CUMULATIVE EFFECTS ASSESSMENT IN CANADA: AN AGENDA FOR ACTION AND RESEARCH

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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) in Canada.

The purpose of commissioning CEARC-sponsored background documents is to provide relevant information and to stimulate discussion on topics of interest to the EIA community. The opinions expressed, however, are strictly the authors' own and do not necessarily reflect the views of the members of the Council or its Secretariat.

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EXECUTIVE SUMMARY

This state-of-the-art review of cumulative effects assessment in Canada, initiated by the Canadian Environmental Assessment Research Council (CEARC), confirmed that cumulative effects are having an increasingly significant impact on the quality of natural and social environments in Canada. Accordingly, it was concluded that CEARC should continue to focus part of its program on cumulative effects assessment.

The many identifiable cumulative effects, when viewed as single cause and single effect processes, were grouped into 13 sets of cumulative effects issues that are considered to be of particular significance for Canadians over the next decade or two. They are:

- long-range transport of air pollutants;
- urban air quality and airshed saturation;
- mobilization of persistent or bioaccumulated substances;
- cumulative effects associated with climatic modification:
- occupation of land by man-made features;
- habitat alienation;
- habitat fragmentation;
- losses of soil quality and quantity;
- effects of 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;
- accelerating rates of renewable resource harvesting; and
- long-term containment and disposal of toxic wastes.

There is a surprisingly diverse set of examples in which cumulative effects have been recognized and brought under a system of control and management in Canada. The scientific and institutional factors that promoted a successful approach to the analysis and management of cumulative effects in Canada can be summarized as follows:

- cumulative effects are more readily managed if there are determined efforts to achieve co-operative agreements where there are complex divisions of jurisdictional responsibility;
- cumulative effects have a greater chance of successful management if there are determined efforts to involve interested parties during the development of co-operative regulatory agreements;
- cumulative effects that directly threaten human life result in more successful management approaches than do less threatening or less readily understood cumulative effects;
- cumulative effects that are a result of well-understood pathways have an increased chance of successful management.

In many cases, the apparent successes are a result of distinctive circumstances that possess no guarantee of effective application to cumulative effects of other forms or in other jurisdictions. Several relationships between complexity of jurisdictional controls and the management of cumulative effects have been well documented and this review concluded that under the appropriate circumstances jurisdictional complexity, by itself, is not a deterrent to effective management of cumulative effects if the will to act is present.

It was confirmed that there are well-defined limitations in the degree to which project referrals and project-specific environmental impact assessments can be adapted to manage cumulative effects successfully. Despite this confirmation, the present review did result in recommendations that involve steps within existing environmental impact assessment procedures.

In general, this review confirmed the CEARC hypothesis that current approaches for both scientific analyses and institutional arrangements to manage cumulative effects remain inadequately developed in Canada. To address these weaknesses, cumulative effects management requires action on three fronts, identified in this review as: (i) ecosystem-management links; (ii) research-ecosystem links; and (iii) research-management links. Recommendations for an action program and a research agenda are presented for each of these fronts.

RECOMMENDATIONS RELATED TO ECOSYSTEM-MANAGEMENT LINKS

RECOMMENDATION 1

CEARC needs to maintain a strong interest in the institutional aspects of cumulative effects assessment; one way to do so would be to sponsor detailed analyses and research designed to improve institutional performance in each of the 13 sets of significant cumulative effects issues facing Canadians,

RECOMMENDATION 2

CEARC, planners, policy makers, environmental managers and interest groups seeking to secure action to manage cumulative effects should pay careful attention to planning and communications.

RECOMMENDATION 3

CEARC should initiate or encourage an evaluation that would focus specifically on the system linkages between the various phenomena that comprise the long-range transport of air pollutants (LRTAP), including acidic deposition, oxidants and toxic chemicals deposition, with emphasis on evaluation of the effectiveness of scientific and institutional treatment of the system linkages amongst the LRTAP components (sub-systems).

RECOMMENDATIONS RELATED TO RESEARCH-ECOSYSTEM LINKS

RECOMMENDATION 4

CEARC should consider a detailed analysis of one example of a cumulative effects pathway that combines the characteristics of significant knowledge gaps and institutional complexity because of widely dispersed causative factors; this combination of circumstances results in the most difficult form of cumulative effects to manage; habitat fragmentation is a candidate subject for such an analysis.

RECOMMENDATION 5

CEARC should promote at least one long-term study in a biophysical research subject that is fundamental to an understanding of cumulative effects, and which requires research of more than five years duration for its resolution; the objective would be for CEARC to sell the idea that certain cumulative effects questions will never be answered unless there are mechanisms to ensure that long-term financial support will be available when warranted; research on stress in ecosystems and degradation of whole ecosystems are examples of long-term research questions that could be promoted in this context.

RECOMMENDATION 6

CEARC should ensure that some cumulative effects research focuses on functional relationships within severely disturbed ecosystems that are being rehabilitated.

RECOMMENDATION 7

CEARC should initiate a detailed evaluation of several alternative avenues by which research data are gathered for intended application to cumulative effects assessment; a related objective would be to assess the relative attention being given to research at various levels of integration from cell to total ecosystem.

RECOMMENDATION 8

CEARC should initiate or encourage research into the application of general systems concepts to the evaluation of ecosystem perturbations for potential cumulative effects.

RECOMMENDATIONS RELATED TO RESEARCH-MANAGEMENT LINKS

RECOMMENDATION 9

CEARC should encourage and support a search for mechanisms that would result in better linkages between epidemiological and environmental research.

RECOMMENDATION 10

CEARC should encourage the initiation of at least one cumulative effects study that is well suited to integration of scientific and socio-economic aspects at the research stage; a candidate topic is research into the applicability of the “bubble concept” to airshed management for the control of atmospheric cumulative effects in Canada.

RECOMMENDATION 11

CEARC should encourage a comprehensive examination of existing regulatory standards in Canada to assess their effectiveness in preventing cumulative, deleterious impacts.

RECOMMENDATION 12

CEARC should focus its attention on new approaches for research that have been difficult to undertake to date because of insufficient data to verify the assumed cumulative effects problem.

In the text, each recommendation is accompanied by suggested steps for CEARC or others to consider for implementation of the recommendation. Those recommendations that could be considered for implementation immediately are so identified; other recommendations will require short-term (three to five years) or long-term (greater than five years) attention by CEARC and others. Specific steps to make the various approaches work and significance of the specific recommendations for addressing cumulative effects issues within environmental impact assessment procedures and within environmental planning systems are outlined in the text for each of the 12 recommendations.

The terms of reference for this review posed the following question: Can cumulative effects management be improved by contributions from regional environmental planning and area assessments? The question was answered in the affirmative, but the review focused more attention on the reverse question: Can regional environmental planning and area assessments be improved by deliberate incorporation of cumulative effects assessment criteria? The answer to this question was also in the affirmative.

CHAPTER 1: INTRODUCTION

Environmental impact assessment (EIA) continues to be the subject of detailed reviews (e.g., Shopley and Fuggle 1984) and evolving frameworks for action (e.g., Conover et *al.* 1985a, 1985b). Two elements of EIA, in particular, remain under active debate. The first aspect of EIA that is still evolving deals with the meaning of *significant* when it is used in the phrase "significant environmental impacts." Recent analyses by Beanlands and Duinker (1983), Duinker and Beanlands (1986), and Erdle and Baskerville (1986) dealt with the meaning of significance. The second evolving aspect of EIA deals with cumulative effects, the importance of which has been recognized by the Committee on Applications of Ecological Theory to Environmental Problems (CAETEP), of the U.S. National Research Council's Board on Basic Biology, and by the Canadian Environmental Assessment Research Council (CEARC). Proceedings of a 1985 U.S.-Canada workshop, entitled Cumulative Environmental *Effects: A Binational Perspective,* (CEARC and U.S. NRC 1986) contained an introductory explanation as follows:

> *Cumulative effects of multiple environmental perturbations of natural and social systems were identified by CAETEP and CEARC as needing study because there did not appear to be any clear and unambiguous definition of cumulative effects* assessment, *despite the widespread recognition of its importance. In addition, there is increasing concern that neither scientists nor institutions work at the temporal and spatial scales needed for the assessment of cumulative effects. In short, traditional project-specific environmental* assessment is *not* adequate for many environmental *problems resulting from multiple perturbations that often involve several jurisdictions.*

The 1985 workshop explored the issues cited above and resulted in a number of recommendations on ways to improve the management of cumulative effects. As a result of the 1985 workshop, CEARC initiated this state-of-the-art review of cumulative effects assessment in Canada. CEARC requested suggestions on the scientific and institutional arrangements required to guide research into cumulative effects assessment in Canada over the next few years. In the meantime, CAETEP (1986) also addressed the problem of cumulative effects in the report *Ecological Knowledge and Environmental Problem Solving: Concepts and Case Studies.*

CEARC'S FOCUS OF INTEREST

The terms of reference for this research specified that CEARC would like to test two hypotheses: that cumulative effects are having an increasingly significant impact on the quality of natural and social environments in Canada; and that current approaches for both scientific analysis and institutional arrangements to manage cumulative effects are inadequately developed in Canada.

Specific recommendations were requested to answer the following questions:

- Which environmental issues and ecosystems deserve highest priority research into cumulative effects over the next 5- 10 years?
- What parameters or criteria should guide this research effort?
- What specific steps should be followed to implement a research program over the next five years?. What specific measures can be immediately implemented to enable better assessment and control of cumulative effects?

Recognition of recent changes in approaches to environmental assessment is an essential part of the review. These changes were characterized in the CEARC request-for-proposal as follows. Previous to the 1970s, environmental management decisions were based on a referral process, under which various government agencies commented on project proposals according to their respective mandates. During the 1970s, the environmental assessment process was developed to co-ordinate these referrals and to enable more intensive scientific analysis of specific issues to be undertaken on a project-by-project basis. The environmental impact assessment approach was a response to increasing size and complexity of projects, greater uncertainty in predicting impacts and growing concerns of the general public and special interest groups to become involved in the decision-making process.

More recently, attempts have been made to develop area-wide or regional environmental management plans to provide a broader geographic context for assessing multiple project developments. Examples of the latter include water quality assessment in the Great Lakes, air quality objectives for metropolitan areas and proposals for land use planning in northern Canada. Efforts are now being made to link environmental planning to the referral and environmental assessment processes. A major incentive for the present study is the search for specific steps to make the various approaches work.

The CEARC request-for-proposal noted that the time and space boundaries administered by decision-making institutions do not always coincide with the time and space scales required for cumulative effects analysis. There are, however, exceptions in which special institutional arrangements or agreements have been developed to co-ordinate cumulative effects assessment for specific issues. A good example is the Great Lakes Water Quality Agreement of the International Joint Commission, Given this setting, CEARC also expressed an interest in the following questions:

- What are the most significant cumulative effects issues that Canadians will face over the next decade or two?
- In relation to the question above, where should we place our research priorities?
- Where cumulative effects have been specifically addressed, what scientific and institutional factors promoted a successful approach to their analysis and management?
- What are the relationships between complexity of jurisdictional controls and the management of cumulative effects?
- Can the referral and project-specific environmental impact assessment processes be adapted to manage cumulative effects successfully?
- Can cumulative effects management be improved by contributions from regional environmental planning and area assessments?
- What specific steps are needed to make the various approaches work?
- Based on current knowledge, collective experience and the existing institutional framework, what practical guidance can be given to those responsible for addressing cumulative effects issues within environmental impact assessment procedures, and within more general resource management systems?

THE SOCIO-ECONOMIC INTEREST

Social impact assessment has been considered in a separate report (CEARC 1985) and is not the subject of this review. It is essential, however, to maintain a focus on the links between the ecosystem, research, and management components of cumulative effects assessment (see Figure 4 in Chapter 3). Those links, and the place of socio-economic aspects within the management component, are outlined in Chapter 3.

Considerable effort is currently being made across Canada, including under the auspices of the Canadian Council of Resource and Environment Ministers, to define the scope and variables to be considered for social impact assessment. These studies suggest that social impact assessment is a field that must continue to evolve before widely accepted and tested analytical frameworks are possible.

Two key criteria guided the inclusion of socio-economic analyses in the present review. The first is that environmental changes and processes that appear to be cumulative are rarely the focus of mitigative measures until they are recognized to have links with human health or other social and economic measures of human well-being. The second criterion resulted from a deliberate decision to focus only on socio-economic impacts, processes or factors that are environmentally cumulative. Clearly, this excludes a variety of social and economic cumulative changes, involving sociology, global economics and other complex subjects that could be analysed in their own right, independently of any links with the biophysical environment.

TIME SCALES OF INTEREST

As indicated by the title of this report, the present review addresses an action program and a research program, with the implication that rather different time scales may be involved for immediate action and for research programs. In response to this need, the recommendations resulting from this review are referenced to one of three arbitrary time scales:

- Steps that can be taken immediately to improve assessment and control of cumulative effects;
- Steps that require short-term research and institutional changes of three to five years duration;
- Steps that require long-term research of more than five years duration.

GEOGRAPHIC SCALE OF INTEREST

The present review focuses on Canadian cumulative effects assessment at a national (Canadian) scale rather than on international-scale problems, particularly where recommendations are involved. In the case studies selected for this review (Chapter 5), examples of “medium” geographic scale were selected. This arbitrary scale refers to ecosystems that could involve, for example, the area of a major Canadian watershed, or regional atmospheric processes that cover a large section of Canada. With this arbitrary criterion, the study team chose to ignore examples of cumulative effects that occur at a local level, such as studies involving one experimental lake or one disposal site for liquid effluent. Similarly, cumulative changes that occur on a global scale, such as the well-documented build-up of atmospheric CO_2, the increasing presence of “Arctic haze” or the suspected “sink” of industrially generated chemical compounds in the basin of the Arctic Ocean, were not selected for biophysical review because of their immense geographic scale.

The decision to omit cumulative effects of global scale was not intended to belittle their importance. As stressed by CAETEP (1986), the major elements of organisms — carbon, nitrogen, oxygen, sulphur and phosphorus — are part of massive global cycles that involve both living and non-living components of the biosphere. Except for phosphorus, these elements can be present as gases, and the magnitudes of their movements are being substantially modified by human activity. It is now known that today’s anthropogenic fluxes of sulphur are approximately equal to those of the natural sulphur cycle (Andreae and Raemdonck 1983). The significance of these circumstances for cumulative effects management was summed up by CAETEP *(1986)* as follows:

> Changes in global *biogeochemical* cycles affect *environmental problem-solving at specific sites and are beyond the control of managers. But they are the most important of the cumulative effects of individual projects, because the perturbations are largely the sum of the inputs of specific*

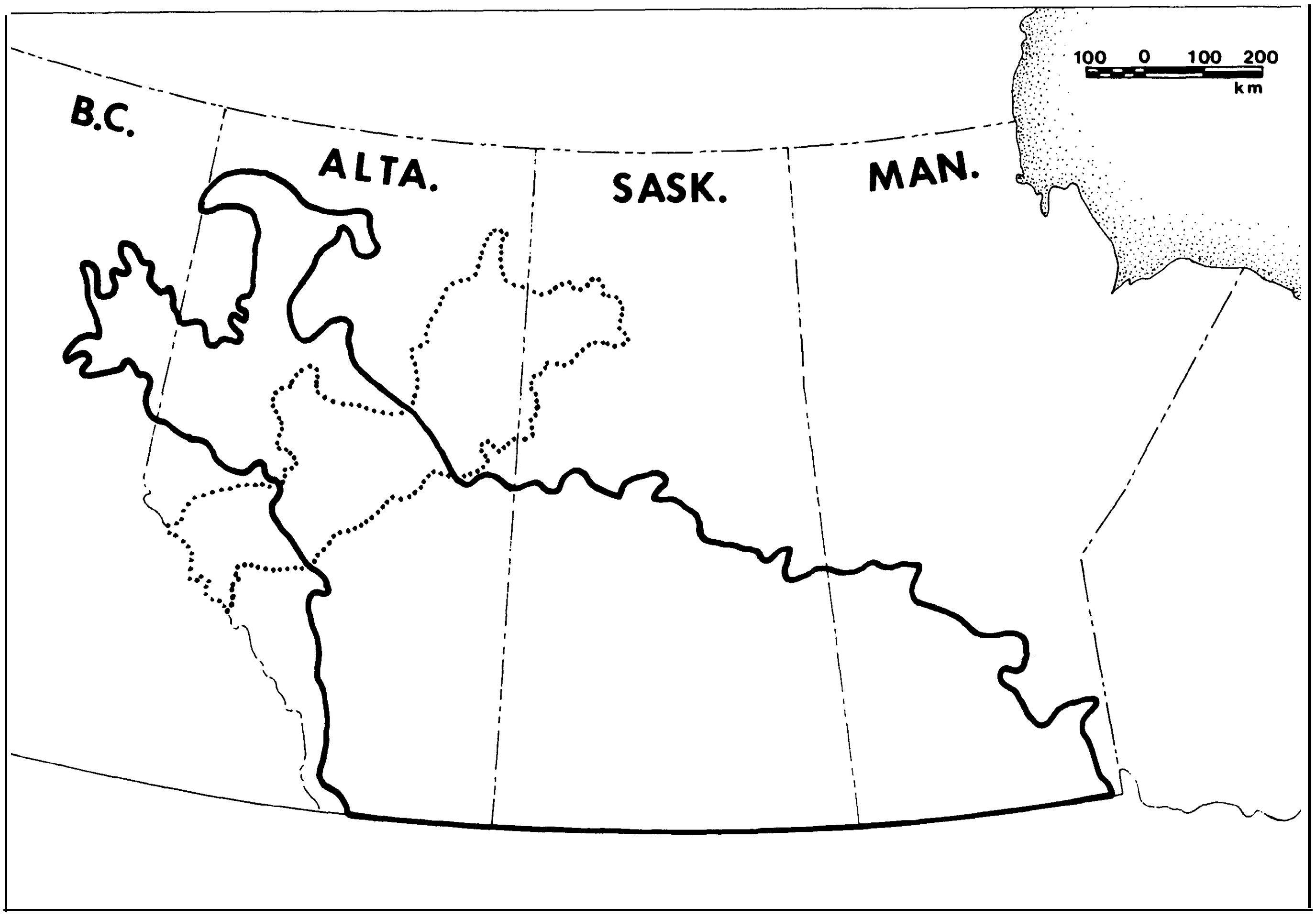

Figure 1. Location of Athabasca River Basin Case Study (dotted outline) and Prairie Provinces Case Study Area (heavily outlined).

projects. One of the most challenging problems in maintaining high environmental quality is to find ways of reducing undesirable effects of individual projects on biogeochemical cycles. This requires dealing with the cumulative impacts of many projects.

