Appendix B: Literature Review © Michelle Boyle, 1998

About this literature review…

The purpose of this appendix is three-fold:

- To provide an annotated list of references for anyone studying ecological monitoring and indicators in the context of societal goals.

- To summarize some 150 articles, reports and books providing information on the topic areas of:
  monitoring programs and indicator frameworks;
  monitoring program attributes;
  indicator selection criteria, and;
  existing sets of indicators.

- To provide a justification for pursuing the thesis (i.e. that it makes a valuable contribution to the area of monitoring).

In addition, a list of relevant World Wide Web locations is provided as a further resource for those readers with access to the Internet. Finally, a description of the literature search procedure is included.

Further explanations may be found at the beginning of each section. Throughout the review, indented single-spaced paragraphs preceded by a bullet (•) indicate a brief summary of the content of the document referenced in bold. These summaries are linked throughout with commentaries by the author which appear in normal paragraph format (1.5 line spacing).

All references in this section may be found in the bibliography to the main thesis document. (THESIS: An Adaptive Ecosystem Approach to Monitoring, M. Boyle, 1998)

Core Literature

An abundant literature on indicators, frameworks and related topics exists. There are some noteworthy authors/documents listed (alphabetically) below that can provide the interested reader with a substantial foundation in the state-of-the-art of the theory and practice of monitoring programs and approaches. It is important to acknowledge that much of the literature in this regard originates from Canada, or from the International Joint Commission (IJC) which oversees the implementation of the Great Lakes Water Quality Agreement. In researching the case study it was found that Ontario provincial ministries, including OMNR itself, have produced a number of world-class contributions in this area.

Indicator Frameworks and the Development of Indicators

- **Adriaanse (1993) - Indicators for environmental policy**

  The purpose of this book is to assess the performance of environmental policy for progress towards sustainability in the Netherlands. Indicators are developed using a pressure-state-response model and presented with a full explanation of methodology. Also provided is a thorough discussion about indicators - their functions, types, characteristics, and desirable properties - as well as commentary on the phases of the development process. Procedures for aggregating information and converting indicators to indices are included.

  See also:
  - Hammond et al. (1995) - a framework for assessing environmental policy performance in the context of sustainable development at the national level for a variety of countries; based on the same principles as the above document

- **K. Davies (1991) - Monitoring for cumulative environmental effects**

  Davies explains the key concepts, definitions and implications of cumulative effects monitoring. She then reviews and compares seven such programs, draws conclusions about their effectiveness, and points out areas which still require development.

See also:

- references for the Niagara Escarpment and Oak Ridges Moraine cumulative effects monitoring programs found in the next subsection, 'Specific Applications'
- Cocklin, Parker and Hay (1992) - a general discussion and typology of cumulative environmental effects, including a comparison of monitoring approaches

- **Environment Canada, Ecosystem Science and Evaluation Directorate (Davies, Rapport and Brady, 1992 Draft) - ecosystem health indicators**

Explains the concepts of ecosystem health and undertakes a comprehensive review of frameworks and approaches to ecosystem indicators and objectives. It then provides a rationale and suggestions for a national framework for developing indicators of ecosystem health. The Appendices contain a selection of published environmental indicators.

See also:

- Canadian Council of Ministers of the Environment, Water Quality Guidelines Task Group (Draft, 1994) - framework for developing goals, objectives and indicators of ecosystem health based on the above discussion paper

- **Environment Canada (1991) - State of the Environment Reporting development**

In leading the development of SOER indicators, Anne Kerr discuss the background and history of initiatives in developing indicators. An excellent commentary on process is included and the methodology is applied to generate a preliminary set of environmental indicators and references organized within the categories atmosphere, water, biota, land, and natural resources and presented in a quasi-workbook format.

See also:

- Kerr (1995) - summary report included with the national set of indicators binder
- Gélinas and Slaats (1989) - background report on selecting indicators for SOER reporting
- VHB Research and Consulting Inc. (1989) - background report on indicators and indices
- references for 'State of the Environment Reporting' listed under 'Specific Applications' in the following subsection

- **R.A. Hodge (1994) - Sustainability indicators**

  An extensive and thorough review of literature pertaining to framework typologies, existing frameworks, indicator selection criteria and sets of indicators. It includes examination of 220 State of the Environment Reports. An original framework is proposed that draws upon economics, systems ideas and human-ecosystem models. It is organized around four domains: ecosystem, interaction, people and synthesis in the context of different reporting requirements for individuals and families, corporations, communities and governments. This document tests the practicality of the framework in a case study of the Great Lakes Basin.

See also:

  - Hodge et al. (1995) - NRTEE book applying Hodge's framework to assess Canada's progress toward sustainability
  - 'V. Maclaren' and references in this section

- **International Joint Commission (Allen, Bandurski and King , 1993) - An ecosystem approach to the management of the Great Lakes**

  In 1978, the Great Lakes Research Advisory Board recognized that a more comprehensive approach to management was needed to fulfill their water quality objectives. This led to on-going research and development into an ecosystem approach that is now used extensively. It incorporates concepts from complex systems theory, such as the notions of holarchy and feedbacks, to facilitate ecosystem understanding.

See also:

  - Council of Great Lakes Research Managers (1991) - framework for developing ecosystem health indicators based on IJC ecosystem approach perspective
  - Cairns, McCormick and Niederlehner (1993) - framework for developing ecosystem health indicators
  - Ryder and Edwards (1985) - conceptual approach for biological indicators in the Great Lakes Basin

- **V. Maclaren (1995), University of Toronto - Urban sustainability indicators**

  Maclaren provides a substantive reviews and synthesis of the concept of urban sustainability, framework typologies, indicator selection criteria, and sample sets of indicators. In addition the document offers a valuable process for developing indicator programs. Three case studies are critiqued in light of the information presented.

See also:

- Maclaren, V. (1996) - urban sustainability reporting
- Campbell, M. and V. Maclaren (1996) - review and assessment of municipal State of the Environment reporting

- **R. Noss (1995) - Indicators of ecological integrity in reserve networks**

  Noss combines principles from conservation biology, landscape ecology and complex systems theory to first develop the concept of ecosystem integrity and then proceeds to determine potential indicators of integrity and disintegrity (or threat) for natural and modified landscapes. The framework is discussed and applied in the context of the design of reserve networks.

See also:

- 'S. Woodley' and references, this section

- **S. Tognetti (in press) - Ecological Economic Models and Indicators for Sustainable Development**

  This document is a preliminary literature review for the SCOPE/UNEP project on Integrated, Adaptive Ecological Economic Modeling and Assessment. The objectives of the project are to review methods in integrated ecological and economic analysis (through case studies) to determine their usefulness in problems of sustainable development. Ecological Economics is a recently formed discipline which aims to integrate economic theory and planning with the Earth's ecological processes and limitations. Tognetti's report provides a thorough review of literature in this emerging area.

- **S. Underwood (1994), University of Michigan - Ecosystem philosophy schematic**

  The schematic is an aggregation of information and concepts on the ecosystem approach and complex systems theory, and presented in the format of a poster-sized diagrammatic. It was originally developed for an IJC policy exercise designed to teach managers about the ecosystem approach and its applications.

  See also:

  - Underwood et al. (Draft, 1995) - results report following a policy exercise for which the schematic presented the ecosystem approach which was to be applied in developing policy for a specific issue

- **S. Woodley (1993), Parks Canada - Monitoring in national parks and protected areas**

  Woodley explains and discusses the concept of ecological integrity at length and presents a framework for its measurement. The framework and the resulting suite of indicators are quite comprehensive (drawing from stress ecology, landscape ecology, conservation biology and an indicator species approach) in that they monitor for ecosystem integrity in general, as well as for specific threats to the ecosystem. Commentary on framework attributes and criteria for indicator selection are also included. The theory and framework are operationalized in a case study of Fundy National Park.

See also:

- Woodley (1991) - article on monitoring in protected areas
- Woodley, Kay and Francis (1993) - book applying ecological integrity in case studies
- Slocombe (1990) - a bibliographic review of environmental monitoring in national parks; categories included are: resource surveys, ecosystems and environmental monitoring, ecosystem stresses and response, landscape approaches, ecological integrity, and assessment of the state of parks
- 'R. Noss' and references in this section
- Kay and Schneider (1992) - article on measuring ecological integrity in the context of thermodynamics
- Kay (1991) - background paper discussing the concept of ecological integrity and the implications for decision support indicators

Specific applications of frameworks

- **Beaufort Sea, British Columbia (Thomas, 1992)**
  - environmental effects monitoring

  This document first discusses definitions and considerations in the design of environmental effects monitoring programs, including: reasons for monitoring, scope, elements of the monitoring plan and an explanation of each element. The process they recommend is then demonstrated by a methodical and detailed application for the Beaufort Sea case study.

- **Ecological Monitoring and Assessment Network (EMAN), (1997, Internet: www.cciw.ca/eman/intro.html)**

  A Canadian national network which brings together often independent environmental monitoring and research activities in an ecological framework (ecozones and regions) to facilitate cooperation and an holistic approach to ecosystem issues, inquiry and understanding. The framework is based on a Stress-Exposure-Response model with emphasis placed on anticipation of human impacts and possible management responses.

- **Niagara Escarpment (MacViro Consultants Inc., 1994, 1995) - cumulative effects monitoring**

  The program explicitly answers the questions: monitoring for whom and how?, monitoring for what and how?, and monitoring where and how? as the first stage of the program development. The result are useful lists of indicators in the categories of ecological monitoring, land use, water quality, etc. A concluding section suggests a plan for GIS implementation of the proposed monitoring program.

See also:

- Whitelaw, Neufeld and Carty (1995) - monitoring system design for Niagara Escarpment
- MacViro Consultants Inc. (1993) - workshop proceedings

- **Northern River Basin (Cash, 1995) - assessing and monitoring aquatic ecosystem health**

  The Northern River Basins Study has published many reports, extensively documenting progress in monitoring design, indicator development and subsequent results. Cash (1995) presents a background paper on different approaches to aquatic ecosystem monitoring. This report is of particular value because it contains a concise literature review and discussion of ecosystem health and clinical ecology - one of the conceptual components that this thesis (and other monitoring programs) draw upon for a theoretical basis. Other NRBS reports are also worth examining, such as:

  See also:

  - Cash et al. (1996) - Northern River Basins Study synthesis report

- **Oak Ridges Moraine, Ontario (Ecologistics, 1994)**
  - cumulative environmental assessment and monitoring

  Contains definitions and a survey of monitoring approaches and proposes a "model" for predicting cumulative effects. Four components are analyzed: performance standards, the monitoring strategy, impact management strategies and planning process considerations. Within the latter, an excellent review is provided of Environmental Protection Policies found in Official Plans as well as a survey of Agency legislation, regulations and guidelines for environmental protection.

See also:

- Oak Ridges Moraine Technical Working Committee (1994) - more generally about planning strategy, draft for public discussion

- **Pensacola Bay, Florida**
  (1996, Internet: http://www.dep.state.fl.us/nwd/INTRO/INTRO.htm)

  This document by the Florida State Department of the Environment serves as background information to the Pensacola Bay pilot project (prototype for monitoring of other areas in Florida) and covers such topics as: ecosystem management and planning, conceptual frameworks, and development of the indicator system. The latter topic identifies relevant issues which lead to a preliminary set of indicators. These potential indicators are then evaluated using a specified list of selection criteria. A categorization system considering adequacy of data, availability and cost, helps to assess which of the potential indicators should be implemented for a particular case.

- **State of the Environment Reporting**
  (1997, Internet: http://www.doe.ca/envhome.html)

  SOER has been widely adopted for different scales and sectors (for example: national, regional, municipal, watershed, Canadian National Parks). The national program developed by Environment Canada analyses and describes environmental conditions and trends of significance. Its primary focus is the natural environment - social, economic, and health conditions are discussed only as they relate to the biophysical. Key questions are: What is happening to the environment? Why? Why is it significant? And what are we doing about it? A condition-stress-response framework is employed to address these queries.

See also:

- see 'Environment Canada - State of the Environment Reporting development' in the previous subsection

- Environment Canada (last revised, 1995) - set of selected national indicators including measurement results over time
- Hodge (1994) - reviews 220 national, regional and sectoral State of the Environment documents from all over the world
- Canadian Council of Ministers of the Environment (1992) - an effort by provincial ministers to develop a core set of harmonized indicators to be used by governments for State of the Environment reporting

OMNR and Other Provincial Ministry Documents

This section is included to point to organizational references that were consulted for constructing the Issues Framework and the Conceptual Model for the case study (in addition to discussion with OMNR staff). In the process, several valuable documents on monitoring and indicator development that already existed internal to the provincial government were discovered. These documents would are recommended for reading regardless of the specific application of the monitoring program.

Stated Goals and Objectives

Directions '90s, Directions '90s Moving Ahead in 1995 (OMNR, 1990, 1995a)

> MNR goals and objectives are clearly listed, including desired outcomes of actions. The statements are based on an ecosystem approach to resource management.

Ecological Sustainability Leadership Program Manual (OMNR, 1995b)

> The manual is used in courses to teach senior managers about OMNR's mission of ecological sustainability and the importance of its achievement. Modules on resource management and ecological principles relate the concepts to specific OMNR business sectors.

An Ecosystem Approach to Living Sustainably: A Perspective for the Ministry of Natural Resources (Gray et al., 1995)

> This discussion paper reviews the concept of living sustainably and outlines a framework to assist organizations in developing resources and programs that support an ecosystem approach to management.

- **Performance Measurement in MNR: Frameworks to Action (Petersen, 1994)**
  This paper presents a possible framework for building a system of performance measurement for MNR strategic objectives. Of particular note, is the discussion on the holarchical structure of measurement ranging from Vision to Strategies to Activity Level Management and the importance of indicators/measures that relate to each of them.

- **State of the Resources Reporting (OMNR, Info. Access Section, 1995 Draft)**
  The document begins with terms of reference that includes goals, definitions and issues to define the context. It focuses on four pillars: MNR business goals, Information needs (frameworks and measures), Information Management (collecting, recording, manipulating and retrieving data), and Project Management and Implementation (practical aspects of operationalization). Conclusions on their findings in each area are drawn.

- **Performance Measurement for Land Use Planning in Ontario (Bens, 1995)**
  The report explains the usefulness of performance measurement as a results-oriented tool for the management of programs and policies, resource allocation, and demonstration of public accountability. A framework, criteria for selecting indicators, and the resulting performance measures are developed and discussed. Complementary initiatives are included in the Appendices.

- **Towards an Ecosystem Approach to Land-Use Planning (Neufeld et al., 1994)**
  This document published by the Ministry of Environment and Energy (MOEE) reviews key concepts and characteristics associated with the ecosystem approach, identifies MOEE issues and progress in its implementation, and provides the context for future actions to encourage and facilitate progress at the municipal level in implementing an ecosystem approach. The interdependent components discussed are: ecosystem boundaries, objectives, information and management, monitoring and cumulative effects assessment. Several MOEE case examples (e.g. Niagara Escarpment, Remedial Action Plans) are included.

Sectoral applications:

This body of literature includes good examples of the development and application of monitoring frameworks for individual sectors.

- **Measures to evaluate aquatic ecosystems in Ontario (OMNR, Fisheries Protection Evaluation Committee 1993)**
  Reviews MNR policy directions and some options for program evaluation measures. The report then proceeds to develop measures for identified strategic actions and discuss implementation and a public consultation process.

- **Managing the Land: A Medium-Term Strategy for Integrating Landscape Ecology into Environmental Research and Management (Merriam, 1994)**
  Assumes the landscape requires aggressive management and future policy changes and proposes a strategy to provide the required information. Arguments are supported by sound ecological principles and strong recommendations on process, a conceptual basis and methodology. Parameters of landscape types are included.

- **Proposal for Research on the Impacts of Timber Management on Other Wildlife (OMNR, Other Wildlife Working Group, 1995)**
  Seeks to show how timber management affects wildlife, why, and how to measure it. It demonstrates relationships between policy, ecosystem dynamics and integrity, and wildlife habitat and dynamics. Discussion of forest management issues and linkages to current research programs are also helpful components.

Background Literature Review

Approximately 100 articles, journal articles papers, reports and books (including ‘core literature’) form the basis of the background literature identified as important to review in the areas of ecological monitoring and indicator development. Information was extracted and organized into four categories:

1) Monitoring Programs and Indicator Frameworks;
2) Attributes of a Monitoring Program;
3) Indicator Selection Criteria; and
4) Sets of Indicators.

Each of these categories is explained in further detail, along with brief summaries from the cited works, in the following subsections. Full references may be found in the bibliography to the main thesis document. An explanation of the search procedure used to collect this body of literature is also included.

Monitoring Programs and Indicator Frameworks

This thesis makes explicit the distinction between "monitoring programs" and "indicator development". The latter is but one element of the activity of monitoring. This important differentiation was often lacking in the reviewed literature, the two terms often being used interchangeably or ambiguously. To make matters more confusing, in some cases indicators were generated from a "framework", while others were based on a "(conceptual) model". Again, these words were often used interchangeably, yet sometimes they did connote different ideas. Very few used a conceptual model as well as an indicator framework. This thesis advocates the deliberate development of a conceptual model (i.e. perspective; the way the world/system works) *and* an indicator framework (i.e. categorizations; what is important to monitor?) in the context of societal goals. These are then meshed together to lay the foundation for indicator generation and selection.

Largely for the above reasons (and because of the wide variety of the literature surveyed), a logical organization of this section was challenging and is somewhat arbitrary.

The first step in the 'evolution' of ecological monitoring occurred with the realization that studying impacts of an ecosystem disturbance for only the immediate area and over a short period of time proved insufficient. Serious long-distance, long-term, cumulative and non-point source impacts were soon revealed. But very little was known about the system processes which were at work. Thus, support was given to begin long-term and large-scale monitoring programs to learn more about ecological systems (e.g. what should be considered 'normal' functioning) and to study the effects of disturbances to this regime. The summaries below describe some current monitoring programs:

- The **Integrated Monitoring (pilot) Program** was initiated in Finland to attempt the integrated monitoring of air pollution effects on small catchment ecosystems under the UN/ECE Convention on Long-range Transboundary Air Pollution **(Nihlgård and Pylvånåinen, 1992).**

  The short-term objectives of the program, are:

  1. To establish a network of IM-sites, using comparable methodologies.
  2. To provide a comprehensive description of within and between site variability.
  3. To evaluate relationships between atmospheric deposition of sulfur and nitrogen compounds and ecosystem responses. Use of information from both the IM-network and other long-term data sets will be necessary.
  4. To validate existing models and provide preliminary predictions of ecosystem responses to changes in deposition of sulfur and nitrogen compounds.
  5. To anticipate future trends and make appropriate recommendations for the long-term program.

  The long-term objectives of the program are:

  6. To monitor the current and future state of ecosystems and provide an explanation of changes in terms of causative environmental factors in order to provide a scientific basis (e.g. critical loads) for emission controls.
  7. To develop and validate models for the simulation of ecosystem responses and use them (a) in concert with survey data to make regional assessments, (b) to estimate responses for actual or predicted changes in pollutant stress.

  The monitoring program consists of state and effect variable measurements within ecosystems (e.g. amounts, concentrations, organisms, elements in compartments), driving variables (such as climatic, chemical and land use) and effect (process) variables (e.g. reproduction, physiological growth and decomposition, runoff and groundwater) which are changed by the driving variables. All are linked through consideration of feedback mechanisms.

- A Canadian national network called the **Ecological Monitoring and Assessment Network (EMAN)** (1997, Internet: www.cciw.ca/eman/intro.html) is designed to bring together often independent environmental monitoring and research activities in an ecological framework, usually organized by ecozones and regions. The individual monitoring activities are termed Ecological Science Cooperatives and each conducts long-term monitoring, process research and experimental studies. The stated aim of the program is to facilitate cooperation and an holistic approach to ecosystem issues, inquiry and understanding with the belief that there is value-added in the combination of research intensive to the site, and extensive standardized variables across the country. The program attempts to make links between science and policy and provide useful information in anticipation of change for management purposes.

- The **Environmental Monitoring and Assessment Program (EMAP)** organized in the United States (Internet: http:/www.epa.gov/emap/) is an inter-agency program for basic monitoring on conditions and trends for all significant ecosystems in the country. It provides a coordinating framework to gather and integrate measures within and across different classes of ecological resources. It also intends to assess the cumulative effects of environmental stresses on those resources (e.g. estuaries, rivers, forests, wetlands, deserts and agro-ecosystems) and in this way gain understanding of ecosystem function. There are three core elements: general screening - the current status of the ecosystem; diagnostic - the stresses and pollutants the ecosystems are exposed to, and likely causes; and, risk assessment - which ecosystems are at greatest risk.

- **Messer (1992)** discusses the concept of *regional ecological endpoints* which was adapted by EMAP to carry out this assessment. Analyses using this approach are comprised of a distribution of indicators over a well-defined regional resource of interest, plus annual surveys of sites chosen as probability samples. Indicators are linked to environmental assessment endpoints (similar to targets or thresholds) which can be estimated by measurement endpoints. An example may help to clarify this concept: an identified resource of interest is sustainable fish harvest. The assessment endpoint might be proportion of lakes with/without reproductive trout and the practical surrogate measurement endpoint would then be the proportion of lakes with trout (as recorded caught by fisherman). Evaluation occurs at the population, community and landscape levels. Indicators are amalgamated into indices for the use of non-technical audiences.

- **Magnuson (1990, 1992)** describes the **Long-Term Ecological Research (LTER)** program in the United States which consists of a network of sites across the country which focus research on time scales of years, to decades, to a century and examine ecological processes over longer periods than most other processes. LTER sites include temperate and tropical forests, prairie, desert, alpine and arctic tundra, agricultural fields, lakes, rivers, coastal wetlands, and an estuary. At each site major questions are addressed related to patterns and controls of primary production, food webs, population abundance and distribution, organic matter accumulation, and biogeochemical cycling, as well as questions related to disturbance frequency and effect. Some common measures and questions are used consistently at each location to allow for comparison and generalizations across different ecosystems.

- **Smith (1992)** discusses a similar proposal for a **Canadian** version of the **LTER** program. Its intent is to provide an information base for environmental management in Canada and has been incorporated as part of the Canadian Global Change Program (CGCP). The LTER program background and proposals for monitoring are explained in greater detail in a report published by the Royal Society of Canada who sponsors the CGCP entitled Looking Ahead: Long-Term Ecological Research and Monitoring in Canada (RSC, 1995).

- **Bella, Jacobs and Li (1994)**, writing on the framework used by the **U.S. Global Change Program**, perceive most research to follow what they define as a predictive model. They believe this framework is insufficient for resolving problems posed by global change and instead propose the use of their system response framework which "directs research toward useful indicators of change rather than precise predictions" (p.489). Table 1 (p.493) compares these two approaches. The system response recognizes that technological, social and ecological systems are adapting and self-organizing systems which have mutually reinforcing relationships. The SR framework focuses on the disorders expected when the rate of climate change is great enough to break down the existing ordered processes and something new will emerge. They classify these responses into mild, serious and catastrophic. Indicators are developed to provide information on the extent and rate of global climate change through the objectives of identifying climate-sensitive ecosystems, processes, landscapes and populations, as well as signs of disorder within these systems.

