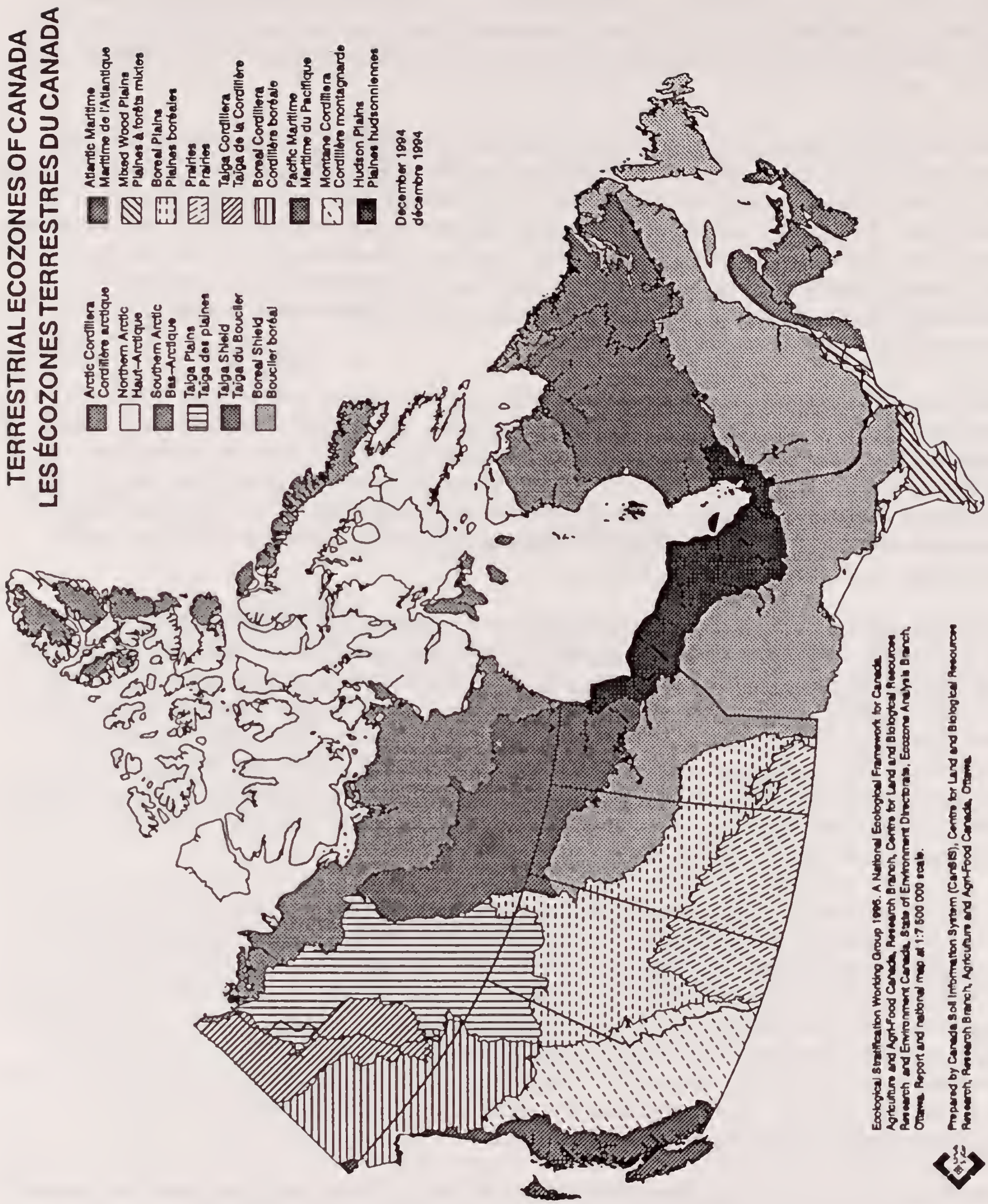


Figure 3: Terrestrial Ecozones and Ecoregions of Canada.

Ecoregions are subdivided into ecodistricts based on landform, vegetation and soil development. In the agricultural areas of Canada, previously defined agro-ecological resource areas (Dumanski et al. 1993) were incorporated as much as possible into the national framework as ecodistricts. Ecodistricts are displayed on a separate series of regional map coverages at a scale of 1:3M and represent the level within the framework that is often useful for environmental monitoring, modelling and reporting. Nested within the ecodistricts are the polygons that make up the Soil Landscapes of Canada, a series of 1:1M scale soil maps (Shields et al. 1991). Although not specifically a part of the national ecological framework, the Soil Landscapes of Canada map series provides a suitable digital cartographic information base upon which to aggregate the larger scale products of ecological regionalization (Figure 4).

Indicators are calculated, measured or modelled at site, field, watershed or regional scales. Because the levels in the framework are nested, results can be generalized, if appropriate, and reported cartographically at either a local (ecodistrict), regional/provincial (ecoregion), national (ecozone) or even international (ecozone) scale. In a similar way, socio-economic data, particularly Census of Agriculture data, may be linked to the environmental data within the framework on a polygon basis at the most appropriate level.

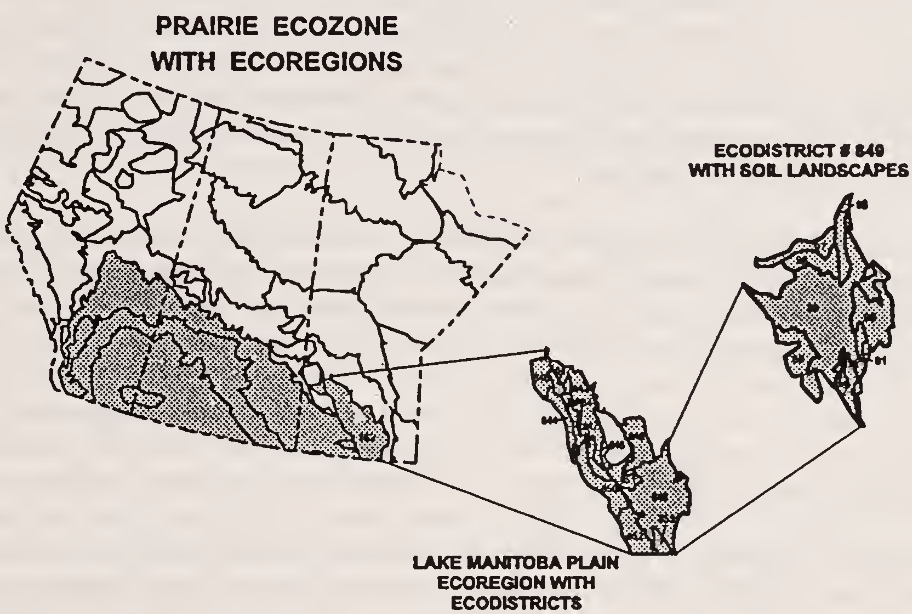


Figure 4: Cartographic Nesting of Levels of the Ecological Framework Showing the Relationship of Ecozones, Ecoregions and Ecodistricts to Soil Landscape Polygons.