THREE CASE STUDIES

As outlined in preceding sections, a major purpose of this review was to examine scientific and institutional aspects of cumulative effects assessment in Canada to identify concerns and research priorities for a representative sampling of natural environments. Because it was not possible to examine a broad range of ecosystems, three examples (case studies) were selected for more detailed analyses (Chapter 5). The rationale for selecting the case studies was as follows. To obtain the broadest representative sampling of natural environments it was desirable to include a case study from each of the three major components of the biosphere — air, land and water. This commitment guided the selection of study team members who were invited to respond to CEARC's request-for-proposal.

For the water component of the biosphere, a marine example of cumulative effects could have been selected; however, marine waters were excluded because, first, the request-for-proposal suggested the analysis of only two or three case studies and, second, the statement of work for this study specified that "natural environments include watersheds, lakes, estuaries, terrestrial systems and the atmosphere." Because marine waters were not specified in the request-for-proposal, it was decided that the freshwater component of estuaries would be given precedence over the marine component if an estuary were to be selected as a case study. With this rationale, specialists were invited to be members of a study team that would collectively possess an interest and background experience in cumulative effects relating to atmospheric, terrestrial and freshwater components of the biosphere. There was a broad range of choices from which to select a specific case study within each of the above components, and two criteria to assist with the choice. The prime criterion was the research or environmental management background of study team members. In the 120 days available for the review, there was no alternative but to select case study topics in which individual team members had current or recent direct involvement. The second criterion came from the CEARC statement of work which indicated that the case studies should focus on settings in which cumulative effects have been specifically addressed.

The selected case studies emphasize: cumulative effects in which the atmosphere is the principal medium of movement from source to receptor organism or habitat, using leaded gasoline as an example; cumulative effects in aquatic habitats of a major watershed, the Athabasca River Basin in Alberta; and land-use practices, habitat fragmentation and soil changes in the prairie provinces. Location of the Athabasca River Basin case study is shown in Figure 1 in the area (dotted outline) that extends northeasterly across Alberta and includes a portion of northwestern Saskatchewan. The prairie provinces case study area is shown in the heavily outlined area of Figure 1 and extends from the Peace River region of British Columbia and Alberta southeasterly to southern Manitoba. The leaded gasoline case study is national in scope and is not geographically identified in Figure 1.

Recognized cumulative effects that can be related to follow-up changes to legislation, regulation, planning procedures or administrative arrangements are subjects of key interest to CEARC. A major purpose of the case studies outlined in Chapter 5 is to focus on measures that have been tried, the way in which decisions were made and the factors that influenced the management of cumulative effects.

CHAPTER 2: THE MEANING OF CUMULATIVE EFFECTS

Cumulative effects occur when at least one of two circumstances prevail: persistent addition of a material, a force, or an effect from a single source at a rate greater than can be dissipated; or compounding effects as a result of the coming together of two or more materials, forces or effects, which individually may not be cumulative.

The phrase "cumulative effects" normally conveys an image of accumulation, or progressive increases of some sort. The progressive increase of carbon dioxide concentrations in the earth's atmosphere is a cumulative change; but so too is the progressive loss of soil nitrogen from farmlands, the loss of wildlife habitat in areas converted from non-cultivated to cultivated ecosystems, or the loss of soil and habitats due to erosion of shorelines and land surfaces. For simplicity, the diagram of basic functional pathways that contribute to cumulative effects (Figure 2) identifies effects associated with persistent additions, but it should be understood that there are analogous functional pathways for cumulative effects that result from the persistent loss of a material, a force, or an effect at a rate greater than can be replaced. The suggestion that cumulative effects pathways that result from a variable that is progressively increasing can be conceptually equated with a variable that is progressively decreasing is used solely for the purpose of simplifying the cumulative effects classification (Figure 2). Cumulative effects that involve "nibbling" processes (CEARC and U.S. NRC 1986) may be controlled by functional pathways that bear no similarity to pathways resulting from an additive process. Figure 2 and the examples in this chapter could be repeated on the basis of cumulative effects associated with variables that are decreasing in magnitude but the distinctions that would be revealed by such duplication of the concepts portrayed in Figure 2 is better left as a future research activity for CEARC.

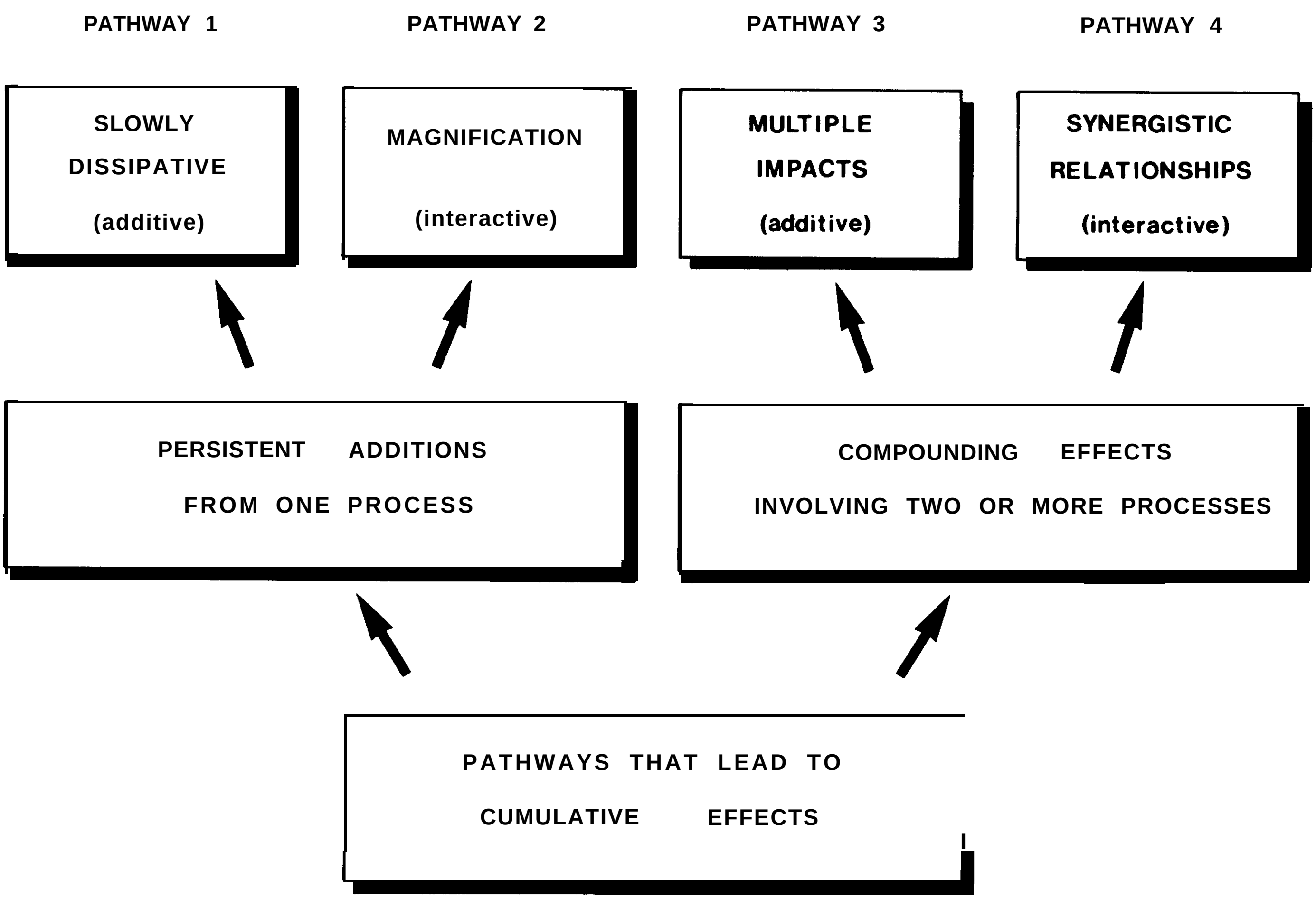

Figure 2. Basic Functional Pathways That Contribute to Cumulative Effects

On each of the two main branches shown in Figure 2 (persistent additions versus compounding effects) there are two distinctive kinds of pathways that can lead to cumulative changes — pathways that involve additive processes and those that involve interactive or multiplicative processes.

Ecosystem functions are complex, with the result that a process that is considered to have cumulative effects may involve some pathways that are additive and some that are interactive. Furthermore, a process that is initially additive because it is the *only* process currently active to create cumulative effects in an area may later become interactive when other cumulative effects processes are superimposed on the same area. The progressive conversion of forest to ecosystems dominated by early-stage successional shrub species could, by itself, be considered an additive process. If, however, this form of ecosystem conversion is a stimulus for subsequent agricultural clearing or attempts to eliminate shrubs by repeated herbicide applications, then a variety of compounding cumulative effects could result. Consequently, the schematic diagram shown in Figure 2 is not intended to portray four mutually exclusive kinds of cumulative effects. Some examples of the four kinds of functional pathways that can lead to cumulative effects are presented below. Relationships between these four basic pathways and other ways of classifying cumulative effects, particularly in relation to "space-crowding" and "time-crowding," are summarized in this chapter.

PATHWAY 1 — PERSISTENT ADDITIONS FROM ONE PROCESS, WITHOUT INTERACTIVE RELATIONSHIPS

Biogeochemical cycles and other linkages between the physical, chemical and biological components of ecosystems, as well as linkages between biophysical and socio-economic systems, make it difficult to find examples of cumulative effects that are not interactive in some way. Purely additive cumulative effects, without interactive complications, would prevail if one imagined a pathway that involved no contact with living organisms. Such a hypothetical example is of little practical value. If radioactive substances were added to water, soil or sediment at a rate that exceeded the rate of natural radioactive decay, and if such substances were not conspicuously involved in food-chain concentration, the process would be an example of Pathway 1. The phrase "slowly dissipative" is used in Pathway 1 of Figure 2 to convey the condition involved in this example, namely, the inability to disperse or absorb materials, forces or effects at a rate equal to or greater than the rate at which they are received.

Another example of an additive pathway without interactive or magnification effects would be the progressive addition of industrial wastes to deep-well disposal sites, with the gradual addition of contaminants to the groundwater system. In this case, the non-interactive pathway would likely remain that way for only a certain period of time. The contaminated groundwater would eventually make biological contact at groundwater discharge sites or by human withdrawal of groundwater from wells. At this stage a variety of interactive effects would be possible. This example suggests that, in a number of cases, a time lag is all that is required for a purely additive Pathway 1 to become an interactive Pathway 2. It is also possible to visualize a non-interactive pathway of cumulative effects that does involve organisms. For example, Munn (1975) presented a flow chart, based on work by Sorensen (1971), that identified an impact on commercial shellfish as a result of the cumulative increase in area of urban impervious surfaces and the resulting increase of freshwater flow into estuaries. This example of an additive pathway is diagramatically shown in Figure 3. Whether it is classified as Pathway 1 or Pathway 3 (Figure 2) depends upon whether urban development is viewed as one process or a combination of many process.

PATHWAY 2 — PERSISTENT ADDITIONS FROM ONE PROCESS, INTERACTIVE BECAUSE OF BIOMAGNIFICATION

Biomagnification, or biological magnification, is a popular term for food-chain concentration, a subject well publicized by Carson (1962) and reviewed by Woodwell (1967) two decades ago. The release of certain persistent radionuclides and pesticides into ecosystems provides an excellent example of cumulative effects through Pathway 2. An enduring Canadian example of food-chain concentration involving strontium-90 is available from figures published by Ophel (1963) for a lake that received low-level atomic wastes. Data are expressed in Table 1 as concentration factors which refer to the ratio of an organism's radionuclide concentration to the concentration in the environment.

Cumulative effects management clearly requires a knowledge of factors that influence ecological processes such as food-chain concentration. For example, although DDT use is now

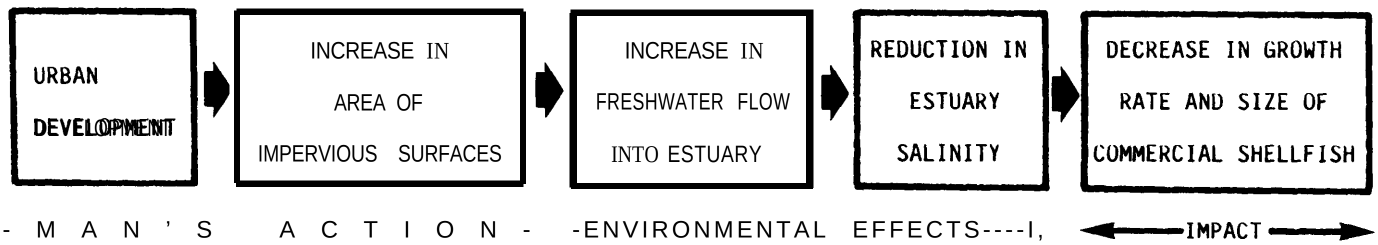

Figure 3. Impact on commercial shellfish as a result of the cumulative increase in area of urban impervious surfaces and the resulting increase of freshwater flow into estuaries (Munn (1975) based on work by Sorensen (1971)).

well regulated in North America its history is instructive because it involves a cumulative effects pathway in which very small amounts of a pollutant not lethal to individual organisms are ultimately lethal to the population. This process was documented by Hickey and Anderson (1968) with the demonstration that predatory birds were not directly killed by DDT that they ingested but that this and other chlorinated hydrocarbon insecticides interfere with egg shell formation by causing a breakdown in steroid hormones. The result is readily breakable eggs that prevent successful reproduction of the species. A detailed analysis of the environmental management lessons resulting from the DDT experience is provided by Buckley (1986).

Table 1
Concentration Factors of Strontium-90 in Various Parts of an Aquatic Food Web (from Ophel 1963)

Food Web Component	Concentration factor
lake water	1
bottom sediment	200
aquatic plants	300
clam tissue	750
minnows	1,000
beaver bone	1,400
perch bone	3,000
muskrat bone	3,900
mink bone	1,000
perch flesh	5

For management of cumulative effects related to radionuclides, recognition of differential responses in different kinds of ecosystems is an essential step. A review of radio-ecological concentration processes by Aberg and Hungate (1967) revealed that concentration factors are likely to be greater in nutrient-poor environments than in nutrient-rich ones. Also, concentration factors can be expected to be greater in aquatic than in terrestrial ecosystems since nutrient fluxes in the "thin" medium of water are more rapid than in the "thick" medium of soil (Odum 1971).

