AGRI-ENVIRONMENTAL INDICATOR PROJECT

Agriculture and Agri-Food Canada

RESEARCH AND DEVELOPMENT NEEDS IN MONITORING AGROECOSYSTEMS IN CANADA

C.A.S. Smith

Research Branch, Agriculture and Agri-Food
Canada, Whitehorse, YK

Workshop Proceedings Paper

October 1995

PREFACE

The Agri-Environmental Indicator (AEI) Project of Agriculture and Agri-Food Canada was initiated in 1993 in response to recommendations made by a number of agencies, organizations and special studies. The overall objective of the project is to develop and provide information to help integrate environmental considerations into decision-making processes at all levels of the agri-food sector.

In the process of developing a core set of regionally-sensitive national indicators, a number of research issues have arisen. The issues revolve around the availability and reliability of relevant databases, the appropriate use and validation of process models in the calculation of past and future trends, and the extrapolation of site specific data to regional and national scales. This paper was initially presented at the First North American Workshop on Monitoring for Ecological Assessment of Terrestrial and Aquatic Ecosystems, Mexico City, Mexico, September 18-21,1995.

Research results in the form of discussion papers, scientific articles and progress reports are released as they become available. These may be obtained through the Environment Bureau, Policy Branch, Agriculture and Agri-Food Canada, Sir John Carling Bldg, 930 Carling Ave, Ottawa, K1A 0C5. A comprehensive report is planned in the period following the 1996 Census of Agriculture.

Questions and comments on this paper should be addressed to:

Scott Smith
Yukon Land Resource Unit
Agriculture and Agri-Food Canada
P.O. Box 2703
Whitehorse, YK Y1A 2C6

phone: (403) 667-5272
fax:(403) 668-3955

Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

The research effort to design and monitor the health of agroecosystems in Canada has evolved over the last 3 to 4 years. Within Agriculture Canada, data used in making assessments are collected through field monitoring programs and obtained from census statistics, remote sensing instruments, crop insurance records, soil surveys and provincial land use surveys. Our primary objective is to try to measure the long term sustainability of various farming systems. Risk assessment is one method useful for soil and water degradation. Alternatively, a balance is calculated, as in the case of assessing farm input use efficiency, greenhouse gas dynamics and nutrient budgets. In the case of agroecosystem biodiversity, the scientific sampling protocols required to make these assessments are still under development. Many physical process models can be extremely valuable in making sustainability assessments, however, most are designed for use on plot or site scales. A major challenge is to extrapolate site modelling and monitoring results to broad regional landscapes (ecoregions) for national and international interpretation and presentation.

1.0 INTRODUCTION

This paper briefly reviews some of the major issues that researchers face in the development of agri-environmental indicators based on my experience working with Agriculture and Agri-Food Canada.

Most of the issues that we face are generic in nature, they could apply as well to any other resource sector. Universal problems relate to availability of resources, expertise and data. Technical problems stem from our lack of understanding of the ecosystem processes as they occur in agricultural ecosystems and how we can aggregate and generalize information about these processes at very broad scales. The general process we followed to define a set of indicators and a general overview of the project are presented in the paper by McRae *et al.* (1995). My comments relate to the research and development constraints and issues that we have experienced to date.

2.0 DEFINITIONS AND TYPES OF ASSESSMENTS

2.1 Definitions

Researchers have debated extensively the definitions of many of the terms used in ecological monitoring and assessment activities. Ultimately the definition can affect the direction and scope of the research effort. From the standpoint of agriculture, the concept of sustainability remains elusive. Agricultural sustainability is location and time specific, universal approaches to measure it are not applicable even though there are universal principles that can be used to define it (Dumanski and Pieri, 1995). The work on agricultural ecosystems in Canada follows the general definition of sustainability of the Bruntland Commission (WCED, 1987) wherein sustainability is defined as meeting the needs of the present, without compromising the ability of future generations to meet their own needs.

The definition of agri-environmental indicator adopted by Agriculture and Agri-Food Canada is:

> "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 resource, preferably in relation to standard, value, objective or goal" (McRae *et al.* 1995).