For agri-environmental indicator development, to the extent possible, flexibility is being built into data management and reporting procedures. Ideally, data will be captured at a detailed level (such as the farm level) and then aggregated and reported, as indicators, at whatever scales are most appropriate to specific users such as, for example, on an agro-ecological basis, by watershed, by commodity group, by province or nationally. In some cases, however, data limitations will limit the ability to tabulate and report indicators at many different scales.

3.3 Data Collection and Integration.

To develop and validate AEIs, credible, relevant and scientifically rigorous data are required. New opportunities to collect data that are national in scope are few. Furthermore, data required to address environmental problems often must be land-based (i.e. geographically positioned on the earth's surface). Such data collection can be costly and generally beyond the realm of governments in the 1990s. Consequently, there is a need to fully utilize existing datasets as much as possible while also taking advantage of opportunities to fill data gaps as appropriate vehicles and funds permit. In the short term, those indicators making use of available data can be developed now and used to begin reporting on the sustainability of Canadian agriculture.

Partnerships with other stakeholders and agencies are required for the successful development of many of the indicators and the AEI project seeks to build on and integrate past and ongoing research. For example, Agriculture and Agri-Food Canada has gathered detailed data relating to the nature, condition and use of agricultural soil resources and land management practices. Databases such as the Canada Soil Information System (CANSIS) and the Soil Landscapes of Canada database store basic soil data (e.g. soil type, slope class) collected through soil surveys and other mechanisms. The Census of Agriculture operated by Statistics Canada is another key data source for AEIs. Environment Canada collects data related to water quality, habitat availability and other variables. Non-government conservation agencies collect information on wetlands and wildlife. Provincial departments of agriculture and environment, as well as industry organizations, collect and use data on such variables as land use, cropping practices and farm inputs. Despite these efforts, however, significant data gaps exist that can only be overcome through inter-agency collaboration and focused efforts to collect, standardize, manipulate and integrate data.

Data derived from different sources can be integrated or combined using the spatial approach described in section 3.2. For example, the national Census of Agriculture has tremendous potential for supporting analytical studies on AEIs, but it is limited by its lack of locational accuracy and has traditionally been available only on the basis of politically defined spatial units, such as Enumeration Areas, Census Subdivisions or Crop Reporting Districts. The Soil Landscapes of Canada database stores data on the inherent nature of Canada's agricultural soils (e.g. texture, slope, depth) which, although useful, cannot be used by themselves as indicators. However, when both information sources are integrated, numerous possibilities emerge from an indicator development viewpoint.

To render possible the reporting of indicators derived (in whole or in part) from the census on an agro-ecological basis, census data have been retabulated on the basis of Soil Landscape of Canada (SLC) polygons, which places them into a spatial framework that is more appropriate for developing and reporting some AEIs. Since SLC polygons are themselves nested within ecodistricts, information can be rolled up within the units of the ecological land classification system described earlier for indicator analysis and reporting.

The Census of Agriculture, with its coverage of all farms every 5 years and wide variety of variables, provides a comprehensive picture of the major characteristics of Canada's agricultural industry at a point in time, while also supplying detailed information on small geographic areas not available from other sources. In general, the data can be sub-divided into four sections:
- farm structure, relating to farm size and ownership characteristics;
- crops and land use, detailing the distribution and area of crops, pasture and other land;

- livestock, relating to the type of animals and the size of herd; and
- economics, covering capital investment levels and the dollar value of inputs and sales.

In 1991, in response to the need to track adoption of various management practices by producers, a section was added on land management dealing with tillage practices (conventional, conservation and no-till), summerfallow management and use of conservation structures such as windbreaks, winter cover crops and grassed waterways. To build on this for 1996, an additional question dealing with manure application methods has been added.

Certain questions proposed for inclusion in the 1996 Census of Agriculture were not suited to self-enumerative collection, including questions on quantities of inputs applied (by active ingredient, by crop); frequency and timing of input application; manure storage; and methods used to help decide the type and amount of inputs to apply. Although producers may have been willing and able to answer, some questions took too long to complete and were deemed too burdensome for inclusion in the census. Where a self-enumerative vehicle is inappropriate, other collection options may be considered. The Census of Agriculture provides an excellent list from which to draw a representative sample to conduct follow-on surveys and collect data using other techniques, such as personal interviews or a computer assisted telephone interview (CATI) approach. While more costly to implement, these collection methods are perhaps better suited for collecting this type of environmental data.

Due to the cross-cutting nature of and linkages between the AEIs, many of the variables from the Census of Agriculture and other data sets will contribute to the development of several components of various AEIs. For example, land management variables used to track adoption of soil conservation practices are, in turn, required inputs to other indicators such as Soil Degradation Risk, Indicator of Risk of Water Contamination and Greenhouse Gas Balance. Tracking tillage practices and cropping patterns across Canada is essential to the development of a soil cover indicator component. In other words, the outputs (i.e. results) from one indicator are often inputs to another. It is important to recognize these linkages and the "value added" capability of indicator development.

3.4 Modelling Approaches.

For prospective AEIs, the development of a predictive capability is required which links changes in production activities and practices to the environment. Policy development requires information on expected outcomes that can be attributed to government policy initiatives. Both direct and indirect impacts must be identified, measured and assessed against the stated objectives for a policy prior to implementation.

To obtain and use prospective AEIs, an integrated predictive capability is being developed within AAFC. This is limited at the present time to the Prairie grain-livestock economy and to wind and water erosion indicators in the form of the CRAM-EPIC modelling system. This system is a linkage of two separate models: the Canadian Regional Agriculture Model and the Erosion Productivity Impact Calculator. The system is operational and has been used recently to assess the economic and environmental implications that would result from reform of western grain transportation policy as it relates to historically subsidized rail freight rates and to commodity sales pooling programs operated by the Canadian Wheat Board. Examples of outputs from the CRAM/EPIC model are presented in section 4.2.