PATHWAY 3 — COMPOUNDING EFFECTS INVOLVING TWO OR MORE PROCESSES, ADDITIVE THROUGH NON-INTERACTIVE MULTIPLE IMPACTS

Regions that are subjected to a variety of sequential industrial or public works projects are often referred to as experiencing cumulative social or biophysical impacts. In fact, a commonly held perception of cumulative impacts is that they are a set of effects of economic development that cannot be attributed to a single source. Examples include reports prepared under titles such as the following: The Cumulative *Impact of Development on the Rock and Granular Material Resources of the Mackenzie Delta Area* (Inglis 1976); *Cumulative Impact of Development of the Mackenzie Estuary/Delta, N. W. T.* (McTaggart-Cowan 1975); and *Cumulative Socioeconomic Monitoring: Issues and Indicators for Canada's Beaufort Region* (Carley 1984). More recently, Sadler (1986) stated: "In classic form, however, cumulative impacts accrue from multiple sources of development and/or discharge, whether combined incrementally or in a non-linear manner." O'Riordan (1986) also noted that the term "cumulative impact assessment" generally is understood to embrace the analysis, interpretation and management of the accumulation of impacts resulting from a number of individual developments on the environment.

The authors cited above are discussing what might be more accurately called "accumulations of diverse effects" rather than diverse processes contributing to one effect in a cumulative way. The difference is subtle but worth noting. For this review, multiple impacts of this kind were considered to be a subset of Pathway 3 (Figure 2). This pathway is considered to be synonymous with the class of cumulative effects that Clark (1986) described as "impacts cumulative in kind" which arise when "different kinds of sources impose similar consequences on a valued ecosystem component." As summarized below in the section "Summary of Cumulative Effects Pathways," this pathway is also exemplified by processes referred to as "nibbling" (CEARC and U.S. NRC 1986).

A different example of Pathway 3 is that based on the non-synergistic occurrence of carbon dioxide and chlorofluorocarbons in the atmosphere. Both are increasing in concentration as a result of man's activities but they are derived from different processes. Both have the potential to raise atmospheric temperatures but involve different mechanisms to achieve this effect (Bach 1984; Perner 1979; Whelan 1985). The important point that distinguishes this example from Pathway 4 is that carbon dioxide and the chlorofluorocarbons act independently to create a cumulative temperature increase, but do so without synergistic interactions between the two.

PATHWAY 4 — COMPOUNDING EFFECTS INVOLVING TWO OR MORE PROCESSES, INTERACTIVE THROUGH SYNERGISTIC RELATIONSHIPS

Synergism (Pathway 4 in Figure 2) refers to the circumstance in which the total effect of an interaction between two or more agents is greater than the sum of the effects of the individual agents. One of the most commonly cited examples of synergism is "photochemical smog," which is considered to be more toxic, in the presence of ultraviolet radiation in sunlight, than the nitrogen oxides and hydrocarbons from which it is formed. "Photochemical smog" consists of peroxyacetyl nitrate (PAN) and ozone, both of which cause eye-watering and respiratory stress in humans. In addition, ozone can kill plants by increasing the respiration of leaves; PAN can kill plants by blocking photosynthesis (Taylor *et a/.* 1961). There is now speculation that the cumulative effects of nitrogen oxides and hydrocarbons may be just as important as sulphur dioxide in the impairment of tree seedling growth.

THE SPECIAL ROLE OF THRESHOLDS IN CUMULATIVE EFFECTS PATHWAYS

Thresholds were identified in the CEARC request-for-proposal as a difficult aspect of environmental impact assessment. *Thresholds* and cumulative effects are terms that have been used in the ecological literature for a considerable time. For example, Belyea (1952) described these concepts in relation to the responses of balsam fir to spruce budworm defoliation. The essential step now is to translate the ecological interpretation of these concepts into ideas that are meaningful for cumulative effects assessment. Thresholds are particularly meaningful when they can be used as signals of fundamental changes to the functions or behaviour of an ecosystem.

There is not a simple definition of *threshold* when the term is used in an ecological sense. The concept commonly refers to the intensity or duration of a stimulus that is required to produce a response in an organism or an ecosystem. For purposes of this review, the term is interpreted broadly to include several related concepts and several terms that are used as synonyms. As examples of synonyms, CAETEP (1986) referred to "stability boundaries or thresholds" and May (1977) referred to "thresholds and breakpoints." Related concepts include the view that natural multi-species assemblies of plant and animals possess "several different equilibrium points" (May 1977) and that complicated ecosystems may have many alternative "stable states" (Loucks 1985; May 1977).

Thresholds have been used in applied research in a variety of ways. For example, their uses in analyses involving acid deposition in aquatic ecosystems have been described by Newcombe (1985). European research on the effects of accumulation of air pollutants in forest ecosystems (Ulrich and Pankrath 1983) examined threshold levels for heavy metal injury to plant roots. Researchers in Europe are continuing to test the application of the concept of stress and strain, which Levitt (1980) introduced to biology from its origins in physics. Several current hypotheses on the mechanisms by which acid deposition is a driving force for forest ecosystem destabilization may be relevant for CEARC to consider for further research related to cumulative effects assessment in Canada.

Cellular and physiological processes are particularly relevant for improving our understanding of thresholds. For example, within marine molluscs the lysosomal system of the cell serves as an important site for accumulation of contaminants entering the animal. Contaminating compounds above a certain concentration will eventually confer damage on the lysosomal membranes, with toxic consequences to the cell. The cumulative result of these cellular events is an increase in protein turnover which, if sufficiently large, may alter the metabolic nitrogen quotient of the animal and reduce its scope for growth. This coupling of responses at the biochemical, cytological and physiological levels suggests their usefulness as an integrated toxicological index of cumulative effects (Bayne 1985).

In summary, thresholds, while not a definition of cumulative effects, are of central importance to the subject. All too often, events associated with the occurrence of a threshold level in a biophysical system serve as the trigger for political, administrative and socio-economic recognition of a cumulative effects problem. This circumstance suggests that action programs and research that focus on "early warning signals" are better approaches to cumulative effects assessment than those based on action to lessen or reverse cumulative changes that have reached certain chemical, biological or economic breaking points (thresholds). This is not a novel suggestion because, like people, ecosystems lend themselves best to environmental planning and management programs based on prevention rather than cure.

SUMMARY OF CUMULATIVE EFFECTS PATHWAYS

The four pathways outlined in Chapter 2 incorporate the diverse concepts of cumulative effects into a relatively simple framework. Clark (1986) focused on multiple sources of environmental disturbance that impinge upon the same valued environmental component and he indicated that:

> *The* characteristic "multiple" nature of *the sources of cumulative impacts may* arise in *three* ways: *the* same kind of *source recurs sufficiently frequently through time; the* same kind of *source recurs sufficiently densely through space; different kinds of sources impose similar consequences on a valued environmental component.*

In the conclusions and recommendations of the 1985 cumulative effects workshop, CEARC and U.S. NRC (1986) presented a classification that included five types of cumulative effects. The same five categories were used by CAETEP (1986). These are listed below in relation to the four pathways proposed in this report (Figure 2).

Types of cumulative effects listed by CEARC and U.S. NRC (1986) and by CAETEP (1986):	Equivalent functional pathway as defined in this report:
Time-crowded perturbations	Pathways 1 and 3
Space-crowded perturbations	Pathways 1 and 3
Synergisms	Pathway 4
Indirect effects	Potentially all pathways
Nibbling	Pathways 1 and 3

The comparisons above indicate that "time-crowding," "space-crowding" and "nibbling" are prominent features of additive pathways, whether from a single source (process) or from multiple sources (processes) — Pathways 1 and 3. It could be argued that "time-crowding," "space-crowding" and "nibbling" can potentially occur in all of the four functional pathways shown in Figure 2. However, in the case of interactive processes (Pathways 2 and 4) other functional processes assume a dominant role. Synergisms that result from compounding effects from two or more different types of perturbations are clearly a distinct type of cumulative effect (Pathway 4) and the same is true for biological magnification (Pathway 2). CEARC and U.S. NRC (1986) did not distinguish biological magnification from other forms of time-crowded or space-crowded perturbations, although bioaccumulation was recognized by Beanlands and Duinker (1983) as one possible basis of a strategy for environmental impact assessment.

The Athabasca River Basin case study and the prairie provinces case study contain several examples of cumulative effects that arise from indirect pathways. However, the present review found little basis to suggest that a distinct type of cumulative effect was associated with "indirect effects" produced at some time or distance from the initial disturbance or produced by a complex pathway. For purposes of this review, "indirect effects" as defined by CEARC and U.S. NRC (1986) can be associated with any of the four pathways shown in Figure 2.

The need to focus sharply on pathways that result in cumulative effects was stressed by Clark (1986) who suggested that one of the most useful roles for science in environmental impact assessment is to reduce as many apparently cumulative problems as possible to simple cases of single cause and effect. Another reason for focusing on pathways such as those shown in Figure 2 is that there is a tendency to view as "cumulative" any environmental impact that is long term or repetitive at regular intervals. Some environmental effects are readily recognized as merely repetitive or cyclical, but for many other effects the question of whether the involved processes are cumulative is, in fact, a topic of required research. Many processes are long term and repetitive, perhaps also conspicuous, but this does not necessarily mean they are cumulative. An example of the latter would be man's placement of organic materials onto land. Such materials might be manure or the by-products of agricultural, horticultural or silvicultural crops. Their decomposition by soil microbes normally results in no adverse cumulative effects; the same would not necessarily be true if large quantities of organic wastes were placed in aquatic ecosystems. Another example of a repetitive process that would not be expected to result in cumulative effects is the release of radionuclides that are of little ecological interest because of their extremely short half-life or because they do not concentrate as they are passed through food chains (Jordan 1986).

CHAPTER 3: CONCEPTUAL FRAMEWORK FOR CUMULATIVE EFFECTS ASSESSMENT

For purposes of this review, a conceptual framework was developed on the basis of three linked components — an ecosystem component, a research component and a management component. The framework is illustrated in Figure 4, in which the three pillars, in cross-section, represent the ecosystem research and management components. Cumulative effects management involves action along the three horizontal links which are depicted as research-ecosystem links; research-management links; and ecosystem-management links. Vertically the three pillars portray a continuous connection between cumulative effects that occur at a local geographic scale (bottom cross-section), at a regional scale (midpoint cross-section) and at a global scale (top cross-section).

The vertical dimension of the diagramatic conceptual framework (Figure 4) reminds the reader of the importance of spatial relationships in environmental problems. This subject was reviewed in a separate chapter by CAETEP (1986) and Sadler (1986) stressed that environmental quality ultimately is indivisible, regionally and globally. Such a continuum forces one to ask at which geographic scales should attempts be made to integrate and develop perspectives on cumulative impacts. The three arbitrary slices through the vertical continuum in Figure 4 are not intended to deny the linkages between local and regionally expressed cumulative effects nor between regional and global ones. The three positions in the vertical dimension merely represent the levels at which environmental problems are usually perceived. When it comes to cumulative effects management most effort is at the local level, yet all three case studies of the present review (Chapter 5) reveal that the major cumulative effects tend to be expressed at a regional scale. Cumulative effects on a global scale were not analysed in this review.

THE ECOSYSTEM COMPONENT

Pathways that lead to cumulative environmental effects are pathways within ecosystems. The very fact that it is easier to think of examples of interactive pathways than additive ones is an indication that biophysical cumulative effects occur largely because of the functional connections between the atmosphere, land, fresh and salt water, and the organisms that live in each of these parts of the biosphere.

The ecosystems in which cumulative effects occur involve interchanges of energy and matter between air, water, land and organisms. As indicated in Figure 4, the technical terms for these four subdivisions are atmosphere, hydrosphere, lithosphere and biosphere. For the present analysis, these subdivisions were interpreted broadly, as follows: atmosphere includes both the stratosphere and troposphere, even though man's greatest interest is in the lowermost few miles of the atmosphere (the troposphere); hydrosphere refers to the entire hydrological cycle, involving atmospheric moisture, surface freshwater, marine water, soil moisture and groundwater; lithosphere includes soil, rocks, mineral and petroleum resources; and biosphere includes living and dead remains of organisms, including man.

The reference to man as part of the ecosystem requires some additional comment. There are two ways to view man's place in the model shown in Figure 4. One way is to think of man as a doer and manager, in which case the socio-economic aspects of cumulative effects assessment would centre in the two pillars entitled "research component" and in the three panels that link the three pillars (Figure 4). That is the predominant focus of the present analysis.

The other way to view man's place in this model is to consider the human species **as** part of the biosphere. This view is not denied and that is why the ecosystem component of Figure 4 is considered to include man, as is done by analysts such as Barrett (1985). However, to define an action program and research agenda for cumulative effects assessment, it was considered more appropriate to focus on man's socio-economic and institutional activities beyond the role that humans play as the dominant species of the biosphere.

The biosphere raises one additional question in relation to the level of integration at which cumulative effects are studied and managed. The commonly recognized levels of integration include cell, tissue, organ, organ-system, individual organism, population, community and ecosystem. For cumulative effects assessment it is instructive to note a recent reminder by Kimmins (1985) on the importance of selecting a meaningful level of integration:

> *One of the most important Canadian papers in ecology was written by Rowe (7967). In it he noted that biological systems can be ranked into "true levels-of-biological-integration." Such /eve/s can be defined as the total environment of the levels of biological organizations below them. Three true levels of integration are identified: cells, individuals and ecosystems. Neither populations nor communities are true /eve/s-of-integration, even though they are legitimate /eve/s of biological organization and objects of study. Populations are not the total environment of individuals, nor are communities the total environment of populations or of individuals.*

The emphasis on cells, individuals and ecosystems as the most appropriate levels of integration is reflected in recommendations in Chapter 7. This suggestion will not be universally accepted because many researchers prefer to focus on other levels of integration. For example, Buffington (1976) brought populations and communities into the definition of impact significance:

> *An impact is significant if it results in a change that is measurable in a statistically sound sampling program and if it persists, or is expected to persist, more than several years at the population, community, or ecosystem /eve/.*

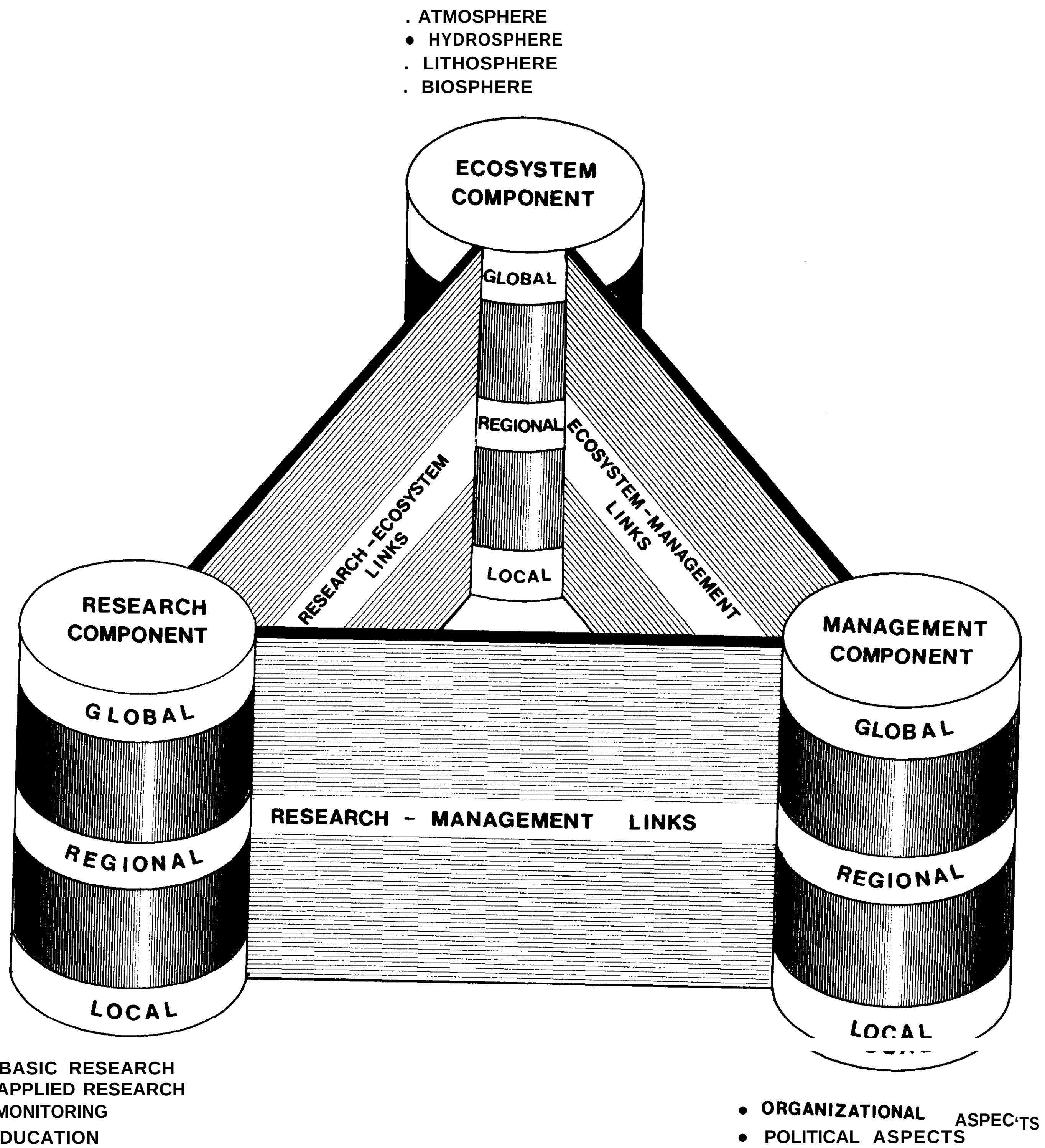

Figure 4. Conceptual Framework for Cumulative Effects Assessment

The CAETEP case study of fragmentation of spotted owl habitat (Salwasser 1986) also looks at small, isolated populations, as did the Newfoundland caribou case study (Kiell et al. 1986). Similarly, the screening method proposed by Duval et *al.* (1985), for the initial stages of an environmental impact assessment process, focused on populations.