As opposed to monitoring, which is the collection of raw data, indicators are statistics or measures that relate to a condition, change of quality, or change in state of something valued. These statistics act as indicators if they have some added significance and are tied to some specific application. If the number of indicators is reduce by aggregating them according to some formula, then these may be called indices. (Dumanski and Pieri, 1995).

In reality not all indicators refer to some quantitative standard but should relate to some societal value or objective. While the research community has, for the most part, defined the terms we use and the scope of our research and development activities, society's broad environmental objectives (standards) are often not established. When this is the case, making interpretations about the results of these assessments may be problematic.

2.2 Criteria for Selecting Indicators

From the standpoint of scientific rigour, the statistics generated to act as indicators must meet fundamental requirements in order to be credible. The need for an indicator by government policy makers often challenges the ability of the research community to deliver something credible in a timely fashion.

In addition to the need for all indicators to be relevant to policy and environmental issues, Moon and Selby (1995) outlined the following analytical criteria for selecting an indicator:

- availability of data for it's calculation,
- scientific credibility (as measured by statistical defensibility and/or theoretical consistency) of that calculation,
- the ability of the indicator to reflect diversity and status at multiple scales,
- clarity in it's interpretation of change or status, and
- potential comparability to some international standard or method of calculation, if such exists.

The above represents a major challenge to the research community and begs the question "What are the trade-offs that we are willing to make in order to produce a less than perfect indicator, when the alternative is no indicator at all?". The issues of selection criteria underlie almost all of the broader issues of indicator research and development discussed in this paper.

2.3 Types of Assessments

Agri-environmental indicators relating to land, water, air and biodiversity under development are discussed in detail by McRae *et al.* (1995). Table 1 lists these indicators and the types of assessments used for each. No one form of assessment works for all indicators. There are three general types of assessment approaches used by our research team: risk, balance and measured change. These may be characterized in the following way:

2.3.1 Risk

Risk is the assessment of a resource condition measured as a probability of some negative change. This is the approach used in soil degradation assessment where certain soil properties coupled with specific land management actions generate some level of probability of degradation. It requires an understanding of the processes producing degradation but does not require any direct, absolute measurement of degradation. It may or may not involve the use of process models but does require validation of interaction assumptions against actual field responses. This approach is well suited to regional, national and international assessments.

2.3.2 Balance

Balance is the assessment of a resource condition measured as a balance between management input versus output of some material, energy or chemical compound. This is the approach used in assessing nutrient loading, farm input management efficiency, and gas exchanges. The calculations tend to be data intensive, requiring comprehensive information about both inputs and outputs or fluxes. Generally balances are expressed as some sort of index but where appropriate can be expressed in absolute terms (i.e. agriculture has a net contribution to atmospheric CO_2 of 18 Mt ha^{-1} y^{-1}). While balance calculations are generally easiest at site levels, the major research challenge is to determine what the appropriate balance should be and extend these calculations credibly over national scales.

2.3.3 Measured Change

This is the direct measurement of change over time without major data manipulation. In Canada, the use of Census of Agriculture data allows time trends to be developed in terms of the adoption of various soil conservation practices, cropping systems and land use. This technique may also employ remotely sensed data of any

Table 1. List of agro-ecological indicators and the type of assessment used with each.

Environmental Issue	Performance Indicator	Type of Assessment
Land Resources	Soil Degradation	Risk
	Soil Cover and Mgmt	Measured change
	Farm Input Mgmt	Measured change
	Input Efficiency	Balance
Water Resources	Water Contamination	
	- pesticides	Risk
	- nutrients	Balance
Atmospheric Resources	Greenhouse Gases (CO_2, CH_4, N_2O)	Balance
Biodiversity	Habitat Availability	Measured change
	Species Diversity/Abundance	Measure change

form of data collected in a repetitive manner over time. Ecosystem monitoring for species abundance/diversity, soil benchmark sampling, and spatial analyses of changes in wildlife habitat are examples of measured change assessment. Measured change is retrospective. Extrapolation may generate projected future trends. The major research challenge is to determine ecosystem sampling protocols (such as biodiversity monitoring) or which form of census data to process.

The choice of assessment approach is dependant on data and process model availability, existing monitoring networks, expertise and the nature and intent of the indicator itself.

