THE ASSESSMENT OF CUMULATIVE EFFECTS: A RESEARCH PROSPECTUS

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FOREWORD

The Canadian Environmental Assessment Research Council (CEARC) was established on January 30, 1984, by the federal Minister of the Environment to advise government, industry and universities on ways to improve the scientific, technical and procedural basis for environmental impact assessment (EIA). CEARC is undertaking research in several areas related to improving the practice of environmental assessment.

The Council has chosen cumulative effects assessment (CEA) as one important focus of research and this prospectus describes CEARC's approach to possible research activities in this field.

This prospectus both draws on the results of commissioned research and sets out the directions for further work that the Council will pursue directly and promote in consultation with other organizations. It is also intended to encourage a broader dialogue between the CEA Committee of Council and the wider EIA community.

A number of people have contributed to the development of this prospectus. The CEA Committee of Council particularly acknowledges the assistance of Arthur J. Hanson in providing a critical review of the document.

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INTRODUCTION

The Canadian Environmental Assessment Research Council (CEARC) advises governments and industry on ways to improve the scientific, technical and procedural basis for undertaking environmental impact assessment (EIA). The approach adopted by the Council to achieve its mandate is set out in a document entitled Philosophy ***and Themes for Research*** (CEARC 1986). Specific research priorities for improving the practice of EIA are developed in a series of research prospecti. The present document provides the Council's perspective on the nature of cumulative environmental effects and recommends a research agenda to improve the assessment and management of such effects.

CEARC has placed cumulative effects assessment (CEA) high on its agenda of research priorities for a number of reasons. First and foremost is the difficulty of undertaking sound EIA without consideration of the regional context and cumulative changes resulting from multiple impacts. Second, CEA reflects a number of the research themes adopted by CEARC to guide its activities, namely the integration of assessment within a broader planning context; improvements in the rigour of scientific analysis; and the strengthening of institutional frameworks. Third, CEARC has decided to give priority to problems that cut across conventional scientific and institutional boundaries and impede current practice. Fourth, CEARC is interested in promoting research in issues that fall outside the mandates of other research granting agencies. Finally, CEARC is developing approaches for evaluating environmental impacts of broad policies in addition to specific projects. CEA is a good example of all these interests; it underlines the need for a well organized and long-term approach leading towards a resolution of the scientific and institutional aspects of the problem.

We begin with a brief summary of some background studies and workshops sponsored by CEARC to develop a better understanding of the concept of cumulative effects assessment and an evaluation of current practice in Canada and elsewhere. Based on this review, some immediate research needs are identified. Finally, we present the Council's agenda for CEA research, set in the context of its overall strategy for improving performance and practice of environmental assessment in Canada. Appendix A outlines a conceptual perspective on cumulative effects.

BACKGROUND

Environmental impact assessment is now widely established as a planning process for reconciling economic development with environmental conservation. It still, however, suffers from a lack of credibility with regard to scientific inquiry and procedural efficiency. The EIA process, in particular, is largely concerned with the analysis and management of impacts on environmental and social systems caused by single-project development.

The effective management of cumulative effects associated with multiple developments is now becoming recognized as a major challenge to both scientists and environmental policy makers. Environmental impacts involve changes to natural and social systems due to the addition of materials such as chemicals or imported species; the removal of materials from the environment resulting in fragmentation of natural or social communities; or interference with physical, biological or socio-economic processes. As the pace and scale of development have increased, impacts have come to extend far beyond the influence of individual activities. To some extent, ecological and social systems can adapt to such changes. But it is becoming increasingly apparent that cumulative effects associated with multiple activities can create irreversible changes in such systems or changes that are different in nature from those caused by any single activity or impact.

Social and economic factors are the driving forces in promoting activities that cause cumulative effects. Agricultural policies that encourage increased productivity can result in soil erosion, intensive use of pesticides and other toxic chemicals, and drainage of wetlands and the subsequent loss of habitat and species. Solutions to some of these problems, therefore, may lie not only with improved environmental management, but with a change in fundamental economic policies and social perceptions. Cumulative effects assessment can help forge a transition from project-specific environmental management to a more comprehensive "holistic" approach to the environment.

Cumulative effects fall within a range of spatial and temporal dimensions — from the local (forest harvesting) and short term (a crop rotation), to the global (atmospheric pollution) and long term (climatic change). In general, the scientific and institutional aspects of the problem become more complex as time and space boundaries expand. This complexity is an impediment to understanding the problem and developing workable management solutions, and a reflection of the challenges facing environmental impact assessment as it evolves into a broader-based environmental and resource management tool. Sooner or later, in one form or another, those responsible for managing natural systems will have to address the problems associated with cumulative environmental effects.