Environmental managers appear to have little appreciation of the significance of directing problem analyses to the appropriate level of integration within ecosystems. The level of integration at which specific processes and problems find their most appropriate foci is a complex subject deserving of more attention by CEARC.

THE RESEARCH COMPONENT

As implied by the title of this report, the emphasis in this review is on the two bottom pillars of the conceptual diagram in Figure 4. Recommended research in support of cumulative effects assessment centres on the "research component" pillar and, more specifically, on its horizontal links to the ecosystem and management components. As revealed by recommendations at the end of this review, research to elaborate upon functional pathways of cumulative effects (Figure 2) is visualized as the dominant activity in the horizontal connector entitled "research-ecosystem links" in Figure 4. Research into institutional aspects of cumulative effects management, involving organizational, legislative, political and socio-economic influences upon the management steps, is the dominant activity in the connector entitled "research-management links."

The research component of cumulative effects assessment was interpreted broadly to include four different kinds of activities: i) basic research on subjects such as fundamental pathways (Figure 2); ii) applied research on subjects such as economic incentives to reduce activities that lead to cumulative effects or technological methods to reverse cumulative trends; iii) monitoring of conditions and trends in biophysical and sociological systems; and iv) education. The latter could involve, for example, the preparation of manuals of analytical techniques for cumulative effects assessment, which would be an activity within the connector entitled "research-management links" in Figure 4. Because of the make-up of the study team, emphasis in this review was upon research and monitoring recommendations, with no intent to belittle the importance of educational steps needed for the organizational, legislative, political and social perception aspects of the management component.

In relation to the time scales of interest to CEARC (Chapter 1) much of the recommended basic research and monitoring requires long-term efforts in excess of five years duration. Some applied research and some educational steps can be accomplished in programs that span a three- to five-year period.

THE MANAGEMENT COMPONENT

The three main aspects of the management component (Figure 4) are organizational, political and socio-economic influences. These three aspects are outlined briefly in the subsections below. Potential activities in the links between the management and research components were outlined in the section "The Research Component," above. In the horizontal connector entitled "ecosystem-management links" (Figure 4) the dominant activity is the application and evaluation of all of the approaches and levels at which cumulative effects can be addressed, ranging from project-specific assessments to environmental planning in the broadest sense.

Organizational Aspects of the Management Component

In Figure 4, the term "organizational aspects," rather than "institutional aspects" is used because the latter is sometimes mistakenly interpreted in a narrow way to refer mainly to government-related activities. The second hypotheses advanced by CEARC — that current approaches for both scientific analysis and institutional arrangements to manage cumulative effects are inadequately developed in Canada — was examined in the context of a broad range of organizational arrangements. The latter included not only the institutional arrangements of potential use for implementation of the conceptual framework, as outlined in Chapter 4, but also several other features related to developers who are subject to regulation, a perspective in keeping with the recommendation by CAETEP (1986) that there is a role for certain projects to be treated as large-scale experiments. The latter goal clearly requires a framework with ecosystem-management links broad enough to include industry's role in cumulative effects assessment.

Political Aspects of the Management Component

For this review, the term "political aspects" is interpreted broadly to include legislative aspects. There are a number of political factors that cannot be ignored in management of potential cumulative effects. The first is that a political will to act is required before any institutional arrangement can be put in place or before any substantiated decision can be taken. A corollary of this is that the cumulative effects management system must be accountable to elected representatives. Management must also command public confidence to be effective and to secure compliance with its requirements. This requires good public relations and may call for measures to accommodate public views in the management process.

Decision making does not take place in a vacuum. For example, political realities related to employment may override environmental considerations. In addition, decisions are made in the prevailing political climate. Because political considerations are very influential, group and individual behaviour is of vital importance in any attempt to change or add to the everyday management system.

Socio-economic Aspects of the Management Component

The social and economic consequences of cumulative environmental effects dominate the links between the ecosystern component and the management component in Figure 4. Linkages between cumulative effects, socio-economic effects and institutions is illustrated in Figure 5.

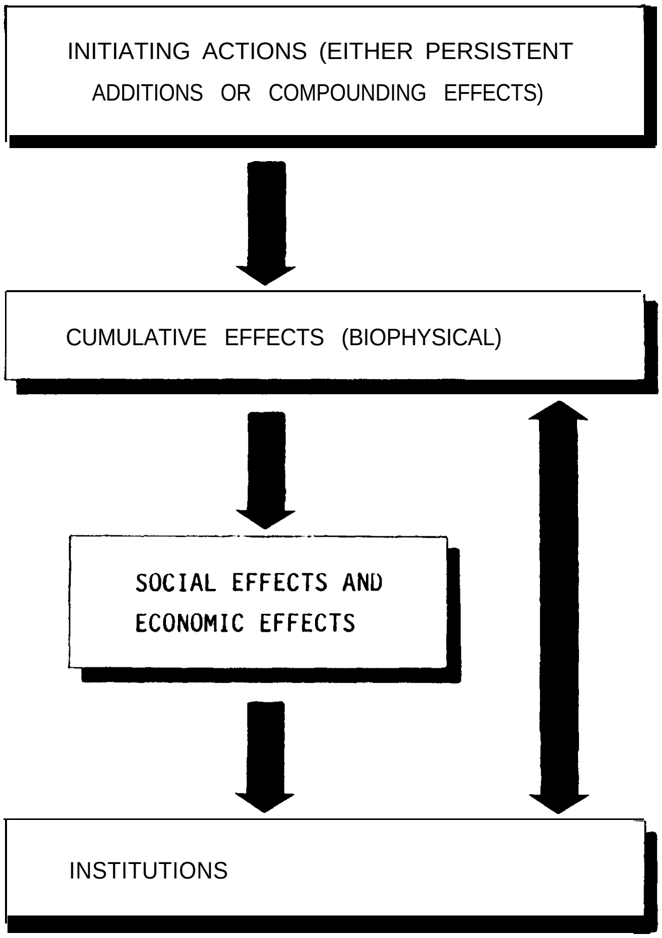

Figure 5. Linkages Between Cumulative Effects, Socio-Economic Effects and Institutions.

The cumulative effects considered in this report are biophysical in origin and the socio-economic framework for this analysis is rooted in biophysical changes and not in effects resulting from general social and economic trends. For example, the cumulative effects on human health and the economic issues related to leaded gasoline are considered. General sociological trends, for instance increasing violence in urban areas, are not.

Environmental management institutions, as they presently exist, are oriented to respond to more "traditional" environmental impacts. The question is whether the structure is capable of identifying and responding to cumulative environmental effects. Today's dominant social and economic perspective is that if cumulative effects are either not identified or are ignored at the biophysical level, the next point at which identification will occur is when cumulative social and/or economic effects on the human population are identified. For example, scientific evidence suggests that proper containment and disposal of toxic wastes is imperative. However, the institutional structures to accomplish this commonly fail until an example of effects on human health results in public awareness.

Cumulative social and economic effects are, for the most part, an indirect or second level of effects which occur if the institutional system fails to identify and respond directly to the cumulative environmental effects. The relationships shown in Figure 5 illustrate that cumulative effects can be identified either directly by the environmental management system or indirectly by responding to social and economic impact of cumulative effects.

An exception to the common circumstance outlined above is the direct cumulative social and economic impacts that can result with a compounding type of initiating action, as portrayed by Pathway 3 in Figure 2. Examples are numerous in those areas where a multiplicity of development projects occur in a relatively remote region. In such a case, there may be cumulative biophysical effects which result from the developments. However, the primary effect is that the way of life of the area's residents will be altered by the multiple (compounded) effects of the development projects.

The emergence of a major social or economic impact related to a cumulative effect implies that environmental management systems have not been effective in identifying the cumulative changes. In such cases, the identification and/or the environmental management mechanisms have simply not responded to the initial biophysical evidence. Thus, the important question is how the indirect social and economic effects associated with cumulative effects can be incorporated into the identification system and into environmental planning and management institutions.

CHAPTER 4: ALTERNATIVE INSTITUTIONAL ARRANGEMENTS FOR RESPONDING TO PERCEIVED CUMULATIVE EFFECTS

This section focuses on the ecosystem-management links shown in the conceptual framework (Figure 4) by outlining four broad alternative institutional arrangements for handling cumulative effects and by identifying some of the links between cumulative effects assessment, environmental planning and environmental impact assessment.

Much of the literature on cumulative effects is concerned with the recognition and assessment of effects rather than action to counter them. For an action program, it is suggested that four steps are required to deal with cumulative effects. The first step is recognition of a potential problem (research-ecosystem links, Figure 4). This can occur as a suspicion by a knowledgeable person, as a prediction arising from scientific or technical analysis or by the detection of an actual effect. In other words, recognition may occur by intent or by accident. Recognition of a possible effect should be followed by the second step, which is assessment of its reality, magnitude and probable consequences (research-ecosystem links, Figure 4). The third step should be to formulate an appropriate response (research-management links, Figure 4), and the fourth step is to take action to implement that response (ecosystem-management links, Figure 4).

There are institutional arrangements in place which have assisted the identification of cumulative effects and which have supported research to identify their mode of action. It cannot be said, however, that there are institutional arrangements in place that have led to effective action to mitigate or control all cumulative effects that extend beyond simple jurisdictional boundaries. For this reason, the treatment of institutional arrangements in this report focuses on the last two of the four steps mentioned above.

The four suggested steps parallel the sequential elements of the general model of environmental impact assessment in Canada and the United States, as discussed by ESSA (1982). This process was developed to deal with individual projects and, in general, the proponents of specific projects are expected to identify impacts and propose action to avoid or mitigate them. Because most cumulative impacts identified to date are not confined to small areas, particular ecosystem elements or specific political mandates, the question of how to define and implement responses is more difficult than the question of how to recognize them.

The institutions with responsibility to act are best placed to arm themselves with advice about what to act upon. Therefore an institutional arrangement that can manage the third and fourth steps identified above should be able to ensure that the first and second steps have been taken. The real problem of dealing with cumulative effects is to ensure that these institutions do obtain the necessary information, perform objective analyses and take appropriate action. As Fox (1986) points out, this is really a problem for social scientists concerned with human organizations and government. Recommendations relating to this problem are presented in Chapter 7.

Any attempt to control cumulative impacts through legal liability is unlikely to be successful because of the difficulty of attributing cumulative effects to all operators that are potentially contributing to them. Realistically, control can only be achieved through a body with the wide-ranging powers necessary to plan, encourage and regulate economic activity; this means government. In contemplating government intervention, it is necessary to consider how complex the process of government control is likely to be. In cases where cumulative effects are a general rather than a specific result of economic development, they touch on the responsibilities of almost every part of government. As an example of the latter, the Department of Indian Affairs and Northern Development (1982) tabled a chart that set out the process for regulation of proposed oil and gas developments in the Beaufort Sea. The complex chart included 20 different approval pathways, several of which reach to the cabinet level, and 89 boxes that indicate regulatory activities that contribute to approval decisions. Many departments and agencies of three governments are involved. This example demonstrates that any attempt to control cumulative effects must involve many government agencies and a complex institutional arrangement that is already in place. The requirement, therefore, is a form of massive centralized control which, due to the abatement of "megaproject" industrial activity in the north, has not yet been effectively tested by a significant development application.

There are several alternative approaches to achieve the desired control. These are: (i) legislation or cabinet directive; (ii) adding another layer of review to the existing process; (iii) creating a separate department or agency with responsibility for control of cumulative impacts; or (iv) any one of a variety of advisory mechanisms.

LEGISLATION OR CABINET DIRECTIVE

This alternative is based on the imposition of a solution from the top. It requires political will and political courage, and it can be a most effective method. An illustration of the use of legislative action was the requirement for use of smokeless fuel for domestic heating and industrial use in the United Kingdom in the late 1950s. This measure virtually eliminated the occurrence of severe smogs in large cities. A Canadian example of the exercise of political will, and the imposition of a solution from above, was the action of the Ontario government to protect the Niagara Escarpment during the 1970s. This action was effective at the time, but it has been undermined in recent years by the granting of exceptions to land-use restrictions.

Such an approach can be effective on an *ad hoc* basis, but for general or repeated action it may not be practical. The effort required to mobilize a government for legislative or major policy action is too great to allow frequent repetition. Some formal institutionalized process is usually necessary to deal with continuous or recurrent phenomena. Several alternatives are suggested in the subsections that follow.

ANOTHER LAYER OF REVIEW

Examples of the introduction of another layer of review into the regulatory process, or of an additional procedure that must be followed before development projects are approved, include the many environmental impact assesssent processes to which development proposals are submitted by governments, and the socio-economic impact assessments that new or significantly altered regulation must undergo in both the Canadian and American federal governments. These processes tend to operate by referrals of specific projects to an assessment body which reviews material submitted by the industrial proponent.

The Federal Environmental Assessment Review Office (FEARO) attempted to improve on the traditional system of project referral in its treatment of the Beaufort Sea development proposals. In addition to addressing specific impacts, the three proponents were asked to assess the impacts of their combined development proposals on a regional scale. It was hoped that this would lead to more effective review of cumulative effects, but the results were disappointing. The proponents did not deal effectively with cumulative effects, with the exception of socio-economic changes in local communities. Some of the documents filed at the hearings did attempt to assess cumulative impacts at the regional scale (Naysmith et *a/*. 1983; Roots 1983), but this did not lead to specific panel recommendations on the subject. In general, cumulative effects were not a major focus of the panel report.

By the nature of project referral, the onus to produce diagnoses and solutions is on the industrial proponents, although government departments may be asked to provide information about how they intend to manage the developments. Proponents are generally not well equipped to respond to cumulative effects issues and do not consider such analyses to be their responsibility. There is widespread opinion that project referral is not a satisfactory method of dealing with cumulative impact because the onus to produce solutions is on the proponents. Their responsibility is limited to their own project and its contribution to cumulative effects. There is widespread opinion that it is unreasonable to expect a project proponent to deal with cumulative impacts on a regional basis, or to be concerned about the possible “add-on” effects of some future project that may occur in the same geographic area as the proponent’s project.

Another difficulty of introducing an additional layer to the regulatory or approval process is that of integrating it into existing arrangements. FEAR0 has been frustrated by its inability to ensure that panel recommendations are always acted upon and in some cases it has tried to make them enforceable. It has campaigned, so far unsuccessfully, to obtain the legislative backing to achieve this. It has, however, managed to introduce some complex administrative procedures to monitor the outcome of panel recommendations. Departments with the responsibility to administer the pertinent legislation have tended to resist FEARO's proposals on the grounds that panel recommendations tend to emphasize environmental values, whereas regulatory decisions also have to take legally enforceable, socio-economic and political factors into account.

CREATION OF SEPARATE AGENCIES

The creation of new agencies or departments to deal with specific administrative or regulatory problems is a common practice. There are several variations of this method. One is the establishment of an independent regulatory agency. Examples in Canada are the Atomic Energy Control Board (AECB), National Energy Board (NEB) and Northern Pipeline Agency (NPA). The United States also uses this method, with prominent examples being the Securities and Exchange Commission (SEC), the Federal Energy Regulation Commission (FERC) and the Environmental Protection Agency (EPA).

A second variation of the method is the rearrangement of programs into different departmental combinations. In Canada, the shuffling of programs between the Department of Fisheries and Oceans, Department of Environment, Department of Indian Affairs and Northern Development, Department of Energy, Mines and Resources and Agriculture Canada is a recurrent phenomenon. In the United States, the combination of existing programs under the National Oceanic and Atmospheric Administration (NOAA) is an example of an administrative organization empowered to deal with environmental quality, including cumulative impact; it is also an organization that appears to be relatively effective.

The federal Canadian experience in rearranging departments has not been encouraging. Departments have been rearranged to bring about combinations of programs that are apparently more rational than what went before. The creation of Environment Canada falls into this category. Departments have also been rearranged to change departmental emphasis and to introduce new priorities by juxtaposing programs intended to exert certain influences on each other. The recent experiment of combining External Affairs and certain parts of Industry, Trade and Commerce is an example. In general, the latter type of rearrangement requires greater changes than the first. Evidence for this is provided by the fact that programs such as the Canadian Wildlife Service, the Canadian Forestry Service and Parks Canada have retained their identity, their practices and their priorities, despite their frequent moves from department to department.