3.0 RESEARCH AND DEVELOPMENT ISSUES

The following sections describe in more detail some of the issues that Canadian researchers face in the development of agri-environmental indicators.

3.1 Understanding Ecosystem Processes

Indicator development is dependant on our understanding of the ecosystem processes involved. While we understand the basic processes of soil erosion, and are constrained mainly by available data, the same may not be the case with the process dynamics of soil faunal populations. Yet biodiversity of agroecosystems is considered an important measure of ecosystem health and therefore defines clearly research needs in this realm. While the pathways of the hydrologic cycle are reasonably well understood, good quantitative estimates of the magnitude of flows in specific components of agroecosystems under varying regional climatic conditions are often difficult to make.

The result is that national evaluations of water contamination are limited to simple risk assessments. Similarly, until we understand and can accurately model the dynamics of nitrous oxide in agroecosystems, we cannot determine the total greenhouse gas contributions to the atmosphere from agriculture. The scientific community cannot produce credible statements about ecosystem health if it does not understand the functions, transformations and interrelationships that occur within it. We usually operate with partial knowledge of the system and this requires that we validate our indicators , modify our computations and revalidate continuously.

3.2 Expertise and Data Availability

Expertise and data availability define the limits of what can be done. Within Agriculture and Agri-Food Canada we determined that soil compaction was an important component of our soil degradation assessment. Indicator development has yet to proceed on this issue because there was not a soil physicist to develop the assessment. Therefore partnerships between government, university and private research organizations become an important part of any large research effort.

The issue of data availability involves both the quantity and the quality of data. Any approach to developing an indicator, be it process model, expert system or simple measurement of adoption of soil conservation practises, requires access to some form of data. The data available must be of sufficient quality to support the required reliability of the indicator value and the variability of the data should be such that the variability of the calculated indicator values determined from the data is acceptable (Moon and Selby, 1995). Are estimated values for ecosystem attributes acceptable, are single values, are means and standard deviation necessary? When making national assessments are the data from across the country collected/determined in a consistent manner and how reliable are they? Temporal assessments are often hampered by changing sampling or analytical methods over time. Inconsistent, unreliable data generate inconsistent unreliable indicators. With the proliferation of new resource databases there is a fundamental need to insure we properly document data properties so that their quality and usefulness can be determined.

3.3 Integrating Socio-economic Data with Biophysical Data

There is an accepted international movement toward monitoring and reporting on the environment according to ecological (ecozones, ecoregions, etc) rather than political spatial units. In order to undertake certain assessments it is necessary to effectively link the required socio-economic data to these ecological units. Traditionally, most of these data have been organized along political boundaries - county, state, province, country, etc. This integration is more complex than undertaking simple GIS "overlay and extract" procedures. Data must be allocated, a time consuming process of intersection and examination.

In Canada, agricultural census data are spatially organized through various levels of census units that generally reflect population density and political boundaries. Dumanski *et al.* (1994) were able to summarize the status of land management practices on agricultural land in Canada by province. However, when census information is overlain with 1:1,000,000 scale soil map polygons, information about management systems can be matched to soil type - the key step in making soil degradation risk assessments. Unsupervised digital "overlay and extract" resulted in agricultural data being assigned to soil polygons where no agriculture was possible (rocklands, wetlands, escarpments, etc) or where crop production known to occur only on well drained soils was assigned to polygons dominated by poorly drained soil. Because wildlife data are stored according to game management zones, forest inventory data by forest management units, and groundwater data by county, we face this issue in all sectors. Assigning site specific data in order to characterize spatial units can also be a challenge. We are faced with a long process of first transforming historical data sets, and in the future, compiling monitored data along common ecological frameworks for reporting purposes.

3.4 Management / Distribution of Disparate Datasets

Within the relatively small circle of agri-environmental indicator researchers in Canada, where necessary, we should all be accessing the same datasets. When older data are transformed, (as is the case with our historical census data), new satellite datasets purchased, or specific model input formats completed, these should be maintained and made readily accessible to all. Unfortunately, duplication of these activities within the research community has occurred.