The overall objective is to develop a predictive capability for all key AEIs. The analytical capability will eventually be extended to also investigate longer term sustainability questions relating anticipated changes in resource quality back to production and agricultural income projections.

3.5 Indicators Identified for Development.

The process of identifying appropriate AEIs for Canadian agriculture has been an iterative one characterized by ongoing discussions between researchers, analysts, policy-makers, national and regional farm organizations and stakeholder groups such as environmental organizations.

In the initial phase of the work, 49 potential indicators were identified by AAFC to provide a basis for discussion. These indicators were clustered around a range of agri-environmental issues. Through an interactive consultative process spanning an 18 month period, the potential indicators were reviewed, ranked and ultimately integrated/combined, and others dropped, to arrive at a core set of six performance indicators and their components. To date, two national consultation workshops have been held with stakeholder and client groups to garner input into the design of the project and the selection of indicators (McRae and Lombardi, 1994; McRae, 1995). A multi-stakeholder advisory committee is planned to provide a mechanism for ongoing discussion and input into the indicator project.

Each of the AEIs, illustrated in Figure 5, is linked to a key agri-environmental issue and a corresponding performance objective. The comprehensive indicators are composed of several attributes or components (some of which may, by themselves, be considered AEIs) which are, in turn, based on the integration of specific data. It must be emphasized that the core set of indicators does not constitute a comprehensive set as several important issues, such as compaction of soils, are not presently covered.

The indicators are at various stages of development. Preliminary results for several are presented in Section 4.

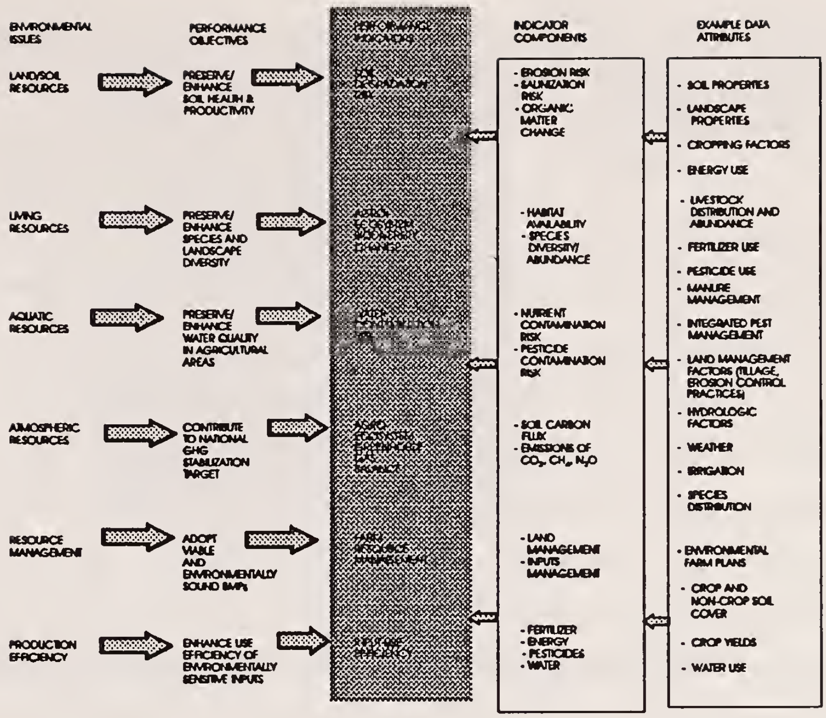


Figure 5: Linkages between agri-environmental issues, objectives, performance indicators and supporting data.

4.0 SELECTED EXAMPLES OF AGRI-ENVIRONMENTAL INDICATORS.

This section provides examples of some of the AEIs currently being developed. These examples are for illustration purposes and, with the exception of soil erosion risk, erosion control practices and tillage practices, have not been peer reviewed or published in the scientific literature. Consequently, they should not be reproduced and reported or referenced elsewhere as indicative of actual trends and conditions in Canadian agriculture.

4.1 Farm Resource Management – Soil Cover and Management Component.

The indicator component is comprised of two related sub-components: trends in farm-level adoption of selected soil conservation practices and trends in area of agricultural land under various classes (low, medium and high) of soil cover.

Table 1 and Figure 6 illustrate two aspects of land management derived from the land management module of the 1991 Census of Agriculture - use of selected erosion control practices and tillage practices used to prepare land for seeding. Extent of adoption of selected soil conservation practices provides an indication of how soil erosion and land degradation issues are being addressed across Canada (Trant, 1993) and perhaps also of the need for erosion control. Not all agricultural lands require erosion control and some practices are only applicable in some regions and not in others (e.g. strip cropping in the prairie region). Since 1991 was the first time such questions were asked through the census, these data effectively constitute a baseline against which future census data will be compared.

TABLE 1: Erosion control practices in Canada, 1991 (percent of farmers reporting)						
Province	Forages	Winter cover crops	Grassed waterway s	Strip-cropping	Contour cultivation	Wind breaks
British Columbia	23	11	10	2	5	29
Alberta	43	4	17	10	11	29
Saskatchewan	22	6	17	11	10	16
Manitoba	35	9	11	5	13	37
Ontario	44	20	15	4	7	12
Quebec	52	4	4	1	4	8
New Brunswick	44	10	4	5	8	8
Nova Scotia	44	12	4	3	8	7
Newfoundland	37	7	4	1	7	12
Prince Edward Island	72	9	11	4	10	16
Canada	42	10	13	9	10	15

Source: Dumanski et al. 1994.

Together and in combination with other census data (not shown) this information reveals that, in general, producers are taking concrete steps to address soil degradation issues:

- the use of erosion control and seedbed cultivation practices varies considerably by region of Canada;
- farm operators with 85% of seeded area used some form of soil erosion control or soil conservation practice. Conversely, four and one-half million hectares (15%) had no erosion control applied and were not tilled using a conservation technique, although not all of these lands require erosion control; and
- farms with the most potentially erosive crops are the most frequent users of four out of six erosion control practices.