This does not mean that redirection of existing departments to deal with a new problem or rearrangement of programs for the same purpose cannot work. Some American examples such as NOAA seem to be successful. Perhaps what is required is a more fundamental reorganization than is usually attempted.

This would require legislation that is new in concept rather than "enabling" legislation that is designed simply to make new administrative arrangements legal. It would also require radical changes in program management which may have to be achieved against strong oppostion.

A third variation of the method is the use of co-ordinating bodies. These may be as simple as inter-agency committees at the administrative level, or they may be more visible and more ambitious, as in the case of land-use planning authorities. At first glance, land-use planning authorities might appear to be appropriate recipients of responsibility for dealing with cumulative effects. However, there are a number of reasons why this may not be very effective. Within the provinces, most land-use planning authorities have responsibility for too small a geographical area to cope effectively with cumulative effects. They are not always given sufficient funds to directly undertake or to hire specialist contractors qualified to deal with issues. Finally, they generally do not have authority to take the action necessary to deal with many kinds of cumulative effects. To illustrate, in Alberta municipal and regional land-use plans may be overridden by the provincial government in the case of any significant economic or urban development.

Co-ordinating bodies are generally designed to soften competition between departments where their various mandates and responsibilities come into conflict. Most co-ordinating bodies are committees with administrative status only and have no powers beyond the power of persuasion. The result of their lack of authority is that their deliberations usually end in compromises and trade-offs, to the detriment of any intent to follow a consistent policy. A more elaborate form of co-ordination is practiced by various planning programs and authorities. As outlined below, land-use planning is one type of program that has considerable relevance to the problem of cumulative effects. Land-use planning authorities at the municipal level tend to be relatively powerful but at provincial and federal levels they are less so. Because effectiveness is dependent upon power, it is not surprising that most cumulative effects management, when it does occur, is at a local level. This circumstance is identified as a matter for CEARC's attention in one of the recommendations of this report.

The success of independent regulatory agencies depends on their having a strong legal mandate. Without such a mandate, they are likely to be outmatched in any conflict between agencies. On the other hand, if their mandate is strong but narrow they may become unresponsive to other agencies and interest groups, and even to the government that created them. They are also often accused of becoming the "captives" or advocates of the industries that they are intended to regulate. Nevertheless, the independent regulatory agency is probably the most powerful method available for dealing with the recurrent or persistent phenomena that characterize cumulative effects management. If designed and operated wisely, it is probably also the most effective. The Law Reform Commission of Canada has reviewed the record of independent regulatory agencies in great detail in a series of reports (Law Reform Commission of Canada 1980), and has recently made recommendations for their perfection (Law Reform Commission of Canada 1985).

ADVISORY MECHANISMS

There are two kinds of advisory groups that might be employed to grapple with the problem of cumulative effects. One is a standing committee or established program that is expected to continue operating for many years. The other is an *ad hoc* group constituted to give advice about a particular subject or problem. The first group includes advisory committees, like CEARC itself, and more elaborately established bodies such as the Science Council of Canada, the Economic Council of Canada, and the Law Reform Commission Of Canada. The power of these bodies is generally restricted to the power to persuade.

The second group includes royal commissions, boards, committees of inquiry, and a variety of lesser investigative committees. These bodies often have extensive powers to obtain information and to conduct analyses. They rarely have the power to require that their findings or recommendations be acted on. They do, however, have an advantage in persuasive power over the first group because, in most cases, their recommendations receive wider publicity. The role of such investigative groups to enhance Canada's approach to management of cumulative effects is not yet tested.

LINKS WITH ENVIRONMENTAL PLANNING

Environmental planning is a rapidly evolving field and it is a testing ground for a variety of management techniques such as co-operative administrative programs, agreements, contracts, protocols, and memoranda of understanding. It is not surprising, therefore, that many analysts are looking to environmental planning for cumulative effects management, and some of them have argued that if there was effective environment planning there would be no cumulative effects problems. For example, Robilliard (1986) stated the case as follows:

> *Briefly, comprehensive, environmentally based planning is an appropriate substitute for the entire impact assessment, including the generally-poorly-focused assessment of cumulative impacts. This is an argument for the "top down" view as the only correct way to live.*

A similar suggestion also arises for totally different reasons. A repeated theme in the international literature is the idea put forward by Russell and Portney (1985) that an important foundation for long-term environmental management is to acknowledge the uncomfortable fact that pollution is a ubiquitous problem and not simply a short-term ethical aberration created by modern market societies. Once this circumstance is acknowledged, it is evident that any specific steps that are carried out under the label of cumulative effects assessment must be implemented within the broader set of activities that are collectively referred to as environmental planning. The ubiquity of cumulative effects means that their management must be on an area planning basis rather than on a project basis; in turn environmental planning that does not routinely incorporate cumulative effects assessments is incomplete planning.

A Canadian example of the planning approach to cumulative effects assessment is provided in the Elk-Flathead area in the extreme southeastern corner of British Columbia. Faced with the existing and potential coal mine developments, the Ministry of Environment required a strategic analysis to assess cumulative impacts in relation to the resources under the ministry's mandate, including water supplies, water quality, air quality, fish and wildlife (B.C. Ministry of Environment 1985). The important point to note for this review is that the latter example is a determined attempt to accomplish the two prerequisites specified by Roots (1986) for handling cumulative effects through comprehensive planning procedures: the controlling mechanisms should match the geographic dimensions of the areas to be managed; and the institutional responsibility for controlling activities must be integrated rather than fragmented.

To anticipate the degree to which cumulative effects can be recognized and managed in a setting where environmental management and area assessments dominate over a project-specific approach, it is important to note that planners operate in environmental management at two main levels (Roberts and Roberts 1984). The first level is concerned with stating goals, options and the broad zonation of land-use priorities. This activity involves the integration of a wide variety of activities that contribute to cumulative effects, including agriculture, forestry, fisheries and wildlife harvesting, industrial development, transportation and recreational uses of land and water. The second level involves developmental control in which specific proposals are appraised by planners for their conformity with the overall goals and their appropriateness to specific locations. It is at the latter level that environmental planning and area assessments have the greatest opportunity to make decisions based on cumulative effects criteria. To achieve the latter, major attention will need to be given to the challenge presented in the CAETEP (1986) report, where it was argued that it is not lack of ecological information that leads to poor environmental planning, but simply the lack of its proper application.

LINKS WITH ENVIRONMENTAL IMPACT ASSESSMENT

From CEARC's point of view, cumulative effects assessment must be viewed in the context of environmental impact assessment because the latter is central to CEARC's overall objectives, recently stated as follows (CEARC 1986):

a) advising on the need for and adequacy of research related to environmental impact assessment;

b) reviewing and commenting on the use of scientific information about the environment and the place of environmental impact assessment in planning and development; and

c) encouraging new ideas and research directed towards improving the concept, practice and effectiveness of the assessment of social and environmental impacts.

Another important point is that it is in the context of EIA that one can most readily address the role of the developer in recognizing and managing cumulative effects. The key reason is that in most jurisdictions the developer has initial responsibility for the environmental assessment of activities (Couch 1985). Consequences of this state of affairs were summarized by organizers of the 1985 cumulative effects workshop (CEARC and U.S. NRC 1986) who listed four shortcomings of environmental assessment that is focused on specific projects:

- *it ignores the additive effects of repeated developments in the same ecological system, e.g., the effects of the loss of wetlands and disposal of toxic chemicals on fish habitats and productivity.*
- *it does not deal adequately with precedent-setting developments that stimulate other activities, especially in fragile environments.*
- *it ignores change in the behaviour of ecological systems in response to increasing levels of perturbation, e.g., nonlinear functional relationships.*
- *it does not encourage the development of comprehensive environmental objectives that reflect the broad goals of society.*

The proposal by CN Rail to twin its rail track from near the Alberta border to Vancouver has resulted in the first environmental assessment panel committed to an examination of cumulative impacts, perhaps the first example of a public enquiry into cumulative assessment in Canada (O'Riordan 1986). Despite this precedent-setting step for environmental impact assessment in Canada, there remains active debate over the degree to which environmental impact assessment procedures can be modified and improved to integrate cumulative effects assessment. On one side of the debate are researchers typified by Conover *et al.* (1985b) who state that their impact. assessment framework "is capable of accommodating cumulative impacts or, more properly, additive, repetitive, chronic (long-term persistent), and synergistic impacts." On the other side of the debate are analysts such as Erckmann (1986) who suggest that there are major differences between environmental impact assessment (EIA) and cumulative impact assessment (CIA):

> *EIA is site-specific, CIA usually is not. Apart from obvious differences in the scale of the respective enterprises, CIA has one other feature that EIA normally does not. CIA is a form of pattern analysis, and cumulative effects management is the management of patterns. Much effort in CIA must go into the detection and analysis of trends, with the development of elaborate accounting procedures. in short, CIA needs some scientific input that EIA does not. in addition to a system for identifying trends in sources and effects, management of cumulative effects requires analytical tools for detecting critical thresholds — in effect, a warning sys tern.*

Erckmann concluded that to expect cumulative effects to be dealt with only by EIA would make EIA "an even more superficial 'shotgun' affair than it already is." Other difficulties were summarized by O'Riordan (1986), particularly in relation to the fact that a single jurisdiction is generally in control of impact management when dealing with the environmental impacts of a single project. Yet cumulative effects, by their inherent nature, tend to involve various levels of government to the extent that no single authority can assume control. Clark (1986) expressed doubts that environmental impact assessment practice gives adequate attention to the way that damages to individual valued environmental components accumulate to cause an overall degradation of whole environmental systems and proposed this as a topic for further study.

A significant evolution is taking place in the concept and procedures of environmental impact assessment. Form its origins as a narrowly focused procedural step in the approval of specific projects, environmental impact assessment is developing into an integral part of a more comprehensive management process (CEARC 1986). One consequence of this evolution is an increased potential for incorporation of mediation procedures into EIA processes. The practice of environmental negotiation and mediation has expanded quite rapidly in the United States (see Bingham 1986). Recent Canadian initiatives in this area and the prospects for further development were reviewed in a special issue of Resolve (18(2) 1986). (See also Haussmann 1983; Shrybman 1985.) The process of environmental negotiation is of interest to CEARC, which recently convened a workshop on its institutional implications (workshop proceedings forthcoming). Based on a recent mediation experience described in the Athabasca River Basin case study (Chapter 5), this review suggests several steps of possible interest to CEARC for further analyses of mediative processes as a means for dealing with interactive types of cumulative effects within environmental impact assessments.

Environmental impact assessment has the potential to evolve in another way that will also link it more closely with the research needed for cumulative effects assessment. Some analysts have suggested that environmental impact studies could be viewed as hypotheses about how the environment will be affected by a particular project (CAETEP 1986; Lewin 1986). Correct monitoring of various environmental parameters throughout the project would then constitute an ecological experiment on a scale far beyond what would be feasible through conventional funding agencies. The information gained by such means would then be applicable to future projects of a similar nature. The rationale behind this suggestion is that careful monitoring is essential to anyone who wishes to document the effects of projects, test the predictions made in impact statements, detect changes in baseline conditions, and detect cumulative effects. If the evolution of EIA is in the direction of treating projects as experiments, the links between EIA and cumulative effects assessment will be strong.

CHAPTER 5: SOME CANADIAN EXPERIENCES IN CUMULATIVE EFFECTS ASSESSMENT

When one examines how cumulative effects have been handled in several parts of Canada, there are no clear-cut "successes" or "failures." Most examples contain elements of both. It is possible, however, to identify factors and circumstances that help or hinder success. Even the most successful approaches still face hurdles created by administrative complexities, knowledge gaps and perception problems. Several Canadian approaches to cumulative effects management are outlined below. The first three sections draw upon information from the three case studies undertaken as part of this review. The other selected examples deal in a less detailed way with regulation of radiation hazards in Canada and the Great Lakes Water Quality Agreement.

CASE STUDY: THE CUMULATIVE IMPACT OF LEADED GASOLINE

Cumulative Effects Pathways Involved

The lead in gasoline issue in Canada was selected as a case study to illustrate the treatment of a cumulative effects problem whose main pathway involved the atmosphere. The cumulative nature of the effects is based on the fact that the use of leaded gasoline produces airborne emissions of particulate lead that have resulted not only in the increase in ambient airborne lead levels but also in increased lead levels in water, urban topsoil and dust, and in foods. The airborne levels of lead provide a direct means by which human lead levels — in blood, soft tissues and skeletal tissue — accumulate due to continual exposure. In addition, there is the delayed response in human lead burden as a result of the use of leaded gasoline as the emissions move through environmental media and eventually into the food chain. In relation to the functional pathways shown in Figure 2, the leaded gasoline case is an example of both Pathway 1 (additive in a slowly dissipative setting) and Pathway 2 (interactive through involvement in the food chain).

Relationship to the Conceptual Framework for Cumulative Effects Assessment

This case study adds an important dimension to the ecosystem management links and the research-management links shown in the conceptual framework for cumulative effects assessment (Figure 4) because it draws attention to an example in which regulatory actions were taken *after* a cumulative effect had occured. This sequence should be distinguished from the situation where regulations may be introduced after a cumulative effect has been assessed but before the effect occurs. The ideal sequence for the lead in gasoline issue would have been a cumulative effects assessment when lead anti-knock additives were proposed in the 1920s. In this context, it is clear that the use of leaded gasoline effectively mobilizes lead in the environment and in man in a cumulative fashion, and given the predictable, potential adverse health effects, the use of leaded gasoline would likely have been prohibited had a cumulative effects assessment been conducted. This view has been expressed in a dissenting opinion included in a U.S. National Academy of Sciences Report (NAS 1980). Even in this case, involving effects of a substance that is fairly well understood toxicologically, scientific dose criteria did not appear to play a prominent role in the final regulation development process. This suggests that it is optimistic to expect that cumulative effects assessments of existing impacts will yield unequivocal results by quantitative, scientific approaches.

Since 1974, regulations issued under the authority of the 1973 Canada Clean Air Act have limited the lead content of gasoline. These regulations formed the basis for reducing the atmospheric emissions of lead from automobile sources, thereby lowering the lead levels to which the Canadian population is exposed. The initial regulations, together with the revisions over the years, and their current status including proposed regulatory actions, are summarized in Table 2.

The current regulations stipulate allowed limits for lead in lead-free gasoline (0.06 g/imperial gallon) and the lead content of leaded gasoline. The latter is currently 0.77 g/L and, as of 1 January 1987 it will be 0.29 g/L. The current regulations also prescribe reporting schedules for gasoline refiners. Other government initiatives currently under way include a commission that has been undertaking a review of Canadian policy regarding the lead in gasoline issue. The Royal Society of Canada has been undertaking this work since 1984.

Enforcement of the lead-free gasoline regulations is undertaken by the Environmental Protection Service (EPS), Environment Canada. The enforcement program consists of a two-tiered sampling and analysis program. Samples are collected by Clean Air Act inspectors from regional EPS offices and the lead content is measured on-site, at retail outlets, marketing depots and refinery storage tanks. Sources with lead content above the prescribed limit are subjected to an enforcement procedure whereby a second sample is taken and analysed in a regional laboratory.

The enforcement program for leaded gasoline is similar to that for lead-free gasoline, but the majority of samples are collected from refineries and bulk depots. Samples in violation of the prescribed lead content are seized and the disposal of the

Table 2
Summary of Lead-in-Gasoline Regulations

Date	Reference	Subject	Provisions
19731 10/31	Canada Gazette Part II Vol. 107, No. 21 SOR/73-663	Lead-free gasoline	Maximum Permissible Level: 0.06 g Pb/imperial gallon in lead-free gasoline 0.006 g P/imperial gallon in lead-free gasoline Effective Date: 1 July 1974 Measurement Method: As per DOE SRM Report EPS 1-AP-73-3
1974/07/31	Canada Gazette Part II Vol. 108, No. 15 SOR/74-459	Leaded gasoline	Maximum Permissible Level: 3.5 g Pb/imperial gallon (0.77 g/L) Effective Date: 1 January 1976 Measurement Method: As per DOE SRM Report EPS 1-AP-73-3 Reporting: All Canadian producers to report quarterly on the volume and lead content of premium, regular, lead-free and other gasoline grades. Also, quarterly report of lead additives purchased (bs) and used or disposed of, or stored.
1975/02/26	Canada Gazette Part II Vol. 109, No. 5 SOR/75-104	Leaded gasoline, amendment	Gasoline produced or imported into Canada for use in aircraft was exempted.
19801 10/25	Canada Gazette Part I Vol. 114, p. 6523	Intent to investigate the phase-down of lead content in motor gasoline	Formal notice of a socio-economic impact analysis (SEIA).
1983/03/12	Canada Gazette Part I Vol. 117, p. 2246	Intent to amend regulations and to assess control options for phase-down	
1984/05/04	Canada Gazette Part II Vol. 118, No. 10 SOR/84-359	Leaded gasoline	Definition: Gasoline not to include aircraft use Maximum Permissible Level: a) 0.77 g Pb/L (3.5 g/imperial gallon) prior to 1 January 1987 b) 0.29 g Pb/L on or after 1 January 1987 Measurement Met hod: As per DOE SRM Report EPS 1-AP-73-3, revised January 198 1 Reporting: Quarterly report by all producers on the volume and average lead concentration in premium, regular, lead-free and other gasoline. Separate reports for imported and locally produced products. Quarterly reports on the lead additives purchased, used, disposed, lost or stored.
1984/02/ 18	Canada Gazette Part I Vol. 118, p. 1420	Proposed amendment to the leaded gasoline regulations.	Summary of the socio-economic impact analysis (SEIA) of the lead phase-down control options.

sample is supervised by EPS staff. Violators are fined. The regulations require petroleum refineries to report quarterly on their gasoline production and lead usage including that for imported products.