Keeping digital information organized in accessible form is best left to data management professionals. Every research organization needs them, to make decisions about software environments, to assist with data modelling, to coordinate the formatting of data for the plethora of process models that we use and finally, to oversee data quality control. As we become more sophisticated in our analytical techniques, such as the development of the agro-ecological economic modelling system constructed around the Canadian Regional Agriculture Model (Figure 1) (Agriculture Canada 1995), data management, coordination and distribution become increasingly critical. We must not underestimate the resources necessary to enable the effective use of information technology in our assessments.

3.5 Model or not to Model

There is no shortage of models to choose from relating to many of the major agroecosystem functions. Moon and Selby (1995) reviewed available models with application nutrient contamination of groundwater from agriculture alone.

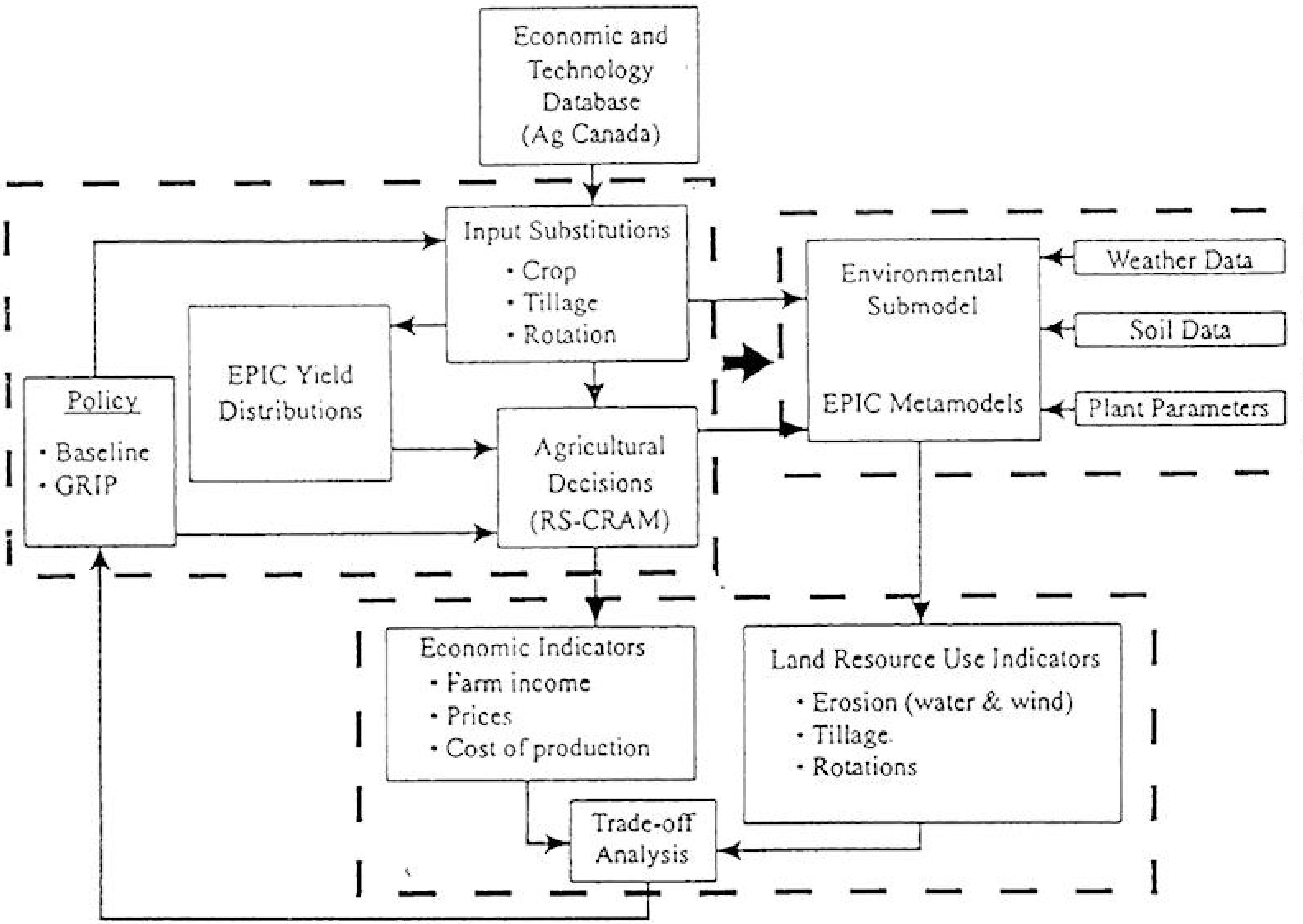

Figure 1. The agro-ecological economic modelling system linking the Erosion Productivity Impact Calculator (EPIC)and the Resource-Sensitive Canadian Regional Agricultural Model (RS-CRAM). Data management becomes increasingly important as the number of disparate datasets that must be integrated into the system increases.