- Another example of a networked site monitoring program is called **LRTAP (Long Range Transport of Air Pollution, Jeffries, 1992)** program which has engulfed ecological monitoring of any anthropogenic perturbation and thus requires organization in an integrated holarchical manner. This means that the study is designed (i.e. type of monitoring, sampling frequency, amount of data etc.) according to the type and rate of the process to be monitored and the need for information (evaluation complexity). The information gathered is then linked through a conceptual model to the development of environmental policy based on the results of monitoring.

- The draft report written for the **Canadian Council of Ministers of the Environment (1994)** drew from the earlier mentioned Eco-Health discussion paper (Davies, 1992). Their ecosystem-based management approach for developing goals, objectives and indicators of ecosystem health is comprised of four principle activities or steps which serve as a monitoring framework:
    1) Scope the issues and collate the existing ecosystem knowledge base (cyclical process);
    2) Articulate ecosystem goals and objectives;
    3) Develop (or select) ecosystem health indicators to gauge progress towards ecosystem goals and objectives; and
    4) Conduct targeted research and monitoring.

    They emphasize the use of a participatory multistakeholder process to consensually establish ecosystem goals and objectives and the importance of linking indicators to objectives in order to provide relevant information for decision making. To select a comprehensive suite of indicators (and make the framework operational), they cite various categorizations of indicators (Table 1, pp.17-18): Council of Great Lakes Research Managers (1991), Rapport and Davies (1992), Environment Canada Indicators Task Force (1991), Organization for Economic Cooperation and Development (1991), Kelly and Harwell (1989), Knapp et al. US-EPA (1991), and Cairns (1992).

- **Davis (1993)** presents a step down plan for the development of natural resources monitoring programs in natural areas. The three major components involve: (1) developing a conceptual model of ecosystems to monitor; (2) conducting design studies; and (3) monitoring system health. The process required for each step to be accomplished is illustrated in a diagram (Figure 1, p.102) and detailed in the text. Closely following this methodology serves as a framework to the practical development of indicators in step (3).

- **Whitfield, Neufeld and Carty (1992)** propose that monitoring for sustainable development should provide information on the state of ecosystems, of natural resources, and of environmental conditions affecting human health. To this end, a monitoring program must: measure complex attributes; it must be rapid and predictive, and, it must allow the assessment of risk of ecosystem state change. To accurately predict future ecosystem changes, processes that give rise to change must be the focus of monitoring. Since there is uncertainty as to future states, probabilities and risk assessment are used rather than precise measurements. A list of ecosystem attributes (e.g. trophic structure state, nutrient dynamics, energy flow, resilience) is provided to demonstrate the types of measurements which are called for.

  Design of a monitoring program for sustainability requires:
  1) analysis of the main processes and structural characteristics of each ecosystem under consideration;
  2) identification of the known and potential stressors;
  3) development of hypotheses about how these stressors may affect each ecosystem, and;
  4) identification of measures of environmental quality and ecosystem health to test these hypotheses.

  It is recognized, however, that links of cause and effect need not necessarily be made: a cause that *may* lead to an effect could be sufficient justification of preventative action; conversely, an effect not linked to a cause is still of concern. In either case, the monitoring program will have done its job if it identifies ecological changes that may occur, and potential causes.

- The **Canadian State of the Environment Reporting** program (see **Environment Canada, Indicators Task Force, 1991**) is another prominent example of monitoring programs in progress. It utilizes an ecosystem health stress-response approach to develop general screening indicators for health assessment and broadly-based diagnostics. The program was unique in that it was the first such endeavor to choose an ecosystem classification as the basic reporting unit rather than political boundaries. It also identified a taxonomy of major stresses acting on large scale ecosystems. One of the stipulations for indicators is the strongly constraining criterion that only "off-the-shelf" data may be used. (Indicator development under this program is discussed below.)

With this introduction, a general discussion regarding frameworks to develop indicators for these programs and others, is possible. Frameworks define what is important to measure for a particular monitoring program. Noted here are two authors that have reviewed many monitoring programs and concluded that most frameworks can be grouped into definable types:

- A report was produced for the Eco-Health Branch of Environment Canada **(Davies, Rapport and Brady, 1992)** on indicators for evaluating and reporting ecosystem health. It includes a typology of frameworks (identified by Environment Canada's SOER Branch):
    - *issues framework*: indicators categorized under issue areas (e.g. climate change, hazardous waste, acid rain); dynamic (specific issues change over time)
    - *environmental media framework*: e.g. air, land, water
    - *resource sector framework*: divides environment along traditional sectoral lines (e.g. forestry, energy, agriculture, fisheries); some integration of economic well-being with environmental health.
    - *environmental process framework*: environmental reporting using categories of: environmental conditions or environmental responses to human activities, human contributions to environmental conditions (stress), and human (management) responses to environmental conditions.

  In addition, there are several basic frameworks when focusing on the concept of environmental health:
    - *environmental standards, guidelines and objectives*: provides important dimensions of health and limits other stresses, e.g. habitat fragmentation
    - *integrative indicator species:* integrative means that the species is important in the organization of the system so that its presence implies a healthy system and its absence an unhealthy one
    - *ecosystem distress syndrome*: empirically derived set of indicators that differentiates stressed from unstressed ecosystems; premise of inter-related systems ("supra-organisms")
    - *agglomerative indices*: reduction of large data sets to a weighted average of many factors (e.g. Inhaber, 1974 - index of quality of Canadian environment; Karr, 1991 - Integrated Biological Index for aquatic systems)
    - *stress-response statistical system*: developed originally by StatsCan and adapted for reporting on the state of regional environments; taxonomies of major stress pressures and shows linkages between the stresses from human activity, ecosystem responses and policy; identifies five major sources of

stress: harvesting, physical restructuring, extreme natural events, contaminant loadings and exotic species loadings.

These frameworks can be operationalized at different levels, for example: project; regional; watershed or drainage basin; or, on a large scale like State of the Environment Reporting (SOER). Table 7, a "Comparison of Different Conceptual Frameworks for Evaluating and Reporting Ecosystem Health" and Table 8, "Comparison of Different Operational Approaches for Evaluating and Reporting Ecosystem Health" are reproduced and included at the end of this section.

The report by Davies, Rapport and Brady also summarizes and critiques existing monitoring program frameworks in Appendix C. Those covered are:

U.S. EPA Environmental Monitoring and Assessment Program
Canadian State of the Environment Reporting
IJC Framework for Indicators of Health in the Great Lakes
OECD State of the Environment Reporting
Environment Canada, National Set of Environmental Indicators Approach (as at 1991)

With the exception of OECD, these monitoring programs are covered in this section of the Literature Review.

- **Maclaren (1995)** reviews several existing examples of frameworks for indicator development (these will be listed in a later discussion on sustainability frameworks). From synthesizing and supplementing these examples, she devises a typology of frameworks (used in the development of sustainability indicators):

  domain based: effective for ensuring all dimensions of sustainability are covered, i.e. environmental, social, economic
  goal based: reduces the number of indicators required; examples: carrying capacity, basic human needs
  sectoral: good for governments, follows local divisions e.g. housing, transportation, welfare
  issue based: popular but lacks structure to link to sustainability or policy
  causal: conditions-stress-response model.

The most useful in practice is generally a *combination* of more than one type of framework, as noted by Maclaren. Any framework is likely to, and should, stem from the 'conceptual model' of how the system works. As knowledge and understanding have increased, conceptual models have also evolved. Many current monitoring programs are based on a stress-response model. When an ecosystem is stressed by a strong enough disturbance it will respond and change. The stress-response model attempts to link stresses with responses and therefore provide an early warning or prediction of how and when a system will respond to influences. Several examples of indicator frameworks which utilize this model are provided below. State of the Environment Reporting is one of these examples. Some of the ideas which went into its development are presented, along with a variety of applications. The discussion then turns to additions and evolutions in the concept of stress-response and the more recent notions of monitoring for ecological integrity and for cumulative effects. Again, examples of indicator development for each of these is presented in the following text:

- **Thomas (1992)** discusses considerations in the design of effects monitoring strategies using the case study of the Beaufort Sea Environmental Monitoring Program (BEMP). Initiated in 1983, the emphasis of this program is on testing impact hypotheses using a systematic evaluation of linkages between industry activities and "valued ecosystem components", i.e. components of the ecosystem deemed important. The basic purpose of monitoring is to ensure that stressors (e.g. hydrocarbons) do not exceed "acceptable levels". This maximum acceptable effects level concept is fundamental in the design of the monitoring program and the selection of indicators. It determines what to measure and the number of samples (and hence cost) required to resolve the actual effect from natural variability.

- The **Florida Department of Environmental Protection (1996)** undertook the development of indicators to provide a current snapshot of the Florida environment, a historical perspective on how it got there, and some idea of the future. Their World Wide Web site presents the theory and development of the indicator system for the Pensacola Bay in particular. First, issue areas were identified and broken down into subissues:

Water Budget	- flow
Water Quality	- turbidity - nutrients - metals/toxics - pathogens
Sediment Quality	- contamination
Native Biodiversity	- exotics - habitat degradation/loss - species population change
Balancing Human Use and Demand for Natural Resources	- navigational maintenance impacts on the ecosystem - upland development and land use - human use of natural resources

Indicators were derived from this issues list following the OECD's (Organisation for Economic Cooperation and Development) framework for organising indicators. This framework suggests three different, but related and integrated, types of indicators for each environmental issue: pressure indicators (measures of pressures on the environment due to human activities), state indicators (measures of the quality of the environment, and the quality and quantity of natural resources), and response indicators (measures that demonstrate how and how much society is doing to respond to environmental changes and issues). The advantage of this framework is that it results in a group of indicators for each issue that address the sources of the problem, its current status, and what is being done about it.

A holarchy of indicators was also developed to assess the quality of indicators measuring environmental parameters. Data types 1 (actions by federal/state/regulatory agency) and 2 (responses of regulatory community or society) are administrative, bureaucratic, or activity measures and are only weakly associated or completely unassociated with the capacity to measure environmental quality. Data types 3 - 6 (changes in: discharge/emission quantities; ambient conditions, quantity of natural resources; uptake and/or assimilation; health, ecology or other effects) are measures that reflect environmental performance. Ideally, all indicators should measure whole system conditions (type 6). Indirect measures may also be used which reflect concerns of significance to environmental issues or policy but are not themselves indicators of environmental performance.

- A background report on indicators and indices in Canada **(VHB Research and Consulting Inc., 1989)** reviews the history of approaches in Canada which attempt to describe the State of the Environment. A few are mentioned here.

In the early 1970s, Inhaber developed an Environmental Quality Index (EQI) which classified natural resources into constituents of air, land or water. The index measures resource availability, the quality of the resource related to human health and welfare, and human induced stresses on the resource. There is also a component which highlights pressing environmental concerns, e.g. pesticide use. A complicated process is followed to aggregate the subindices into a single index over a common time frame and normalized geographically by the population which the resource serves. The EQI does not address the economic implications of resource availability and quality nor mitigative activities. Policy effectiveness is interpreted by change in the availability and quality of resources. A number of air quality indices measured in the short (i.e. hourly or daily) or long term (annually). Inhaber also contributed an air quality measure that incorporated air quality outside of urban centers into the index.

Statistics Canada’s program in 1986, “Human Activity and the Environment”, focused on human induced stresses on resources. The statistics measure human activities that affect the environment, the environmental response, and the human response to such changes.

The report also describes a number of indicator initiatives in the United States and Europe.

- The **Stress-Response Environmental Statistical System (STRESS; Rapport and Friend, 1991)** framework has most influenced SOE reporting. It recognizes a two-way relationship between stress on people and on the ecosystem through a multi-faceted categorization of stresses. There are four categories of statistics: human activity stressors, environmental stressors, environmental response, and collective and individual human response. The framework links transactions between humans and nature through public policy.

- **The Stakeholder Group on Environmental Reporting (1987)** adapted the STRESS framework used by Environment Canada but included measures of the effectiveness of societies' responses to environmental problems (regulation, expenditures, re-ordering priorities, selection of technology). The modified framework data categories are listed below:

Environmental Assets	- size and evolution of resource stocks - effectiveness of management responses and expenditures
Environmental Change Agents	- human activities with potential for environmental change - actual pollution loadings, land conversions, etc. resulting from these economic activities - effectiveness of current standards, licences, codes etc. which currently control these impacts
Measures of Environmental Quality	- levels of air, water and soil quality - human health and exposure - standards, regulations, programs, etc. designed to achieve target levels

In addition, for each category, multiple causes and effects, indirect causes and effects, and delayed causes and effects must be considered.

- The **National Set of Indicators (EC, SOE Directorate, last revised 1995)** eventually developed under the Canadian SOER initiative, is based upon three principle goals for sustainable development: assuring the maintenance and integrity of ecological life support systems; assuring human health and well-being; and, assuring natural resource sustainability. These principles are translated into broad theme areas which form the basis of the framework in addition to "pervasive influencing factors" (population, life-style, and consumption patterns). Important issues under each of these themes are decided upon by employing a multi-stakeholder consultation process. For each issue, potential indicators of stress, condition and societal response are derived and developed.

- Canada's Green Plan to develop the above national framework of indicators for sustainability was one of the first monitoring initiatives to "think, act and plan in terms of ecosystems". This comprehensive approach required that the entire country be mapped in terms of standardised, multi-scale geographical reporting and monitoring units. Starting in 1991, the following terrestrial units were reviewed and redefined **(Marshall, Smith and Selby, 1996)**:

Unit	Description Criteria	Map Scale
ecozone	defined by macroclimate, major vegetation types and subcontinental scale physiographic formations	1: 7 500 000
ecoregion	subdivisions of ecozones; defined by regional physiography, surficial geology, climate, vegetation, soil, water and fauna	1: 7 500 000
ecodistrict	subdivisions of ecoregions; defined by landform, parent material, topography, soils, waterbodies and vegetation (useful for resource management, monitoring and modelling)	1: 2 000 000
polygons	subdivision of ecodistricts; defined by Soil Landscapes of Canada series	1: 1 000 000

This spatial framework is supported by the ARC-INFO GIS database at Agriculture Canada. The nested levels of ecological generalisation are linked to existing federal and provincial scientific databases on climate, land use and socio-economic attributes. State of the Environment reports are generated using this framework and associated databases of information.

State of the Environment Reporting has been adapted and applied at various scales and to many types of monitoring activities. **Hodge (1994)** examined some 220 versions of State of the Environment (SOE) documents with a(n) international, national, provincial/regional, municipal, ecosystem component (i.e. air, water, forests and oceans) or corporate/industry perspective. A few samples are presented below:

- Another review of some existing SOE reporting frameworks may be found in an OMNR document entitled **State of the Resource Reporting (OMNR, Information Access Section, 1995 Draft)**. They name several (in order of increasing complexity): resource and pollution statistics, state of the environment reporting describing issues by industrial sector, environmental media, and resources, SOER using a Stress-Response framework, SOER using an ecosystem approach, and sustainability reporting.

State of the Resource Reporting is not intended as a reporting framework itself, but is a subset of SOER which examines resources by sector. Its purpose is usually to describe the stock, changes in quality and its relationship to social and industrial use of the resource. The reporting focuses on measures, indicators and benchmarks for the status of natural components and the human activities related to them.

- The SOER approach has also been adopted at the regional and local levels. One of these initiatives assesses the **State of the Don Watershed (Ecological Services for Planning Inc., 1995; The Don Watershed Regeneration Council, 1997)** and the results are communicated in the form of a report card measuring advances toward set goals that is published every three years. The general principles which guide achievement of the Task Force's vision for the Don are: protect what is healthy, regenerate what is degraded and take responsibility for the Don. To evaluate success, several indicators of progress were developed under four general themes: caring for water, caring for nature, caring for community, and getting it done. The framework recognizes humans as an integral part of this heavily urbanized setting and adopts a holistic approach. It narrows the broad themes of water, nature and community by establishing major functions which are important to monitor. For example, Nature is separated into Tableland and Valleyland and each of these has components of terrestrial habitat, aquatic habitat, special areas and linkages. A long list of indicators which would satisfy comprehensive measurement of these properties was generated. Key indicators were then selected with an emphasis on those measuring positive accomplishments for community encouragement. Realistic and achievable targets have yet to be set.

  Examples of other report cards are also reviewed. The Fraser Basin Management Program in B.C., the federal State of the Environment Report and the Hamilton-Wentworth's Vision 2020 report card are described.

Using the stress-response conceptual model as a basis, other monitoring initiatives developed the notion further by including exposure to stress as one of the main contributing factors to system response:

- **Shackell, Freedman and Staicer (1993; Freedman, Staicer and Shackell, 1992)** perceive three components when analyzing stress upon ecosystems: stressor, exposure, and response. Stressors are usually the result of human activities (such as pollutants, climate change, harvest) but also include natural events. Exposure accounts for the duration of stress to the ecosystem. It incorporates the intensity of the stress at a particular point in time as well as the accumulated dose over a period of time which are both important when studying the effects of stressors like toxic substances and rates of habitat loss. The response, then, is the change which occurs in organisms and/or the ecosystem as a whole as a result of the stressor and exposure, for example mortality and changes in productivity. Indicators for each of these components would comprise the ecosystem monitoring program. (Note that their 1993 paper applied the approach in the Atlantic provinces, while in 1992, the framework was expressed as a proposal for a national monitoring program.)

- **Hirvonen (1992)** uniquely uses a visual framework in the form of a box matrix for indicator development for a particular scale or resource area of interest (a photocopy of the matrix is included at the end of the "Monitoring Programs and Indicator Frameworks" section). The axes represent: spatial context (scale), issues of concern and the category of indicator. Categories include indicators that measure: the response of the ecosystem to stress, the intensity and duration of the exposure and the stressors themselves. The presentation of the box matrix emphasizes the spatial linkages to response, exposure and stressor indicators.

Some authors attempted to expand the stress-response model by enhancing its usefulness in identifying and diagnosing problems:

- **Rapport (1992)** writes of trends in the evolution of indicators which may lead to new designs of indicator development frameworks. He identifies three emerging concepts in their design. *Early warning* generally uses signs in indicator (sensitive) species as clues to ecosystem degradation that has not yet manifested strongly in the system. It makes use of this information and forecasting models to relate particular stressors to probable effects. The problem of entangling cause and effect relationships is eliminated with the notion of integrated indicators *reflecting multiple stressors*. Again, indicator species are the prime vehicle of measurement. Finally, *diagnostics and ecosystem medicine* follows an analogy to human medicine. At the screening stage, symptoms of pathology are sought (e.g. changes in species diversity, productivity, nutrient cycling). A diagnostic stage then "rules in" or "rules out" probable causes. Overall, there is a focus on system health and especially the functioning of critical self-regulatory processes.

- The **Council of Great Lakes Research Managers (CGLRM, 1991)** provides a context for their indicator framework in three broad goals to sustainable development: self-maintenance or self-sustainability of the Great Lakes ecosystem; sustained use of the ecosystem for economic or other social purposes; and, sustained development to insure human welfare. Ecosystem objectives are then set for each of these goals. The framework which emerges uses a "medical" orientation relating effects to probable causes and requires three types of indicators for each of the objectives to assess management actions:

  1) compliance
     - Are ecosystem objectives being met?
  2) diagnostic
     - If not, what are the causes of non-compliance?
  3) early warning

- How can impending noncompliance be predicted before it is detected?

- **Jenkins and Sanders (1992)** state that populations and communities are of primary concern in terms of effects (i.e. what we see and would like to see), but the initial impact occurs at the molecular level and propagates upward to the higher levels of biological organization. Therefore, molecular and cellular processes are the most sensitive and a framework based on this observation can provide early warning for adverse affects at higher levels of organization.

  The framework which they have developed from this idea is a multi-tiered approach to surveillance monitoring. Tier I asks: Is there biological stress? If not, no further action is taken at that time. If the answer is yes, then Tier II queries: What group of contaminants is causing the stress? At Tier III the relevant question is: Which specific contaminants are responsible (if possible)? Different indicators are required at each Tier. The approach is similar in its "filtering" method to that of ecosystem medicine proposed by Rapport (1992) and promises to be cost effective since monitoring for specifics is only required if biological stress is encountered at Tier I.

A document prepared for Environment Canada included ecosystem fitness as another aspect of measurement:

- **Davies, Rapport and Brady (1992)** recommend a framework designed to track stress (from natural events as well as human activity), ecosystem response and the linkages between the economy and the environment. It is founded upon a multistakeholder consultation process to clearly articulate the objectives for monitoring. From these objectives, specific targets must be agreed upon and only then are indicators developed, based upon available scientific information and data. Potential indicators are organized around four categories:

  general screening - to assess the current state of the ecosystem
  diagnostic - to assess the causes of degradation in the health of the ecosystem
  risk factors or stress indicators - to monitor the natural and anthropocentric stresses to which the ecosystem is exposed
  fitness (eco-health) - to assess the capability of the ecosystem for recovery after the stress is removed

  Thus, the four key questions the framework should address are:

  1) Is the state of the environment improving or degrading (general screening)?
  2) If degradation or ecosystem pathology is found, what are the most probable causes, taking into account the ecosystem dynamics and lag effects (diagnostic)?

3) What changes may be expected in particular ecosystems in the near future, given present management practices and stresses from human activity (risk assessment)?
4) How can we determine the "healthiness" of an ecosystem, i.e. its capabilities rather than its disabilities (ecosystem fitness)?

Monitoring under the stress-response model has proven limited to addressing only narrowly defined questions regarding known cause and effect relationships in a system. Thus, the notions of monitoring for ecosystem health and, more recently, integrity have attempted to allow an evaluation of the overall status of the system.

- **Stokes and Piekarz (1987)** wrote a report following a workshop to assist Environment Canada in developing ecological indicators for sustainable natural resources. The report described the Adaptive Environmental Assessment and Management Approach (AEAM) to selecting environmental components for measurement and monitoring. An important point they make is that it is usually impractical to monitor for environmental effects at the ecosystem level directly. It is, therefore, more useful to focus on the processes and populations for detection of change. In assessing cumulative effects the focus should be on the carrying or assimilative capacity of the ecosystem to receive early warning for structural or functional "surprises". The key question is: Are there indicators that serve to measure how close an ecosystem is to a threshold? As an example, they cite a "top down" or holistic approach that uses indicator species as a bellwether of system degradation or collapse.

- Out of a workshop sponsored by the **Canadian Council of Ministers of the Environment (CCME, 1992),** a report was produced in an effort to develop a "core set" of harmonized indicators (which could be interpreted and reported by CCME members in a consistent manner for SOE reporting and related activities) and it included the notion of monitoring for general health. The task group proposed an overall framework within which various environmental indicators could be situated and explained. It involved three "levels" of indicators: those pertaining to ecosystems (indicators of environmental condition/health), stressors (indicators of human activity stressful to the environment) and programs (indicators of program performance). The latter allows assessment of results in relation to original goals, objectives and targets. Their intent was to draw as much as possible from existing indicator efforts which related to their chosen issues of focus: global climate change, air quality, water management, packaging reduction, solid waste management, hazardous waste and contaminated sites management, and chemicals management.