The regulations themselves contain no provision for routine revision at prescribed times or in the event of specified conditions. Notwithstanding this, the regulations are currently undergoing revision in order to lower the content of leaded gasoline. Formal assessment of the efficiency of the regulations in terms of observed trends in environmental effects are lacking. However, there have been published reports describing two aspects of the issue: trends in the number of samples collected and analysed, the number of violations, gasoline production data and the lead content of fuel; and trends in ambient airborne lead concentration data.

There are no formal requirements for the analysis and interpretation of ambient concentration data and there appears to be no co-ordinated program for assessment of the human health implications of lead as they relate to the regulations. Over the years, there have been very limited studies on the blood lead levels in the Canadian population.

Ecosystem and Research Components of the Leaded Gasoline Problem

To focus on the ecosystem and research components of the cumulative effects conceptual framework (Figure 4), it is instructive to look first at the technical basis for the regulations and then at data dealing with exposure of the Canadian population to lead.

The promulgation of the lead in gasoline and leaded gasoline regulations in 1973 and 1974 was preceded by a review of lead in the Canadian environment by the Associate Committee on Scientific Criteria for Environmental Quality of National Research Council Canada (NRCC). Health and Welfare Canada were also requested to provide advice on the safety of using lead in gasoline. Documentation is apparently lacking to link the promulgation of the 1973 and 1974 regulations to health effects or to other socio-economic considerations of the lead in gasoline issue. Stated differently, dose-response relationships of lead did not play a role in establishment of leaded gasoline regulations.

Scientific knowledge at the time (1973) suggested that: "normal" range of blood lead levels was from 15-40 μg/dL; the North American blood lead levels were similar to those elsewhere; variations in blood lead levels were due largely to dietary intake, and ambient urban lead levels may not materially affect blood lead levels (NRCC 1973). The distribution of lead in the body was recognized to occur in skeletal (over 90%) and soft tissue pools. A slow accumulation of lead occurs, over a time scale of about one month, until there is equilibrium between intake and excretion. The levels at which chronic lead poisoning occurs were uncertain, but a blood lead threshold of 80 μg/dL for chronic lead poisoning was suggested At that time (1974), there was a lack of data on the long-term effects of lead on man, especially at low or normal levels. In relation to the cumulative effects conceptual framework (Figure 4), it is evident that work related to research-ecosystem links does not always precede action within the ecosystem-management links.

The accepted indicators of early and specific lead exposure were considered to be urine and blood lead levels, but the relationship (inhibition) between S-aminolevulinic acid dehydrase (ALAD) in erythrocytes and blood lead levels (down to 5 μg/dL) was recognized. More recent evidence on the human health effects of lead has led to the adoption by the U.S. Centers for Disease Control (CDC) and by Health and Welfare Canada, of a safe blood lead level of 25 μg/dL. The basis for the adoption of the current safe levels arose from the following health effects:

- effects on the ematopoietic system and related cellular processes
  - — ALAD inhibition
  - — heme biosynthesis
  - — the vitamin-D hormone system
- effects on the nervous system
  - — neurobehavioural and neurodevelopmental effects
- blood pressure effects.

It should be noted that not all of these effects have been demonstrated to occur at low blood lead levels (25 μg/dL) and indeed there is considerable controversy in some cases as to the existence of an effect at all, particularly in relation to nervous system and blood pressure effects. Sensitive groups, especially children, may experience effects at levels that are "normal." There is some evidence that children may be sensitive to blood lead levels between 10 and 20 μg/dL (Boeckx 1985). The Toronto Board of Health currently considers 20 μg/dL as the safety criterion, but public pressure is being applied to reduce this criterion to 15 μg/dL for children.

The interim report of the Royal Society of Canada (1985) recommended that the proposed leaded gasoline regulations for 1987 will have beneficial effects and that the reduction in blood lead levels which the 1987 regulations will achieve will be sufficient to protect almost all segments of the Canadian population against the known harmful effects of lead exposure. The commission recognized the possibility that ongoing research may indicate even lower blood lead levels at which harmful effects occur.

In 1970 it was estimated that exposure of the Canadian population to lead was predominantly by airborne particulate matter and that nearly 74% of the airborne emissions arose from automobile emissions from leaded fuels. Such exposure occurs either directly by inhalation or by consumption of material contaminated by deposition of airborne lead. The average daily intake of lead by an average Canadian was estimated at 140 μg from food, 20 μg from water and 15 μg directly from air. The average fraction absorbed was estimated at 10% each from food and water and 30% from air (NRCC 1973). Similar estimates were derived in the 1982 Health and Welfare Canada study.

It is now clear that the use of leaded gasoline very effectively mobilizes the inorganic lead and results in widespread atmospheric emissions, especially in urban areas with large automobile fleets. The atmospheric fate of lead is such that the residence time is long and dispersion is facilitated by the small particle size, inefficient atmospheric removal mechanisms and high chemical stability. Furthermore, the lead deposited in soil is easily reintrained and therefore there is effective recycling of the particulate lead. All of these processes could have been predicted on the basis of existing knowledge long before regulatory action occurred. Society's ability to act on the basis of existing information must, however, be seen in political and historical perspective. That is, it is unlikely that a choice to ban the use of tetraethyl lead could have been made in the 1920s.

The U.S. National Academy of Sciences report on environmental lead (NAS 1980), the second NAS assessment of the subject, provided a review of the effects of exposure to lead in the environment but stopped short of presenting criteria for regulatory standards or guidelines. The latter was left to the U.S. Environmental Protection Agency (EPA), which had commissioned the NAS studies.

A minority of the NAS Committee felt that its recommendations had not been stringent enough. In fact, in the opinion of members of the NAS Committee who endorsed the dissenting opinion, the deliberate mobilization of a persistent, and therefore cumulative, toxic substance like lead, in a form that would be dispersed in the environment in the end use, should be banned. That is, the question of what is the acceptable level of accumulation of lead in the environment was irrelevant, in the view of the dissenting group. They stated that there should be no tolerance for release of a substance whose accumulation would be limited only by the amount produced.

This point of view represents a perspective on cumulative effects that has not often been acknowledged in regulation of exposure to environmental contaminants. It does not appear to have been addressed in the Canadian assessment of lead in gasoline. Both the Canadian Environmental Contaminants Act and the U.S. Toxic Substances Control Act take the perspective of the NAS Committee dissenters, that substances whose physical/chemical and biological characteristics imply deleterious cumulative impacts may not be permitted in dispersive end uses.

The Management Component of the Leaded Gasoline Problem

A social and economic assessment process and several institutional and regulatory steps were the key activities in the management component of the conceptual framework (Figure 4).

The earlier (1973 and 1974) regulations make no reference to the scientific or socio-economic basis for the regulations. Interestingly, a 1982 Environmental Protection Service report (Miszkiel 1982) asserted that the lead-free gasoline regulations were necessary for the efficient operation of catalytic converters. However, there was no reference to the basis for the leaded gasoline regulations. In this context, it is essential to clearly distinguish between the lead-free and leaded gasoline regulations. The former are based only on the technological requirements for the use of catalytic converters, since lead poisons the catalyst.

The 1984 regulations had the benefit of a completed socio-economic impact analysis (SEIA) process. The intent to investigate the reduction of lead in gasoline was published in the *Canada Gazette* in October 1980. Seventeen technical and scientific reports were commissioned by EPS for the SEIA of which two dealt with health effects (Jan and Sheffield 1983; Labuda and Landheer 1983). In addition, Health and Welfare Canada prepared the report *Human Exposure to Environmental* Lead (Health and Welfare Canada 1982) for the Department of Environment. Also available at that time was the Jaworski report on the' effects of lead in the Canadian environment (Jaworski 1979). There were over 800 submissions by industrial and other interested parties as provided by the SEIA process.

The EPS reports dealt extensively with the costs associated with gasoline production and leaded anti-knock additives, the distribution and operational costs associated with various fuel types, manufacturing costs and the technological aspects of the use of unleaded or lower-leaded fuels. That is, the social desirability of reducing the lead content of gasoline as a perceived amelioration of the cumulative impact on human health seems to have been accepted as given, so that the economic impact of achieving that goal was really the only issue. Industry responses, typified by that of Ethyl Canada (1982) addressed primarily the issue of the SEIA's cost estimates and did not generally tackle the issue of whether further mandatory reduction of the lead content of gasoline would actually have a demonstrable effect on human tissue lead levels or on the health of exposed persons. In other words, the alleviation of exposure was assumed to be related to improvement in health, with no substantiating evidence.

The development of regulations for lead in gasoline in Canada paralleled similar activity by the U.S. Environmental Protection Agency. EPA's proposed lead phase-down met with industry objections similar to those experience in Canada, partly because many of the Canadian companies are subsidiaries of U.S. parent companies. In 1976, the U.S. Supreme Court upheld a lower court decision in favour of EPA's position, arguing that EPA was empowered to protect public health without having to establish "rigorous step-by-step proof of cause and effect." EPA's activities and support of them by such legal decisions undoubtedly influenced the course and context of the Canadian proceedings. The absence from the Canadian deliberations of a rigorous discussion of quantitative relationships among lead content in fuel, airborne lead and alleviation of health effects, then, is understandable.

The Environmental Protection Service (EPS) is the government institution mandated to enforce provisions of the Clear Air Act in Canada. The EPS regulatory process consists of four milestones, two of which allow for public participation, The regulatory process starts with a published Problem Assessment Report which recommends the investigation and design of possible regulatory options for intervention to solve a problem. The four stages are as follows:

- control options — assignment of resources to identify control options;
- draft control instrument — includes the socio-economic impact analysis;
- proposed control instrument — the prepublication instrument; and
- final control instrument — formal announcement in the Canada Gazette, Part *II*.

The SEIA is normally prepared when regulation or amendment to a regulation is the control instrument. The first two stages involve public participation. The SEIA process provides the opportunity for any interested party to make submissions concerning the proposed regulatory action. It should be noted that the EPS mandate provides for EPS to initiate or be supportive of other government departments that may require regulatory or legislative action for the protection of the environment. The leading role of EPS in the lead in gasoline issue is clear.

Supportive roles have been played by Health and Welfare Canada and by the National Research Council Canada. The mandate of Health and Welfare Canada, through the Health Protection Branch in this instance, is to promote the health of Canadians including the reduction of illness associated with environmental hazards. NRCC established the Associate Committee on Scientific Criteria for Environmental Quality as a result of the federal government's mandate to develop scientific guidelines for defining the quality of the environment. Recently, in 1984, at the request of the Minister of the Environment, the Royal Society of Canada (1985) was commissioned to provide the Minister with independent advice on the issue of lead in the Canadian environment. The commission has no authority and it acts entirely in an advisory capacity.

Implications of the Leaded Gasoline Case Study for Cumulative Effects Assessment

The institutional arrangements associated with the lead in gasoline case study were quite simple. The focal role of EPS was clear but the extent to which the technological and health effects issues influenced the decision-making process are difficult to assess. The technological considerations were provided through the use of independent consultant reports on studies for the SEIA, but there were numerous direct submissions by manufacturing and other industrial groups.

The process by which the findings of the SEIA were translated into precise levels for the lead content of leaded gasoline remains unclear. It appears that the levels of lead in gasoline may be established based on health effects, on economic criteria, or technological factors. In the case of unleaded gasoline, the regulations were based entirely on technological and social issues, specifically the need for proper functioning of catalysts and to ensure the supply of lead-free fuel. Establishment of the level of lead in leaded gasoline did not appear to make use of available dose-response functions for lead exposure due to leaded gasoline. The requirement base would be knowledge of relationships between lead in gasoline, lead in air, lead in blood and the health effects. In this context, the lack of Canadian National Ambient Air Quality Objectives for lead is surprising. The recent U.S. EPA Criteria Document for ambient lead (Environmental Protection Agency 1985) makes use of the relationships between ambient lead levels and blood lead levels and its associated health effects in the population groups of greatest risk. EPA has set standards for ambient airborne lead and it is interesting to note that three provinces in Canada, those with the three largest cities, have established ambient air quality standards for lead.

The health effects issues were championed by representatives of Health and Welfare Canada who strongly supported the phase-down of lead in gasoline as a means to reduce blood lead levels. The stated primary objective was to reduce the human lead exposure and burden through reduction of lead automotive emissions. The cost-benefit analysis was not applied to the health effects, though they were applied to other control options. In the socio-economic impact assessment for the lead-in-fuel phase-down, cost-benefit analysis respecting the human health effects was not attempted. There are approaches to valuation of human mortality, and to a certain extent morbidity, but they are rough tools at present. Until better linkage between data on health effects and their causes can be achieved, it will be difficult to conduct rational cumulative human health effects assessments.

The approach taken by the Royal Society of Canada provides a rational, though challengeable, basis for establishing lead levels in gasoline. This approach suggests that further reduction in gasoline lead levels will have beneficial effects by reducing further the lead in blood levels. It is anticipated that more details on this aspect will be provided in the final report of the Royal Society of Canada. The interim report of the Royal Society of Canada discussed two aspects of the lead in gasoline issue that are of importance in the assessments of cumulative effects. The first issue is the need to consider health effects that may result from the use of alternate anti-knock agents and the second is the effect that the proposed regulation of hydrocarbon and carbon monoxide emissions would have on the lead in gasoline issue. These aspects highlight the need to consider all appropriate environmental consequences of an activity and the need to establish co-ordinated actions between regulatory initiatives that have not only common research-ecosystem links, but also the same ecosystem-management links (Figure 4). In relation to the first issue, it is evident that the effects of changes in engine technology on emissions from cars with catalytic converters were not addressed nor was there any apparent effort to associate the lead emissions with other automotive emissions.

The second issue focuses on the impact that the recently promulgated regulations limiting hydrocarbons, carbon monoxide and nitrogen oxides emissions from light-duty vehicles (LDVs) and light-duty trucks (LDTs) will have on the leaded gasoline regulations. These regulations, referred to as the $HC/CO/NO_x$ regulations, will require the use of unleaded fuel for LDVs and will effectively increase the number of cars requiring the use of unleaded gasoline. Interestingly, the SEIA for the $HC/CO/NO_x$ regulations did make note of the reduced lead health impacts of the $HC/CO/NO_x$ regulations, along with the major effects namely, acid rain and oxidants. It could be argued that the effects of toxic particulate pollutants associated with diesel especially, and with automobile exhausts generally, should have been considered also.

Since the lead and the $HC/CO/NO_x$ emissions have common sources and undergo transformations in the same air masses, it only seems prudent to consider their impacts together. The common features of the lead in gasoline and the acid rain and oxidants issues beg questions related to synergistic effects and for integrated, holistic, environmental assessment. It is clear that the regulatory process has not always made these links, neither through research-ecosystem links nor through research-management links (Figure 4). It should be noted that a single institution has played the lead role in both issues, but its legislative mandate necessarily is restricted to Canada.

As far as development of suitable arrangements for future treatment of environmental problems is concerned, there is a need to improve existing methods and a need to develop new institutional arrangements by which related environmental problems can be assessed. Although the long-range transport of $HC/CO/NO_x$ and acid rain has been recognized, the associated SEIA did not include explicit consideration of the international aspect of the issue. It is clear that existing institutions do not have the necessary mandates to deal with international environmental problems that have cumulative effects. In this context, it is also relevant to ask whether existing institutional arrangements are appropriate to deal with problems that cross municipal and provincial jurisdictions as a result of long-range transport, through all media.