There is current interest in promoting sustainable development in Canada (National Task Force on Economy and Environment). Cumulative effects analysis can contribute meaningfully to this discussion. It encompasses multiple developments on a broad geographical scale and requires research that integrates economic, ecological, and social considerations.

Cumulative effects have been recognized for some time, although they may have been described in different terms. At the global level, examples include the build-up of carbon dioxide in the atmosphere and acid precipitation in eastern North America and Europe resulting from multiple emissions of sulphur dioxide. Many of the scientific and management studies on the Great Lakes have focused on cumulative impacts of multiple uses of that large system (Francis 1979). The ongoing program to develop an integrated management system for the Fraser River estuary in British Columbia may also be seen as a reaction to the cumulative effects of development, which have proven to be difficult to control through a sectoral approach (Sonntag et *al.* 1987). The problem is also well recognized in the United States where major studies and programs have been mounted by both governments and the private sector (CAETEP 1986). In at least one jurisdiction (Maryland), the cumulative effects of development must be addressed under the state's planning legislation.

Council's Research Program

The Council has conducted a three-phase research program on the assessment of cumulative effects to date. First, a binational workshop on cumulative environmental effects was organized in conjunction with the U.S. National Research Council Committee on the Application of Ecological Theory to Environmental Problems (CAETEP) in February 1985 (CEARC and U.S. NRC 1986). Second, CEARC commissioned two studies on the state of the art of cumulative effects assessment practice in Canada and elsewhere by Western Ecological Services (Peterson et *a/.* 1987) and Environmental and Social Systems Analysis Ltd. (ESSA) (Sonntag et *al.* 1987). The intent of the second phase was to move from a problem-scoping exercise (the CEARC/NRC workshop) to focus on practical questions about the scientific methodology and institutional arrangements for CEA. Third, in the fall of 1986, the Council contracted a team of consultants from across Canada to develop a "reference manual" for undertaking CEA in a variety of environmental systems. The Council anticipates that the report will be published as a companion volume to this prospectus. The proceedings of the binational workshop (CEARC and U.S. NRC 1986) and the state-of-the-art reports are summarized below, since they provide the substantive background to this prospectus.

Binational Workshop

The objectives of the binational workshop were to define more clearly the nature of cumulative impacts, to consider in general terms the effectiveness of current scientific and management approaches to dealing with these problems, and to outline future directions for research in this area. The workshop brought together 30 participants from Canada and the United States to examine the issues of cumulative effects on terrestrial, freshwater, marine, and atmospheric ecosystems. Theme papers and commentaries dealing with the respective scientific and management dimensions of these four systems provided the basis for wide-ranging discussion. The workshop proceedings represent a wealth of ideas concerning current concepts of CEA and the major challenges facing future research and application in this area. For present purposes,, the key questions of the workshop are dealt with below.

What Are Cumulative Effects?

Cumulative effects proved difficult to define since the concept of cumulative effects assessment'was viewed from a number of different angles. A typology of cumulative environmental effects was prepared to assist in classifying various types of cumulative impact. This classification, which incorporates previous attempts at a definition (Vlachos 1982: 61; U.S. Council on Environmental Quality 1978: 1508.7/8), is outlined in Table 1.

Cumulative effects occur when:

- impacts on the natural and social environments take place so frequently in time or so densely in space that the effects of individual "insults" cannot be assimilated; or
- the impacts of one activity combine with those of another in a synergistic manner.

Individually, these impacts may not be qualitatively different from environmental effects associated with single-project developments, but collectively they often require different kinds of research and management approaches if they are to be dealt with effectively.

How Effective Are Present Approaches

Cumulative effects, by their nature, require an integrated approach, one that links scientific analysis and management procedures and relates decision making to the time and space scales at which the changes in environmental quality occur. Existing approaches to impact assessment are not well adapted to cope with these problems. Project-specific analysis and mitigation, for example, generally do not take account of:

- additive effects of several developments on ecological systems;
- effects of secondary activities derived from primary development;
- non-linear ecological responses to increasing development pressures;
- synergistic or feedback effects of impacts on the environment: and
- dynamic "patchiness" or "ecotone" effects because of variable interactions in space or time.