- Part of the U.S. E.P.A.'s EMAP national assessment of the state of ecological resources involves rangelands (arid, semi-arid and dry subhumid areas). The objectives of this program are **(Breckenridge, Kepner and Mouat, 1995)**:

- estimate the current status, trends, and changes in selected indicators of the condition of the nation's ecological resources on a regional basis with known confidence
- estimate the geographic coverage and extent of the nation's ecological resources with known confidence

- seek associations between selected indicators of natural and anthropogenic stresses and indicators of the condition of ecological resources
- provide annual statistical summaries and periodic assessments of the nation's ecological resources

With these objectives in mind, the EMAP Rangeland Resource Group identified regional issues and critical assessment questions related to rangeland conditions. A conceptual model linking key biophysical and societal processes in rangelands was mapped out. (Overall societal values of focus were determined to be: productivity, biological integrity and aesthetics.) Specific monitoring questions derived from the above analyses then lead to the development of indicators, which thus integrated important ecological and societal components. Components of the conceptual model and associated indicator categories are listed below (the diagram on page 50 of the article illustrates how the various components are linked together):

Component	Indicator Categories
Socio Economic	jobs, recreation, aesthetics
Stressors	soil and vegetation, physical disturbances, drought, fire, pathogens, pollutants and water development
Landscape	riparian extent, land use patterns, ecotonal shifts, fractal dimensions
Atmospheric Inputs	Bowens ratio, albedo, solar radiation, precipitation, wet/dry chemistry, wind
Terrestrial Vegetation	biomass, assemblages, diversity, exotics, genetic biomarkers
Terrestrial Fauna	relative abundance, demographics, morphological asymmetry, habitat, biomarkers
Soil Micro and Macro Flora/Fauna	microbial and invertebrate decomposers, consumers, nutrient cyclers
Soils: Physics	profile; structure; organic matter, litter and soil crusts; erosion and disturbance; hydrologic properties
Water	quantity balance, quality, soil moisture, historical water table fluctuations
Biogeochemistry	methane production, foliar and litter chemistry, soil chemistry, soil energy, nutrient transport

- **Svanberg (1996)** presents us with the challenge of monitoring in the Baltic Sea. Bordered by nine nations with a diverse coastline, and having problems with point (e.g. urban, agricultural run-off, industrial discharges) and non-point pollution sources, it requires the use of a variety of frameworks for different dimensions. Eco-epidemiology complements traditional ecological indicators in regional, chemical and field monitoring. Plus, there is a continuous unprejudiced search for harmful known and unknown substances in the environment. Several different programs complement one another to address the different dimensions of this system:

Program	Monitoring Dimensions
Baltic Monitoring Program (BMP)	natural conditions and routine measurements of contaminant levels; basic hydrography and hydrochemistry; harmful substances in water and biota; biology
Swedish National Environment Program (PMK)	long-term and large-scale environmental changes, pollution transport; conditions in areas not subject to local effects
industrial monitoring	monitoring of discharge to local water and air (responsibility of polluter)
Toxic Effect Indicators	monitoring birds and seals; researching detection of substances before it harms individuals
Integrated Fish Monitoring	measures several levels of biological organisation (e.g. concentration of substances in tissue, biochemical/physiological effects, frequency of sick/deformed individuals, age distribution, population density), including exposure and response parameters

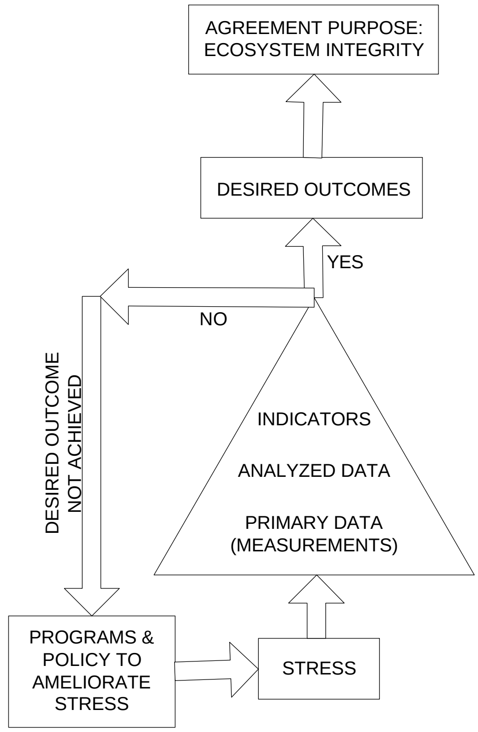
- A similar situation is presented in another large area of inland waters, the Great Lakes. The major difference is that this bioregion is governed by a single body - the International Joint Commission - formed to implement the Great Lakes Water Quality Agreement (1972, amended 1987). The **IJC (1996)** developed indicators to assess progress toward the objectives of the Agreement. The framework is based on the pressure-state-response model but has incorporated an ecosystem approach and complex systems theory. In fact its main goal is to achieve ecological integrity of the Great Lakes system.

  Here, 'pressure' implies the direct and indirect pressures, including human activities that cause environmental change. 'State' is the physical, chemical and biological condition of the natural world (measured at different scales, e.g. local, regional, global), plus human health and welfare. 'Response' incorporates the changes in policy or behaviour (by governments, private sector, households and individuals) that is made in reaction to the effect of pressures on the ecosystem, human health and human welfare.

  In essence, four important questions may be answered by using this concept:

1) What is happening in the environment (state)?
2) Why is it significant (effect)?
3) Why is it happening (pressure)?
4) What are we doing about it (societal response)?

The figure below represents the link between policy decisions, program actions and defined desired environmental outcomes (that will lead to ecological integrity):



The application of this framework involves assumptions made about stresses, measurements and indicators in relation to implemented programs and policies. If the desired outcome is not achieved, the process is reiterated so that policy is subsequently revised to work towards ecosystem integrity. The pressure-state-response model and the above framework are useful because they are simple and may be applied at any scale.

- **Fritz (1993)** devised a framework for the very specific application of vegetation monitoring for the Canadian Heritage Rivers system. It is based on a conceptual model of vegetation dynamics that describes whole system properties: the structure, process and composition of vegetation and the feedback between it and both the local and global environment. It recognizes a horizontal heterogeneity and vertical stratification of vegetation structure which is interpreted for a given time period as a successional stage. The framework thus requires a holarchical representation of indicators to adequately monitor internal changes and external influences, all of which may be due to abiotic, biotic and/or cultural factors. For each level (individual, population, community and ecosystem) structure, composition and process, as well as the overall physiognomy were judged as important indicator areas.

The concept of integrity is emerging as a further advancement to the notion of health in ecosystems:

- Incorporating the idea of the natural-human continuum, **Regier (1992)** presents a general framework to monitor the self-integrative and regenerative capabilities of an ecosystem. He claims that three sets of indicators must be developed: those to ensure the preservation of wild ecosystems, those to monitor the recovery of degraded ecosystems and lastly, those that will guide efforts towards natural/cultural mutualism within a settled landscape.

- **Kay (1991)** proposes a framework for describing responses to environmental change which is rooted in complex systems theory and the notion of ecological integrity. While this is not actually a framework to develop indicators, Kay discusses the implications of the theory for decision support indicators and sets the conceptual stage which would be the basis for indicator generation.

- **Kay and Schneider (1992)** present a thermodynamic framework to discuss ecological integrity. Measures of ecosystem organization are concerned with energy use and energy degradation. Indicators would point to ecosystem structure (i.e. energy flow through the system) and function (i.e. amount of energy captured and the way in which it is degraded) to appraise the current state of the system. Context (history and external influences) is extremely important in assessing the ability of the system to continue self-organizational processes and renew and regenerate. The integrity of the system, however, is based on a value judgment in deciding which of a suite of ecologically sound system states is preferred. The choice of specific indicators from the list of potential ones, must therefore, be devolved to the broad stakeholder group.

- The **Other Wildlife Working Group of the OMNR (1995)** prepared a proposal to examine the question of what the impacts of timber management are on "other wildlife". This report is mentioned here because of the methodological approach (a science framework and implementation plan) that was built prior to beginning research which incorporates ecosystem integrity. The realization was made that in order to conduct the research, it was first necessary to examine the "big picture" including all the components required for the undertaking. Components of the framework consist of forest management issues, the formulation of the research question, the study design and organization, and the products (knowledge, tools and models, and new guidelines). Related programs are incorporated as appropriate. To understand the question and issues, conceptual models were developed to illustrate ecosystem dynamics and integrity and to see the linkages, direct and indirect, to policy. Complex systems notions (e.g. holarchy theory, Holling's figure 8) play a key theoretical role in the models.

- **Lajeunesse et al. (1995)** claim the necessity of evaluating the ecological integrity of protected areas. (Recreation and aesthetics must be second to this goal.) Evaluating integrity of ecosystems requires the consideration of levels of biological organisation (e.g. individuals, species, communities). They identify five aspects that are important to assess in monitoring in natural areas:
    - systems sensitive to change due to minor environmental fluctuations
    - sensitive species and communities
    - species in flux, i.e. undergoing natural or human-caused changes in population structure
    - threats occurring within the park boundaries (visitation trends, impacts)
    - plant communities where management interventions have been done

    The analysis leads to the calculation of indices: a biological value index, an abiotic fragility index and an ecological sensitivity index (which is derived from the first two). Finally, the ecologically sensitive areas are mapped. This can then be used to set objectives for ecosystem management and intervention, and to predict results (i.e. what the landscape will look like).

- In California, only about 10% of the original extent of habitats and ecosystems remain. Monitoring these areas for ecological integrity and biodiversity has become critical. Analogous to human health, criteria and indicators for ecological integrity may be thought of as ways to take nature's "temperature" **(Soulϑ, 1995)**. This is a conservationist perspective (concerned about all species, habitat and interactions) rather than purely an interest in maintaining ecosystem services (e.g. water, timber and other natural resources that humans use directly). To monitor biodiversity and integrity, indicators must be scale dependent and may be direct or indirect measures of potentially harmful phenomenon. An example of a direct indicator of biodiversity would be: species richness (i.e. the number of species and the abundance of target species). Chemical concentrations in the environment, thinning of the ozone layer, greenhouse gases, pH of lakes, and road abundance and quality are all examples of indirect measures which are expected to be reflected by a reduction in biodiversity and integrity in ecosystems.

- **Woodley (1991, 1993)** developed a "two-pronged" framework for monitoring ecosystem integrity in parks and protected areas. He first categorized cause and effect relationships into four possible cases:

known stress - known effect
known stress - unknown effect
unknown stress - known effect
unknown stress - unknown effect

The first prong, *threat specific monitoring* is useful in the first two cases. It involves predicting responses, creative scenario writing, statistical approaches, and is mindful of feedbacks and lags. The remaining two cases require *ecosystem integrity monitoring* which draws from the fields of stress ecology, landscape ecology and conservation biology. It incorporates a suite of indicators and uses a holarchical approach paying special attention to structure and function of the ecosystem.

Threat specific monitoring alone can never achieve a system level understanding. Ecosystem integrity monitoring is therefore necessary and complementary to account for deficiencies that are present in ecosystem science at any one time.

- **Noss (1995)** uses the concept of ecological integrity and draws from conservation biology, landscape ecology and complex systems theory to devise indicators for the design of representative reserve networks. The working model of network design proposed consists of core areas, multiple-use buffer zones, and some form of connectivity. The factors that influence optimal size are social as well as physical, biological, ecological with the intensity of management increasing as reserves become smaller and more isolated from one another (only the largest, wildest reserves are self-maintaining). Given this, it is of the utmost importance that indicators correspond to stated conservation goals and particular research and management questions related to these goals. Goals and objectives stem from the principles of ecological integrity which Noss believes incorporates the ideas of ecosystem health, biodiversity, stability, sustainability, naturalness, wildness and beauty.

The framework is based on three major objectives:

1) Sustain key geomorphological, hydrological, ecological, biological, and evolutionary processes within normal ranges of variation, while building a conservation network that is adaptable to a changing environment;
2) Maintain or restore viable populations of all native species in natural patterns of abundance and distribution; and
3) Encourage human uses that are compatible with the maintenance of ecological integrity.

Measurable indicators of ecological integrity cover three levels: the landscape-region, the community-ecosystem and species. The landscape-regional level is considered in terms of the structure of patch characteristics, patch dispersion, and access, flow and disturbance. At the community-ecosystem level, structural, compositional and functional measures are considered as well as Karr's index of biological integrity (IBI). Finally, at the species level, measures are developed for genetic integrity and demographic integrity (or lack thereof).

The consideration of cumulative effects has been another parallel progression in the conceptual models underlying monitoring activities. It developed as the focus of monitoring has increasingly shifted from identifying specific stresses and responses, to viewing the system as a whole.

- **Cocklin, Parker and Hay (1992)** present a general discussion on cumulative environmental change. They include a typology of cumulative environmental effects (Table 1, p.35), as well as a comparison of various approaches to monitoring (i.e. indicator species, early warning signals, indices, life history studies, biotic size spectra, and distress syndromes) which would prove useful in the development of a framework for a particular application.

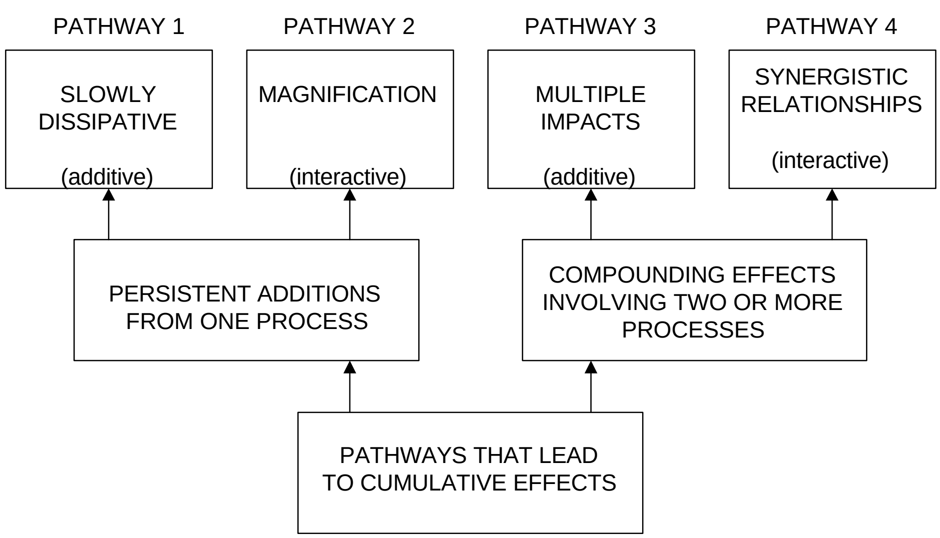
- **Davies (1991)** prepared a document for The Federal Assessment Review Office and Environment Canada which reviews seven environmental monitoring programs with a cumulative effects focus. The seven programs are: The Fraser River Estuary Water Quality Plan; The Upper Fraser River Environmental Monitoring Program; The Columbia River Integrated Environmental Monitoring Program; The Puget Sound Ambient Monitoring Program; The Peace-Athabasca-Slave River Basin Environmental Monitoring Program; Monitoring in the Great Lakes Basin; and, The Plan Saint-Laurent (Monitoring Component). From this review, Davies concludes a substantive list of guiding principles to be considered in the monitoring of cumulative effects. The principles fall under the general categories of: management, goals, indicators and parameters, appraisal and criteria, data collection, data management and interpretation, and information reporting and uses. The seven programs are then compared and evaluated in light of their success at incorporating these guiding principles. A copy of Table 5, which summarizes this comparison is included at the end of the "Monitoring and Indicator Frameworks" section.

- **Munn (1994)** writes on Cumulative Environmental Assessment (CEA) which has been encompassed by the traditional Environmental Impact Assessment (EIA) process, thus increasing the spatial and temporal scales which must be considered. Because the long-term is uncertain, it warrants predicting possible future scenarios, or "future histories" and, therefore, the design of an early warning system. The Ministry of Environment and Energy (MOEE) is in the process of developing a range of indicators based on an ecosystem approach and focused on Valued Ecosystem Components (VECs). The VECs are defined by a small number of keystone variables - some that are model-based (i.e. ecosystem function) and some that reflect environmental concerns of various stakeholder groups. CEA uses existing databases where possible and nests within the framework of State of the Environment Reporting.

- The **Canadian Environmental Assessment Research Council (1988)**, commissioned two studies on the state of the art in cumulative effects assessments by Western Ecological Services (WES - Peterson et al., 1987) and Environmental and Social Systems Analysis Ltd. (ESSA - Sonntag et al., 1987). Drawing on the reports from these two sources, a binational workshop, consultations and their own internal expertise developed a research prospectus for cumulative effects assessment that serves as the conceptual model and framework for monitoring. CEARC began with ESSA's framework (Sonntag et al., 1987) for identifying important human activities, and essential system processes and structures, in spatial and temporal context. Each is represented by a three dimensional matrix:

Activity Matrix	activity type axis	- single, multi, multiple, global
	spatial extent axis	- local, regional, global
	time horizon axis	- short, medium, long
System Matrix	system axis	- ecological, social, economic
	spatial resolution axis	- local, regional, global
	recovery rate axis	- fast, intermediate, slow

Filling in this framework is important to understanding the cause-and-effect relationships that characterise the four "pathways" of project activity and ecological change. That is (WES model - Peterson et al., 1987):



Comparing these pathways to a typology of cumulative effects reveals the following analysis:

Type of Impact	Applicable Pathway
Time-crowding	1 and 3
Space-crowding	1 and 3
Compounding	2 and 4
Time lags	1
Space lags	1 and 2
Indirect effects	all (potentially)
Patchiness (nibbling) effects	all (potentially)

A chart explaining this typology of cumulative impacts appears in the section entitled “Sets of Indicators” of this Background Literature Review.

- The cumulative effects monitoring framework for the **Niagara Escarpment (MacViro Consultants Inc, 1994, 1995; Whitelaw, Neufeld and Carty, 1995)** flows directly from the purpose and objectives of the Niagara Escarpment Planning and Development Act. The purpose provides the overall vision, and the seven objectives form the broad areas which the framework focuses upon: terrestrial ecology, water, recreation, open landscape character, land use and public access. A list of questions was developed for each objective to translate the Act into queries which the monitoring program is to help answer. Ecosystem boundaries and internal monitoring components (e.g. cliff faces, wetlands, recreational areas) were chosen appropriately in order to be relevant to the monitoring questions. Indicators, techniques and targets were then developed. Monitoring targets are the quantitative and qualitative criteria that help to define the significance of measured indicators. This method of objectives and questions leading directly to the indicators and targets ensures that there is a clear link between the policy and the information which the monitoring exercise supplies. The final portion of the framework involves information management and reporting which incorporates the collection and interpretation of the data.

- Simultaneously, a cumulative environmental effects framework was also being developed for the **Oak Ridges Moraine Area (Ecologistics Ltd., 1994)** which considers the impacts of multiple land use developments (only). It consists of five components: a ‘model’ for predicting cumulative effects, performance standards, a monitoring strategy, impact management strategies, and planning process considerations.

  The impact prediction model (here, meaning a sequence of analysis procedures which can be followed with consistency from one application to the next) conducts the assessment of impacts on three levels. The first is an area-wide or regional level (e.g. across the whole Moraine, or for municipalities and their Official Plans) whose purpose is to identify and prioritize sub-areas which require a more detailed assessment. The second model is applied within the priority sub-areas (e.g. subwatersheds or significant landscape features) to determine the affects of Official Plan amendments that apply to large areas, or to help formulate secondary plans. Finally, a third model refers to the site-specific assessment of the effects of a development application on its immediate environment. The level one model, for example, considers proposed as well as existing land uses, the natural resource base and defined valued ecosystem components (VECs) to evaluate risk and assess standards already in place. Structural components are identified for each level in the categories of aquatic, terrestrial, special feature, visual/cultural landscape, and/or resources.

Straddling the evolution of the ecological conceptual model, the integration of social and economic dimensions has been recognized as important. A shift is also occurring in the human goals which motivate monitoring activities. People are increasingly concerned with living sustainably and wish to assess progress toward this goal. In the last few years, there has been an explosion of sustainability monitoring initiatives. As well, the performance of policies intended to effect change are of interest. Some of the indicator frameworks already mentioned (e.g. CGLRM, 1991; Whitfield, Valiela and Harding, 1992; many of the State of the Environment initiatives) explicitly state sustainability as the impetus for monitoring. More examples are presented below:

- **Azar, Holmberg and Lindgren (1996)** believe that socio-ecological indicators are important for sustainability because they can provide early warning of problems. Environmental quality indicators detect problems only when it is already too late. They can serve as a tool in planning and decision-making processes at various administration levels of society. The formulation of socio-economic indicators is based on four principles of sustainability:
    - substances extracted form the lithosphere must not systematically accumulate in the ecosphere
    - society-produced substances must not systematically accumulate in the ecosphere
    - physical conditions for production and diversity within the ecosphere must not become systematically deteriorated
    - the use of resources must be efficient and just with respect to meeting human needs

  Models linking these processes and interactions are then developed to come up with quantitative indicators to measure each of these principles.

- **Maclaren (1995)** reviews a variety of indicator development frameworks oriented toward urban or community sustainability:

State of the Environment Reporting (focus: conditions of the natural environment and human activities affecting the environment)
Healthy Cities (human health and a healthy environment)
Quality of Life (social and economic conditions in urban areas)
Community-oriented Model of the Lived Environment (components of environmental integrity, economic vitality and social well-being)

The author also describes in detail three implemented frameworks that demonstrate characteristics included in her typology of indicator frameworks (the typology is discussed at the beginning of the "Monitoring and Indicator Frameworks" section):

1) UK Local Government Board Sustainability Indicator Framework (goal based)
2) Hodge's Sustainability Indicator Framework (domain and causal based)
3) Sustainable Society Indicators (domain and causal based)

- **Hodge (1994, 1995)** designs a conceptual framework (or model) to guide the assessment and reporting of sustainability. It draws upon insights from State of the Environment Reporting, macroeconomics and models of the human-ecosystem relationship, and is consistent with complex systems theory. He identifies four domains of data and information which form the strategic elements to serve as areas of diagnosis or indicator domains: ecosystem, interaction (e.g. stress on ecosystem from human activity), people, and synthesis of the other three.

  The framework is operationalized by linking each domain to a set of goals and objectives, and mapping out an assessment holarchy. In the case of ecosystem, for example: the bioregional unit is divided into air and climate, water, land, and biota. Biota is subdivided into species health, habitat, biodiversity, nutrient stocks and flows, and primary productivity. Similarly for the other areas, and so on. Indicators are derived from this holarchy under the consideration of the reporting needs for different decision making groups: individuals and families, corporations, communities, and all levels of government.