The lead-in-gasoline case study demonstrates that, in the development of regulations, it is necessary for cumulative effects assessment to take a holistic view of effects. This would eliminate the apparent separate treatment of related environmental issues. As outlined in the case study there is a need to consider all appropriate environmental consequences of an activity and a need to establish co-ordinated actions between regulatory initiatives that have not only common research-ecosystem links, but also the same ecosystem-management links (Figure 4). It is also evident from the case study that existing institutions do not have the necessary mandates to deal with international environmental problems that have cumulative effects.

CASE STUDY: SELECTED CUMULATIVE EFFECTS IN AQUATIC SYSTEMS, ATHABASCA RIVER BASIN, ALBERTA

The Athabasca River Basin is a major drainage system in western Canada (Figure 1) and contributes a large amount of flow to the Mackenzie River drainage system. The Athabasca River mainstream encompasses a wide spectrum of fishery habitat, ranging from a clear, cold, stream in its upper tributaries to a slow-flowing, silt-laden river near its delta. Some locations, especially those within Jasper National Park, are of national significance, and many others throughout the basin are of local, regional or, in some cases, provincial significance. In addition to the important considerations related to fish production, water from this basin is also required for competitive uses such as urban and industrial consumption and agricultural applications.

The region has been subjected to progressively increasing demands form many sectors within the last century. All have resulted in “cumulative” change. Some of the key activities leading to cumulative effects include: surface and in situ extraction of oil sands; urban development; recreational activities; agriculture; forestry; conventional oil and gas development; and use of insecticides for insect control. Clearly, each of these could not be examined exhaustively in a brief case study. Two selected examples were chosen because they are currently of significance to environmental managers within the region. Alberta’s blackfly control program and the regulation of effluents from petroleum-related industries provide two contrasting and instructive perspectives on how cumulative effects management is strongly influenced by jurisdictional boundaries and regulatory mandates.

Before focusing on these two selected examples, it is useful to note the existing variety of approaches to long-term management of cumulative effects within the basin. These approaches range from those used within Jasper National Park at the extreme upper end of the drainage basin, through to large-scale, but site-specific, environmental monitoring and research programs in downstream areas, particularly within the oil sands region and in the Peace-Athabasca Delta region. Each approach has the effect of establishing some limits on the rate of “acceptable” impacts and each approach entails significantly different strategies.

Clearly, Jasper National Park represents the most conservative approach to the management of cumulative change in the study region. In the national park, a specific region has been set aside with strict guidelines in place to govern the rates and types of human activities that are allowed. Nevertheless, the designation as a national park has connotations beyond maintenance of a “pristine environment.” Some cumulative changes do, in fact, occur there. Steadily increasing numbers of visitors create demands for accomodation. There is also increased traffic, wildlife deaths, and emissions of effluents and other wastes. On another scale, the designation as a park prevents forestry operations and enhances forest fire protection activities. Maturity of the forest increases with time, perhaps making it “cumulatively” more susceptible to catastrophic changes from fire, insects and diseases. The national park example demonstrates that even the most conservative management strategies for minimization of cumulative impacts nonetheless permit the steady encroachement of at least some effects.

The other extreme in the basin, both geographically and developmentally, is the oil sands development region. Industrial development there contributes significantly to major cumulative impacts through emissions of H_2S and SO, to the atmosphere, through emissions of a variety of chemical compounds to aquatic habitats and through major open-pit mining and its associated land-use impacts.

Cumulative Effects Pathways Involved

In the Athabasca River region, enormous swarms of blackflies (*Diptera:Simuliidae*) often emerge in agricultural areas anc cause severe disruption to cattle production. The problem has been dealt with through direct larvicidal treatments of the mainstream of the Athabasca River with insecticides, chiefly methoxychlor. The river is treated by agents acting under licence for interests supported by the Department of Agriculture. These treatments, carried out twice annually, lead to cumulative effects primarily through Pathways 1 and 2, as defined in Figure 2. The economic impacts arising from the flies is felt by the farmers, but the source of the pest is a large river, a zone that is technically outside the legislative mandate of the Department of Agriculture. Fisheries and environmental agencies, which have the responsibility for protection of rivers, find themselves caught between the politically active and powerful agricultural interests and their mandate to protect the aquatic "environment."

The insecticide treatments kill enormous numbers of the pest fly larvae, but they also kill many non-target invertebrates. Not surprisingly, there has been considerable debate about the significance of such treatment to the aquatic ecosystem (Wallace 1986a). As the treatments are licensed by government and proceed in order to lessen a pest species of economic importance, the obvious environmental impacts are discounted. Hence a jurisdictional loophole has allowed, even encouraged, repetitive treatments to be done in spite of cumulative effects on populations of aquatic organisms.

In contrast to the insecticides used for blackfly control, effluents from oil sands mining operations have been closely monitored and regulated. Ironically, these effluent discharges are much less toxic than methoxychlor to invertebrate species of the river and, in fact, may actually augment primary aquatic productivity in some cases (Lock et *a/.* 1981; and Wallace, *in* press). These long-term effluents, if they caused impacts comparable to the government-licensed blackfly treatments, would probably be the focus of an outcry for regulated controls.

Turning to potential cumulative effects pathways associated with industrial oil sands activities, it must be recognized that the chemical composition of bitumen changes radically upon being upgraded to synthetic crude oil, as shown by Speight and Moschopedis (1981) who compared the properties of bitumen and synthetic crude. The synthetic crude shows an increase in carbon and hydrogen and a decrease in sulphur. Also, the hydrocarbon structure is significantly different in that synthetic crude has no asphaltene or resins. The upgrading processes whereby the bitumen is changed chemically into crude oil obviously produces waste products and these are mainly contained within the wastewaters, although much of the sulphur lost from the bitumen is dispersed atmospherically or reduced to elemental sulphur. A considerable amount of water is used in the upgrading process and a great deal of research effort has gone into characterization of the organic constituents contained within the effluents produced from the Suncor project (Hrudey 1975; Lake 1976; Strosher and Peake 1976, 1978).

It is apparent that a variety of organic carbon products can enter the Athabasca River around Fort McMurray, and although the river is not devoid of carbon products naturally, the process effluents differ in amount and composition from the naturally occurring compounds. It is also known that certain hydrocarbon products are very toxic or even lethal to aquatic biota, even in very small amounts, particularly the low molecular weight hydrocarbons. Unfortunately, little is known of sub-lethal effects of these products such as fish tainting, but it has been suggested that aromatic compounds are a likely candidate. These are usually only found in very minute quantities, often below the detection limit of normal study methods.

Upstream of the oil sands processing areas are pulp and paper wastewater input sites on the Athabasca River, a fact that further emphasizes the difficulties inherent in assessing, or pinpointing, causal sources of cumulative impacts in "multiple-use" basins. Although one would expect that dilution and oxidation of potential contaminants would be complete before reaching Fort McMurray, it is still possible that some tainting of fish could occur. There is clearly a potential for multiple impacts (Pathways 3 of Figure 2) to occur in habitats of the Athabasca River system.

The rate of uptake of odorous (and hydrocarbon) compounds by fish can be very rapid. The rate can be influenced by the compound concentration, exposure time, water temperature, and perhaps most importantly, the species and physiological state of the fish. The species of fish can also influence the route of uptake, in that bottom feeders might ingest more hydrocarbons (both in food and sediment particles) than would planktonic feeders or predators. There have been several studies on the fish species that occur in the oil sands area (Bond 1980; Machniak and Bond 1979). The important fish species, in terms of commercial value, domestic harvest, and tainting potential, are whitefish and walleye. Walleye are predators and whitefish bottom feeders; hence, one might expect species differences in uptake of odorous compounds and tainting potential.

The bioaccumulation of petroleum hydrocarbons is related to their affinity for certain components in biological membranes and cellular materials, especially those lipophilic components. A good predictor of the potential for a particular hydrocarbon to accumulate in an organism is its octanol-water partitioning coefficient. This is based upon the ratio of the hydrocarbon tendency to concentrate in either n-octanol or in water, when exposed to a mixture of these two solvents. A wide range of petroleum hydrocarbons, including effluents from synthetic fuel production, have high octanol-water partitioning coefficients, and are readily bioaccumulated by aquatic organisms (Pathway 2 of Figure 2). This also explains why fattier parts of fish tend to reveal higher concentrations of hydrocarbon residues than do other tissues. Hydrocarbon residues in freshwater fish are generally either petroleum related, or from pesticide spraying programs. In the former category, Ackmann and Noble (1973) detected hydrocarbons in Athabasca River whitefish flesh that had a similar composition pattern to a sample of diesel oil that had spilled into the river.

The foregoing discussion illustrates the complexity of assessing, controlling and mitigating cumulative impacts within the Athabasca River Basin. Not only are the sources and nature of effluents to the river complex, but each has its own regulatory ("end of pipe") standards. The existing standards tend to ignore cumulative effects by whatever pathway (Figure 2) they may be developing.

Relationship to the Conceptual Framework for Cumulative Effects Assessment

For the blackfly control program, complexities of the cumulative effects pathways involved and uncertainties associated with the present state of the art for monitoring ecological conditions in large river systems reveal several important linkages between the ecosystem, research and management components of the conceptual framework for cumulative effects assessment (Figure 4). To illustrate these linkages it is important to note that the cumulative effects associated with larvicidal treatments occur in rivers that are so large that attempts to measure the impacts have been generally unsuccessful. Techniques of sampling both invertebrate and fish populations in such large rivers are in their infancy and only gross changes are measureable. Institutional rivalries take advantage of such uncertainties and scientific debate has gone on for several years between fisheries scientists and agricultural scientists — protagonists, each with their own jurisdictional vested interests — as to whether and under what conditions the treatments should continue.

Agricultural pests that originate from rivers, unlike grasshoppers, fall between present jurisdictional and administrative controls. As a result, the annual treatments and cumulative impacts will probably continue with regulatory agencies pitted against each other and each unable to solve the problem. The progressive advance of downstream use will, predictably cause an eventual confrontation between the upstream and downstream "users" and resolution will probably proceed along political and legal, not scientific, lines. Industrial and domestic users of downstream waters presently discontinue their water supply intakes during time of passage of the insecticide in the river. Native users, however, do not enjoy such luxuries.

Ecosystem and Research Components of the Selected Cumulative Effects

The difficulty of quantifying aquatic data in a river as large and long as the Athabasca is a major impediment to assessment of cumulative impacts. It is known that the insecticide kills far more benthic invertebrates than any other single impact, and that the pesticide is biodegradable in fish flesh. No major fish kills have been reported, although mortality has been suspected for small, susceptible larval fishes. What is not well known is the long-term, cumulative ecological consequences to the river system and its fisheries populations. Such consequences may be beyond our abilities to measure for decades.

Some compounds, such as phenols, are well known as fish-tainting chemicals, and are carefully regulated. However, there are many diverse compounds in petroleum effluents that are potentially of consequence for aquatic systems. What is known is that there is a steady release of material from natural and man-made sources into the river system, each with unknown cumulative effects.

There is a strong likelihood that tainting of freshwater fish within the oil sands area is associated with various components of the upgrading of the oil sands, because so many of the tainted fish cases in the literature have implicated hydrocarbon compounds from refineries. However, a complicating factor is that some hydrocarbons are found naturally in the Athabasca River and its tributaries in the vicinity of Fort McMurray. This is due to the erosion of the surface bitumen and its incorporation into the water column and bed material. Natural seepage has led to levels of hydrocarbons, and other constituents of the tar, which make the waters unacceptable for many purposes (Afghan and Mackay 1980).

The rising competitive demands for water use in the Athabasca River Basin will undoubtedly result in more frequent conflicts. The role of government agencies in monitoring cumulative impacts and in predicting them is highly questionable, however, since detection of even the most significant impacts is often by chance. The oil sands region has been subjected to some of the most intensive environmental research in Canada, yet we still do not have quantification, or even thorough identification, of hydrocarbons in effluents allowed into the system. Effluent limits are based on crude standards that tend to ignore the complex nature of hydrocarbon species. Furthermore, little has been done to link artificial and/or natural contaminants with residues detected in ecological systems (Wallace 1986b).

The Management Component of the Selected Cumulative Effects

The selected examples used in this case study are illustrative of a jurisdictional lapse leading to the continuance of long-term impacts in the face of a defined agricultural problem. The effects have been tolerated because user demands for waters in the downstream regions have allowed a range of impacts without producing conflicts. Each end-user has a distinct view of the basin and the priorities for use and protection. There is no accepted agency capable of dealing with such conflicts except at the political level.

In an era of conflicting water demands in the region from industrial, municipal and other sources, it is possible that allocative demands may cause significant conflicts over the existing blackfly control practices. For instance, native communities along the Athabasca River have registered their objections to the treatment. Furthermore, representatives of Fisheries and Oceans Canada have recorded strong misgivings about the long-term effects to the ecosystem. Attempts to stop the treatment have, however, quickly run afoul of strong agricultural interests which are, in turn, actively supported by government agencies that administer the larvicidal treatments in the rivers.

It is also noteworthy that cumulative impacts may be occurring in this large river system without the knowledge of regulatory or research agencies. A good example was the closure of the large commercial, freshwater fishery in Lake Athabasca in the early 1980s due to a serious fish tainting problem. The source was attributed to an oil sands operator, but evidence is still to be presented in the scientific literature, even though significant litigation has resulted under the Canada Fisheries Act (Wallace 1986b). This example is illustrative of several aspects of cumulative "change" in large ecosystems. First, only a massive alteration to an ecosystem, in this case the entire fish stock of Lake Athabasca, led to the recognition that something was wrong. Second, the change was detected by sources high on the food chain, involving commercial fish, and resulted in legal and economic actions such as fishery closure and compensation payments. Interestingly, no major fishery research programs were initiated, since it was assumed, with some justification, that the tainting episode was due to one massive release of pollutants to the river by an oil sands refinery operation.

Regional atmospheric emissions cannot be mitigated once released, so here the strategy must focus on the maximum recovery of sulphur compounds allowed by technology and economics. The emissions, nontheless, must result in long-term cumulative change on a regional scale and contribute at national and international scales as well. At the site-specific level, land disturbance will result, by the end of the mine's lifetime, in a significant change to landforms of the lease area. Further, the enormous tailings pond areas, filled with toxic chemicals and other unrecoverable materials, may contribute to significant cumulative atmospheric and groundwater changes over time.

The approach to cumulative effects management in the oil sands region has been threefold: special regional baseline studies; long-term monitoring; and government enforcement programs. The Alberta Oil Sands Environmental Research Program (AOSERP) was established as a federal-provincial research study of the baseline conditions in the oil sands region. The study, revolutionary at the time, recognized the magnitude of the proposed developments and focused on regional baseline studies, beyond the more site-specific impact research done by proponent companies. Although the program was fraught with organizational conflicts and ended with the federal government prematurely unilaterally withdrawing from it (Wallace 1981), the research was a unique attempt by federal and provincial agencies to address acute and cumulative effects. Baseline data so collected may serve as a valuable benchmark against which future changes may be observed.

The second approach, long-term monitoring, is a more conventional strategy. In the Athabasca River Basin, research into acidic deposition and effluents is carried out by established research agencies. They, unfortunately, do not predict cumulative change but merely act as monitors of it. The closure of the Athabasca Lake whitefish fishery due to tainting of fish flesh is an example in which cumulative change was noted but not studied in detail beyond its detection.

Government enforcement programs, the third approach, contribute to the day-to-day monitoring and enforcement of legal limits governing atmospheric and aquatic emissions and in implementation of operational programs in reclamation. Here, cumulative effects are rarely seen, except in instances where catastrophic releases of pollutants have contributed to such effects. For example, phenolic tainting in the Athabasca Lake whitefish was thought to have resulted from an emergency release by an oil sands operator and enforcement actions were initiated.

In summary, cumulative effects management occurs on three levels, each addressing different periods of time and spatial dimensions. Reclamation procedures are implemented on a daily basis, as is effluent monitoring, but each area incrementally contributes to major, cumulative changes in landforms and in the quality of aquatic habitats.

Are there lessons to be derived from these various institutional approaches? One shortcoming is that there is too little integration of the three approaches. For instance, daily limits on effluents rarely are based on meaningful standards related to long-term cumulative change. Acute toxicity data for fish may completely miss important, long-term cumulative effects of hydrocarbon tainting or slow accumulations of heavy metals in food chains. Further, long-term acidification of regional soils may be slowly contributing to mobilization of heavy metals into aquatic systems. These questions suggest that long-term cumulative effects may be linked. Existing institutional structures tend, however, not to focus on linkages but on specific sources of inputs to natural systems.

There are few examples where the long-term monitoring systems are adapted to provide data directly back into daily effluent monitoring licensing agencies. These functions are often split jurisdictionally and institutionally. It is well known that regulatory standards rarely address truly long-term damage to ecosystems. It is unfortunate that so little "ecosystem research" is initiated to better understand the individual and collective influences of effluent standards. The Athabasca oil sands development is a good example of a case in which such research programs have been initiated, but significant cumulative impacts have nevertheless occurred and heavy metal accumulation is now known to be ongoing (Syncrude Canada Ltd. 1985).