The first issue is the required validation of any given model to Canadian climate-landscape conditions. Many of the agricultural models available have been developed in the United States. Biogeochemical transformation coefficients, crop-weather growth responses, even the effects of seasonal frost, will necessitate model modifications in order to more accurately emulate local conditions. Indicator development is supported by a network of 26 soil benchmark sites distributed across Canada representing major farming systems (Wang *et al.* 1995). Intensive monitoring at these sites allows validation of indicator modelling results and their extrapolation over regional landscapes.

A second issue relates to scale. There are a number of excellent models that are of use to the developers of agri-environmental indicators. One such model is CENTURY which is used to estimate the rate of change of carbon in soil. This is a site specific computer simulation of the dynamics of soil organic matter. The erosion prediction impact calculator (EPIC) was designed to evaluate long term, soil degradation impacts on site crop productivity.

Quantitative models of chemical fate in soil (LEACHM, PRZM) are available to estimate the amount of a pesticide partitioned in soil water (MacDonald and Spaling, 1995). As these models are generally site-specific and applicable only at the most detailed spatial levels, a tremendous amount of development is require to modify these to operate with regional functionality and to be less data intensive. An example of this was the use by Smith *et al*, (1995) of CENTURY to produce a national evaluation of soil carbon loss using generalized soil information and extrapolating results over areas of similar soil great groups. The success of this approach awaits validation. On-going work of this nature is one of the research directions of the National Soil Data Base group of Agriculture and Agri-Food Canada.

Process-based models are not always necessary nor appropriate for all indicator development. They can however play a role in helping researchers understand particular components and functions of ecosystems. In summary, the use of a model to make predictions in a context for which it has not been validated in an appropriate way constitutes an abuse, and can be particularly serious when government policy is involved (Addiscott *et al.* 1991).

3.6 Temporal and Spatial Considerations

To assist in the monitoring, modelling and extension of results, Canada has developed a hierarchical system of ecological units ranging in scale from 1:1,000,000 to