- **Munasinghe and Shearer (1995)** introduce their book with a discussion of biogeophysical sustainability. In looking for an organizing principle for its measurement, they identify three levels of activity:

  1) determining general measurements of sustainability (to define the basis for biogeophysical sustainability at the ecosystem or landscape level)
  2) aggregate these generic measures into indicators and identify specific measurements for each indicator; and
  3) identify the status of the generic list at regional and global levels by creating a composite index

  Their analysis begins at the second level, based on the parameters required by decision makers:

landscape composition and patterns
production of goods and services
biological diversity
water quality and quantity
soil properties
energy and nutrient flows
atmospheric composition, and
climate

For each, specific variables and a range of acceptable values must be identified. In addition, the following human dimensions were considered to have an important impact:

human influences (e.g. land use change or subsidies to landscapes like fertilizer)
human demography, and
human well-being

A list of issues that should be considered when developing a set of indicators are:

scale (local, national, regional, global)
purpose and use of the indicators (policy or broad resource allocation, specific management)
values (health, ecology, rules-of-thumb) are to be used to specify the boundaries of sustainability

- **Rees (1996; Wackernagel et al., 1993)** assess human impact on a region (or even the entire biosphere) by calculating "carrying capacity". Carrying capacity (is the maximum load that can safely be imposed on the environment by people. A framework for sustainability monitoring is provided by the concept. By measuring the maximum load and the current load imposed, the gap between the two represents how far we are away from the goal of living sustainably. Relatively few indicators are needed, although they are data intensive and require many assumptions in their calculation. However, it is an effective way to illustrate that we are living way beyond our means. The framework is also a useful tool to test different possible scenarios that could occur in the future under various management schemes and monitor progress. Definitions of the indicators are provided in the table below:

Appropriated Carrying Capacity	- the biophysical resource flows and waster assimilation capacity appropriated per unit time from global totals by a defined economy or population
Ecological Footprint	- the corresponding area of productive land and aquatic ecosystems required to produce the resources used, and to assimilate the waters produced, by a defined population at a specified material standard of living, wherever on Earth that land may be located
Personal Planetoid	- the per capita ecological footprint

Fair Earthshare	- the amount of ecologically productive land/ocean "available" per capita on Earth
Ecological Deficit	- the level of resource consumption and waste discharge by a defined economy or population in excess of locally/regionally sustainable natural production and assimilative capacity
Sustainability Gap	- a measure of the decrease in consumption (or the increase in material and economic efficiency) required to eliminate the ecological deficit on a regional or global scale

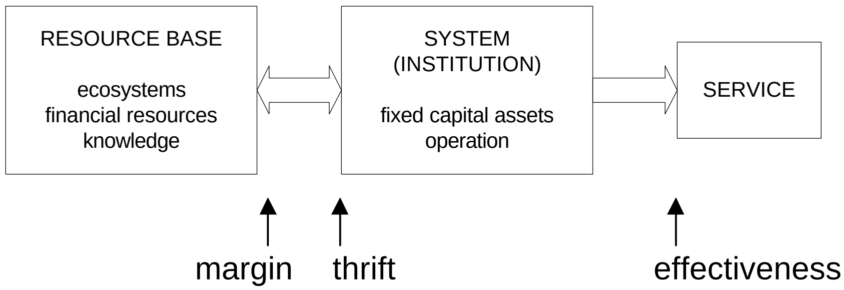
- **Sawicki and Flynn (1996)** discuss the evolution of neighbourhood indicators which has naturally followed on the heels of urban indicators. (Current technology such as desktop G.I.S. and devolution of social programs to the local level, has encouraged this process.) They present us with five lessons learned in their development and use of neighbourhood indicators:
  - indicators must be linked to a specific policy purpose
  - geographical indicators are more important than subject area indicators because policy is administered through geographical units, and because neighbourhoods and cities are what affect quality of life
  - clearly distinguish from the outset between indicators that measure neighbourhood well-being and indicators that measure the well-being of the neighbourhood residents
  - use unbundled indicators (i.e. not tied to an overall index)
  - the value of neighbourhood indicators to make and evaluate policy, and search for causes of change is just beginning to be realised.

- The **Canadian Council of Forest Ministers (1995)** undertook to define sustainable development in the context of forest management. The process of definition involved setting explicit sustainability criteria for important components. Collectively, they comprise a framework from which indicators can be derived. Ecological components are: conservation of biological diversity, maintenance and enhancement of forest ecosystem condition and productivity, conservation of soil and water resources, and forest ecosystem contributions to global ecological cycles. Human dimensions of sustainability include: the multiple benefits of forests to society and accepting society's responsibility for sustainable development.

- **Neave, Dumanski and Kirkwood (1995)** discuss a Framework for Sustainable Land Management (FESLM) with five "pillars" or objectives:
  1. productivity - maintain or enhance
  2. security - reduce level of production risk
  3. protection - of natural resource potential; prevent soil and water degradation
  4. viability - economically
  5. acceptability - socially

  All five objectives must be fulfilled in order to perpetuate sustainability.

- **Nilsson and Bergstrom (1995)** propose the Sustainable Development Record Method for assessing and comparing the sustainability of social institutions. Material and energy flows are used as representative indicators of the impacts of institutions on environmental systems.



  - margin: Can inflows and outflows be sustainably maintained without impairing the resource base and essential ecological functions?
  - thrift: Does the system require a modest input of material, resources and energy?
  - effectiveness: How effective or appropriate are services provided by the system?

  Sustainable Development Record indicators are quotients with the numerator and denominator in accordance with the economic logic of the above diagrammatic relations. They are independent (within limits) of scale, i.e. the same indicators can be used for a portion as well as the whole of the municipality.

A growing body of literature is also forming that is specifically focused on monitoring the effectiveness of policy related to sustainability and the environment:

- **Adriaanse (1993)** develops a framework for assessing the performance of environmental policy in achieving progress toward sustainability and applies it to his home country of the Netherlands. The framework is based conceptually on the pressure-stress-response model and on the structure of the "integrated environmental policy approach" (which has been adopted for the national environmental protection act). Indicators reflect key features of environmental policy and are categorized by themes (issues) and target groups (addressing environmental stressors). Subindicators for identified significant contributing components of the main indicators are also included. The theme areas cover: climate change, depletion of ozone layer, acidification, eutrophication, dispersion of toxins, disposal of solid waste and disturbance of the local environment. Targets and indicators are organized sectorally on environmental pressures: agriculture, traffic and transport, industry, the energy sector, refineries, the building trade and consumers. A first attempt is also made to incorporate and report regionally based indicators.

- Also in a sustainable development policy evaluation context, **Hammond et al. (1995)** follow Adriaanse's pressure-stress-response framework and augment it by organizing the issues (for which indicators are derived) within a model of human interaction with the environment. The model describes four interactions or categories:

  source - energy, food, and natural resources used in economic activity
  sink - use and dissemination or ultimate disposal of products and energy services which create pollution and waste
  life support - essential life-support services provided by the earth's ecosystems (especially unmanaged ones)
  impact on human welfare - polluted air and water and contaminated food affecting human health and welfare directly

  Composite indicators, indices, can then be constructed for each of these types of interactions: i.e., resource depletion index, pollution index, ecosystem risk index and index of environmental impact on human welfare.

- **Bens (1995)** argues the need for performance measurement for planning policy in Ontario and applies a framework to accomplish this task which is intended for implementation by municipalities. Within this context, he suggests that the most appropriate process/framework to use as a basis, is the strategic planning process already employed by several municipalities in Ontario. The process begins with community participation to determine stakeholder opinions and desires. A planning strategy is developed by integrating both internal and external inputs which is compared to an audit of the existing situation (e.g. community profile, strengths and weaknesses, ranking of issues). A Game Plan sets the vision, goals and objectives, followed by an Action Plan to implement it. The monitoring component is used both as an assessment and a refining tool. Indicators fall out directly from the strategic plan - for each of the parts, and for the plan as an integrated whole. They measure past performance and also are used to inform iterative changes to the strategic plan.

- **Petersen (1994)** discusses performance measurement as an overall agency task within MNR and presents a framework for indicator development. He claims that a system of performance measurement makes measurement objectives clear, identifies key system components, and supports a participative and progressive approach. There are four components of the framework:
  1. Structure: purpose and objectives, Best Practices, common vocabulary
  2. Core Elements: core business units, cause-effect analysis, critical success factors, indicators/measures
  3. Applications: how information is used in planning and decision making
  4. Coverage: extent of measurement, percentage of resources measured

  These components are holarchically related, with structure as the base and coverage at the top. Organizational culture (what is thought to be important) and support functions are major contributing factors to effective performance management. This holarchy also defines a process toward indicator development since the definition and investigation of each of the components is completed in a step-wise fashion.

- On a different note, but still associated with the evaluation of policy, **Dover (1995)** proposes a framework for assessing and classifying dimensions of policy issues (i.e. relative magnitude and characteristics) in order to set an appropriate and better informed agenda for action. This task has become a necessary step in dealing with the complexity and high stakes of many environmental problems which we face today. Policy concerns can be generally described by problem-framing attributes and response-framework attributes. The components of each are listed below:

Problem-framing attributes:
1. Spatial scale of cause or effect;
2. Magnitude of possible impacts (for human and natural systems);
3. Temporal scale of possible impacts;
4. Reversibility;
5. Measurability of factors and processes;
6. Degree of complexity and connectivity.

Response-framing attributes:
7. Nature of cause(s);
8. Relevance to the polity;
9. Tractability (availability/acceptability of means);
10. Public concern (level and basis of concern);
11. Existence of goals.

Following placement along these scales for a particular problem and the policy which addresses it, a second judgment involves situating the issue within a general taxonomy. A three-way categorization is used and defined by:

1. *Micro-problems*: where most problem attributes are placed at the lower end of each scale; the day-to-day challenges faced by policy makers in environmental management.
2. *Meso-problems*: where the majority of the relevant attributes are in the middle range; problems are significant and may be prominent on the public agenda, but do not pose systemic threats to the present pattern of consumption or overwhelming challenges to existing policy processes.
3. *Macro-problems*: where the majority of attributes are in the upper range; these are the big issues of sustainability - multi-faceted, complex, fraught with uncertainties and ignorance, spatially and temporally diffuse, highly connected to other issues, and threaten major possible disruption of human and natural systems.

Dover stresses that undertaking this exercise will not tell us, for example, if a problem is irreversible or not. Rather, the purpose is to make more apparent and repeatable the things that are critical to such a judgment, and the reasons why. This framework is useful from a monitoring perspective because indicators may be developed based on the dimensions of the attributes and assist in informing the decision making process.

Attributes of a Monitoring Program

In the context of monitoring programs, many authors discuss criteria for selecting indicators. (These are reviewed under the section entitled "Indicator Selection Criteria".) During this exploration, however, it was found that in many cases the criterion need not apply to each individual indicator, as long as it is a characteristic that is demonstrated by the entire set of indicators or the monitoring program overall. It is useful to separate out these qualitatively different attributes and view them as checklists to ensure that a monitoring program is comprehensive and is able to fulfill its intended purpose. Note that occasionally criteria/attributes apply to each individual indicator, as well as to the set of indicators or framework. These are included in both sections.

This section contains lists of attributes extracted from the background literature reviewed. By their very definition as universal characteristics, the attributes defy any logical organization. They have been loosely grouped by the general orientation of the monitoring framework in which they were suggested: biological/ecological (including ecosystem health and integrity), cumulative effects, human use of resources and sustainability, and environmental policy.

Biological/Ecological (including ecosystem health and integrity)

- **Stokes and Piekarz (1987)** consider Hodson's list that biological monitoring programs to measure the state of the environment should be:
    - early warning systems - in time to prevent loss of beneficial uses of the ecosystem
    - specific to an individual chemical or group of chemicals and insensitive to other confounding factors (e.g. fishing pressure)
    - related to exposure and other significant chemical effects by strong-dose relations.

  Stokes and Piekarz also cite Rapport for two attributes that the set of indicators should possess. They should be relevant to agreed upon notions of ecosystem health (e.g. productivity, quality of biotic community, diversity, etc.) and responsive to a wide variety of pressures versus honed to only a few circumstances. Other considerations at the ecosystem level are: the degree of specificity or generality, and; retrospective or prospective (i.e. early warning or after-the-fact with respect to detecting ecosystem changes).

Attributes that were agreed upon at a workshop for their own initiative include: generally quantitative with some qualitative indicators; and, reflecting the state of the environment.

- Of **Woodley's (1993)** list of criteria for ecosystem monitoring and assessment in parks and protected areas, many are important characteristics of a suite of indicators or a monitoring program in general:

    - ideally capable of providing continuous measurement from polluted to unpolluted (stressed to non-stressed) conditions
    - based on a collection of measures, interpreted by experts, i.e. Not on single criteria such as the presence/absence of a species or condition
    - focus on critical indicator species, i.e. not dependent on a census or even inventory of large numbers of species
    - reflect our knowledge of normal succession or expected sequential changes which occur naturally
    - accommodates a wide range of spatial and temporal scales
    - account for catastrophic changes that occur in ecosystems; programs must be adaptive to change with changing conditions
    - based on ecosystem versus institutional boundaries, e.g. park assessment must be based on the ecosystem it is part of, not the official park boundary
    - provides early detection of change, with some that are long term and diagnostic in nature

    In his 1991 paper, Woodley included an additional three criteria:

    - be compatible with variables used in qualitatively based modeling studies
    - designed for specific ecosystems because the sensitivity of various elements of ecosystem structure and function varies between ecosystems
    - monitoring should be done in two ways: in general for the ecosystem and also for the known specific threats to the system

- Attributes of sets of indicators have been explicitly defined for the three tiers of the framework which **Jenkins and Sanders (1992)** developed for biomarkers. Tier I (seeking evidence of biological degradation) indicators should be non-specific in response, react to most major classes of contaminants, and provide an integrated picture of the organism's ability to function. Tier II (seeking causes of degradation by contaminant groupings) indicators should respond in a specific manner to distinct classes of contaminants. Finally, Tier III (seeking specific causes) indicators should provide information as to which specific contaminants are responsible for evaluations at the Tier I and II levels.

- The **Canadian Council of Ministers of the Environment, Water Quality Guidelines Task Group (1994 Draft)** puts forth six functional criteria of a national framework for evaluating ecosystem health:

- be based on scientific concepts and attributes explicitly identified by the manager/user
- be applicable in diverse operational situations at different scales and in different ecosystems
- provide information about the 'health' of an ecosystem, not just about single environmental media or individual species
- ensure that information on ecosystem health at one scale is related to that at other scales (e.g. community, population, landscape), as well as laterally within a scale or level
- use existing information whenever possible and avoid committing substantial new resources
- contain mechanisms for evaluating and reporting on ecosystem health in a timely and effective manner to people and organizations which require this information

In addition, they provide key points to consider for indicator selection (i.e. for sets of indicators):

- indicators must be related to ecosystem goals and objectives
- to reduce the possibilities of error in decision-making, no single individual indicator should be used as the sole basis for decision-making; indicators should be applied as a comprehensive suite
- indicator selection should be guided by a set of selection criteria acceptable to all decision making parties involved
- selection of an indicator suite should be based on the best possible measures to address an ecosystem's objective, and not only on available measures (then data and research gaps can be identified and focused upon; interim measures can be used until data gathered for appropriate indicators)

- The **International Joint Commission (1996)** devotes a chapter to the discussion of indicators and criteria. They first mention some basic characteristics of a good indicator, most of which may also be considered as qualities or attributes of the entire monitoring program:
  - User driven, i.e. useful.
  - Policy relevant, i.e. pertinent.
  - Highly aggregated: many components but, in the end, few in number.
  - Able to quantify and simplify information.
  - Flexible: Amenable to reconsideration as conditions change, new issues arise, and responses to some problems begin to work.
  - Capable of reflecting a spectrum of conditions ranging from the living system back through the chemical and physical environments to the sources of stresses.

  The Commission believes that the monitoring initiative must take into account three broad categories: targets, programs and measures in the Great Lakes Water

Quality Agreement; scientific completeness, and; the importance of both senior policy makers and the public being able to understand and use the information. Part of their task is to identify individual selection criteria for these categories that should apply to each indicator (see “Indicator Selection Criteria”).

The overall goal of the Commission is to achieve ecosystem integrity for the Great Lakes. They have identified nine desired outcomes which will relate to this goal:

fishability
swimmability
drinkability
healthy human populations
economic viability
biological community integrity and diversity
virtual elimination of inputs of persistent toxic substances
absence of excess phosphorous
physical environment integrity

A suite of indicators must be chosen to measure each of these desired outcomes and hence make an assessment of ecological integrity. In order to make this relationship valid, each suite of indicators must fully characterise the desired outcome and evaluate progress toward the Agreement goal and targets.

- In reviewing the design of the Beaufort Sea Monitoring Program (BEMP), **Thomas (1992)** mentions some general attributes of environmental effects studies, they must:
  - address the uncertainties associated with environmental impact prediction (e.g. difficulty in detecting an impact in a naturally variable, poorly understood environment)
  - assess the effectiveness of mitigative measures
  - re-assure the public that environmental degradation is not taking place
  - be designed, conducted, analysed and reported in a manner which is scientifically defensible, relevant, and which will allow confidence to be placed on results and conclusions

  Later, when discussing the scope of the project, Thomas lists the concise attributes that guided the design of BEMP:
  - it should be based on general principles rather than specific detailed steps; this recognises that in the end, no two effects monitoring studies will be the same;
  - it should stress the generic aspects of effects monitoring;
  - it should focus on measuring change in the chosen monitoring variables on the following bases:

    a) temporal - short-term vs. long-term
    b) spatial 1 - based on natural oceanographic boundaries,
    i.e. nearshore vs. offshore
    c) spatial 2 - based on scale of effects, i.e. local (near-field)

vs. regional (far-field);

- it should focus on routine aspects of operations, not catastrophic events such as oil spills;
- it should exclude compliance monitoring;
- it should recognise unique constraints placed upon effects monitoring studies by the arctic marine environment and the subsequent need to stress practical approaches to study designs (measurement);
- it should be simple and straightforward, and;
- it should provide guidance to industry.

- In a **1995** paper on biodiversity indicators in California, **Soulϑ** provides guidelines for selecting indicators. The set of indicators should:
  - be relatively inexpensive and easy to monitor
  - not be chosen solely in accordance with the current fad (e.g. global positioning devices to map features and track wildlife; "bandwagon" species)
  - provide early warnings of ecological deterioration
  - (at least some) be educational, assuming an objective is to involve the public
  - (some) be "umbrella" species that require large areas of undisturbed habitat to support viable populations (e.g. wolves)
  - include elements from all levels of biodiversity: genes, species and ecosystems
  - be a component of long-range master planning.

- One of **Kelly and Harwell's (1990)** list of selection criteria for indicators measuring ecosystem recovery can be met only by a suite of indicators:
  - relevance to the recovery process
    - short-term and long-term processes
    - refugia, colonizing capacity
    - adaptations to new physical constraints

- **Waltner-Toews and Nielsen (1995)** cite OECD (1993) and Costanza et al. (1992) to produce a list of indicator criteria for application in agroecosystem health, several of which are appropriate for monitoring program attributes:
  - can be measured within a time frame that renders them useful for promoting health or preventing or curing dysfunction;
  - assesses the emergent properties that characterize a holon;
  - are relevant to policy (action);
  - should link at least some goals or issues that cross dimensions or boundaries in the system holarchy; and
  - should be amenable to establishing methods of screening to move from coarse to refined indicators in defining problems

- **Krugmann (1996)** discusses characteristics of a set of indicators to better measure desertification:

    - desertification issues occur in a holarchy or cascading series of levels, therefore, micro-, meso- and macro-indicators must be included
    - perspectives, experiences, processes and actions at different levels must also be included
    - the set of indicators should be dynamic, signalling and reflective of change in variables over a certain period of time
    - indicators should be specific to given ecological, cultural, social or economic contexts, or to gender or class issues
    - both quantitative and qualitative indicators should be included
    - some indicators may measure a parameter indirectly, while others should measure effects directly

- **Breckenridge, Kepner and Mouat (1995)** suggest three qualities of monitoring programs for rangeland health:
    - temporal and spatial variability
    - ability to assess shifts between ecotones
    - anticipatory (has early warning potential)

- In their monitoring initiative to assess the success of the provincial fisheries program, the **Fisheries Program Evaluation Measures Committee (OMNR-FPEMC, 1993)** develop criteria for selecting indicator organisms. One of these criteria applies to the set of indicators:
    - flexible, able to incorporate new information and changing public perceptions

Cumulative Effects

- **Regier, Lister and Kay (1994)** advise that a monitoring program to assess cumulative environmental effects for the Niagara Escarpment should:
    - take into account the cumulative environmental effects of past and present projects, developments and activities
    - take into account the cumulative environmental effects of multiple projects, developments and activities, of the same and different types
    - take into account cumulative effects of the biophysical environment, as they may relate to social and cultural objectives of the [Niagara Escarpment] Act
    - use ecological units that affect abiotic and biotic factors and are holarchical to incorporate ecosystem processes and systems which occur at different scales
    - facilitate understanding of the cumulative environmental effects so that informed decisions can be made at the project level

- facilitate understanding of the ecological conditions of the Niagara Escarpment Plan Area
- be based both on state-of-the-art scientific approaches and methods, as well as on stakeholder values and knowledge
- be capable of general regional monitoring and intensive site-specific monitoring
- provide a method for monitoring land use and change
- be capable of using existing data and information on past and present environmental quality
- be designed so that the requirements for new data and information on cumulative environmental effects must be practical and feasible
- be designed so that the data collected are referable to locations and areas as in a "Geographic Information System" (GIS)
- be cost effective in the long term

Furthermore, they provide criteria for integrative indicators and indices relevant to natural features. Those that apply to the set of indicators are listed here and the remainder, applying to each individual indicator, appear in the "Indicator Selection Criteria" section (some may be found in both sections):

- be sensitive to a variety of stresses and should integrate the effects of multiple stresses
- be sensitive to change in a wide range of intensity of the stresses
- include specialized organisms which are extremely sensitive to perturbations in their environment
- include less specialized organisms which have more tolerance to perturbations and survive up to some threshold and then decline with continued stresses
- be anticipatory and capable of providing an indication of degradation before serious damage occurs
- directed to obtain unique data and information including some types that are already being collected but not to duplicate concurrently collected data and information

With slight modification, these lists are used in the Niagara Escarpment Plan Area Monitoring Program to guide the development of their framework and selection of indicators (MacViro Consultants Inc., Phase I Report, 1994).