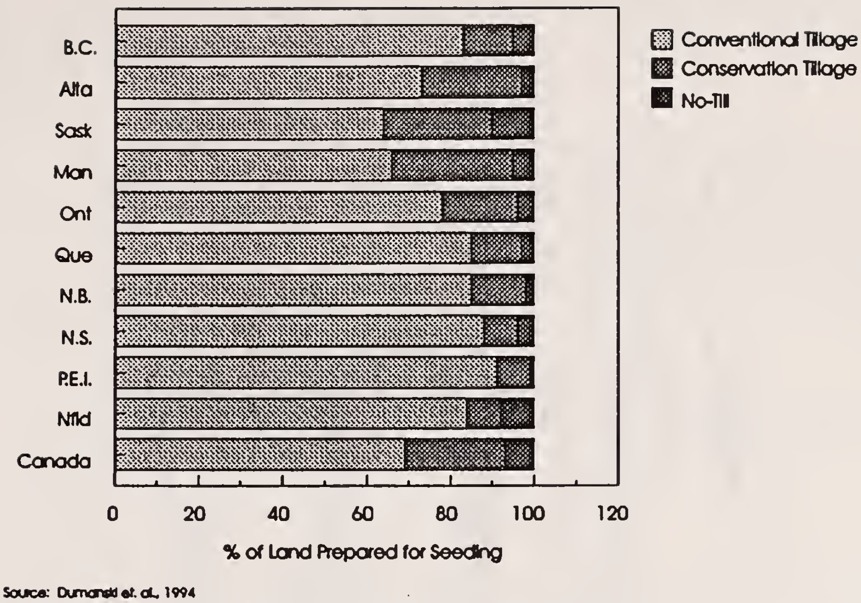


Figure 6: Tillage practices used to prepare land for seeding in Canada, 1991.

Changes in soil cover on agricultural land between 1981 and 1991 are illustrated in Figure 7. Land under high cover is at less risk of soil erosion and degradation than land under low cover. The indicator reflects the amount of soil cover provided based on prevailing cropping and tillage practices.

Soil cover is estimated based on the principles outlined in the revised universal soil loss equation, as follows: individual crop types are cross-referenced to the tillage practices under which they are grown and the various potential combinations are classified into three classes of soil cover -- low, medium and high. Assignment of each combination to a cover classification is based on expert opinion and research results. For the 1981 year, it is assumed that all tillage is conventional. To illustrate: grain corn under conventional tillage is classified as a low cover crop, under conservation tillage as a medium cover crop and under no-till as a high cover crop. Silage corn is considered a low cover crop regardless of the tillage practice used. Areas under various cover classes are computed and summed. The indicator is presently calculated nationally and at the provincial level and will eventually be extended to the ecodistrict level.

Based on the analysis presented in Figure 7 and on related data, the following preliminary trends are apparent for the period between 1981 and 1991:

- nationally, cropland as a proportion of farmland has increased from 47% to 49%, an increase of about 2.5 million hectares;
- the portion of farmland in summerfallow and in pasture has decreased from 15% to 12% and 31% to 30% respectively;
- the proportion of cultivated land (annual crops) with low cover and medium cover has decreased from 34% to 22% and 53% to 46% respectively; and
- the proportion of cultivated land with high cover has increased from 13% to 32 % .

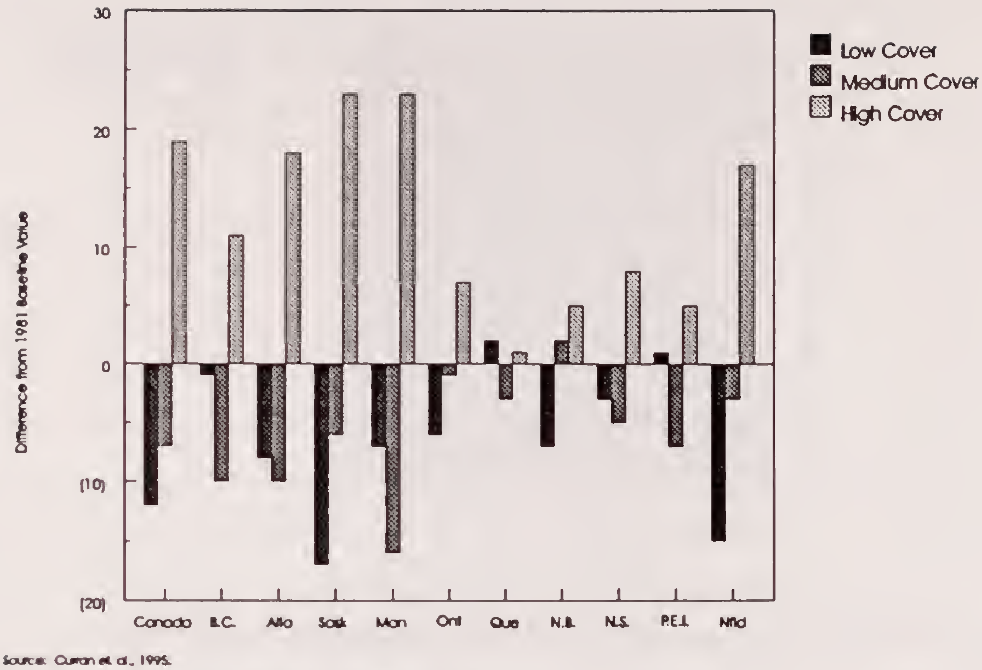


Figure 7: Soil cover change between 1981 and 1991.

From a soil quality perspective, these trends are generally encouraging as the risk of erosion is expected to have declined between 1981 and 1991 due to increases in cover. Increased soil cover also benefits biodiversity and recycles soil carbon, thus limiting carbon dioxide emissions. Nationally, the increase in soil cover is attributed to the adoption of land tillage practices that maintain residue on the surface. However, shifts in cropping patterns from crops with higher residue levels to those with lower residue, such as from grain corn to soybeans or from wheat to canola, partially offset these gains. (Curran et al. 1995).