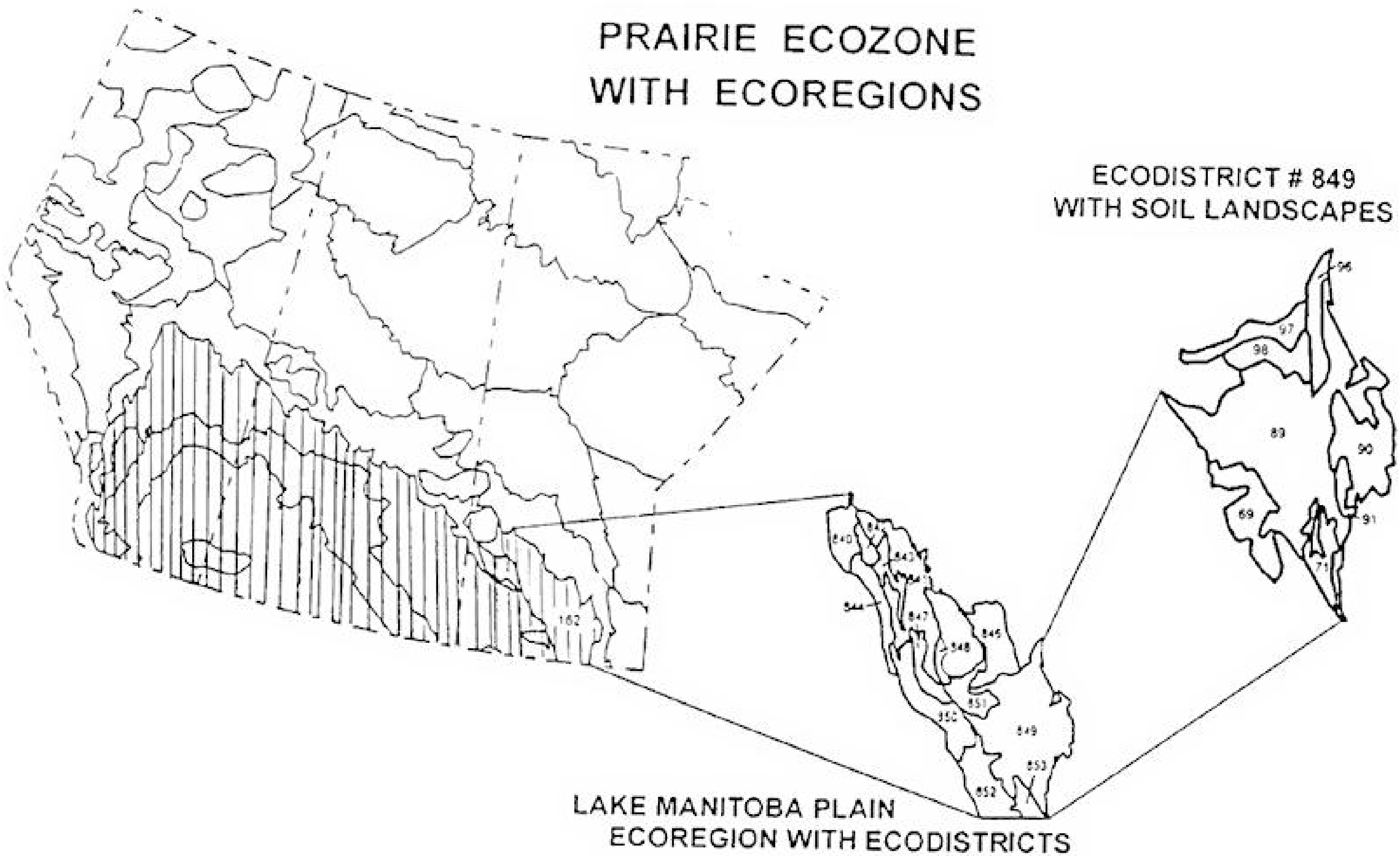

Figure 2. Ecological units are "nested" within the hierarchical structure in the national ecological framework. Monitoring and assessment are linked to the soil landscape polygon and results may be compiled or reported at any appropriate level in the system through aggradation or extrapolation.

1:7,500,000 (Ecological Stratification Working Group, 1995). This cartographic system incorporates nested polygons within which information can be aggregated and reported at ecodistrict, ecoregion or ecozone levels (Figure 2). Examples of the use of this framework are given in McRae *et al.* (1995). While the correlations necessary to prepare the national coverages of these ecological map units are complete, linking and compiling resource data to this common cartographic base remains an ongoing task as discussed previously.

We develop an environmental indicator to assess where we have come from, where we are now and project future trends based on certain assumptions. Prospective indicators are model based, retrospective indicators can be simple compilations of data. Until model development and validation have moved farther ahead, future projections, with only a few exceptions, will be limited to extrapolating trend lines from past measured values.

3.7 Interpretation and Communication of Results

Interpretation of indicators can vary depending on the scale used to report the results. The aggregated result may obscure the local reality. For example, we may report that a new agriculture support policy will result in no net increase in soil erosion in the Prairie ecozone of western Canada. Yet within this ecozone, local farming systems will change with the result that significant increases (or decreases) in soil degradation will occur at the ecodistrict level. We may report that the national nutrient balance for Canadian agriculture is neutral, and this would be interpreted as good. The reality may be that ecoregions within western Canada have negative balances (indicating soil nutrient reserve mining) and in eastern Canada positive balances (indicating ecosystem contamination).

It is sometimes difficult to establish the benchmark or threshold value above or below which an interpretation can be made. Where environmental objectives are not defined, interpreting assessment results as "good or bad" can be problematic. One might ask the question whether 5 T ha^{-1} y^{-1} loss of soil C is acceptable in the Great Plains? When assessing ground water contamination from fertilizers, do we measure our results against standards for drinking water, irrigation water, national standards or international standards?