- In the development of the Oak Ridges Moraine cumulative effects monitoring program (**Ecologistics Ltd., 1994**), the following principles were used as guidelines. The program should:
    - be practical, easily accomplished, easily understood and affordable
    - accommodate the assessment of cumulative effects of growth on the Moraine and adjacent areas
    - be capable of the application based on the existing data base on environmental conditions on the Moraine

- be capable of accommodating new information and values in an on-going process
- be capable of assessing the implications of various sets of objectives or endpoints (i.e. performance standards)
- provide a clear statement as to how the effects of proposed changes in land use will be evaluated in order to predict effects on the natural environment

- **Stevenson (1994)** provides selection criteria which apply to the entire set of indicators or to the program for cumulative environmental effects itself (see also "Indicator Selection Criteria"):
    - provide information on key valued social, economic, and ecological components (VECs)
    - be compatible (or 'nest') with indicators used in provincial/regional environmental monitoring programs, or the proposed set of national environmental indicators
    - measure cumulative environmental effects which are potentially substantial, irreversible, transgenerational, or catalytic
    - be able to adapt and incorporate new information
    - be sensitive to the magnitude, direction and duration of stress
    - be diagnostic and interpretable; provide a means of distinguishing stresses involved, predicting environmental thresholds, measuring assimilative capacities, anticipating and monitoring change

Human Use of Resources and Sustainability

- **Liverman et al. (1988)** provides attributes appropriate for sets of sustainability indicators:
    - sensitive to changes in time
    - sensitive to changes across space or within groups
    - predictive or anticipatory
    - provides insight into whether changes are reversible or controllable
    - reference or threshold values available

- **Hirvonen (1992) and Marshall, Hirvonen and Wiken (1993)** present some indicator selection criteria that are characteristics the monitoring program as a whole may possess:
    - early warning capability
    - flexibility (in methodology, data resolution of application, and modification of indicators as new scientific information becomes available)

- The **Council of Great Lakes Research Managers (1991)** blended the work of several others with their own to generate a list of criteria for indicator selection (see

'Indicator Selection Criteria"). Though not inferred by the authors, we believe some of these may also be seen as attributes of a monitoring program:

- biologically and socially relevant
- sensitive to stressors without an all or none response or extreme natural variability
- broadly applicable to many stressors and sites
- diagnostic of the particular stressor causing the problem
- historical data are available to define nominative variability, trends, and possibly acceptable and unacceptable conditions
- anticipatory, i.e. capable of providing an indication of degradation before serious harm has occurred; early warning
- potential for continuity in measurement over time
- of an appropriate scale to the management problem being addressed
- timely, i.e. providing information quickly enough to initiate effective management action before unacceptable damage has occurred

- A workshop sponsored by the Canadian Environmental Advisory Council (CEAC) was dedicated to discussions on the design of indicators for ecologically sustainable development. One of the ensuing publications (**Ruitenbeek, 1991**), identifies five new fundamentals which should be reflected in the next generation of decision support indicators. They should:
    - reflect a *broader scope* - the economy and human behavior within it should be acknowledged as a subset of the broader ecosystem which supports them
    - reflect *distributive elements* which are important from a social equity viewpoint - e.g. both costs and benefits of environmental degradation on various income and interest groups
    - have applications as a forward-looking *projective tool* rather than just a descriptive tool for monitoring current or past conditions
    - reflect *explicit linkages* between human economic behavior and the degree of vigor and productivity of the broader ecosystem
    - recognize the *inherent uncertainty* in ecosystem behavior and responses

- Again, in the case of **Maclaren's (1995)** list of criteria for selecting indicators of urban sustainability, a few may be chosen as attributes of the sustainability reporting program:
    - relevant to stated goals
    - comparable to targets or thresholds
    - comparable with other jurisdictions

Maclaren also examines three case studies in depth and records the indicator selection criteria which each used in developing sustainable community/city indicators. Two of these used criteria that may be included in this section:

Regional Municipality of Hamilton-Wentworth

- reflective of a balance between environment, economy and social/health aspects
- potentially useful for effecting change

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- comprehensiveness - measure all dimensions of the issues of concern, in this case, urban sustainability
- responsiveness - sensitive to changes over time and in different cities
- disaggregation - capable of being used at different levels of aggregation
- understandable - understandable and accessible to policy makers

- **Hodge (1994)** proposes that a system of reporting driven by values of sustainability should focus on the following characteristics:

  I. Respect and concern for the ecosystem, by:
  - using a time horizon in the reporting system that captures both human (short) and ecosystem (short and long-term) time scales;
  - adopting a spatial frame of reference for assessing actions and decisions that extends beyond political and other boundaries to encompass the full extent of affected ecosystems; and
  - analyzing individual ecosystem components (e.g. air, groundwater, surface water, soil, fauna, flora, etc.) within the context of the connected ecosystem.

  II. The interaction between people and the ecosystem, by:
  - addressing the complete range of chemical, physical and biological stress on the ecosystem - including that occurring naturally and that imposed by human activities;
  - adopting an anticipatory perspective when dealing with the manner in which indicators, time-horizons and analyses are expressed, so that in the reporting process there will be a forward-looking thrust instead of just a description of past and current conditions; and
  - recognizing and accepting uncertainty as an inevitable occurrence instead of an impediment to good decision-making.

  III. Respect and concern for people, by:
  - using assessment criteria that respect the existence of alternative and changing values when evaluating progress;
  - assessing the distribution of environmental, economic, social, and cultural costs and benefits by examining their impacts on different social groups;
  - including ways to measure participation and control in decision-making; and
  - using both quantitative and qualitative measures that draw on both objective data and information as well as subjective information such as intuitive understanding based on experience of everyday life, including experience gained from subsistence and traditional lifestyles.

In addition, excerpted from his list of indicator selection criteria, the following characteristics should apply to the set of indicators overall (not necessarily to each indicator):

- facilitate forward, anticipatory application as well as historic and current analysis;
- be sensitive to changes over time, space and in the case of the human subsystem, be sensitive to differences between sub-populations;
- facilitate comparison between like system components being assessed; and
- facilitate action needed to both reinforce positive results and correct negative ones.

- **Nilsson and Bergstrom (1995)** present five leading principles for the choice of indicators for assessing the ecological and economic consequences of municipal resource use policy. While these principles are not exactly attributes of the monitoring program, they certainly guide the development and choice of the final set of indicators:
    - non-violence principle: using less resources is better or preferred
    - theory principle: all questions and answers should be rigorously formulated in theoretical terms before looking at empirical indicators
    - hit-the-board principle: rough and relevant is preferable to precise and expedient (to hit the board is enough; to hit the bullseye often requires too much effort
    - cluster principle: if you need reliable information and available indicators are too rough, it is better to design a cluster ("close" but independent measures) of rough indicators than a single, perfect one
    - salami principle: analyse separately each "slice" (aspect) of efficiency, thrift, and margin of the means-end spectrum to make possible the assessment of complex goals.

  (The framework for development of these indicators appears in "Monitoring and Indicator Frameworks". Please refer to this section for a better understanding of this monitoring effort.)

- The **Florida State Department of Environmental Protection (1996)** suggests that it is useful to list, with as much precision and completion as possible, the specific criteria used to define an acceptable indicator for that system. Attributes defining the set of indicators should be:
    - the geographic scope of the indicators (national, state-wide, regional, ecosystem, local)
    - the selection criteria used
    - the acceptable types of indicators (environmental, program, administrative)
    - the availability of data (are data available now or are there prospective indicators?)
    - the purpose of the monitoring system.

In particular for the Pensacola Bay, standards employed in the development of indicators are:

- the geographic scope of the indicators must measure an activity or condition that affects the defined area of the Pensacola Bay ecosystem
- the indicators must reflect important dimensions of one of the five strategic issues
- any Type A indicator must meet the indicator selection criteria (these criteria and the indicator type definitions may be found in the section also entitled "Indicator Selection Criteria").

As well, two of the mentioned indicator selection criteria are applicable as attributes of the whole set of indicators:

- The indicators should provide information to a level appropriate for making policy decisions. Highly specific and special parameters, useful to technical staff, will not be of much significance to policy staff or management decision-makers.
- Indicators expressing changes in ambient conditions or changes in measures reflecting discharges or releases are acceptable, but not preferred. Process measures (e.g. permits, compliance and enforcement activities, etc.) are not acceptable.

Environmental Policy

- **Adriaanse (1993)** lists the requirements which indicators for environmental policy should meet:
    - given their limited number, indicators should be as aggregated as possible
    - they must have a definite appeal, partly by being aptly presented
    - they must reflect a trend, with a time scale that is tailored to the problems
    - they must relate to cause and effect, or in other words to the causal chain
    - the course of actual developments in time must be seen in relation to existing policy objectives and necessary measures, wherever possible
    - they must be verifiable and reproducible

In addition, he discusses four key points to consider in the development of policy indicators:

1. Quality aspects - of data, of methodology (clearly defined, described and socially and scientifically acceptable)
2. Sensitivity in time - method of composing indicators sensitive and reliable enough to bring out medium-term and long-term effects
3. Policy relevance - indicators should derive directly from the policy structure
4. Recognizability and clarity - carefully constructed, yet at the same time simple and clear design

- **Bens (1995)** talks about "Do's" and "Don'ts" of creating a framework for performance measures:

  DO
  - deal with a holarchy of policy objectives and promote linkages between them
  - have clear, meaningful and achievable goals and objectives
  - be relevant and easily understood by the public
  - link outcome to policy
  - ensure a feedback loop
  - be transferable and flexible to other jurisdictions
  - be cost effective and time efficient
  - allow for both subjective and objective variables

  DON'T
  - try to do everything
  - use a strategic plan to justify policy

- In proposing his framework for situating environmental problems and policies on scales of relative magnitude and characteristics, **Dover (1995)**, simultaneously supplies a list of attributes that the development of any monitoring framework dealing with complex environmental issues should consider.

  The policy problem attributes and scale descriptors which he suggests are:

  Problem-framing attributes:
  1. Spatial scale of cause or effect;
  2. Magnitude of possible impacts (for human and natural systems);
  3. Temporal scale of possible impacts;
  4. Reversibility;
  5. Measurability of factors and processes;
  6. Degree of complexity and connectivity.

  Response-framing attributes:
  7. Nature of cause(s);
  8. Relevance to the polity;
  9. Tractability (availability/acceptability of means);
  10. Public concern; (level and basis of concern);
  11. Existence of goals.

Indicator Selection Criteria

A list of criteria that make a "good" indicator may be used to select amongst potential indicators. In many cases, these criteria are universal across monitoring programs. Nonetheless, to meet the unique needs of specific monitoring programs, the list of criteria must be redefined and agreed upon by all users of the information in each case.

The literature has been surveyed for the criteria recommended by various authors and/or employed in specific monitoring programs. It was often found that no distinction was made between criteria to which each individual indicator should conform, and attributes that the set of indicators, or even the monitoring program as a whole, should posses. In this background review and in the main report these qualitatively different characteristics are dealt with and discussed separately. Thus, this section is complementary to the previous one entitled "Attributes of a Monitoring Program" and for many cited authors, a portion of their criteria list appears in each section. Some characteristics are appropriate for individual indicators and the set of measures in general, and are included in both lists.

Because many criteria that define good indicators are applicable regardless of the type of monitoring program, these reproduced lists of selection criteria are organized somewhat arbitrarily. They have been grouped according to the broad orientation of the monitoring program in which they were utilized: biological/ecological (including ecosystem health and integrity), cumulative effects, human use of natural resources and sustainability, and environmental policy.

Biological/Ecological (including ecosystem health and integrity)

- **Woodley (1993)** reviewed several authors in researching criteria for indicators to implement for monitoring in national parks. He cites: Cook 1976, Miller 1984, Butler 1984 on characteristics of monitoring programs; Miller 1984 and Cook 1976 for criteria of measures; and Schaeffer et al. 1988 for ecosystem health indicator criteria. Through consideration and synthesis of these lists, Woodley developed his own set of criteria for ecosystem monitoring and assessment, and indicators. Most of the list of characteristics apply to the whole set of indicators in a monitoring program, and are thus included in the section: "Attributes for Monitoring Frameworks".

    - easily and reliably measured
    - have a defined reference level with variance, if possible, and design data collection in this way

- **Kelly and Harwell (1990)** suggest criteria specifically for selecting indicators of ecosystem recovery:

    signal-to-noise ratio
    - sensitivity to stress
    - intrinsic stochasticity (indicator resistance to normal variation)

rapid response	- early exposure (little time lag)
	- quick dynamics
	- stress-specific sensitivity
reliability of response	- specificity to stress
ease/economy of monitoring	- field sampling, lab expertise, available data, history etc.
relevance to endpoint	- intrinsic
	- string of ecological connections
feedback to regulations or management	- adaptive management potential
	- holarchical suites of indicators

'Relevance to endpoint' here means the direct or indirect relationship to issues of human interest or concern. The article explains each of these criteria in greater detail.

- In their discussion of selection criteria **Stokes and Piekarz (1987)** cite **Rapport's** three R's of well-chosen environmental indicators at the ecosystem level:
  - relevance - to agreed upon notions of ecosystem health (e.g. productivity, quality of biotic community, diversity, etc.)
  - reliability - some indicators are unreliable given the present technological capacity
  - robustness - responsive to a wide variety of pressures vs. honed to only a few circumstances

- **The Council of Great Lakes Research Managers (1991)** and **Cairns, McCormick and Niederlehner (1993)** cite the following authors in reviewing indicator criteria: Macek et al. 1978, Hammons 1981, Ryder and Edwards 1985, Hellawell 1986, Suter 1989, Edwards and Ryder 1990, and Kerr 1990. They found some common characteristics in these lists and synthesized and augmented them into a list for their own use in monitoring for ecosystem health:
  - measurable, i.e. capable of being operationally defined and measured using a standard procedure with documented performance and low measurement error
  - interpretable, i.e. capable of distinguishing acceptable from unacceptable conditions in a scientifically and legally defensible way
  - cost-effective, i.e. inexpensive to measure, providing the maximum amount of information per unit effort
  - integrative, i.e. summarizing information from many unmeasured indicators
  - historical data are available to define nominative variability, trends, and possibly acceptable and unacceptable conditions
  - non-destructive of the ecosystem
  - potential for continuity in measurement over time
  - of an appropriate scale to the management problem being addressed
  - not redundant with other measured indicators, i.e. providing unique information

- timely, i.e. providing information quickly enough to initiate effective management action before unacceptable damage has occurred

These criteria are weighted (from 1 (low) to 3 (high)) according to the purpose of the indicator, i.e. assessment, trends, early warning, diagnostic, linkages. For example, if an indicator is used for trend analysis, it is very important to have continuity of measurement. Whereas, if the purpose is early warning then it is a desirable but not necessary characteristic. All "perfect" indicators are: interpretable, sensitive, collectable by standard sampling methods and minimal cost, and are supported by historical data sets.

- The **International Joint Commission (1996)** devotes an entire chapter to the discussion of indicators and criteria. They first mention basic characteristics of a good indicator:
  - User driven, i.e. useful.
  - Policy relevant, i.e. pertinent. Is the indicator driven by policy for budget and/or management purposes?
  - Highly aggregated: many components but, in the end, few in number.
  - Able to quantify and simplify information.
  - Flexible: Amenable to reconsideration as conditions change, new issues arise, and responses to some problems begin to work.
  - Capable of reflecting a spectrum of conditions ranging from the living system back through the chemical and physical environments to the sources of stresses.

  (It is also possible to view these as qualities inherent to a monitoring program. Thus, this list is reproduced under "Attributes of a Monitoring Program".)

  The authors go on to cite and examine criteria for selecting specific indicators from the Council of Great Lakes Research Managers, Eyles and Cole and the Environmental Indicators Task Group of the ITFM (International Task Force on Monitoring). These lists are included in Appendix C of the report. The IJC then discusses an appropriate list for its purposes. Common sense dictates that indicators be: measurable with available technology and at a reasonable cost; scientifically objective, reliable, and valid for assessing or documenting ecosystem quality; timely; easy to understand; and useful for providing information for management decision making. As well, the Commission feels it must consider criteria from the three broad categories of : criteria related to the Great Lakes Water Quality Agreement (i.e. targets, programs and measures in the Agreement); criteria related to scientific completeness (see below), and; criteria related to understandability (by both senior policy makers and by the public).

  IJC (1996): Indicator Selection Criteria for Scientific Completeness (applying to each indicator).
  - Is the indicator necessary to characterise the desired outcome properly and to evaluate progress?
  - Is the indicator relevant, i.e. important and of value?

  - Is the indicator scientifically valid?
  - Are historical data and information available to define trends and possibly acceptable and unacceptable conditions, and can measurements be made currently and in the future?
  - Can the data and information be interpreted in terms of the desired outcome?
  - Can reference or target values be established?
  - What are the costs to acquire the data and information, and can confidence be placed in them?
  - Is the indicator sensitive, i.e. without an all-or-none response or extreme natural variability?
  - Is the indicator timely, i.e. providing data and information quickly enough to initiate effective action?
  - Is the indicator anticipatory, i.e. capable of providing early warning, an indication of change before serious harm has occurred?
  - Is the indicator integrative, i.e. possessing the capacity to combine a variety of diverse data and information?
  - Is the indicator broadly applicable, e.g. to more than one desired outcome?

- **Breckenridge, Kepner and Mouat (1995)** chose potential indicators by beginning with key process connections (e.g. atmospheric input, landscape, biogeochemistry, socio-economic), identifying indicator categories and iteratively refining the detail. Specific indicators for each category were suggested by scientists. This list of potential indicators was then evaluated and reduced by comparing each one in light of the following criteria:
  - applicable and readily interpretable across different regions
  - correlation with change in ecosystem process
  - temporal and spatial variability
  - best periods to sample (index period)
  - ability to be quantified by synoptic or automated monitoring
  - labour, equipment, analytical and data analysis costs
  - amount and quality of available data
  - ability to assess shift between ecotones
  - responsive/sensitive to change
  - anticipatory (has early warning potential
  - degree of environmental impact from sampling
  - status of method (established vs. experimental)
  - cost-effectiveness

- The **Fisheries Program Evaluation Measures Committee of the OMNR (OMNR-FPEMC, 1993)** developed a series of potential measures for assessing the success of the provincial fisheries program. Their general criteria for selecting indicator organisms, including the factors to consider, are as follows:

Representative	- an indigenous species
	- widespread distribution
	- interacts with other natural/human components
	- habitat requirements well understood, niche dimensions documented
Biologically Relevant	- to stated goals, objectives and issues of concern
Sensitive	- with a graded response to stress
	- usually thrives in high-water quality and good habitat
	- sensitive to stressors at different sites, i.e. regional variability
	- sensitive to both single and multiple stresses
	- responses to stressors are both identifiable and quantifiable
	- responsive to short-term change
Diagnostic	- possess diagnostic capabilities of stressors causing the problem
	- have a target or threshold level against which to compare
Measurable	- capable of being defined and measured
	- inexpensive to capture and measure
	- availability of historic measures
	- standardized measuring techniques
	- use of historic data series
Interpretable	- interpretable in a scientifically defensive way
	- reported in a simple, understandable fashion
Continuity	- can be measured over time (temporal continuum)

- **Waltner-Toews and Nielsen (1995)** incorporate selection criteria by the OECD (1993) and Costanza et al. (1992) to produce a list in the context of agroecosystem health (see also "Attributes of Monitoring Frameworks for the remainder):
    - can be measured at the level at which they will be used for decision making;
    - the cost of measuring them in terms of economics and technical intensity is not excessive;
    - can be measured within a time frame that renders them useful for promoting health or preventing or curing dysfunction; and
    - are analytically sound.

- **Stokes and Piekarz (1987)** also cite Ryder and Edwards' (1985) list of criteria for choosing an appropriate indicator species:
    - have a broad distribution in the environment
    - easily collected and measured in terms of biomass
    - indigenous and able to maintain itself through natural reproduction
    - interacts daily with many components of the ecosystem
    - available historical (preferably quantitative) information pertaining to abundance and critical factors

    - well-documented and quantitative niche dimensions
    - gradual response to a variety of human induced stresses
    - suitable for laboratory investigation
    - generally recognisable as important to humans
    - indicate aspects of ecosystem quality other than those represented by accepted parameters

- The Beaufort Sea Environmental Monitoring Program (BEMP) recognised that not all potential indicators will be suitable for monitoring for contaminants. Each biological variable was assessed using a list of selection criteria (**Thomas 1992**; citing IMCO et al. 1980) that are reproduced below:

Ecological Criteria

- ecological significance: can the effect be shown, or convincingly argued to be related to an adverse or damaging effect of the growth, reproduction or survival of the individual or the population and ultimately on the well-being of the community/ecosystem?
- relevance to other effects: can the effect be related to other effects at higher or lower levels of organisation?
- specificity: how specific is the effect in relation to the causative agent?
- reversibility: to what degree can the variable return to its original level when the causative agent is removed?
- range of taxa: is the effect specific to particular taxa?

Efficiency Criteria

- quantitative aspects: does the effect bear a quantitative or predictable relationship to the cause?
- sensitivity: what intensity of stressor is required to elicit the response?
- scope: over what range of intensity of stressor is the effect observable?
- response rate: how quickly is there an observable effect? Hours? Days? Years?
- signal to noise: can the effect (signal) be easily detected above the natural variability (noise)?
- precision and accuracy: can the effect be measured accurately and precisely?

Administrative Criteria

- cost: how expensive is the measurement of the variable in terms of capital equipment, operational costs (manpower)?
- application: to what extent has the effect been used in a field monitoring program and shown to be related to the cause (in this case contaminants)?
- relevance to Beaufort Sea: is there anything about the use of the measurement that would be precluded by the isolation and special operating constraints occurring in the Beaufort Sea?

After considering each indicator, its appropriateness for use in the Beaufort Sea location was indicated by a categorical system:

+++ highly recommended and appropriate for use on a routine basis

++ recommended for selective use only
(lack of proven record or limited by the location)

+ not recommended (unproved relevance or impractical in location)

- In the special case of choosing bio-indicators for climate change, **De Groot, Ketner and Ovaa (1995)** successively apply these criteria as a filter for the selection of indicator species consider the following characteristics in an indicator species:
    - climate sensitivity - species sensitive to climate changes
    - habitat constraints - species regularly distributed throughout study area
    - position in distribution range - climate changes are observable earlier in species performance at the border of the distribution range (those in the middle are more robust)
    - dispersal capacity - species capable of dispersing relatively easily even in a fragmented landscape
    - functional position - species representative of a whole functional group of interacting species in food web, i.e. keystone species
    - suitability for monitoring - identification and monitoring of species not too difficult, i.e. recognisable, observable and samples easily taken
    - etc. (specific criteria to project)

  For any species chosen, data and information must be available and scientifically sound.

- **Regier (1992)** offers the general statement that a particular ecological indicator should relate closely and clearly to nature's value as perceived within a practical context. He notes that this is important because shifts occur in the dominant rankings of mind sets and values.

- In developing measures for ecological integrity, **Noss (1995)** states that the most important criteria in reducing the list of potential indicators to a workable set are:

  1) a validated relationship of the indicator to the phenomenon (ecological integrity) of interest;
  2) convenience and cost effectiveness of the indicators for repeated measurement;
  3) ability of the indicator to provide an early warning of change or trouble ahead; and
  4) ability of the indicator to distinguish changes caused by human activity from "natural" changes.

  This last criterion is the most difficult to satisfy. Noss also emphasizes that these criteria would result in quite different indicators being selected, depending on the peculiarities of each region or site.