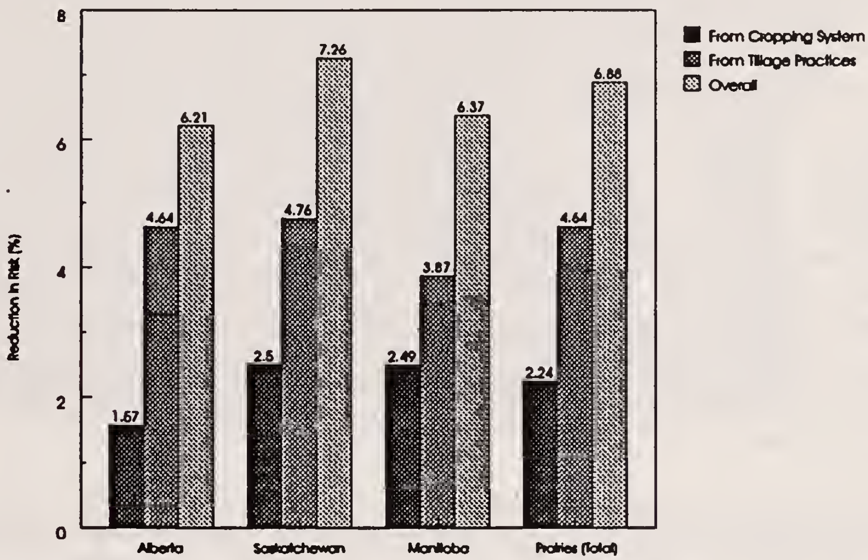
4.2 Soil Degradation Risk – Erosion Component.

The Soil Degradation Risk indicator includes erosion, salinity and soil organic matter components. Results are presented here for the erosion component only with a complete analysis of all components reported in Acton and Gregorich (1995).

Soil erosion is an issue that has received considerable public attention in Canada. The issue was publicized nationally by Sparrow (1984) and substantial efforts have been made since then to address erosion concerns (e.g. National Soil Conservation Program, Land Management Assistance Program, Permanent Cover Program, Green Plan, etc.). Producers have voluntarily moved to adopt farm management practices to improve land management, as illustrated in Table 1 and Figure 6 above.

An indicator has been developed to evaluate progress in reducing erosion risks and to identify areas which remain at higher relative risk of erosion. The indicator is calculated at the Soil Landscapes of Canada polygon level using land use and management data coupled with the corresponding soil and slope information. The Universal Soil Loss Equation and the Wind Erosion Equation are used to integrate the required data and to calculate the indicator components. Although calculated in tonnes/hectare/year, the erosion indicator is reported in risk classes due to the generalization of the erosion models at such broad scales. A total of five classes are reported, ranging from low, moderate, tolerable, high and severe. Tolerable rates of erosion are those that have been shown to permit the long term sustainability of crop production.

Table 2 and Figure 8 report changes in the risk of water and wind erosion respectively from 1981 to 1991. Water erosion is reported nationally while wind erosion is primarily of concern in the prairie region. For both water and wind erosion, the indicators reveal that important progress has been made in reducing erosion risk. Figure 9 provides a spatial overview of water erosion risk changes on the Canadian prairies between 1981 and 1991 and demonstrates how this analysis can be used to direct soil conservation efforts at high-risk areas.



Source: Wall et. al., 1995

Figure 8: Reduction in the risk of wind erosion in the Prairie Provinces between 1981 and 1991.

As mentioned in Section 3.4, a prospective capability has also been developed for the soil erosion indicator component for the prairie region. A modelling system integrating economic and environmental variables is being developed based on the Canadian Regional Agricultural Model (CRAM) and the Erosion Productivity Impact Calculator (EPIC). This modelling system is described in detail in Agriculture Canada (1993a, 1993b, 1994, 1995a, 1995b). Similar to the work on the retrospective soil erosion risk indicator, the CRAM-EPIC modelling system currently has the capacity to link wind and water soil erosion rates on the Prairies to farm management practices which change in response to policies, markets, technology or some combination.

TABLE 2 : Reduction in actual water erosion risk per hectare from 1981 - 1991.				
Province	**Cultivated land in 1991 (million ha)**	**Erosion reduction per hectare (%)**		
		Resulting from cropping practice	**Resulting from tillage practice**	**Total**
British Columbia	0.12	7	10	17
Alberta	11.06	6	8	13
Saskatchewan	19.17	6	3	8
Manitoba	5.06	6	3	15
Ontario	3.48	10	11	21
Quebec	1.65	3	3	6
New Brunswick	0.12	2	3	6
Prince Edward Island	0.16	- 9	3	- 6
Nova Scotia	0.12	-3	3	0
Canada	41.42	5	8	11

SOURCE: Wall et. al., 1995.

To predict erosion rates, comparable methodologies are being employed. EPIC is the environmental component which estimates field level yields and erosion rates based on various agricultural and environmental variables. EPIC uses the Modified Universal Soil Loss Equation to predict water erosions rates and the Wind Erosion Continuous Simulation to predict wind erosion. Simulations were carried at the 1:1 million scale based on dominant and sub-dominant soils in Soil Landscape Polygons (CanSIS Landscape Database). Based on a stratified sample and 22,000 simulation runs, summary response functions called metamodels were constructed. Producer response in the form of crop/rotation/tillage choices as predicted by CRAM are passed to the metamodels to determine how changes in farm management decisions would affect soil erosion rates.