Table 1
A Typology of Cumulative Environmental Effects

	Type	Main Characteristics	Examples
1.	Time crowding	Frequent and repetitive impacts on a single environmental medium	Wastes sequentially discharged into lakes, rivers, or airsheds
2.	Space crowding	High density of impacts on a single environmental medium	Habitat fragmentation in forests, estuaries
3.	Compounding effects	Synergistic effects arising from multiple sources on a single environmental medium	Gaseous emission into the atmosphere
4.	Time lags	Long delays in experiencing impacts	Carcinogenic effects
5.	Extended boundaries	Impacts resulting some distance from source	Major dams; gaseous emissions into the atmosphere
6.	Triggers and thresholds	Disruptions to ecological processes that fundamentally change system behaviour	The greenhouse effect; effect of rising level of CO_2 on global climate
7.	Indirect effects	Secondary impacts resulting from a primary activity	New road developments opening frontier areas
a.	Patchiness Effects	Fragmentation of ecosystems	Forest harvesting; port and marina development on coastal wetlands

Source: ***Based on discussions at*** *CEARC/CAETEP* ***Workshop (CEARC and U.S. NRC 7986: 16 1)***

Such effects can be local, regional or global in scale, typically cross jurisdictional boundaries and/or agency responsibilities, and require the kind of co-ordinated institutional arrangements that are sometimes difficult to achieve unless there is a perceived crisis. Recent progress in tackling this kind of problem has been accomplished through regional planning and areawide assessment (e.g., FEAR0 1984). Generally speaking, scientific and management approaches to cumulative effects have been more successful with clearly bounded systems, such as lakes and watersheds, than with more open systems, such as estuaries, marine waters and many terrestrial systems.

What Are the Directions for Applied Research?

Research recommendations directed toward strengthening the scientific and management aspects of cumulative effects were made on the basis of the deliberations of the binational workshop. These recommendations were the basis upon which the Council determined the requirements for the state-of-the-art reviews, mentioned above. CEARC's proposal for conducting the reviews posed two premises:

- that increasingly significant changes to environmental quality are being caused by cumulative effects; and
- that current scientific and institutional approaches are inadequately developed to manage these impacts.

Testing these premises involved a number of supplementary questions:

- What are the most significant types of cumulative impacts at present in Canada, and how will these likely change over the next 1 O-20 years?
- What examples are available of successful scientific and management approaches to dealing with cumulative effects; and why are they successful?
- What types of environments and what kinds of activities are more susceptible to cumulative effects; and what kinds of institutional arrangements constrain or facilitate management?
- How can EIA processes be adapted successfully to manage cumulative effects, and what could be the contribution of regional environmental planning to dealing with this problem.

The above-mentioned review confirmed that cumulative effects are having an increasingly significant impact on the quality of natural and social environments in Canada. Peterson ***et al.*** (1987) identified a number issues that either involve significant cumulative effects now or probably will by the end of the decade:

- long-range transportation of air pollutants;
- urban air quality and air-shed saturation;
- mobilization 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.

The final reports of the two consulting groups contained a total of 23 general and specific recommendations dealing with the scientific, methodological, procedural, and institutional aspects of CEA. Although each consultant group developed its own approach to the problems of CEA, there were a number of basic similarities:

- Each group developed a preliminary conceptual approach as a context within which to analyse cumulative effects. These approaches differ but both provide a useful basis upon which to develop an understanding of this complex problem.
- Both groups stressed the importance of the insititutional and management aspects of CEA. They found that the degree of success in dealing with cumulative effects problems was largely influenced by existing institutional arrangements. Both groups recommended the development of a focused research program (including monitoring and evaluation) leading towards the improvement of institutional performance.
- There was unanimity concerning the need for a "stock taking" of available methods and analytical tools for conducting CEA. In spite of the complexity of the problem, it was concluded that a range of analytical tools does exist and can be effectively applied under certain conditions.
- Both groups recommended that a policy, or set of projects, that create well-defined CEA problems should be selected as a pilot study to test the utility of concepts and approaches being recommended for dealing with cumulative effects.

A Reference Manual for CEA

Based on a review of the first two phases of this research strategy, the Council decided that the most important follow-up step was to prepare a "reference manual" for CEA. The manual will include a "tool-bag" of analytical methods currently used to tackle cumulative effect issues in aquatic, atmospheric, and terrestrial environments.The manual is being designed for use by practitioners of environmental assessment in government and the private sector.