Cumulative Effects

- **Regier, Lister and Kay (1994)** state that information gathered for the Niagara Escarpment monitoring will include diagnostic indicators and indices relating to particular large-scale and long-term cultural stresses but also integrative indicators and indices that relate to the cumulative effects of these stresses. Each of the integrative indicators and indices should:
    - be ubiquitous or characteristic of a healthy or stressed Escarpment system
    - be relevant to the "target conditions"
    - be directly relevant to ecosystemic features that are recognized and valued in their own right
    - be easily observed and measured by informed amateurs as well as by trained technicians
    - be used in other monitoring programs off the Escarpment so comparisons can be made
    - be applicable in different monitoring situations and at different sites
    - be capable of being operationally defined and measured using a standard procedure with documented performance, low measurement error and reproducibility
    - be based on data that may be obtained through non-destructive means

- Also within the general framework of cumulative environmental effects, **Stevenson (1994)** suggests criteria for selecting indicators (again, those that more appropriately apply to the complete set of indicators are listed under "Framework Attributes"):
    - rely largely on existing data
    - provide information on a key valued social, economic, or ecological component (VEC)
    - provide reproducible results by different analysts

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- The often referenced article by **Liverman et al. (1988)**, offers the following criteria for choosing particular indicators of sustainability:
    - unbiased (as little biased by the values of western civilization as possible)
    - uses an appropriate data transformation (from raw data to useful indicator)
    - integrative (composite indicators integrating various measures and information)
    - relative ease of collection and use

- In a background report for Environment Canada's State of the Environment Reporting (SOER), **VHB Research and Consulting Inc. (1989)** noted that the criteria for choosing indicators is dependent upon the level of detail required and the extent of the program's defined scope. All indicators must meet the required criteria of: being able to convey understanding to users, utility, and clarity. In selecting some indicators over others, they suggest that the following be considered: the uniqueness of the information the indicator provides; the priorities of the program and how the indicator relates to them; is the measure indicative of multiple environmental features? How many and which ones?; the consistency and availability of the data needed to produce the indicator.

- The following list is a reproduction of the criteria finally chosen by **Stokes and Piekarz (1987)** and workshop participants:

  biochemical and species level
  - found in restricted range in an ecosystem
  - pollution-related
  - scientifically defensible
  - adequate baseline data
  - reliability
  - feasibility

  In addition, those at the ecosystem level should:
  - reflect the state of the environment
  - be understandable to policy makers
  - be useable by scientists to compile reports but also interpretable by decision makers
  - not be universal

- Another background report for SOER **(Gélinas and Slaats, 1989)** dealt specifically with the issue of selection criteria for indicators. The resulting desirable characteristics of SOE indicators are:

feasible to obtain	- availability - complexity - time - cost
scientifically credible	- assumptions - methodology - technical
understandable	- reference to thresholds - data transformation - presentation
provide early warning detection	
enable the detection of temporal and spatial trends	- applicable for different regions and scales - consistency of methods - predictive models

- **Marshall, Hirvonen and Wiken (1993)** have adopted **Hirvonen's (1992)** list of criteria for the general selection of individual indicators:
    - clarity (understood by the public and decision makers)
    - scientific credibility (quantitative is preferred, but qualitative is also valid)
    - technically feasible (amenable to regulation, analysis, time and cost - but this does not preclude the necessity to do research)
    - spatial representation (interpretive value at scale of interest)

- The **Canadian Council of Ministers of the Environment (1992)** approached the selection of indicators by examining existing measures according to their relationship to CCME's adopted framework and chosen issue areas, frequency of reporting and data updating, geographic coverage of data, rationale, state of readiness, data sets required and available, and any special considerations (such as a relationship to a hard target adopted by CCME). Their "core set" of indicators were decided upon based on this analysis.

- In developing indicators for urban sustainability, **Maclaren (1995)** lists criteria that are frequently used and suitable for sustainability reporting:
    - scientifically valid
    - representative
    - responsive
    - relevant to stated goals
    - based on accurate, accessible and available data that is comparable over time
    - understandable by potential users
    - comparable to targets or thresholds
    - comparable with other jurisdictions
    - cost effective
    - unambiguous
    - attractive to the media

  The weight given to these criteria depends upon the purpose and the audience. A set of core indicators is useful to provide guidance to municipalities and allow for comparison, but most need to be adapted to the locale.

  Maclaren also examines three case studies in depth and records the indicator selection criteria which each used in developing sustainable community/city indicators:

  Sustainable Seattle
    1. The indicator should be a bellwether test of sustainability and reflect something fundamental to the long term economic, social or environmental health of a community over generations;
    2. The indicator should be easily understood by members of the community and generally agreed to be a valid sign of sustainability;

3. The indicator should be appealing to the local media;
4. The indicator should be statistically measurable in the Seattle area and a practical form of data collection should either exist or be possible; and,
5. The indicator should preferably be comparable to indicators that would be available for other communities.

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- measurable
- easy to collect
- credible and valid
- reflective of a balance between environment, economy and social/health aspects
- potentially useful for effecting change

Those choosing from the list of potential indicators were also asked: "Which of the indicators seem to be most important/meaningful to you?" Responses to this question were given weight in addition to the criteria.

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- comprehensiveness - measure all dimensions of the issues of concern, in this case, urban sustainability
- data availability
- responsiveness - sensitive to changes over time and in different cities
- disaggregation - capable of being used at different levels of aggregation
- understandable - understandable and accessible to policy makers
- validity - scientifically valid measures of the phenomenon of interest
- reliability

- **Hodge (1994)** completed a thorough review of indicator selection criteria suggested by various authors: Liverman et al. (1988), Gélinas and Slaats (1989). VHB (1989), Ward (1990), Indicators Task Force (1991), WRI (1990), Tunstall (1992), van den Born et al. (1993), WHO (1993), Gosselin et al. (1991), BCRTEE (1993), Sustainable Seattle (1992), MacNeill and Runnalls (1993), Byer et al. (1979). See pp. 124-128 for these lists.

  Hodge develops his own list of selection criteria with insights gained from the above and comparison to his composition of value-driven characteristics for reporting on sustainability. Indicators of sustainability should:

  - link directly to specific objectives which in turn are nested within general goals motivated by the concept of sustainability;
  - accurately and unambiguously reflect the degree to which the system component being measured meets the related objective;
  - be measurable and based on data which are either available or easily obtainable with a reasonable degree of accuracy;

(See the remainder of this list under "Attributes of Monitoring Frameworks" since they apply more generally to the set of indicators, rather than each individual one.)

- **The Florida State Department of Environmental Protection (1996)** established the following selection criteria that must (or should) apply to each indicator to ensure high and consistent quality:

  Essential Criteria:
  - measurable - The indicator measures a feature of the environment that can be quantified simply using standard methodologies with a known degree of performance and precision.
  - data quality - The data supporting the indicators are adequately supported by sound collection methodologies, data management systems, and quality assurance procedures to ensure that the indicator is accurately represented. The data should be clearly defined, verifiable, scientifically acceptable, and easy to reproduce.
  - importance - The indicator must measure some aspect of environmental quality that reflects and issue of major national importance to states and to the federal government in demonstrating the current and future conditions of the environment.
  - relevance - The indicator should be relevant to a desired significant policy goal, issue, legal mandate, or agency mission (e.g., contaminated fish fillets for consumption advisories; species of recreational or commercial value) that provides information of obvious value that can be easily related to the public and decision-makers.
  - representative - Changes in the indicator are highly correlated to trends in the other parameters or systems they are selected to represent.
  - appropriate scale - The indicator responds to changes on an appropriate geographic (e.g. regional or national) and/or temporal (e.g. yearly) scale.
  - trends - The data for the indicator should have been collected over a sufficient period of time to allow some analysis of trends or should provide a baseline for future trends. The indicator should show reliability over time, bringing to light a representative trend, preferably annual.
  - decision support - The indicators should provide information to a level appropriate for making policy decisions. Highly specific and special parameters, useful to technical staff, will not be of much significance to policy staff or management decision-makers.

  Preferable Criteria:
  - results - The indictor should measure a direct environmental result (e.g. an impact on human health or ecological conditions). Indicators expressing changes in ambient conditions or changes in measures reflecting discharges or releases are acceptable, but not preferred. Process measures (e.g. permits, compliance and enforcement activities, etc.) are not acceptable.

- understandable: The indicator should be simple and clear, and sufficiently non-technical to be comprehensible to the general public with brief explanation. The indicator should lend itself to effective and appealing display and presentation.
- sensitivity - The indicator is able to distinguish meaningful differences in environmental conditions with an acceptable degree of resolution. Small changes in the indicator show measurable results.
- integrates effects/exposures - The indicator integrates effects or exposures over time and space and responds to the cumulative impacts of multiple stressors. It is broadly applicable to many stressors and sites.
- data comparability - The data supporting an indicator can be compared to existing and past measures of conditions to develop trends and define variation.
- cost effective/availability - The information for an indicator is available or can be obtained with reasonable cost and effort and provides maximum information per unit effort.
- anticipatory - The indicator is capable of providing early warning of environmental change.

After each indicator has been assessed according to the above criteria, it classifies it in terms of availability which allows the presentation of indicators that may not currently exist as part of the indicator system. Using this method shows what will be needed to establish a fully functioning system.

Type A: Indicators for which adequate data are available now and can be used to support the indicator without significant cost considerations. A Type A indicator meets all essential selection criteria and most preferred criteria, is presently available for use in its present condition, and can be acquired easily at little or no cost.

Type B: Indicators which are presently feasible, but cannot be provided due to inordinate cost, analytical complexity, or time constraints. Type B indicators are those that could be make available if some barrier can be overcome. The data needed to produce the indicator exist but because of cost concerns, analytical difficulties, time constraints, manpower issues, or some other impediment, the indicator cannot be provided.

Type C: Prospective indicators for which there is no reasonable prospect of development without some extraordinary expenditure of resources. Type C indicators are purely prospective. The data do not exist and there is no clear intent to collect. Type C indicators exist as designs only.

- **Nilsson and Bergstrom (1995)**, present a list of principles for choosing indicators of “sustainable development records” in assessing the ecological and economic consequences of municipal policies for resource use. This list is reproduced under the more appropriate section “Attributes of Monitoring Programs”. One criteria that they require for each indicator, however, is that it must be independent of scale. This is so that the same calculations for the whole municipality can be repeated for any portion of it. Diagnostics of the roots of a problem may be discovered in this manner.

- **Banerjee (1996)** writes of the role of indicators in growing urban regions, particularly for India and other developing countries. Indicators chosen as planning tools must share criteria of validity and veridicality. Also, data must be available and the complexity of the indicator appropriate. These last two are of special concern in the Third World.

Environmental Policy

- **Adriaanse (1993)** uses a short list of criteria for choosing indicators of environmental policy performance for assessing progress toward sustainability:
    - concise (condensed, aggregated information)
    - clear presentation, unambiguous
    - simplification of a complex picture
    - satisfy needs of users (must tailor basic data and method of process)

  The author recognizes and flags the inherent tension between completeness for accuracy and simplicity for understanding when evaluating potential indicators.

- **Bens (1995)** lists generally accepted criteria for selecting performance measures for planning:

Valid - relates to provincial or municipal interests?
- is a scientifically valid measurement of that objective?

Representative - provides an accurate and fairly complete picture of desired outcome?

Responsive - responds to changing conditions and still provides a measure of performance?

Control - able to distinguish who has control or responsibility for the desired outcome or level of performance?

Relevant - clearly relates to policies, objectives and the needs of the various stakeholders involved?

Information Quality - is the information required to produce this measure consistently accurate and accessible in a timely fashion?

Cost - is the information cost-effective to both collect and use?
- does the potential short and/or long term benefit exceed the short and/or long term cost of collection and presentation

Linkages - amenable to cross-measure comparisons, geographically or between categories (i.e. social, economic and environmental)?

Useful - takes into account existing local conditions?
- provides a reliable early warning of positive or negative changes

to these conditions?
- measure specific objectives?

Sets of Indicators

This section is intended to direct interested readers to existing sets of indicators for particular monitoring applications. No effort has been made to record all the indicators. Rather, the following is a meta-list which describes each set and provides a citation for obtaining the document if desired. Full bibliographic references may be found in the reference section of the main document.

Indicator sets have been organized in the following text according to the categories: natural areas and reserves; ecosystem properties, health and integrity; cumulative effects; long-term monitoring; human use of resources and sustainability; and, environmental policy. An additional category of "Other" is included at the beginning for collections of indicators that span many groups. Note that these categories are not mutually exclusive and, in fact, overlap considerably.

Other

- **Statistics Canada (1992, 1994)** has published two volumes cataloguing environmental database holdings of governments, agencies and private organizations at both the Federal and Provincial/Territorial levels. A consistent description of each database is provided listing the following parameters: summary description/purpose, responsible organization and database contact, access mechanisms, variables measured, data acquisition method, geographic coverage, measurement units, period of record, update frequency, storage/output format, computer environment (provincial volume only), restrictions and conditions, price information, corresponding printed sources, languages, user aids available, keywords, and additional information.

- One of the objectives of Environment Canada is to allow external access to government collected environmental information **(Environment Canada, Systems and Informatics Directorate, 1995)**. Specifically, they wish to provide information products that are useful, easily accessible, high quality and reliable. This is made possible by a shared systems approach within the Federal government and Environment Canada's Green Lane on the World Wide Web. A huge amount of information is available here that would help anyone designing or implementing a monitoring program. Links to other useful sites and environmental information holdings are provided.

- The national framework for sustainability in Canada (described by **Marshall, Smith and Selby, 1996**) is stored as layers of map polygons within the Canadian Soil Information System (CanSIS). It also contains a list of descriptive characteristics for each level of the spatial framework - ecozones, ecoregions and ecodistricts. The database is also linked to associated databases on climate, land use and socio-economic attributes. This information system is used to compile State of the Environment Reports, but its broad contents could be of value in many monitoring initiatives from national to local levels.

- In his **1990** paper on environmental monitoring in protected areas, **Slocombe** compares various authors and examples:
  Resource Survey Frameworks (Table I, p.54-55)
  Biosphere Reserve Survey (Turner and Gregg, 1983); Parks Data Sheet (Polunin and Eidsvik, 1983); Resource Description and Analysis (Canadian Parks Service, 1989); ABC Resource Methodology (Grigoriew et al., 1985); Resource Inventory and Baseline Study (Conant et al., 1983).
  Characteristics of Stress/Response Monitoring (Table II, p. 61)
  Odum, 1985; Rapport et al., 1985; Sheehan, 1984.
  Landscape Characteristics with Potential for Monitoring (Table III, p.64)
  Balser et al., 1981; Forman and Godron, 1986; Turner, 1989.
  Qualitative Characteristics of Integrity and Disintegrity (Table IV, p.65)
  International Joint Commission, 1989; Francis et al., 1979.

  While in general these tables do not contribute actual indicators, they are excellent lists to consult in the development of specific indicators. The content of a State of the Environment Report for Waterloo Region (Elkin, 1987; Table V, p.68) is also included.

- **DPIE (1995)** of the Australian Government has published a survey of work on sustainability indicators as an Internet resource. It generally discusses different frameworks and methodologies for assessing sustainability, including references. Many examples of lists of indicators and categories/criteria from which lists of indicators may be derived are reproduced, such as: the relationship between proposed indicators and attributes for sustainable agriculture; urban air pollution levels; WHO and OECD thresholds for indicators of air and water quality; schemes for monitoring terrestrial features, and; short-term indicators for sustainability by environmental issue.

Natural Areas and Reserves

- **Woodley (1993)** discusses various disciplines and the indicators which emerge from these perspectives. Stress ecology (citing Odum 1985, Rapport et al. 1985, Schaeffer et al. 1988, Schindler 1987, Sheehan 1984) focuses on changes in ecosystem structure and dynamics brought about by stress to the system. Measures include: primary productivity, nutrient cycling, rate of decomposition, rates of nutrient loss, changes in species diversity or richness, retrogression, and changes in average body size of organisms.

Landscape ecology (citing Balser et al. 1981, Forman and Godron 1986, Turner 1989) is concerned with spatial relationships and measures are based on patches, networks, and flows. Examples of indicators are: habitat fragmentation, degree of human influence, minimum area requirements, minimum viable population size of key species, and population dynamics of selected species.

Monitoring particular species for change is also a commonly used method for indicating ecosystem health or stress. On page 58, a list of criteria for selection of the species to monitor is provided.

Woodley synthesized these various approaches into a list of indicators categorized holarchically:

individual - reproductive rates of selected individual species
population - minimum viable population size
- minimum viable area
- population dynamics
community - species richness
- nutrient cycling
- change in community size structure
landscape - habitat fragmentation
- productivity
- succession/retrogression
- climate

- The **Canadian Council of Forest Ministers (1995)** provides an extensive and thorough list of indicators for the specific sector of forested ecosystems. Categories for monitoring are organized around concerns for: conservation of biological diversity, maintenance and enhancement of forest ecosystem conditions and productivity, conservation of soil and water, and forest ecosystem contributions to global cycles. An example under the latter classification is 'forest sector carbon dioxide conservation' which is measured by 'fossil fuel emissions', 'fossil carbon products emissions' and 'percentage of forest sector energy usage from renewable sources relative to total sector energy requirement'.

- For the very specific case of monitoring vegetation for river systems, **Fritz (1993)** developed a framework for the Canadian Heritage Rivers. Table 2 (p.7) provides a helpful list of critical ecosystem characteristics. For each characteristic, the scale(s) at which it operates and some general measures to monitor it are given. Table 8 (p.8) takes the reverse approach. For each "level" (physiognomy, composition, structure and process), tools and types of data are summarized which can contribute several kinds of information. The remainder of the report is laid out in a workbook format to explain how to collect and use the data.

- More sectoral information can be found in a strategic recommendation document (**Merriam, 1994**) prepared for the Forest Fragmentation and Biodiversity Project of OMNR and OFRI (Ontario Forest Research Institute). It takes a landscape ecology approach for managing the land in the medium-term. It does not supply sample indicators but does offer a list of biotic, abiotic and human influence parameters which should be included in the Ontario landscape database analysis which is proposed. The Appendix also describes focal projects in landscape reconstitution which together can provide a rich picture of various impacts and interactions within the human-natural continuum.

- A paper from the workshop proceedings of the National Ecological Monitoring and Research Workshop (**Gagnon, 1992**) contains a survey of variables to consider for an ecological monitoring program in the categories of: trees, understory plants, epiphytic plants, plant diversity, soil fauna, litter arthropods, foliage arthropods, birds, soils, meteorological data and atmospheric pollutants.

- **Noss (1990**, Table 1, p.359) constructs a matrix of indicator variables for inventorying, monitoring, and assessing terrestrial biodiversity at three levels of organization: composition, structure, function. Four scales: regional landscape, community-ecosystem, population-species and genetic, are considered. In addition, inventory and monitoring tools and techniques are supplied for each scale.

Ecosystem Properties, Health and Integrity

- **Kay and Schneider (1992)** include lists of indicators for Crystal River Marsh Gut and Chesapeake Bay ecosystems as two case studies for thermodynamic measurement in a specific area.

- **Kay (1991)** references some sample sets of indicators and ecosystem properties. Table 4 (p.39) shows the 18 selected for Green Bay, Michigan from a potential list of 40. He also presents in some detail a comparison made by Wulff and Ulanowicz (1989) of the Baltic Sea and the Chesapeake Bay using flow-analysis techniques. This study could be very helpful in determining important components and processes to monitor in similar systems.

- A detailed account of the development behind the Green Bay indicators may be found in **Harris et al. (1987)**. An ecosystem approach was used to determine important, largely emergent, ecosystem properties of aquatic ecosystems which are summarized in Table 1 (p.622). The intent in this article was to link these properties to management objectives, but they may also be used as the basis to define indicators for monitoring purposes.

- The **Work Group on Indicators of Ecosystem Quality of the IJC (1985)** produced a document on the application of the ecosystem approach to biological indicators and monitoring. While the report does not provide a list of indicators, it is an excellent source of information on ecosystem attributes and criteria for biological indicators of ecosystem quality and candidate organisms in the context of the Great Lakes Basin. This compilation is extremely useful in the development of biologically-oriented indicators.

- To evaluate progress under the Great Lakes Water Quality Agreement, the **International Joint Commission (1996)** listed nine desired outcomes to achieve their overall goal of ecosystem integrity. They explore for each desired outcome: a narrative statement of description; background information, relevance to the Agreement, and guidelines for delisting impaired beneficial uses; relevant impacting stresses, and; indicators to evaluate progress toward desired outcomes. The desired outcomes identified are:

  fishability
  swimmability
  drinkability
  healthy human populations
  economic viability
  biological community integrity and diversity
  virtual elimination of inputs of persistent toxic substances
  absence of excess phosphorous
  physical environment integrity

  The suites of indicators to measure each of these outcomes are lengthy. As one example, absence of excess phosphorous is indicated by: ambient phosphorous concentrations, algal blooms, phosphorous loading, costs for mitigation of nutrient loading exceeding limits, and changes in recreational activity due to phosphorous.

- **Hambly and Angura (1996)** edited a book which brings together the work of a variety of authors in developing indicators for desertification both by international and local organisations. The context is arid and semi-arid regions in eastern and southern Africa. Each of the articles provides examples of lists of indicators that vary across scale and type, and according to values and culture. The contrast between international organisations and community initiatives produces interesting results.

- The process described for developing indicators for rangeland health **(Breckenridge, Kepner and Mouat, 1995)** resulted in a conceptual model of key processes and indicator categories. Components of the conceptual model and associated indicator categories are listed below (the diagram on page 50 of the article illustrates how the various components are linked together):

Socio Economic	jobs, recreation, aesthetics
Stressors	soil and vegetation, physical disturbances, drought, fire, pathogens, pollutants and water development
Landscape	riparian extent, land use patterns, ecotonal shifts, fractal dimensions
Atmospheric Inputs	Bowens ratio, albedo, solar radiation, precipitation, wet/dry chemistry, wind
Terrestrial Vegetation	biomass, assemblages, diversity, exotics, genetic biomarkers
Terrestrial Fauna	relative abundance, demographics, morphological asymmetry, habitat, biomarkers
Soil Micro and Macro Flora/Fauna	microbial and invertebrate decomposers, consumers, nutrient cyclers
Soils: Physics	profile; structure; organic matter, litter and soil crusts; erosion and disturbance; hydrologic properties
Water	quantity balance, quality, soil moisture, historical water table fluctuations
Biogeochemistry	methane production, foliar and litter chemistry, soil chemistry, soil energy, nutrient transport

A discussion of the indicators eventually selected for an initial pilot study is presented on pages 57-59 in the article.

- **Cash's (1995)** report for the Northern River Basins Study covers biomonitoring for both the species level and the community/ecosystem level. For the species level he discusses criteria for choosing bioindicators; kinds of indicators, e.g. diagnostic, linkage; and, types of species level indicators including: indicator species, biochemical, physiological, morphological, behavioural, and life-history traits. Examples of each type of indicator are also provided. For community/ecosystem indicators, Cash again discusses the various types: saprobic (degree of pollution) indices, diversity indices, biotic indices, community comparison indices, functional feeding groups, indices of biotic integrity, multivariate approach - RIVPACS (River InVertebrate Prediction and Classification System), and multivariate approach - BEAST (BEnthic Assessment of SedimenT). Appendix A presents a useful summary of these indicator types along with a brief description, data requirements, and the strengths and weaknesses of each.

- Table 2 on page 27 of **Thomas (1992)** presents a list of potential biological variables for monitoring the effects of contaminants in the Beaufort Sea. The list includes measures for ecological, biochemical, physiological, morphological, pathological and genetic effects as well as an evaluation of its suitability for the monitoring project.