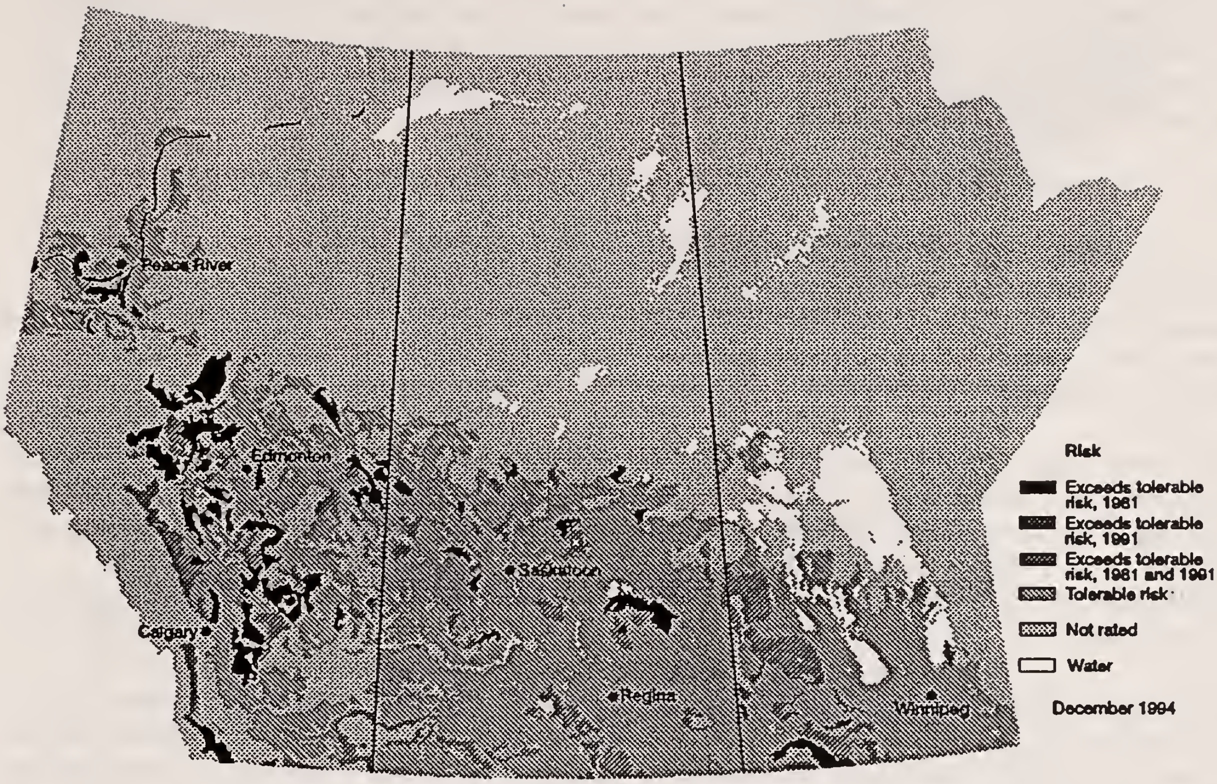


Figure 9: Changes in the risk of water erosion in the Prairie Provinces, 1981 and 1991.

Source: Wall et. al., 1995.

This system provides the integrated information policy makers need in order to assess both the environmental and economic consequences of proposed actions, identifies tradeoffs and can be used to assess mitigation requirements. This system was used recently to provide a quantitative assessment of the implications of eliminating the Western Grain Transportation Act (WGTA) freight subsidy for Prairie grains and oilseeds and reforming the Canadian Wheat Board pooling regime. The CRAM model predicted the following land use changes: (1) a shift from barley and wheat to higher valued, lower volume oilseeds and specialty crops, (2) more summerfallow in some regions, and (3) some land shifting from grain production to forage in other regions. A priori, the first two adjustments would be expected to increase erosion rates while the third one would reduce erosion rates.

The quantitative implications of these policy changes for water erosion rates are as follows. In the western Prairies a movement towards oilseeds and greater use of summerfallow would lead to a small increase (0 to 3%) in water erosion rates. In the eastern Prairies, where the impact of the policy change would be much larger, the net impact of shifting land to forage from grains would reduce the aggregate rate of water erosion. Several areas of the central prairie region would experience no significant change in erosion rates. A similar pattern was found for wind erosion rates (B. Junkins, pers. comm.).

From a policy perspective, the announced changes to the WGTA would not have a significant impact on soil erosion by water for the prairies as a whole. However, information on the predicted erosion rate changes within the prairie region could be combined with the retrospective erosion risk indicator to assess whether those regions identified at high to severe risk coincide with those regions where erosion rate increases are predicted. Efforts to mitigate could be targeted in those areas where a high risk situation would be exacerbated.

4.3 Indicator of Risk of Water Contamination (IROWC) -- Nutrient Component.

This indicator is being designed to assess the risk of water contamination from primary agriculture, which has emerged as a key agri-environmental issue. Risk of contamination is a function of contaminant properties, environmental conditions and specific land use and management practices (e.g. crops grown, inputs used, etc.), thus the indicator must be capable of integrating data on diverse factors in a meaningful way.

The methodology being pursued is to develop the indicator using a partial budgeting approach which will estimate the concentration or amount of potential contaminants available as a result of agricultural activities in comparison to tolerable concentrations as defined by various water quality standards and objectives (i.e. a ratio of the potential contaminant concentration to the allowable contaminant concentration) (Macdonald and Spaling, 1995b). The focus of the IROWC at this time is on nutrients and pesticides.

This approach is preferred to more conventional water quality monitoring approaches because it is directly linked to agriculture as a source of contamination (thus eliminating problems of interpretation due to other potential contaminant sources) and is not dependent on the availability of comprehensive water quality monitoring data, which are expensive to collect in a country as large as Canada. Water quality data will, however, be essential for verifying and calibrating the indicator.

Scale determines the potential level of detail and also the factors which can be included in the indicator. The IROWC will be calculated at the ecodistrict level across Canada and also in selected regions at a more detailed scale. The regional studies will serve to verify that the national (ecodistrict) level indicator correlates reasonably well with more localized conditions and they will provide information for interpreting the national level indicator. Development of the IROWC is in the preliminary stages. A concept paper and a draft methodology paper have been prepared (Macdonald and Spaling, 1995a & 1995b) and the methodology will undergo further development.