A contract has been let to develop the manual, involving a team of consultants located in major centers across Canada. The research team was asked to (1) refine the conceptual model of CEA drafted by the CEA Committee of Council, based on the work of ESSA and Western Ecological Services (see Appendix A); (2) comment on the effectiveness of regional or areawide planning approaches in order to provide a policy context for cumulative effects analysis or management; (3) outline specific analytical techniques currently being used to manage cumulative effects; (4) establish criteria and principles for designing and implementing monitoring programs to assess and manage changes brought about by cumulative effects; and (5) outline effective institutional arrangements that could encourage greater co-ordination between agencies and jurisdictions where impacts cross jurisdictional boundaries.

A second objective of this project was to test the feasibility of applying appropriate methods outlined in the reference manual and the conceptual framework to a selected case study which has multi-jurisdictional and regional planning implications. The case proposed by the Council was that of the cumulative effects of current agricultural and related land use policies and their effects on wetland habitats and associated ecosystems in the three prairie provinces. There is evidence that some waterfowl populations have decreased sharply over the last 10 years or so, making the case study a relevant one for applied research. The analysis would be conducted at a feasibility level only in this phase of the Council's work.

Once reviewed by the Council the reference manual will be released in the spring of 1988 for full discussion with the research and practicing communities in the field of environmental assessment.

CONCEPTUAL PERSPECTIVE ON CEA

Analysis of cumulative effects can be complex because environmental and social impacts of multiple developments themselves interact in different ways over time and space. Consequently, the Council believes that a framework should be developed to identify the different categories of cumulative effects and how these categories may interrelate in time and space, within and between ecosystems.

An initial attempt at developing such a conceptual framework is included in Appendix A. This draft is presented to encourage discussion in the research community and to provide a backdrop for review of the reference manual and case study proposal being developed under the Council's current research agenda.

The framework for analysing CEA incorporates the six basic characteristics of cumulative effects:

1. Scale of impacts can encompass local, regional, national and global effects.
2. Timing of system responses can be short (day-months), medium (years) or long (decades).

3. Multiple activities and systems (economic, social, ecological) can be involved.

4. Interdisciplinary research is required to analyse problems.

5. Multiple agencies are generally involved in managing cumulative effects since such impacts often cross jurisdictional lines.

6. Policy and planning approaches are useful to provide a context for project-specific impact analysis.

These characteristics not only establish the framework for analysing cumulative effect case studies, they also influence the future scope of research identified by the Council. The research issues outlined in the following section are based on the Council's program to date and discussions with a number of practitioners. This section does not provide a complete list of research needs or even a comprehensive one, rather, it is an attempt to stimulate interest to promote some initial activity by the research community.

RESEARCH NEEDS

The Council believes that there are opportunities for productive research in three aspects of cumulative assessment:

- theoretical development,
- scientific and methodological development, and
- institutional development.

These areas are of course interrelated; many research projects may cross into all three aspects. However, this "classification" helps the Council to identify some initial proposals for CEA research.

Theoretical Development

The Council would like to see the preliminary conceptual framework in Appendix A expanded and refined. It is important to improve understanding of cause-and-effect relationships that characterize the four pathways of project activity and ecological change depicted in Figure 1. Particular attention needs to be given to the processes at work in pathways three and four. The problems associated with establishing time and space boundaries for analysing changes due to multiple activities in relatively open systems are formidable. The identification of key indicators and critical thresholds, summarized in the notion of carrying capacity, would prove helpful for sorting out the multiplicity of cause-and-effect relationships and for assessing system resiliancy to change. It will be especially important in this context to try and establish the early warning signals of "structural surprises," the kind of large-scale global discontinuities in environmental systems that result from fundamental technological and economic trends (e.g., the depletion of the ozone layer). Such research offers an important means of shifting away from the traditional stance of cumulative effects management, which is one of "react and cure," to a more proactive approach of "anticipate and prevent." It must also be emphasized that the framework(s) for organizing this conceptual understanding should be capable of application at the local and regional scales at which most assessment and management activities are conducted in Canada, but that they should also be able to incorporate the processes which create global environmental changes.

There are a number of research themes which the Council considers to be important. Some of these are well established lines of scientific inquiry; others are more recent. The Council is prepared to support and promote research into:

- the establishment of spatial and temporal boundaries in relatively open ecosystems — air, land and water;
- evaluation of carrying capacities of various ecosystems to identify critical thresholds at which system effects change significantly; and
- application of effective regional or area planning approaches for linking environmental management with regional economic development where cumulative effects are involved.