- The January to March 1993 results of water quality monitoring for the Fraser River Estuary are reported by **Morse (1994)**. Measuring of an extensive suite of inorganic and organic parameters was conducted. The report also details the monitoring objectives, program design, field procedures, and analytical methodologies. Monitoring initiatives in the Fraser River Basin are recommended reading.

- **Whitfield, Neufeld and Carty (1992)** propose that ecosystem attributes should be monitored when assessing ecosystem health and sustainability, rather than the traditional list of ecosystem components (i.e. concentrations of contaminants, nutrient flux, mass, populations, etc.). Examples of important attributes for monitoring ecosystem health are:
  - contaminants in successive trophic levels
  - trophic structure/state
  - nutrient dynamics
  - primary productivity
  - size spectra
  - biodiversity
  - fluctuation of key populations
  - endangered species
  - exotic species
  - perturbations in patterns
  - energy flow
  - ecosystem state thresholds
  - genotypic/phenotypic diversity
  - resilience
  - self-similarity
  - criticality

  'Self-similarity' means that ecosystems are recognizable as being of the same type despite qualitative and quantitative differences. 'Criticality' refers to the paradox of having some degree of stress needed to keep the system adaptive, yet not too much stress to the point where its organization (current and evolutionary) is threatened.

- The **Canadian Council of Ministers of the Environment (1994)** cites examples of ecosystem health indicators suggested for Lake Ontario (Box 3, p.15) by the Ecosystem Objectives Working Group (1992). Categories include: aquatic communities, wildlife, human health, habitat and stewardship.

- **Schaeffer, Herricks and Kerster (1988)** discuss the assessment of ecosystem health. Table 2 (p.449) presents measures which support diagnosis of illness at the levels of an individual, population, community and ecosystem. Each measure is cross-checked with its applicability to critical ecosystem characteristics: habitat for desired diversity and reproduction of organisms, phenotypic and genotypic diversity, robust food chain, adequate nutrient pool, adequate nutrient cycling to perpetuate ecosystem, adequate energy flux for maintaining the trophic structure, feedback mechanisms for damping undesirable oscillations, and the capacity to temper toxic effects.

- Table 1 of **Noss (1995**, pp.30-32) lists measurable indicators of ecological integrity. Indicators for the landscape-regional level are organized by structural measures of patch characteristics, patch dispersion, and access, flow, and disturbance indicators. The community-ecosystem level includes structural measures, compositional measures, functional measures and Karr's composite index of biotic integrity (IBI). Finally, at the species level measures of genetic and demographic integrity (or lack thereof) are provided. In addition, Table 2 (pp.39-41) demonstrates how to use the indicators to detect integrity, threat or disintegrity, and recovery in two hypothetical regions of Canada: a southern Ontario farmland and a Rocky Mountain wildland.

- **Soule (1995)** lists examples of indicators which may be associated with the measurement of biodiversity and ecological integrity in Californian ecosystems:

Direct Indicators	- number of species and abundance (species richness)
Indirect Indicators	- concentrations of chlorinated biphenyls (e.g. DDT, PCBs) -herbicides, fertilisers and animal wastes contaminate groundwater - atmospheric pollution (e.g. mining, smelting, power by-products) - thinning or stratospheric ozone - atmospheric build-up of greenhouse gases - pH of lakes - roads (edge effects; draw development, farming, resource extraction).

Cumulative Effects

- The **Canadian Environmental Assessment Research Council (1988)** presents the following typology of cumulative effects (useful in developing cumulative effects indicators) along with some examples of each type:

Type	Main Characteristics	Examples
time crowding	frequent and repetitive impacts on a single environmental medium	- wastes sequentially discharged into lakes, rivers or airsheds
space crowding	high density of impacts on a single environmental medium	- habit fragmentation in forests, estuaries
compounding effects	synergistic effects arising from multiple sources on a single environmental medium	- gaseous emission into the atmosphere
time lags	long delays in experiencing impacts	- carcinogenic effects

Type	Main Characteristics	Examples
extended boundaries	impacts resulting some distance from the source	- major dams - gaseous emissions into the atmosphere
triggers and thresholds	disruptions to ecological processes that fundamentally change system behaviour	- the greenhouse effect - effect of rising level of $C0_2$ on global climate
indirect effects	secondary impacts resulting from a primary activity	- new road developments opening frontier areas
patchiness effects	fragmentation of ecosystems	- forest harvesting - port and marina development on coastal wetlands

- Peterson et al. (1987; cited in **CEARC, 1988**) identified a number of issues that either involve significant cumulative effects now or probably will by the 1990's:
  - long-range transportation of air pollutants;
  - urban air quality and air-shed saturation;
  - mobilisation of persistent or bioaccumulated substances;
  - cumulative effects associated with climate modification;
  - occupation of land by man-made features;
  - habitat alienation and fragmentation;
  - loss of soil quality and quantity;
  - effects of the use of agricultural, silvicultural and horticultural chemicals;
  - reduction of groundwater supplies and groundwater contamination;
  - increased sediment, chemical and thermal loading of freshwater and marine habitats;
  - accelerated rates of renewable resource harvesting; and
  - long-term containment and disposal of toxic wastes.

- **R.E. Munn's** edited book **(1994)** focusing on cumulative environmental assessment, includes articles from various authors many of which either provide sample indicator lists or they leave the reader with a solid starting-off point for indicator development.
  - Regier, Lister and Kay - preliminary listing of foci for integrative indicators and indices related to cumulative effects (p.195).
  - Spaling - summary evaluation of methods (tools and techniques) for cumulative effects assessment (p.211)
  - Stevenson - cumulative effects example (hydroelectric power station) with possible indicators and evaluation (p.222-227); indicators matrix (Appendix A, p.229-230)
  - Stigliani - linkages between human activities and retoxification factors (of heavy metals) (p.241)

- The **Cumulative Effects Monitoring Program for the Niagara Escarpment Plan Area (MacViro Consultants Inc., Phase I Report 1994, Phase II Final Report 1995)** summarizes the monitoring objectives, questions, components targets, indicators and corresponding techniques in an easy to read format (Phase I , pp.7-1 to 7-7; Phase II, pp.14-25) for the areas of: terrestrial ecology, water resources, recreation, open landscape character, land use monitoring, and public access. A supplementary document "Niagara Escarpment Cumulative Effects Monitoring Techniques" (MacViro Consultants Inc., 1995) provides more detail on methods and options for indicator measurement. Appendix C of the final report also lists a sampling of existing inventories and monitoring activities for the area. See also Whitelaw, Neufeld and Carty (1995, p.127) for a summary table of monitoring questions, components, indicators and techniques.

- Background Reports 13 and 14 for the Oak Ridges Moraine cumulative effects monitoring program summarize available information and databases for the area, list other potential data sources according to the environmental parameters on which information is desired, and identify data deficiencies (**Ecologistics Ltd. 1994**, pp.3-2 to 3-12).

Long-term Monitoring

- **Shackell, Freedman and Staicer (1993)** organize indicators for ecosystem monitoring by considering the stressors, exposure intensity and duration of stress, and the response of ecosystem and the organisms within it. Examples of each follow:

  Stressor: land use, resource extraction, individual pollutant emissions, climate change, long-range transport of air pollutants (LRTAP), natural disturbances
  Exposure: rate of change in land use, individual pollutant emissions, LRTAP (precipitation, air quality), oxidants, domestic chemical use, agriculture and forestry, forest management, ecological reserves, habitat fragmentation, habitat diversity
  Response: land capability, inland waters (fish communities, fish health, aquatic birds and other biota), forests (productivity, forest communities by site, age-class distribution, etc.)

  The Appendix (Table 1, p.153) of this article lists specific indicators as well as their availability.

- **Anderson, Kurvits and Wiken (1992)** discuss generally the concept of a national ecological monitoring and assessment program for Canada. The Appendices list recent proposals for comprehensive ecological monitoring. These may prove to be sources of ecological information. The following are summarized:

- Canadian Network for Integrated Environmental Monitoring (Environment Canada)
- National Environmental Monitoring Program (State of the Environment Reporting)
- Canadian Long-Term Ecosystem Research Program (Canadian Federation of Biological Societies)
- Monitoring Program for Ecological Reserves in Canada (Canadian Council on Ecological Areas)
- TERRAMON, Newfoundland (Centre for Earth Resources Research)
- Environmental Monitoring and Assessment Program (U.S. EPA)
- Canadian Global Change Program (Royal Society of Canada)

And,

- The U.S. Long-Term Ecological Research Program - discussed at some length.

• There are five sites in eastern Canada networked as part of the Long Range Transport of Air Pollution program (LRTAP) for ecological monitoring (see **Jeffries, 1992** for a short description). Data has been collected at a number of these sites for many years and may provide valuable information for understanding some longer term ecological processes. The sites are:

Kejimjujik	- since 1980
Lac Laflamme	- since 1980
Dorset (Muskoka-Haliburton)	- since mid-1970s
Turkey Lakes Watershed	- since 1980
Experimental Lakes Area	- since 1960s

• A study collecting environmental monitoring information over twenty years at Nanticoke Industrial Complex (on the north shore of Lake Erie) is presented by **Serafin (1989)**. This report is unique for two reasons: 1) such a lengthy database of information (1968-1989) is rare, and; 2) Serafin presents a format and questions to ask when evaluating a monitoring program, as well as his conclusions in this case. The "groupings" measured are:

- water temperature	- filamentous algae and rooted aquatic plants
- water chemistry	- birds
- water movements	- stack emissions (trace elements, particulates, sulphur
- ice cover	dioxide, nitrogen oxides, hydrocarbons)
- fisheries	- ozone concentration
- zoo plankton	- ambient concentration of air pollution
- phytoplankton	(including above emissions)
- bottom fauna	- vegetation surveys

Note that a variety of general ecosystem parameters at various scales are measured, as well as specific threats known to the area. This attribute is not normally seen in monitoring programs of this era, but rather became more common in recent years when the concepts of the ecosystem approach, ecosystem health and integrity were applied to monitoring initiatives.

- An evaluation of the European long-term Integrated Monitoring Programme **(Nihlgård and Pylvånåinen, 1992)** reproduces the results of their three year pilot programme assessing ecosystem state, effect and driving variables for small catchments. The primary focus is on air pollution and transport between systems. Data is presented for: driving variables - physical climate, chemicals, land use and landscape mosaic; state and effect variables - geology and soil morphology, soil chemistry, terrestrial organisms, aquatic organisms, other organisms, throughfall, soil water, runoff and groundwater; and cause and effect relations - climate and biologic variables, deposition and biological variables, soil and runoff and biological variables, and intercorrelations between all of them.

- **Bella, Jacobs and Li (1994)** summarize responses to global climate change which may assist in seeking measures for monitoring programs dealing with climate change as an influencing factor. Technical, social and ecological responses are described and separated into mild, serious and catastrophic changes.

Human Use of Resources and Sustainability

- **Holling (1978**, Appendix A, pp.302-303) cites Leopold et al. (1971) in identifying, to a limited extent, the cause and effect relationship between human actions and impacts. Examples of project actions include: regime modification, land transformation and construction, resource extraction, waste replacement and treatment, accidents, etc. Impacts can be subdivided into:
  A. Physical and chemical - earth, water, atmosphere, and processes
  B. Biological - flora, fauna
  C. Cultural
  The caveat "limited" above recognizes that these indicators are only able to trace the effect one impact may have on one part of the environment.

- **Everitt (1991)** gathers and describes case studies of environmental effects monitoring in Canada. Specific programs are: The Beaufort Environmental Monitoring Project, Pulp Mill Environmental Effects Monitoring, Norman Wells Pipeline Monitoring Program, Columbia Integrated Environmental Monitoring Program, and Proposed Guidelines for Effects Monitoring for Metal Mines Discharging to the Aquatic Environment.

- The **Council of Great Lakes Research Managers (CGLRM, 1991)** offers a general discussion and an evaluation of available indicator approaches and types in the areas of physiochemical, biological and socio-economic indicators. Table 3 (p.33) lists potential indicators to track environmental degradation (in areas of quality, quantity, valuation costs, and management) for categories of human use:

commercial fisheries, drinking water, recreation, industrial and energy and agricultural water use, aesthetics, transportation water use, and human health.

- The **Canadian Council of Ministers of the Environment (CCME, 1992)** endeavored to develop a "core set" of harmonized indicators to be measured and reported consistently by CCME members. Pp. 13 and 14 summarize their choices by types of indicators ("levels"): environmental condition/state indicators, indicators of stressors and program performance indicators. Seven key issues were considered: global climate change, air quality, water management, packaging, solid waste management, hazardous waste and contaminated sites management, and chemicals management.

- The document prepared for Environment Canada's Ecosystem Science and Evaluation Directorate (**Davies, Rapport and Brady, 1992 Draft**) includes, in Appendix A, complete lists of published environmental indicators by the following groups:
  - Organization for Economic Co-operation and Development (OECD)
  - Canada's National Environmental Indicators Project
  - United States Environmental Protection Agency (U.S. EPA)
  - World Conservation Union
  - Steering Committee for a Sustainable Society
  - for Southam News, by Resource Futures International (compares Canada internationally, between provinces, and between selected cities)

- The National Environmental Indicator Series (**Environment Canada, Indicators Task Force, last revised 1995**) presents their list of indicators in a workbook layout with explanations on the issues surrounding the choice of each indicator and its recorded values. The indicators are grouped under four themes:

Theme Area	Indicators Categories
Life Support Systems	climate change, stratospheric ozone, toxins in the environment, biodiversity
Human Health and Well-Being	urban air quality, urban water
Natural Resource Sustainability	marine resource, forest ecosystems, agro-ecosystems
Influencing Factors	energy consumption, transportation

  The indicators are presented in a binder format so that the results may be easily updated. In addition, indicators may be added as new information is desired or data (or funding) for new indicators becomes available.

- The preceding background report to the above (**Environment Canada, 1991**) gave a preliminary list of potential indicators under the following categories:

environment component/ecosystem state
- atmosphere
- fresh and marine water quality
- biota
- land

environment-related human health
- drinking water
- recreational water
- air quality
- toxic residues in food
- radiation exposure
- waste management

natural economic resources
- forestry
- agriculture
- fisheries
- water use
- energy

Indicators under these various categories may be of three types: ecosystem condition (exposure/response), human activity stresses, and management responses.

- **Slocombe (1993)** offers a general discussion and explanation, including some examples, of indicator types: for example, socioeconomic, diversity and ecosystem dynamics. The Appendices provide sample lists of indicators, or characteristics from which indicators could be derived:
  - Sustainable Society Project design criteria (1991)
  - Indicators Task Force, Environment Canada (1991)
  - Characteristics of a Sustainable Economy from Young (1992)

- In a workshop on ecological indicators for state of the environment **(Stokes and Piekarz, 1987)** working groups identified important variables that should be measured for the sustainable management of renewable natural resources. Page 34 presents the results of the fisheries, forests and agricultural sustainability working groups. One example is examining soils: organic matter, wind and water erosion, acidification, salinity and bulk density. Commissioned case studies for biological indicator species, water quality and ecological indicators of the forest environment are presented. In addition, Appendix D contains a publication, by Regier and others, on indicators for fish and aquatic ecosystems.

- An example of a regional State of the Environment assessment can be found in the Don Watershed Water and Nature Report Card (**Ecological Services for Planning**

Inc., 1995). The report offers the 'long list' of potential indicators generated under the 'caring for water' and 'caring for nature' themes (the other two themes, 'caring for community' and 'getting it done' are reported separately). Indicators are given for the following:

water	groundwater	- infiltration, discharge, quality
	surface water	- quality, flow
	airshed	- water balance, quality
	linkages	
nature	tableland	- terrestrial habitat, aquatic habitat, special areas and linkages
	valleyland	- terrestrial habitat, aquatic habitat, special areas and linkages

The selected key indicators are also presented and discussed.

- In May, **1997 the Don Watershed Regeneration Council** released another watershed report card optimistically titled *Turning the Corner*. For each of the chosen 18 indicators: they explain the indicator; state the current direction of trend; discuss "where we were", "where we are" and "where we want to be"; and, finally, plans on "how to get there". The indicators are:

Caring for Water: The River	flow pattern; water quality - human use; water quality - aquatic habitats; stormwater management
Caring for Nature: Habitats and Wildlife	woodlands; wetlands; meadows; riparian habitat; frogs; fish
Caring for Community: People	public understanding and support; classroom education; responsible use and enjoyment
Protect What is Healthy: Protected Natural Areas	protected natural area
Regenerate What is Degraded: Regeneration Projects	regeneration projects
Take Responsibility for the Don: Stewardship	personal stewardship; business and institutional stewardship; municipal stewardship

- For State of the Environment Reporting at the municipal level**, Campbell and Maclaren (1995)** prepared a report which reviews programs for the Regional Municipalities of Ottawa-Carleton, Waterloo and Hamilton-Wentworth as well as the Cities of Ottawa, Toronto, Burnaby and Vancouver (Appendix A). For each, they discuss the scope, target audience, reporting process, structure and content, indicators and more. The main body of the report draws several comparisons between programs initiated in these areas. Table 13 (p. 33) of the report presents a list of the most commonly appearing indicators for the broad categories of biophysical, social and health in the municipal SOE reports that were reviewed.

- The Saskatchewan State of the Environment Report **(Saskatchewan Environment and Resource Management, 1992)** lists possible indicators to be assessed in the categories of: Land, Air, Water and Cultural Environment.

- **Munasinghe and Shearers's (1995)** book is the result of a conference to develop measures of biogeophysical sustainability. A unified list of indicators was generated for the following eight managed and natural ecosystems:
    - agriculture
    - forests
    - rangelands
    - wildlife and wild lands
    - freshwater fisheries
    - wetlands and groundwater
    - coastal resources, and
    - marine fisheries

- **Azar, Holmberg and Lindgren (1996)** argue that indicators of the state of the environment detect problems too late. Instead, they propose a method for developing socio-ecological indicators. These indicators are based on principles of sustainability and measure parameters that appear early in the causal change so that problems may be avoided. They use process models to demonstrate how such indicators could be quantitatively calculated and provide some examples:

Principle of Sustainability	Sample Indicators
substances extracted from the lithosphere must not systematically accumulate in the ecosphere	- lithospheric extraction rates - accumulation of substances from lithospheric extraction in the environment - non-renewable energy supply
society-produced substances must not systematically accumulate in the ecosphere	- indicators for natural occurring man-made substances (anthropocentric flows vs. natural flows) - indicators for substances foreign to nature (production volumes of persistent chemicals, long-term implication of emissions)
physical conditions for production and diversity within the ecosphere must not become systematically deteriorated	- manipulation (of structures, processes and flows) - large-scale transformation of lands - land use (soil cover, nutrient balance in soil, biological diversity) - use of marine and lake resources (species harvests, max. sustainable yield)
use of resources must be efficient and just with respect to meeting	- overall efficiency - intragenerational justice

human needs	- intergenerational justice - basic human needs (daily intake, access to potable water, life expectancy, literacy)

In addition, Azar et. al provide an extensive reference list for more information and sources of available data to calculate these indicators.

- **Ruitenbeek (1991)** attempts to augment a set of sample indicators for Sulfur Emissions to reflect five important principles of an information set for ecological sustainability. The tables on pp.28-29 summarize the principles, basis, rationale, general indicator examples and specific indicator examples.

- **Hodge (1994)** operationalizes his development framework through application to the Great Lakes Basin as a case study. In Chapter 10, for each of the four domains (ecosystem, interaction, people and synthesis) he follows through assessment holarchies to yield indicators, including their current status and trends to make a formal evaluation of the Basin's progress toward sustainability. In Chapters 11 and 12, he analyses the specific areas of energy production, transportation and use as well as surface and groundwater and generates lists of both direct and indirect indicators for important components. This information is also included in Hodge et al. (1995) as a demonstration of the proposal for assessing sustainability presented to the Prime Minister.

  The Appendices (Volume 2) provide a wealth of information. Hodge gives references, discussion and insightful conclusions on 220 State of the Environment Reports with international, national, provincial/regional, municipal, ecosystem component (air, water, forests, oceans), or corporate/industry foci. These references offer implemented indicators for a wide variety of scales and types. Furthermore, he contributes a list of indicator families and indicators organized by decision-making groups for reporting on sustainability and reproduces the 1990 (economic) activity indicators for Ontario and the eight states surrounding the Great Lakes. Finally, he adds a brief discussion on quantitative versus qualitative indicators which may be helpful in the development of measures for any application.

- The State of the Resource discussion paper (**OMNR, Information Access Section, 1995 Draft**) provides several sets of indicators and sources of information in the Appendices. Appendix D gives a summary of short-term indicators by environmental issue generated by the OECD (1993) with measures covering pressures, states and responses. Appendix E reproduces the preliminary list of national environmental indicators put forth by the Indicators Task Force (1991). Appendix F is an excellent resource, providing samples of existing reporting activities where OMNR is a participant for the areas of: general environment, terrestrial ecosystems, wildlife, parks and natural heritage areas, and aquatic ecosystems. Finally, Appendix G summarizes in table format, other organizations (government and non-government) involved in SOE report preparation.

- **Slocombe (1990b)** supplies tables (p.260-261) listing important spatial and temporal scales of critical factors and processes in the Great Lakes Basin. The tables consider fast, medium and slow processes for the local, regional and global scales and add some of the critical variables and transformations (e.g. harvesting, lifestyle changes). This process is completed for each of biophysical, demographic and cultural, economic and institutional factors. Another useful inclusion in this article is a chronological history of the Great Lakes Basin sociobiophysical system, also in table format, which may become valuable for understanding the current state of the system and its responses to future pressures.

- The second portion of the **Canadian Council of Forest Ministers (1995)** document deals with socio-economic issues defining indicators within the general categories of: the multiple benefits of forests to society and accepting society's responsibility for sustainable development. One example would be 'fair and effective decision making' measured by indicators of: 'degree of public participation in the design of decision making processes', 'degree of public participation in decision making processes' and 'degree of public participation in implementation of decisions and monitoring of progress toward sustainable forest management'.