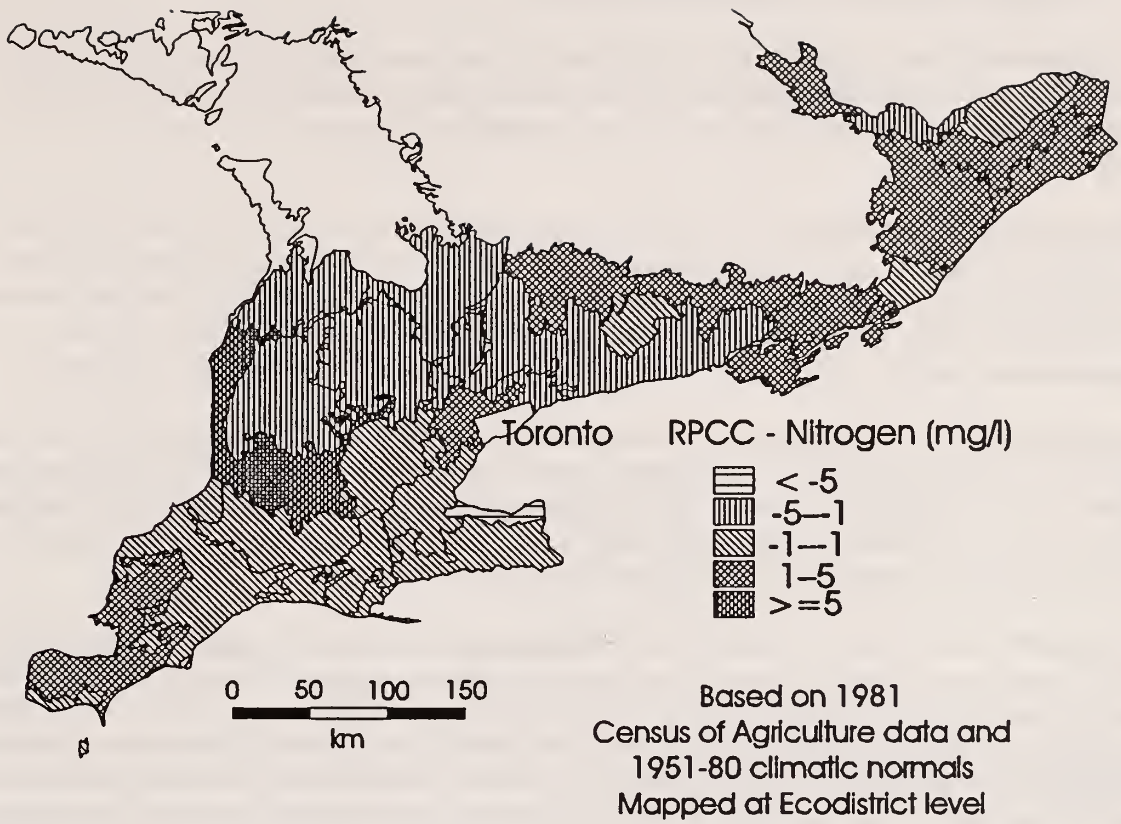


Figure 10: Change in the relative potential contaminant concentration in southern Ontario (nitrogen, 1981-1991).

Source: Macdonald and Spaling, 1995b.

A partial illustration of the IROWC is provided in Figure 10. The figure shows changes in the relative potential contaminant concentration for nitrogen in Ontario between 1981 and 1991 at the ecodistrict level (based on levels harvested in the crop) and is the numerator of the full IROWC ratio described earlier. The results are reported in units of mg/l or ppm with the range going from a decrease of five or less to an increase of five or more. In general, these results are quite encouraging for much of the province, showing no change or a slight decline. The greatest increase is indicated in the ecodistrict which occupies north Middlesex and the western portion of Huron Counties. In addition, there is some indication of an increase in Eastern Ontario, Essex and Lambton Counties and the fringe area. The map illustrates that this type of calculation can indicate some changes that are potentially of the same order of magnitude as the drinking water standard of 10 ppm for nitrate (Macdonald and Spaling, 1995b).

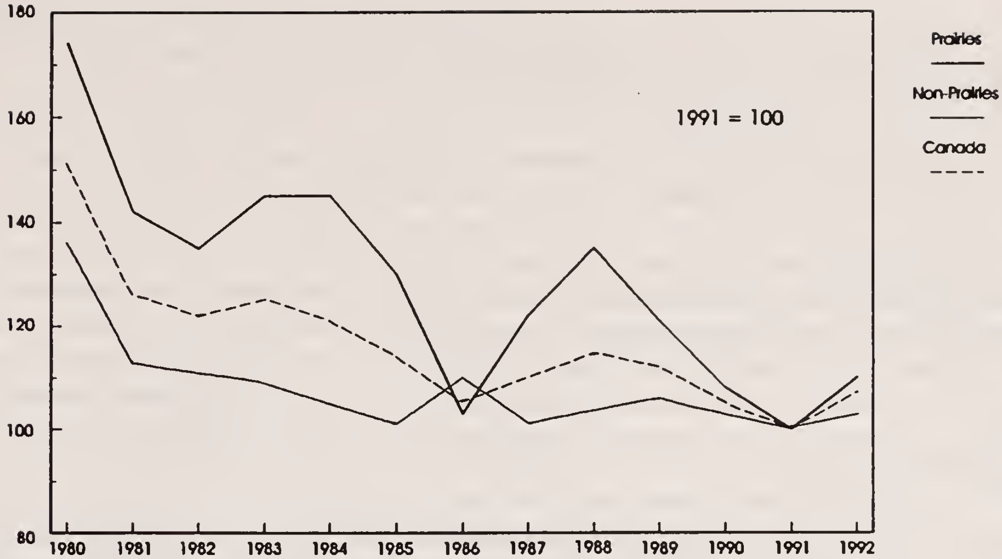
4.4 Input Use Efficiency -- Energy Component.

This indicator provides a measure of the use efficiency (input/output ratio) of chemical inputs of fertilizers, pesticides and energy (farm fuel and electricity) used in Canadian agriculture over time. The trends in this measure can provide an indirect perspective on the potential direction of environmental risks .

Quantities of fertilizer, pesticide and energy inputs are obtained on an annual basis for each input item. Physical quantity data and implicit quantity data (derived from expenditure data in constant prices) are used. These quantities are then aggregated and indexed to a base year using corresponding price and share weights for fertilizers, pesticides and energy respectively. Annual indexes for aggregate output were also developed in the same manner for crop and total output respectively.

The aggregate input index (numerator) is then divided by aggregate crop output index (denominator) to arrive at the indicator of input use efficiency for fertilizers and pesticides as these are, by and large, applied to crop production. For energy, the aggregate input use index is divided by the total output index (i.e. crop and livestock output) since energy is used for both crops and livestock. The reverse of this process gives the partial productivity index for the respective inputs.

The indicator can be calculated at various spatial scales: national, eastern Canada, western Canada, prairie Canada and non-prairie Canada. The dividing line for the eastern and western regions of the country is the Ontario/Manitoba border. On a temporal scale, the indexes are available for the 1961 to 1992 period but the present analysis uses 1980 as the baseline year. Figure 11 illustrates a preliminary calculation of the indicator for energy. Trends from 1980 are indexed using 1991 set at 100. A decrease in the slope of the line indicates that less input is being used per unit of output; an increase denotes the opposite.



Source: Narayanan, 1995.

Figure 11: Input efficiency for energy inputs, 1980-1992.