Scientific and Methodological Development

Cumulative effects assessment poses major challenges to the scientific research community. Such effects, by definition, manifest themselves over extended time and spatial dimensions. In some cases the time frame is longer than that normally involved in research programs, i.e., there may be significant time lags between cause and the recognition of effect, This implies that research on cumulative effects must be long term in nature and supported by monitoring programs spread over appropriate time and space scales. Gaining commitment for such research and monitoring programs may be difficult.

Much of the basic research required to define the problem of cumulative effects is interdisciplinary in nature. Unfortunately, cross-disciplinary research and development is not popular with many scientists or funding agencies. Because most of the basic research on cause and effect in cumulative effects assessment will need to be conducted within major government and university research programs, CEARC has a role to play in promoting and facilitating an integrated scientific approach to the topic.

The basic research required on the problems of cumulative environmental effects must also be matched with focused efforts to develop practical and effective solutions.

Some of the more specific research themes that have been indentified by the Council include the following:

- definition and development of monitoring networks to measure cumulative effects of multiple sources of impacts on specific ecosystems and/or multiple impacts on multiple ecosystems;
- case example analyses from both past and present projects to test analytical techniques and adaptive impact approaches for managing cumulative effects on natural ecosystems; and

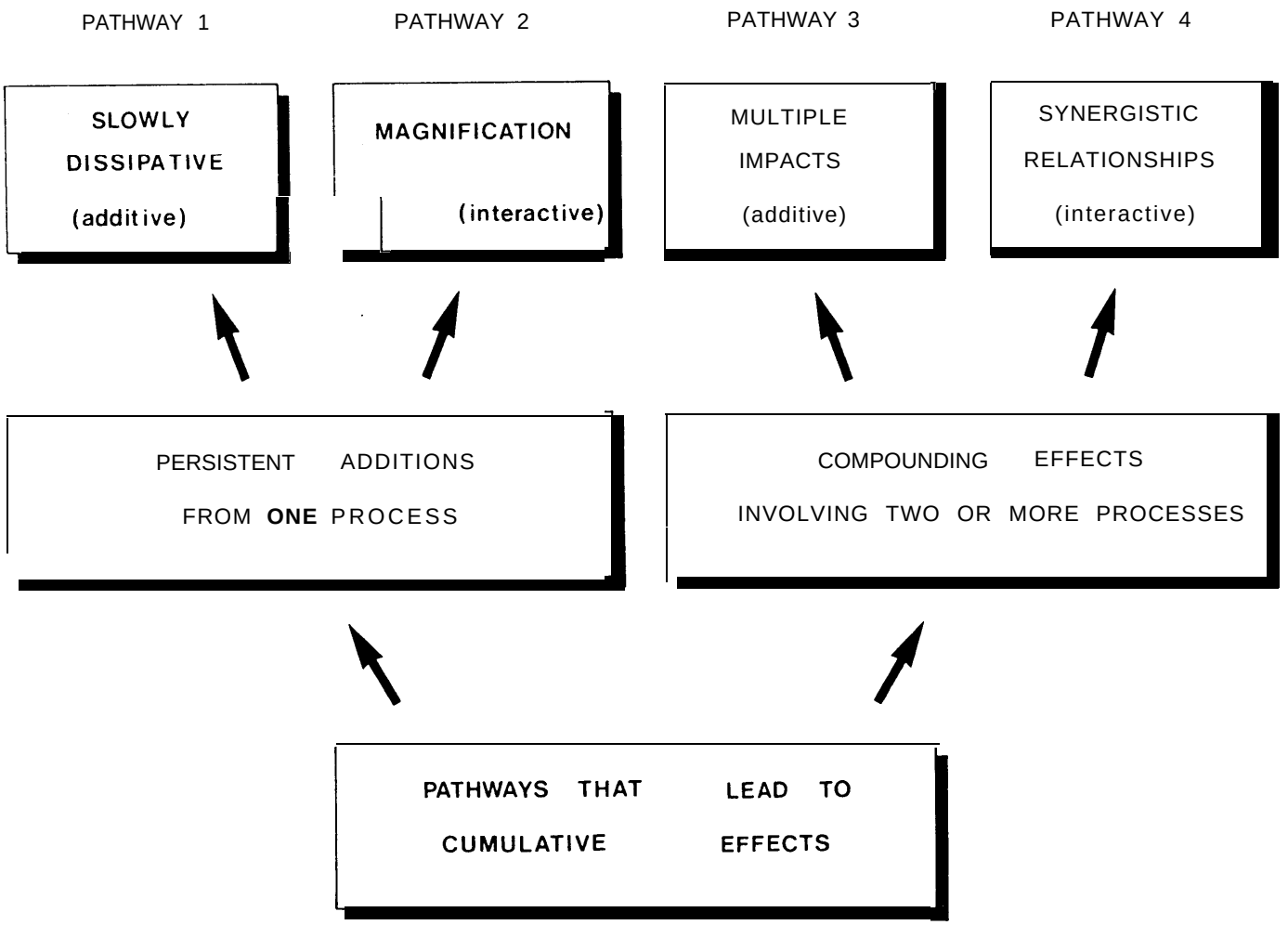

Figure **1.** Basic Functional Pathways That Contribute to Cumulative Effects (Peterson et *al.* 1987)

- improvement of our understanding of functional relationships between cause and system effects associated with multiple impacts on the natural ecosystems.

Analytical methods must be developed that are both defensible from a scientific perspective and useful to those responsible for managing cumulative effects. These methods must incorporate well-designed monitoring programs that will ultimately lead to a better understanding of the complex linkages between multiple and/or sequential developments and their impact on natural systems. Basic research will be required to define monitoring programs to track the structural and functional integrity of ecosystems as they are exposed incrementally to increased levels of stress. Most current monitoring programs are designed to measure changes caused by single projects rather than by multiple projects. Systems that are exposed to several different sources of stress are often not adequately monitored. The analytical methods that are developed will need to be rigorously tested and evaluated through application in case studies or pilot projects. In this context, CEARC may be able to function as a facilitator for such trial applications and oversee the conduct of credible evaluations.

Institutional Development

Institutional fragmentation remains an important constraint to the implementation of improved approaches to cumulative effects assessment and management, especially where such effects cross jurisdictional responsibilities. Research needs could be based initially on reviewing the effectiveness of existing institutional arrangements for addressing cumulative

effects issues, where these effects have been clearly established as a public concern (e.g., the Fraser River Estuary Management Program).