Finally, in Canada a series of "National Environmental Indicator" bulletins and technical supplements presents technical and peer reviewed information to the general public in a simplified format (see Environment Canada (1995) as an example).

Ultimately it is the general public and government policy makers who are the consumers of our research and development products. There is an increasing demand for competent technical writers to portray and communicate this information clearly, accurately and in an unbiased manner to the nonspecialist.

4.0 CONCLUSIONS

The requirement for agri-environmental indicators by government policy makers, international trade agreements, industry producers and the general public provides the research community with an opportunity and mandate to further basic research into agricultural ecosystems, monitoring systems and physical process models. We can utilize both new and old data to make interpretations in a context never before realized. While it is important to respond quickly to this demand, we must be sure that certain scientific fundamentals be followed to ensure the credibility of our results and interpretations.

Most of the research and development issues relate to the availability of scientific expertise, high-quality relevant data, analytical tools and functional spatial frameworks. While our initial developments are limited by these constraints, they also clearly point the way for future research.

ACKNOWLEDGEMENTS

The concepts and issues discussed in this paper stem from reports written by and discussions held with scientists within the Centre for Land and Biological Resources Research. In particular, I would like to acknowledge the ideas and contributions of Drs. David Moon, Bruce MacDonald, Julian Dumanski, Ted Huffman and Phillipe Rochette in this regard.

REFERENCES

Addiscott, T.M. Whitmore, A.P. and Powlson, D.S. 1991. **Farming, fertilizers and the nitrate problem.** CAB International, Wallingford, Oxon, UK. p73-164.

Agriculture and Agri-Food Canada 1995. **Agricultural policies and soil degradation in western Canada: an agro-ecological economic assessment (Report 5: Project Summary.** Technical Report 2/95. Policy Branch, Agriculture and Agri-Food Canada. Ottawa. 34pp.

Dumanski, J. and Pieri, C. 1995. **Comparison of available frameworks for development of land quality indicators.** Draft discussion paper. Agricultural Technology Division , The World Bank. Washington, D.C. 15pp.

Dumanski, J., Gregorich, L.J., Kirkwood, V., Cann, M.A., Culley, J.L.B. and Coote, D.R. 1994. **The status of land management practices on agricultural land in Canada.** Technical Bulletin 1994-3E. Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada. Ottawa. 45pp.

Ecological Stratification Working Group 1995. **A national ecological framework for Canada.** Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch. Ottawa/Hull. Report and map at 1:7,500,000 scale.

Environment Canada 1995. **Climate Change.** State of Environment Bulletin No. 95-2. Environmental Conservation Service, Environment Canada, Ottawa. 2pp.

MacDonald, K.B. and Spaling, H. 1995. **Indicator of risk of water contamination: methodological development.** Working draft document. Research Branch, Agriculture and Agri-Food Canada. Guelph, ON. 31pp.

McRae T.,Hillary, N.,MacGregor, R.J. and Smith C.A.S. 1995. **Design and development of environmental indicators with reference to Canadian agriculture.** Publication pending. Paper presented to the First North American Workshop on Monitoring for Ecological Assessment of Terrestrial and Aquatic Ecosystems, Mexico City.

Moon D.E. and Selby, C.J. 1995. **A nutrient balance indicator: concepts and recommendations.** Unpublished report. Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada, Vancouver, B.C. 47pp.

Smith, W., Rochette, P., Jaques, A., Monreal, C. and Desjardins, R. 1995. **Rate of change of carbon in Canadian agricultural soils for the year 1990.** Unpublished report. Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada. Ottawa. 36pp.

Wang,C., Walker, B.D.,Rees, H.W., Kozak, L.M., Nolin, M,C., Michalyna, W., Webb, K.T., Holmstrom, D.A., King, D., Kenney, E.A. and Woodrow, E.F. 1994. **Benchmark sites for monitoring agricultural soil quality in Canada**. Soil Quality Evaluation Program Technical Report No.1. Centre for Land and Biological Resources Research, Agriculture and Agri-Food Canada, Ottawa. 76pp.

WCED (World Commission on Environment and Development). 1987. **Our common future.** The Bruntland Commission. Oxford Univ. Press.