For on-farm energy use, efficiency has increased both nationally and regionally. This has positive implications for climate change and local air pollution issues. Factors responsible for the improvement in energy use efficiency include improved genetics & plant productivity, reduced tillage, improved fuel efficiency in farm equipment and enhanced farm building insulation.

The input efficiency indicator, while useful in demonstrating aggregate trends over time, has limitations. The use of implicit quantity data introduces some uncertainty in the trends observed, although implicit quantity data do correlate reasonably well with actual use data. More importantly, the indicator does not distinguish between types of inputs (eg. different types of nutrients and pesticides) and cannot be calculated by crop. For these reasons, this indicator is best interpreted in association with information derived from other related indicators (Narayanan, 1995).

4.5 Agroecosystem Greenhouse Gas Balance -- Carbon Dioxide Component.

This indicator will estimate sources and sinks for the three principal greenhouse gases emitted from agriculture and express the net balance in carbon dioxide equivalent units. Carbon dioxide, nitrous oxide and methane are the most important greenhouse gases (GHG) emitted by agricultural sources. Agriculture generates carbon dioxide through the combustion of fossil fuel for farming operations and the production of various inputs (nitrogen fertilizers, pesticides, etc.).

Agricultural soils can act both as a source or a sink of carbon (C). The C content in agricultural soils is a function of the original C content, time elapsed since cultivation began, and crop and soil management. After conversion to agriculture, soil C takes between 20 and 50 years to stabilize to a new equilibrium level. Long-term experiments have shown that soils under conventional tillage or fallow stabilize at a lower C content that those under no-tillage or continuous cropping systems. In order to estimate the net gain or loss of soil C in Canadian agroecosystems, it is therefore necessary to determine, for a given baseline year, the fraction of agricultural soils that have reached their equilibrium of C content (assuming negligible losses by erosion) and the rate of change for those soils that are not in equilibrium. Small quantities of carbon are also stored in farm woodlots.

Nitrous oxide is produced in soils as a by-product of nitrification and denitrification processes. A fraction of this nitrous oxide is released at the soil surface and contributes to the increase in the atmospheric nitrous oxide concentration. The total amount of nitrous oxide emitted from soils is the summation of a background component (resulting from the natural cycling of nitrogen), a manure component (for soils receiving manure) and a nitrogen fertilizer component (for soils receiving nitrogen fertilizers). Manure also generates nitrous oxide during storage in quantities that vary depending on the type of storage practice and the duration of the storage period. Other agricultural sources of nitrous oxide are combustion of fossil fuels and biomass burning. The sources of methane in Canadian agroecosystems are ruminants, animal wastes, wet areas (within agricultural land) and combustion of fossil fuel.

The sources and sinks of GHG in agroecosystems are reasonably well known but the magnitude of the various fluxes is less certain. However, significant research efforts are currently being made to reduce this uncertainty. Another important aspect of the estimation of the contribution of Canadian agroecosystems to GHG is the aggregation of the individual sources and sinks. Emissions of GHG vary greatly depending on various factors related to soil, climate and management practices, which are characterized by high spatial variability. Typical combinations of these factors are being used to represent Canadian conditions.

Partial results of the work on this indicator are shown in Table 3 for carbon dioxide. The calculations estimate the net release of carbon dioxide from agricultural sources in 1991 to have been 20.8 million tonnes, approximately 4.4 percent of the estimated net total for Canada. On-farm fuel use, soil carbon loss and nitrogen fertilizer manufacture accounted for, respectively, 50%, 35% and 15% of the total. Net releases increased slightly from 1986 to 1991 (P. Rochette, pers. comm.).

Research to quantify the net sources and sinks of methane and nitrous oxide is in progress with a view to ultimately estimating a comprehensive net GHG balance for Canadian agriculture.

TABLE 3: Estimated net emissions of carbon dioxide from Canadian agroecosystems (million tonnes).

Year	On-farm fuel use	Soil carbon flux	N-fertilizer manufacture	Total
1986	9.2	7.3	3.2	19.7
1991	10.4	7.2	3.2	20.8

Source: Smith et al., 1995; J. Liu, pers. comm.; Jaques, 1992; Jackson, 1992.

5.0 CONCLUSIONS.

Concerns about environmental issues and the need for sustainable management of ecosystems are placing demands on both the generators and users of environmental information. To be useful to decision-makers, information must be delivered in a useable and understandable form. Environmental indicators are an important tool for delivering information into the decision-making process.

The development of environmental indicators is closely linked to environmental monitoring and assessment. Methods for collecting data and interpreting their significance are essential for the development of environmental indicators. Monitoring efforts need to consider the causes and nature environmental change, coupled with use of objectives and reference thresholds for interpreting the significance of observed trends.

Efforts are underway within Agriculture and Agri-Food Canada to develop agri-environmental indicators for Canadian agriculture. Agriculture's environmental agenda has evolved from its historic focus on on-farm resource concerns to also encompass off-farm concerns associated with impacts on public environmental goods (e.g. water quality, biodiversity). As a result, the agri-environmental policy process has expanded and become more complex, with competing sets of objectives frequently characterized by inherent tradeoffs. To manage this increasingly complex agenda, decision-makers and stakeholders require information to inform their discussions and on which to base and evaluate the decisions taken.

If the efforts expended to develop indicators are to yield the desired results, both the process as well as the substance of indicator development must be considered carefully. The Canadian experience to date in this area suggests that three criteria for agri-environmental indicators stand out above all others: policy relevance, scientific defensibility and regional sensitivity.

To ensure policy relevance, indicators must address critical issues, identify areas and resources at higher relative risk and provide information on whether or not policy objectives associated with the issues are being attained. Both a retrospective and prospective capability is required for indicators to fully address policy assessment and design needs.

The identification of issues and subsequent selection of indicators should be based on a consultative process in which all potentially affected parties can participate. Developed in isolation by an un-representative group or groups (for example, by scientists or bureaucrats), the indicators that emerge run a strong risk of not responding to the needs and concerns of all parties. Identification of appropriate indicators is therefore a process that integrates both scientific as well as policy considerations.

To deliver information to as many users as possible and to ensure regional sensitivity, a capability to report indicators at a range of spatial scales is required. These can be based on ecological units, political units, or both. Finally, a scientific capability is essential for indicator development. Indicators based on poor science will not serve the policy process well and could, in fact, lead to erroneous decisions requiring costly remedial action or loss of agricultural productivity.

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