Examples of other institutionally based research on cumulative effects that have been identified by CEARC include:

- case examples of institutional arrangements to manage cumulative effects where such effects cross jurisdictional boundaries (between provinces as well as internationally);
- analysis of approaches to public consultation on cumulative effects analysis when there are several sources of impact (i.e., more than one proponent or a mix of existing and potential developments): and
- analysis of institutional procedures that encourage integration of social impact analysis with environmental assessment when cumulative effects are involved.

Based on such case experience, guidelines for incorporating CEA into the mandates of public agencies might be developed.

A particularly important requirement in this context is research into interjurisdictional arrangements for managing cumulative effects that are now being recognized as potentially critical (such as the feasibility study into wetland drainage and reduction of waterfowl habitat in the prairies). A second topic is to determine how regional and international jurisdictions can adapt to "structural surprises," which by definition are difficult to predict (see Appendix A). At present, development of effective transboundary arrangements for tracking and responding to major changes that tend to lie outside the control of any one government or country represent a challenging aspect for CEA research.

Finally, improved institutional performance can be realized through the application of audit and evaluation strategies that encompass cumulative effects. The current federal-provincial agreement on the Fraser River Estuary identified a number of opportunities in audit and evaluation of cumulative effects such as a federal-provincial ambient water quality monitoring program, which included biological indicator analysis, and assessment of wetland habitat productivity through regular inventory. Furthermore, a cross-jurisdictional referral system has been established to keep track of all development proposals and evaluate these in the context of existing development and ambient environmental objectives (Sonntag *et al.* 1987).

, RESEARCH AGENDA

In February 1987, the Council reviewed its overall research strategy and decided to focus on a number of functional activities over the next three years. The Council's sponsorship of further research on cumulative effects will be organized around the context of this revised research strategy. In this context the Council's research will focus on strategic issues and demonstration projects.

Strategic Issues Analysis

The analysis of strategic issues analysis involves the application of research to assist policy, planning, and management associated with important resource developments in Canada. Such research would first consider the linkage between policy/planning and single/multiple project developments. The purpose would be to determine the extent to which established policies or regional plans guide and control environmental effects of economic development in, for example, coastal environments or timber harvesting. Second, the research would evaluate how well environmental objectives set out in the context of policy/plans (e.g., ambient quality standards, allocation of resource uses, sustainable yield) have been achieved. Such research would involve monitoring and evaluation programs. This integration of policy/planning, single/multiple project assesssment and follow-up monitoring and evaluation is considered critical in the analysis of a number of strategic issues.