- **Neave, Dumanski and Kirkwood (1995**) reviewed available indicators in the physical, agronomic, economic and social areas in the context of sustainable land management. Chosen indicators (via cited selection criteria) are listed below:

Physical - physical land flexibility	Agronomic - cropping intensity - yield variability - summer fallow - nutrient management - crop influence - windbreaks
Economic - gross margin with and without government support - probability of obtaining break-even yield - debt load	Social - conservation tillage

- **Nilsson and Bergstrom (1995)** present a systems approach to assess the interaction between social institutions and the environment called the Sustainable Development Record Method. The article explains the development of the concept and applies it using an example for sewage treatment plants. The key indicators measure: effectiveness (of services provided), thrift (modest input of energy and materials) and margin (inputs/outputs of management without impairing resource base or ecological function). For the example of the sewage treatment plant:

effectiveness - treatment quality, phosphorous
- treatment quality, BOD_7
- recirculation of phosphorous
thrift - sewage water thrift
- chemical thrift
- financial thrift
- labour thrift
- energy thrift
margin - phosphorous margin
- BOD_7 margin
- chemical margin

- **Rees (1996; Wackernagel et al., 1993)** developed a set of indicators to determine how far we are from living sustainably in a given region or globally. The articles provide formulae and work through examples for the following variables:

Appropriated Carrying Capacity	- the biophysical resource flows and waster assimilation capacity appropriated per unit time from global totals by a defined economy or population
Ecological Footprint	- the corresponding area of productive land and aquatic ecosystems required to produce the resources used, and to assimilate the waters produced, by a defined population at a specified material standard of living, wherever on Earth that land may be located
Personal Planetoid	- the per capita ecological footprint
Fair Earthshare	- the amount of ecologically productive land "available" per capita on Earth, currently about 1.5 hectares (1995). A fair seashare (ecologically productive ocean - coastal shelves, upwellings and estuaries - divided by total population) is just over 0.5 ha
Ecological Deficit	- the level of resource consumption and waste discharge by a defined economy or population in excess of locally/regionally sustainable natural production and assimilative capacity (also, in spatial terms, the difference between that economy/population's ecological footprint and the geographic area it occupies)
Sustainability Gap	- a measure of the decrease in consumption (or the increase in material and economic efficiency) required to eliminate the ecological deficit on a regional or global scale

- **Bens (1995)** reproduces performance indicators developed at a conference on performance measurement for planning in Ontario. The indicators are summarized in table form (pp.12-17) and are categorized by issues covering a wide range of physical and cultural concerns. These issue areas are:

water quality	biodiversity	social concerns
groundwater	wetlands	public streets
surface water	contaminated sites	main streets and downtowns
air quality	flooding/erosion	diversified economic base
natural heritage features	Great Lakes	efficient transportation
fish habitat	natural hazards	servicing and infrastructure
intensification	housing policies	conservation
rural areas	agriculture	mineral aggregates
heritage policies	agricultural separation	abandoned mines

- **Adriaanse (1993)** provides a complete "how to" for the selection, measurement, data aggregation, analysis and reporting of indicators - in this case for the assessment of national environmental policy performance in the Netherlands. The discussion also includes methodologies for indicator comparison, weighting techniques and procedures for deriving indices from indicators.

  Theme indicators are presented in the categories of: climate change, depletion of the ozone layer, acidification, eutrophication, dispersion of toxins, disposal of solid waste and disturbance of local environments. Target group indicators address pressures in the sectors of: agriculture, traffic and transport, industry, energy, refineries, building trade, and consumers.

- **Hammond et al. (1995)** also present their selected indicators for environmental policy in a work book format. The issues from which the indicators are derived are identical to those used by Adriaanse (1993) above (with the omission of disturbance of local environments). Illustrative calculations for constructing composite indicators (indices) from aggregated information are then worked through for: resource depletion, pollution, biodiversity and human impact/exposure.

  Figures 3 and 4 reproduce environmental indicators developed by the OECD and UNEP and by The World Bank (respectively) in the form of a matrix. Sustainability issues are listed in the left hand column with the corresponding pressure, state and response environmental indicators for each issue placed in the appropriate column. For example:

ISSUE	PRESSURESTATE		RESPONSE
climate change	GHG emissions	concentrations env. measures	energy intensity,
biodiversity	land conversion land fragmentation	species abundance comp. to virgin area	protected areas

In this case, a formulated aggregation of the indicators in each column of the matrix will produce an environmental index, a pressure index, a state index and a response index.

- The **Fisheries Program Evaluation Measures Committee (OMNR-FPEMC, 1993)** identified more than one hundred candidate evaluation measures working directly from the policy objectives. The indicators listed thus fall under the categories of: ecosystem evaluation (through both general health concepts and surrogate organisms), public involvement, appropriate evaluation of resources, effective program management and inter-agency coordination, timely communication of knowledge, and firm and effective enforcement.

World Wide Web Sites

This section contains a number of World Wide Web sites which have some relevance to this project and/or to monitoring and indicators in general. The list is certainly not exhaustive! It is meant to provide jumping off points for anyone looking for current and easily accessible information. Subjects pertain to both the ecological and societal systems, and range from scientific information and database holdings, to monitoring and management programs, to policy and communication. Because of this broad scope, no attempt was made to organize the sites by topic areas. The reader will find them below listed in alphabetical order with a short description. Please note that material on the Internet is volatile and the available information may already have changed considerably. A brief explanation of the Web search procedure used is included in the section "Literature Search Procedure".

- **Agriculture and Agri-Food Canada**
  http:// res.agr.ca/
  http://www.agr.ca/
  Agriculture and Agri-Food Canada has an interest in monitoring the environment because the health of the Canadian agri-food industry depends on a healthy environment as well as the long-term sustainability of resources to produce food Canada eats and exports. Examples of environmental parameters of interest are: energy resources, ethanol levels and ground level ozone levels. Through this site it is possible to access: the National Environmental Research Initiative (NERI); the National Ecological Framework (NEF) which maps Canada into ecological divisions; and, the Canadian Soil Information System (CANSIS) profiling soil landscapes of Canada. CANSIS links to the National Soil Database and to the Canadian Land Resource Network (CLRN). More general information about agriculture in Canada can be found at the second listed address - the federal department home page.

- **Biodiversity and Ecosystems Network (BENE)**
  http://straylight.tamu.edu/bene/bene.html
  The network links information on projects and resources (e.g. books, conferences, legislation) pertaining to biodiversity and ecosystem study. The sources of the information are: governments, local communities, universities, museums, zoos, botanical gardens and regional ecosystem networks.

- **Canada Centre for Inland Waters (CCIW)**
  http://www.cciw.ca/
  The CCIW is one of the world's leading centers for water research. It specializes in generating environmental information and knowledge about the Great Lakes. Their home page provides many useful links to other sites, for example Environment Canada's Green Lane, GLIMR, EMAN and others (see below). It is also equipped with search capabilities for government agencies and their information holdings.

- **Center for Ecological Health Research (CEHR)**
  http://ice.ucdavis.edu/Center_for_Ecological_Health_Research/about_CEHR.html
  This research center is funded by the U.S. EPA. Its goal is to understand how multiple stresses affect biological processes in aquatic and terrestrial systems, recognizing that complex ecosystem processes are critical to this evaluation. They hope that, within five to ten years, they will have developed improved indicators of ecological change from multiple stressors, as well as be able to predict and manage population level changes of impacted species.

- **Communicating Great Lakes Environmental Indicators to the Public**
  http://epawww.ciesin.org/glreis/glnpo/data/indicators/indicators.html
  This U.S. EPA site was created for two purposes. One is to provide ideas on the presentation of environmental data and indicators to the public. The other, is to present (as an example) environmental data on toxic contaminants of Great Lakes fish.

- **Ecological Forest Inventory and Analysis (ECOFIA)**
  http://www.msstate.edu/Dept/Forestry/ecofia.html
  ECOFIA is part of the USDA Forest Service and uses an ecological approach to plan for consistent national monitoring of Forest Service resources. The site consists of a collection of regional forest resource and ecosystem surveys, including assessments, inventories and on-going monitoring activities. Ecosystem assessments require timely and accurate resource condition information. Past data must be linked for monitoring with advanced technology, new inventory needs and evolving ecological objectives.

- **Ecological Health Indicators Legend**
  http://earth1.epa.gov/nep/state_indicators/
  This site provides the ability to view various U.S. state maps and visually present EMAP National Estuary Program results for standard indicators of ecological health. The assessment of ecosystem health is recorded as good, fair or poor for the following variables: dissolved oxygen, benthos, sediments, fish, marine debris and water clarity.

- **Ecological Monitoring and Assessment Network (EMAN)**
  http://www.cciw.ca/eman/intro.html

http://www.cciw.ca/eman-temp/reports/publications/framework/context.html
EMAN is a Canadian national network which brings often independent environmental monitoring and research activities (called Ecological Science Cooperatives - ESCs) together in an ecological framework. Information on the ESCs can be easily accessed by selectable sites on national and regional maps. Another section entitled "Research" contains: issues of concern (e.g. biodiversity), core data sets, and bibliographies. The "EcoWatch" link reveals community monitoring programs in Canada. Further description of the network, reports and publications may be found online (at the second listed location above). This location also outlines a framework for monitoring biodiversity changes.

- **Earthwatch - UNEP**
  http://www.unep.ch/earthw/
  Earthwatch is a coordinating mechanism through which UN bodies, in collaboration with government and scientists, gather environmental data and information. The index contains categories of: data types, information methodologies, indicators, standardization modeling and others.

- **EnviroLink**
  http://envirolink.org
  This site was created by a non-profit organization to be a "grass-roots online community" that unites hundreds of organizations and volunteers in over 130 countries. The EnviroLink library allows searching for resources of environmental information.

- **Environment Canada's Green Lane**
  http://www.ec.gc.ca/envhome.html
  http://www.cciw.ca/green-lane/
  The purpose of Environment Canada's Green Lane program is to promote and facilitate public access to environmental information. It is an extensive web site with capabilities to assist a search for publications and other resources by concept description or keywords. A link to "The State of Canada's Environment" is provided (see also SOER below). The second location listed above is the home page for Green Lane - Ontario Region which gives information and descriptions on Environment Canada's regional environmental programs in Ontario. Links to GLIMR, EMAN and other sources are included.

- **Environmental Information Resources**
  http://www.gwu.edu/~greenu/index2.html
  The resource center was created at George Washington University and provides 1000 links to Internet sites on the environment: research, education programs, initiatives, and groups. U.S. environmental resources are catalogued by subject and name. International resources are categorized by country.

- **Environmental Monitoring and Assessment Program's (EMAP) Integrated Approach - Program Guide**

http://www.epa.gov/emap/
http://www.its.nbs.gov/nb/
An aim of the U.S. EMAP is to compare the status and trends in ecological conditions among multiple ecological resources and assesses cumulative effects. Tools must be developed to do this. One objective is to develop and demonstrate indicators to monitor the condition of ecological resources, and to investigate acquisition and analysis of multi-scale data. Measures are integrated within and across different classes of ecological resources (e.g. small estuaries, rivers, deserts). The program guide gives an index of EMAP components and information resources as well as provides a navigator for searching. Links are provided to components, data, documents, contacts, etc.

- **Environmental Protection Agency (EPA)**
  http://www.epa.gov/epahome/finding.html
  The list of contents provides links to many EPA information services and tools. For example, information clearing-houses, data systems, models, and the Center for Environmental Resource Information (CERI).

- **European Forest Institute**
  http://efi.joensuu.fi/
  This is an independent non-governmental research body that conducts research at the European level in order to assist policy and decision making regarding forests in Europe. A "Database Gateway" links to a collection of information on publicly available forestry data, e.g. forest resources, forest productivity and global timber trade flow. Publications and other information on forest resource research are easily accessible.

- **Forest Ecosystem Dynamics (FED)**
  http://forest.gsfc.nasa.gov/
  The NASA/Goddard Space Flight Center - Biospheric Services Branch, makes available unrestricted data from the FED project's G.I.S. database. The project monitors and models ecosystem processes and patterns in response to natural and anthropogenic effects. Ecosystem models, remote sensing and measurements are examples of the tools used to observe and predict ecosystem changes. Links are provided to data bases, G.I.S. images, remote sensing results, etc.

- **Global Change Data and Information System (GCDIS)**
  http://www.gcdis.usgcrp.gov/
  http://www.cgcp.rsc.ca/
  The GCDIS is a cooperative activity of agencies participating in the U.S. Global Change Research Program (U.S. GCRP) to collect the considerable and growing body of information related to climate change. This site is designed to make much of this information easily accessible from one place. Information is available from U.S. and international data sources, libraries, documents, educational resources and much more. One of the links provided leads to the Canadian Global Change (CGCP) web site (the second URL listed above) which has its own publication, project and Internet

resource collections. Both sites are equipped with search engines to expedite finding information on a particular topic.

- **Global Resource Information Database, Arendal (GRID-Arendal) - UNEP**
  http://www.grida.no/inf/about/
  http://www.grida.no/
  This is a searchable global network providing environmental information for decision and policy making. More than 2000 environmental and natural resource databases are held. Data distribution, data cataloguing, archiving and analytical services are offered using G.I.S., remote sensing, database and telecommunications technologies. Links connect to: SOER, Environmental Information Networks (GRID, INFOTERRA, ENRIN and EIS). The second address listed above is the home page for UNEP (United Nations Environment Program).

- **The Grand River Watershed**
  http:/bordeaux.uwaterloo.ca/ecores.html
  An Environmental Information System (EIS) was created at the University of Waterloo as part of an interdisciplinary research agenda to amalgamate and facilitate the sharing of information for a bioregional unit - the Grand River Watershed. The EIS provides maps and databases of sites, project summaries of research, and other types of information such as a directory of environmental stewardship groups within the watershed.

- **Great Lakes Environmental Research Laboratory (GLERL)**
  http://www.glerl.noaa.gov/
  http://www.noaa.gov/
  This laboratory is part of the National Oceanic and Atmospheric Administration (NOAA) which has a mandate to describe, monitor and predict changes to allow for sustainable economic decision making and promoting global environmental stewardship. GLERL is committed to maintain excellence in research while addressing important issues for managing resources and preserving life and property in the Great Lakes and nearshore/coastal marine areas of the country. Research is conducted in the areas of: pollutant effects, water resources, marine resources, climate variability and global change in large lakes, near-shore hydrodynamics and others. NOAA’s web site (the second listed above) provides information and data services listings for projects in their domain.

- **Great Lakes Information Management Resource (GLIMR)**
  http://www.cciw.ca/glimr/intro.html
  Part of the Green Lane network, GLIMR is an index of Environment Canada’s Great Lakes programs, publications and databases. It is also a window to other environmental networks. (See Environment Canada’s Green Lane and CCIW).

- **The Information Highway to the Global Environment (IHGE)**
  http://www.gsf.de/UNEP/contents.html
  This directory of organizations and institutions which are active in environmental monitoring links to programs around the world: from Albania, to Italy, to Peru, to Western Samoa. United Nations Organizations, inter-governmental organizations, non-government organizations, academic institutions, and industrial or commercial organizations are all covered.

- **International Development Research Centre (IDRC)**
  http://www.idrc.ca/resources/index_e.htm
  http://www.idrc.ca/books/reports/1996/
  These two URL addresses lead to a rich source of information and knowledge about development and research carried out by scientists of the developing world. Links are provided to: databases, library, on-line publications (Internet sites relating to international development), images and videos.

- **International Institute for Sustainable Development (IISD), Linkages**
  http://www.iisd.ca/linkages/
  http://www.iisd.ca/linkages/forestry/mont.html
  http://iisd1.iisd.ca/about/
  http://iisd1.iisd.ca/ic/info/ss9504.htm
  The first location listed provides an index of linkages put together by the IISD. The site is intended to be a multi-media resource for environment and development policy-makers. One example is the link to forestry (the second URL listed above; see below also) with details on the Montreal Process, a meeting to develop criteria and indicators to measure sustainable forestry. The third site provides information about IISD itself. Finally, the last site listed above links to the IISD Information Centre. ‘Selected Sources of Sustainable Development Indicators’ is a useful resource which briefly explains the concept of sustainable development indicators and provides a list and short description of book and article references on this subject. IISD also links to many Canadian government sites and organizations as well as ‘Vital Signs’ - an annual publication on key indicators of the state of the planet.

- **Montreal Process for Sustainable Forestry**
  http://www.iisd.ca/linkages/forestry/mont.html
  This is part of the above mentioned site maintained by the International Institute for Sustainable Development (IISD). It contains a large amount of information on sustainable forestry, including criteria and indicators**.**

- **National Ecological Framework (Canada) - Overview**
  http://res.agr.ca/PUB/CANSIS/NSDB/ECOSTRAT/_overview.html
  The purpose of the National Ecological Framework is to organize (combine, analyze, display) information from the ecological monitoring and reporting activities of various levels of government, universities and private sector institutions. The

framework holarchy updates and revises the National Atlas of Canada (1993) and Wiken (1986). A link to ARC/INFO G.I.S. coverage of the mapping is available.

- **National Environmental Data Index (NEDI)**
  http://esdim.noaa.gov/
  This index, also part of NOAA, identifies environmental data and information holdings within the U.S. (and ultimately internationally). The overall goal of NEDI is to gather the widest possible range of environmental data and information to support our ability to protect human health, safety and welfare; maintain and restore ecological integrity, and sustain economic stability and growth.

- **Oak Ridge National Laboratory**
  http://www.esd.ornl.gov/centers/global.html
  http://www.esd.ornl.gov/
  http://www.esd.ornl.gov/iab/iab4-5.htm
  This is a U.S. Department of Environment research laboratory that conducts a wide range of basic and applied research and development to advance the nation's energy resources, environmental quality, scientific knowledge, educational foundations and economic competitiveness. It focuses on: (1) measurement and science instrumentation; (2) data systems; (3) large-scale environmental studies; and, (4) policy, energy, and human systems analysis. The second site listed links to the environmental sciences division, in general, with sections in ecological sciences, environmental analysis, environmental research news and major programs. The third URL address is for 'Monitoring and Assessing Ecological Conditions with a Landscape Pattern. This site answers questions regarding which pattern metrics and land cover data, resolution and extent are useful for monitoring at national and regional scales. References are also provided.

- **Office of Policy, Planning and Evaluation - U.S. EPA**
  http://epawww.ciesin.org/map/polpledu.html
  This URL site is included because it addresses an issue that was found to be lacking in the background literature review of the thesis. The Office claims that dedicated planning exists for social and health care, technology, education and finances, but the equivalent is not done for environmental policy. To this end, they collect data ranging from laboratory test data, to automatic sampling, to monitoring compliance with existing new laws, amendments and reauthorization of environmentally-related policy.

- **Pensacola Bay Ecosystem Management Plan**
  http://www.dep.state.fl.us/nwd/INTRO/INTRO.htm#top
  This site contains an on-line version of a discussion paper by the Florida State Department of Environmental Protection. It is a good resource discussing the development of indicators and conceptual frameworks to be used in monitoring the state of various ecosystems within Florida. Pensacola Bay is the first and 'pilot' project to test their methodologies and indicators.

- **State of the Environment Reporting (SOER) Canada - Infobase**
  http://www1.ec.gc.ca/~soer/
  This site provides general information, methodologies and procedures for developing indicators, as well as results to date, in determining the state of Canada's environment. This program is an impressive initiative by the federal government and has spread to lower levels of government, regions, cities, and natural areas. Searching the web for these other sites could provide useful examples of smaller scale monitoring.

- **A Survey of Work on Sustainability Indicators**
  http://www.dpie.gov.au/dpie/cpd/survey_indicators.html
  This on-line publication is supported by the government of Australia and the Australian National University. The Intergovernmental Committee on Ecologically Sustainable Development (ICESD) aims to measure progress in ecologically sustainable development within Australia and internationally. An excellent review of frameworks for developing sustainability indicators (past and present), methodological considerations, implementation and integration, and local progress is presented. Also included are many existing sets of indicators as examples.

- **U.S. Department of Agriculture (USDA) - Forest Service**
  http://www.fs.fed.us/
  The USDA Forest Service states as its mission to achieve quality land management under a sustainable multiple use management concept to meet the diverse needs of people. The site offers data, research and scientific publications on ecosystem states, processes and influences.

- **U.S. Geological Survey (USGS), Water Information Coordination Program**
  http://h2o.usgs.gov/public/wicp/overview.html
  In 1991, the USGS formed a joint intergovernmental task force with the U.S. EPA to study water quality monitoring at various scales: federal, state, tribal, regional, local and private. Their objective is an increased understanding of regional and national water quality conditions and trends. In addition, they recommend indicators to measure water quality to determine whether state designated standards are being met.

- **WWW Virtual Library: Environment**
  http://ecosys.drdr.virginia.edu/Environment.html
  This library searches for information on the environment (information sources, contacts and research centers) worldwide. Basic categories are described by a subject tree with branches on atmosphere, biosphere, hydrosphere, lithosphere, general and civilization. Examples found within are: biodiversity and ecology, forestry, sustainable development, and many more.

- **Yahoo: Environment**
  http://www.yahoo.com/Environment_and_Nature/
  Yahoo searches the Internet for (lots and lots!) of on-line information by subject relating to the environment and nature. Under each subject area, a variety of information is available (e.g. for ecology - conferences, journals, research and relevant sites). '/indices/' links directly to the databases, research institutes and other Internet sites that it uses to gather the information.

Literature Search Procedure

An important component of the thesis research was the collection and review of existing literature and programs related to monitoring. Helpful information was also found on the World Wide Web. The results of the background review have been presented thus far in Appendix B. This section explains the procedures used in the literature and World Wide Web searches which were first conducted in the Fall of 1995 and then updated in June of 1997.

Background Literature Search

The literature search conducted for this project built upon an earlier database constructed by Marie Lagimondiere, a research assistant at the University of Waterloo. Her database covered literature up to 1992. In addition, the following searches were performed to obtain background material (with an emphasis on post 1992 material):

Environmental Abstracts database
A database indexing approximately 800 international journals and periodicals, as well as books and conference papers, related to the environmental field. Disciplinary areas include environmental studies and management, ecology, geography, architecture, etc. Entries from 1971 to the present are available.
Keywords: ecological monitoring, ecological indicators, environmental monitoring, environmental indicators, environmental policy evaluation, environmental policy effectiveness, indicator selection criteria, monitoring framework, and renewable resource protection.

Current Contents database
A multidisciplinary, scientific database that covers thousands of journals in total. The most important journals in each field are selected and reviewed, and published in weekly issues. The database thus indexes the most recent articles, most of which have not yet been added to other database holdings. Agriculture, Biology and Environmental Sciences (a subset of the total database) was searched for this project from July, 1995 through to the close of December, 1995 and again from January, 1997 through to June, 1997.
Keywords: ecological indicators, ecological monitoring, environmental indicators, environmental monitoring

Canadian Research Index database

This database indexes Canadian federal, provincial and municipal government documents, including: research papers in physical, natural and social sciences; policy papers; important statistics; annual reports; and, any paper published by a government department, or sponsored and published through government financial support. Many relevant subject areas are covered, for example: agriculture, commerce and economics, culture, environment, fisheries, forestry, life sciences, natural resources, earth sciences, planning and much more. Entries are available from 1982 through to the present.

Keywords: ecological indicators, ecological monitoring, environmental indicators, environmental monitoring, monitoring frameworks, environmental policy effectiveness.

bibliographies of 'core' material

The bibliographies of documents which were believed to have made an important contribution to monitoring and indicator development, were used as leads to follow in finding other material. The documents used for this purpose are: Davies, Rapport and Brady (1992 Draft), Hodge (1994), Maclaren (1995), MacViro Consultants, Inc. (1994, 1995), McHattie (unpublished bibliographic review), and OMNR (1995). A 1997 addition to this list is Tognetti (1997).

World Wide Web Search

World Wide Web sites were discovered through searches using both Lycos and the search engine provided by NetScape. They were conducted between the months of December, 1995 and April, 1996. Additional sites were obtained from an index of environmental resources put together by James Kay, Environment and Resource Studies, University of Waterloo.

NetScape Keywords: ecological + indicators

Lycos Keywords: ecological and indicators, ecological and indicators and criteria, environmental and indicators, planning policy and evaluation, monitoring and framework (all keyword searches requested a strong match).