Examples of such strategic issues include the effects of forest policy on environmental systems, agricultural policies on soil conservation and wetland habitats, and waste management strategies on water quality in the Great Lakes. Many of these projects involve cumulative effects as defined in this prospectus. Some are already being researched by agencies or under inter-jurisdictional agreements. In these cases, CEARC would review the results of this research. Other issues, such as the agricultural-wetland interface in the prairies have not yet been tackled on a systematic basis under a cumulative effects framework. CEARC would be interested in assisting the development of this research, if the results of the feasibility study now being undertaken are promising and if there is support from the jurisdictions involved .

This aspect of CEARC's work conforms to the principles set out in the National Task Force on the Environment and Economy, which reported to the Canadian Council of Resource and Environment Ministers in September 1987. The Task Force stressed the need for sustainable development through policies and project designs that integrate economic and environmental management.

Demonstration Project

Most of the research in environmental assessment can best be tested through application to real problem analyses. Thus, the Council would be prepared to assist the practising community to apply the results of the reference manual to present and future CEA problems in Canada. Such research would have to be cost-shared, i.e., the lead government or private sector agency would also have to be willing to assist in funding the research program. The Council has on-going research interests in other aspects of environmental assessment such as mitigation and compensation; risk analysis; post-project evaluation; social impact monitoring and the use of negotiation and mediation to assist in conflict resolution. Case studies that combine a number of these elements, in addition to the CEA component, will gain more support from the Council than projects limited to one of these research areas.

NEXT STEPS

This prospectus will be disseminated to the research community and to environmental assessment practioners. The Council Secretariat would be pleased to receive comments and ideas on the proposed research agenda and other aspects of CEA raised here.

The Council has also taken the responsibility to discuss its research prospectus with practitioners and researchers in the field to share their ideas and to encourage application of new approaches and scientific methods to current project analyses.

The specific steps to be undertaken by the Council with respect to cumulative effects assessment include the following:

- completion and publication of the reference manual on CEA met hods:
- meeting with practitioners in government and industry to explain the manual and encourage application of methods to current and future project assessment;
- facilitating the implementation of the prairie wetland/agriculture case study involving the three prairie provinces: and
- meeting with the research community to encourage research in the three functional areas of CEA — theoretical development, scientific and methodological analysis and institutional analysis,

APPENDIX A

PERSPECTIVES

The Council's CEA committee will maintain a continuing interest in the refinement of a conceptual framework for analysing cumulative effects. Both Western Ecological Services (WES) and ESSA in reports commissioned by the Council, have extended the typology set out in Table 1 of this prospectus. The WES and ESSA models are described below with a view to summarizing the present state of the art and stimulating further discussion between the interested community and the CEA committee.

WES (Peterson et *al.* 1987) identified four types of cumulative effects involving additive and interactive impacts respectively from single and multiple sources (Figure 1). Pathway 1 effects are those that result from persistent additions from one process, without interactive complications. Pathway 2 effects involve biomagnification, a popular term for food-chain concentration, as in the release of radionuclides and pesticides into ecosystems. Pathway 3 effects involve two or more processes, additive through non-interactive multiple impacts. Pathway 4 effects involve two or more processes that are interactive through synergistic relationships.

This framework can be applied to the impact typology outlined in Table 1 as follows:

Time-crowding	Pathways 1 and 3
Space-crowding	Pathways 1 and 3
Compounding	Pathways 2 and 4
Time lags	Pathway 1
Space lags	Pathways 1 and 2
Indirect effects	All pathways (potentially)
Patchiness (nibbling) effects	All pathways (potentially)

ESSA Ltd. (Sonntag et *al.* 1987) have proposed an analytical framework for CEA based upon a simple systems model. An activity matrix is used to identify the 'changes and trends taking place in biophysical and socio-economic systems. Figure 2 indicates that specific actions can take place locally and in the short term, e.g., forest clearcuts; or can be aggregated over large geographic scales and long time-horizons, e.g., long-range transport of sulphur emmissions. The next set in the ESSA framework is a characterization of the "receiving" system (Figure 3). It is organized into three primary subsystems (ecological, social, and economic) and two dimensions (spatial and temporal). Of particular interest are processes that relate to the ability of the systems to respond and recover over time.

The intent of both models is to move toward broadening the scope of analysis, especially the time and space contexts for impact assessment. The Council, through its CEA committee, will undertake further development of these emerging frameworks for CEA, following review and discussion of the reference manual on CEA methods (see the section "Next Steps" in this prospectus).

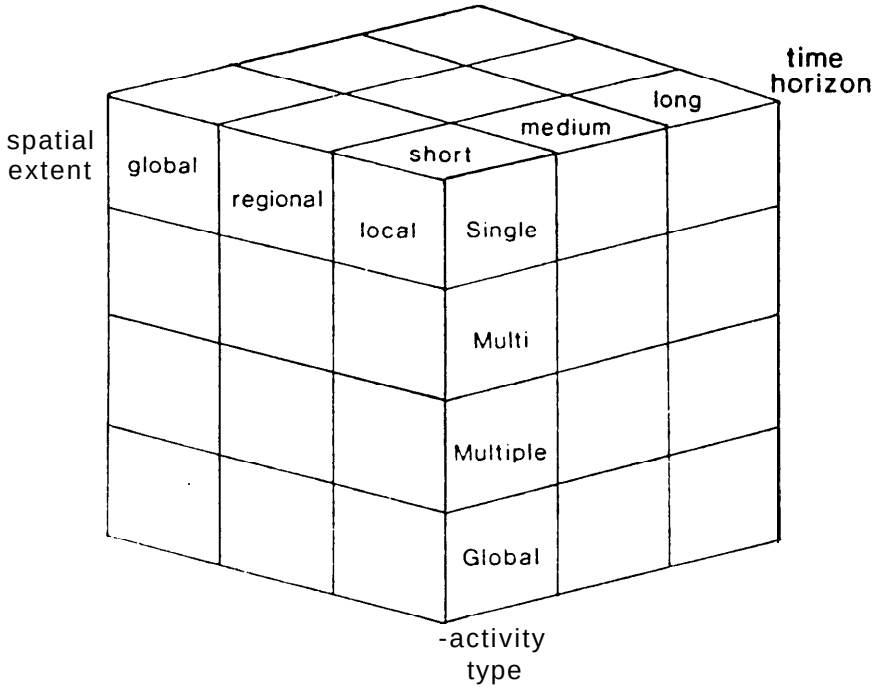

Figure 2. Activity Matrix — Identification of Activities in Spatial and Temporal Context (Sonntag et *a/*. 1987)

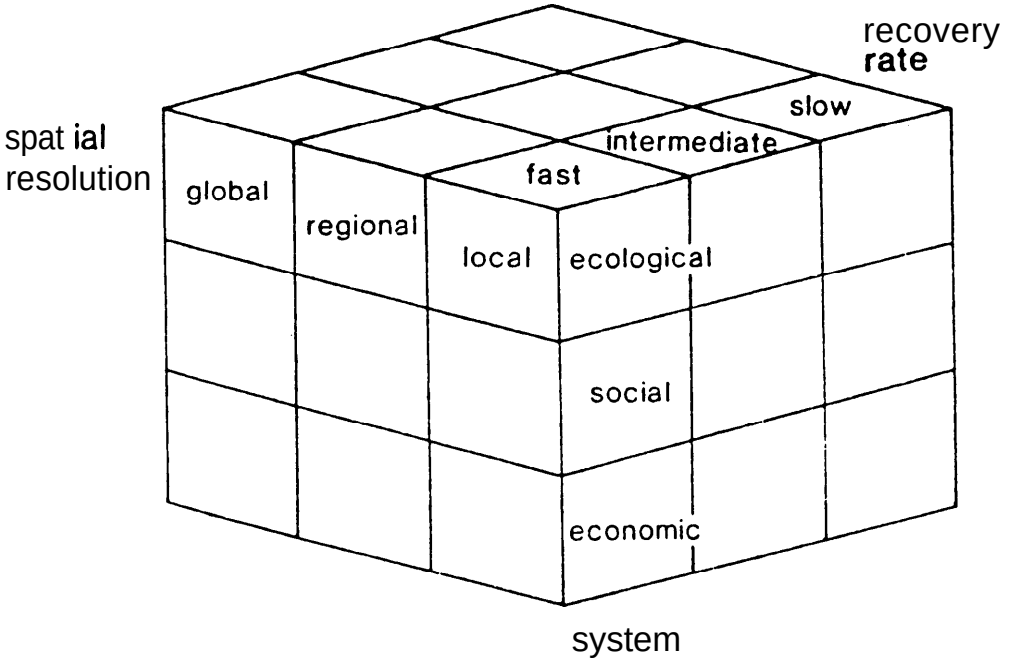

Figure 3. System Matrix — Identification of System Processes/Structure in Spatial and Temporal Context (Sonntag et *a/*. 1987)

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