This case study demonstrates that the legal and organizational structure of regulatory agencies can strongly shape attitudes toward cumulative impacts. In essence, the word "cumulative" is left to various user groups to define. Enforcement or regulatory actions most frequently result from sudden loss of segments of the ecosystem that are valued for either aesthetic or monetary reasons, but the slow loss of resources, over a period of decades, often escapes both regulatory and political attention,

The selected examples outlined in this case study emphasize that each cumulative effect must be viewed carefully. An accurate assessment of all potential consequences of many changes may be difficult to reach, especially in cases where minute, incremental changes over long periods of time occur, as in stream degradation. The slow, incremental changes, however, may exert a far more profound effect on ecosystems in the long term than many sudden, acute impacts. The former are also of importance because, in addition to being insidious, they are invariably more difficult to address due to jurisdictional problems and because it is often difficult to motivate the public and the appropriate government regulatory agencies to address slow, long-term change. Destruction by insignficiant increments (Gamble 1979) is probably the most influential form of cumulative change on a regional scale yet it is the most difficult form to manage.

Implications of the Athabasca River Basin Case Study for Cumulative Effects Assessment

This case study revealed that long-term, cumulative changes (since 1800) are poorly documented. Not until the time of large oil sands mining operations were baseline environmental studies initiated. Major cumulative impacts that may have been initiated at the time of first European contact are now difficult to reconstruct, a circumstance that stresses the importance of the time dimension in cumulative effects assessment. Furthermore, the aquatic system is large enough to make quantitative assessments difficult, an indication that the space dimension is also fundamentally important in cumulative effects management. Predictive models are not available and only massive changes are generally detected. Because of these circumstances, cumulative, and often competitive, user demands on the system may have consequences well beyond the detection capabilities of the existing regulatory or scientific agencies, notwithstanding large research programs carried out in the region.

Allocative conflicts of user demands, when they arise, are most often resolved through political mechanisms and these may ignore scientific evidence or even the regulatory mandates of individual agencies. Regulations may focus on effluents that are controlled by regulation of corporations and may turn a blind eye to pollutants, such as insecticides used in larvicidal treatments, which may cause far more damage to aquatic ecosystems than do the regulated effluents. Existing regulatory structures are known to have failed in protection of the Athabasca freshwater fishery resource on at least one occasion. While the standards for cumulative, hydrocarbon pollutants are presently the subject of reconsideration by regulatory agencies, the sheer number of chemical compounds being assessed presents major problems for regulators. The inadequacy of this approach, in the long term, was described by Hamilton (1986) as follows:

> *Despite the clear and unequivocal evidence that the current approaches for "freshwater" management are woefully inadequate, the agencies and bureaucracies that now have this responsibility are controlled primarily by persons who are committed to "pipe" and "technology-based" standards.*

Hamilton (1986) concluded that less focus should be devoted to detailed EISs and that managers should:

> .... *consider the larger processes that are impacting on a given issue . . . . [so as to] . . . . foresee more of the cumulative impacts of interacting processes, policies and programs.*

Hamilton (1986) further stressed the need for less reliance on regulation as a means of sustaining the long-term viability of freshwater ecosystems. This view was also reached by Orians (1986), who noted that:

> .... *chemical monitoring is often favoured because regulatory standards are cast in terms of concentrations of chemicals rather than on the presumed biological effects of those concentrations.*

O'Riordan (1986) noted that in another river system, the Fraser River estuary, where there was a significant threat to environmental quality posed by multiple discharges and habitat losses, a federal-provincial agreement was signed in 1977. The plan formulated analyses of wastes, trends in receiving water quality and establishment of water quality objectives. In the Athabsca River Basin there has been a trend toward similar approaches. The disruptions of ecosystems and renewable resource harvesting in the Peace-Athabasca Delta as a result of upstream hydro-electric construction illustrates the extreme "worst case" of mitigative attempts following poor project and basin impact assessments. The Alberta Oil Sands Environmental Research Program (AOSERP) is another example, at the opposite extreme perhaps, of much detailed "baseline" research carried out parallel with major oil sands development activities. However, much of this abundance of baseline data remains unincorporated into subsequent basin standards or objectives.

There are other examples of attempts to initiate more broadly based concepts in basin management in Alberta. The recent plan for the South Saskatchewan River Basin (Alberta Environment 1984) and the Cold Lake – Beaver River Water Management Study (Alberta Environment 1983) attempted to place multiple use conflicts within a planning framework. Although much remains to be done before such plans achieve practical and implementable results, they represent significant steps toward a broadened scope of environmental analysis and management. For example, the authors of the South Saskatchewan River Basin Plan noted (Alberta Environment 1984):

> .... we *cannot manage any one river in isolation from others. We must consider how decisions about the use and management of water in one basin will affect . . . . the other two basins.*

The Cold Lake – Beaver River Water Management Study (Alberta Environment 1983) was also designed to plan for the management of surface and groundwaters in two basins. The potential for large water withdrawals for oil sands developments catalyzed the planning process, in light of water quantity and quality obligations set out in the Alberta-Saskatchewan Master Agreement on Apportionment. The Cold Lake – Beaver River basin plan was innovative in that it was intended to "guide and/or serve(s) notice to the various water users on how their water needs will be met in conjunction with those of other water users." This short-term plan sets out the province's intention to restrict withdrawals in certain areas, protect instream water needs, maintain control over water management and monitoring and restrict waste and runoff impacts.

Such broadly based planning clearly includes social and ecological systems and hence public input has been sought for each plan. The South Saskatchewan plan has, for instance, been the subject. of extensive hearings conducted by the Alberta Water Resources Commission, for which a final report is expected in the near future. One of the direct values from such a process is that it tends to develop a context for existing and future developments within the basins.

Another more recent publication by oil sands producers shows considerable promise for industry-based cumulative effects assessments (Syncrude Canada Ltd. 1985). A long-term monitoring network was established to measure accumulations of atmosphere-borne heavy metals and acidification effects in the region. This early warning system shows considerable promise when placed in the context of a lo-year monitoring report and indicates that proponents themselves may be a vital component in extending the EIA process as a first step in cumulative effects monitoring. This industry initiative should be more closely examined by CEARC for wider, potential applications to cumulative effects assessment in Canada.

The divided jurisdictional approaches for management responsibilities in major river basins tend to be subsumed within wider regulatory control mechanisms and strategies. For example, O'Riordan (1986) suggested that one means of dealing with the dichotomies of centralization versus decentralization is through the development of environmental mediation techniques, since decisions "based on negotiations can be more adaptive than those proposed by centralized institutions." In Alberta this has yet to be demonstrated conclusively in the basins examined. However, recent initiatives by the Energy Resources Conservation Board (ERCB) with the Fort MacKay Indian Band in reviewing the Syncrude Mining Application show considerable promise in attempting a mediated settlement in lieu of lengthy hearings.

The value of EIA as a component of a regional decision-making process is indicated by the Fort MacKay-ERCB initiative. Although a recent Syncrude EIA emphasized the site-specific aspects of the mine expansion application, the response from the Fort MacKay Indian Band in the ERCB mediation forum focused on concerns at two levels: site-specific (project) and regional concerns. The emergence of regional concerns in the Band's response is the most intriguing development of this mediation process. First, regional aspects are outside the terms of reference of the normal ERCB review process and are not covered by the Syncrude EIA. Second, the focus of the Band, as intervenor, was much broader than the prescribed guidelines for EIA. Thus, the mediative process initiated by the ERCB achieved several breakthroughs: it broadened the focus of the EIA to include regional concerns; it allowed traditional jurisdictional lines of related agencies (Alberta Environment and Alberta Fish and Wildlife Division) to be melded into a broader discussion of issues related to the development proposal; it by-passed the need for adversarial hearings processes; and it allowed direct negotiations between the proponents, the intervenor and government agencies.

In effect, this mediative process has significantly extended the traditional boundaries of the EIA process and gave the regulatory agencies a much-improved decision-making perspective. Further, the proponents were provided with an opportunity to respond directly to intervenors and to negotiate solutions as part of the EIA review process before regulatory decisions were rendered by the licensing agency, or at least in concert with them.

Sadler (1986) anticipated a similar evolution towards mediation in cumulative effects management by noting that:

> .... *sophisticated mode/s fail to provide useful long-term impact predictions. However, simpler models, which incorporate the pros and cons of mitigation alternatives, can be instrumental in arranging negotiated solutions to problems .... Where problems are encountered is in moving away from bargaining as a process for coping with scientific uncertainty toward mediation as a process for reconciling value conflicts.*

The uncertainty of predicting cumulative effects may be partly overcome by the evolution of ongoing mediation-negotiation practices among the parties-at-interest. The success of environmental management within bounded systems and the enormous difficulties in managing more open (estuarine or inter-jurisdictional) regions emphasize the potential importance of such an approach. Eventually, the traditional centralized approaches to environmental mitigation may be outmoded entirely in cumulative effects management. The Fort MacKay – ERCB example from the Athabasca River Basin may be pointing the way to a mediation process in which the large centralized institutions, which have until now held the sole mandate for environmental control, may become but one party in broader consultation.

The linkages of EIA and basin planning may yet be demonstrated in ways not traditionally considered by existing agencies. The suggestion by Beanlands (1986) that EIS guidelines could "define the management unit(s) involved or give criteria by which boundaries could be established" is a good one. However, it is rare to date for EIA work to venture into a potentially political arena. Both the impact assessors (proponents) and regulatory agencies have a strong, vested interest in not allowing such assessments to expand. However, they may welcome the concept of guidelines that clearly define the boundaries for assessments, although most proponents have been reluctant to enter into discussions of impacts outside of their own lease areas.

The Athabasca River Basin case study suggests that the potential of EIA processes will be limited until presently available legislative mechanisms are employed. Another alternative is for EIA processes, in cases such as the Athabasca or South Saskatchewan river basins, to focus on existing basin planning initiatives. However, the Athabasca River Basin experience suggests that EIA processes could be improved only in a limited way by such an approach. A prerequisite is the early implementation and development of regional basin management plans within which EIAs could be emphasized. Such an initiative cannot be expected to derive first, or solely, from the EIA process itself, but from broader government-based initiatives at basin strategy planning. In this context, CEARC could focus attention on successful examples and encourage their use elsewhere.

There are also indications from the Fort MacKay – ERCB initiative that encouragement of basin planning initiatives, when combined with more traditional EIA processes, could be catalyzed by mediative or negotiated processes among the parties-at-interest. Although this is a newly developing area, initiatives within the Athabasca Basin show considerable promise. In such a setting, EIA could move from being the centre of the regulatory-review process to being an issues identification step in much broader institutional and regulatory procedures. CEARC should consider research on potential strategies for implementing such mediative solutions within the context of existing EIA processes. CEARC could be a leader in identifying the regions, projects and parties-at-interest for which such processes could be implemented.

To advance these ideas, CEARC could fill an important role by promoting education and dissemination of information on successes in cumulative effects management across Canada. The use of specific successful examples, such as that developed by Syncrude Canada Ltd. (1985), could assist agencies to assess and to try examples from other regions. While perhaps well known among academics, these management applications are often poorly understood among other resource managers across Canada. CEARC could have a formative role in developing strategies for communication among the decision-making bodies and in encouraging the implementation of long-term cumulative effects monitoring networks.

CASE STUDY: LAND-USE PRACTICES, HABITAT FRAGMENTATION AND SOIL CHANGES IN THE PRAIRIE PROVINCES

This case study examines several selected cumulative effects in a large geographic area that extends from the Peace River region of northeastern British Columbia to southeastern Manitoba, and from the Canada-United States border north to the forestry-agriculture interface zone at the southern edges of the boreal forest (Figure 1). A large study area such as this collectively experiences a wide variety of cumulative effects involving atmospheric, terrestrial and freshwater ecosystem components. However, this case study limited its focus to terrestrial cumulative effects. It emphasizes examples of specific problems associated with the management of cumulative effects when these are the result of many small actions that, individually, are considered to be environmentally insignificant.

There have been few megaprojects in the region and significant concentrations of major disturbances to pre-existing ecosystems are limited to urban areas, oil sands mining, coal mining in southern Saskatchewan and the Alberta foothills, and the Lake Diefenbaker reservoir on the South Saskatchewan River. Intermediate intensity disturbances (less intensive than major man-made changes but more intensive than general agricultural and forestry operations) are associated with: localized areas of severe habitat fragmentation as a result of road networks and cleared seismic lines such as in the Swan Hills of Alberta; networks of petroleum production facilities at many locations in Alberta, western and southern Saskatchewan and southeastern Manitoba; pulp mills and associated harvesting operations at Hinton, Alberta and Prince Albert, Saskatchewan; and the areas surrounding several potash mines in Saskatchewan.

Particular emphasis was placed on low-intensity cumulative changes that occur throughout the study area. The apparently insignificant increments associated with many small operations present special challenges to assess and manage cumulative effects on a regional scale. Land-use changes, habitat fragmentation, several kinds of soil changes associated with agricultural practices, and the increasing dependence on agricultural chemicals were selected to focus on what Odum (1982) has called the “tyranny of small decisions.”

Water-related issues were not examined, although they are an integral part of cumulative effects management in the case study area. Several water issues were outlined above and other recent water-related analyses included those by Alberta Environment (1984), Lane and Sykes (1982), Mackenzie River Basin Committee (1981), Pearse et *al*. (1985), Sadler (1983, 1984).

Cumulative Effects Pathways Involved

The examples in this section focus on cumulative changes that result from thousands of individual operations over a large area. The examples involve the additive Pathway 1 shown in Figure 2 as well as multiple impacts (Pathway 3).

Competition between agricultural and forest uses for land bases of suitable capability is the central issue associated with the agriculture- forest interface across Canada, and a number of cumulative effects result from this competition. Particularly in the western provinces, farming and forestry commonly compete for the same land (Fox and Macenko 1985). In British Columbia, Alberta and Manitoba, the general trend has been the expansion of agricultural expansion at the expense of the forest land base. Some limited agricultural expansion has also occurred locally in Saskatchewan. In the period 1961 to 1976, a major westward shift of farming in Canada was accompanied by greater intensification of cultivation on the best land and abandonment of land less suited for farming. In the main farming area of the prairie provinces, the average farm size in 1976 was over 300 hectares, an increase of 20 % from 196 1. The Peace River region of northwest Alberta and northeast British Columbia experienced the greatest advance, with a 60 % increase in average farm size to 313 hectares by 1976 (McCuaig and Manning 1982).

An agroclimatic resource index (ACRI) has been used to determine areas most valuable for agricultural production. Saskatchewan and Alberta together have 61% of Canada’s prime agricultural lands with ACRI values of 1.4 and 1.5, respectively. Only 15 % of Canada’s farmland has ACRI values of 2.0 or greater, principally located in Quebec and Ontario. Replacement of lost high capability agricultural land by new agricultural land must necessarily be at the agricultural margins, particularly the Peace River district of Alberta and British Columbia, the northern clay belt of Ontario and scattered areas in the Maritimes. The ACRI of the Peace River district is 1.0. This means that to replace lost prime agricultural land (ACRI of 2.0) twice as much land would be required at the margin in the Peace River district where climate limits the kind of crops possible. The cumulative socio-economic result is that replacement can only be accomplished at progressively higher costs for land development, energy and transportation per unit of food produced (Lands Directorate 1985). The alternative to use of marginal areas for replacement of lost prime agricultural land is more intense use of existing prime agricultural land, at the risk of other forms of cumulative land degradation.

While agricultural expansion has occurred in the last few decades at the northern margin of the case study area, some of the most productive agricultural land has been permanently lost to urban expansion and other forms of construction. The juxtaposition of high population density and inherently valuable agricultural lands has resulted in serious conflicts in land use. In Canada as a whole, more than 3.5 million acres of farm land changed to urban use between 1961 and 1976 (Senate Standing Committee on Agriculture, Fisheries and Forestry 1984). The increase in built-on land in Alberta alone amounted to a 145.2 % increase between 195 1 and 1981 (Bird and Rapport 1986).

Urban expansion has also had an impact on prime waterfowl land in Alberta, British Columbia and Saskatchewan (Lands Directorate 1985; Warren and Rump 1981), but widening and extension of roadways is an even greater source of cumulative effects. In Alberta up to four times as much land was consumed by roads, highways and other transportation systems than was consumed by urban areas, based on information compiled up to 1977 (Thompson 1977). Substantial increases in the aggregate length of paved roads occurred across Canada since 1960 but the second greatest proportion of change (204%) occurred in the prairie provinces where the extent of paved roads increased from 18,731 kilometres in 1960 to 56,988 kilometres by 1975 (Bird and Rapport 1986). Such land-use changes lead to fragmentation of wildlife habitat.

To sustain a healthy population of most wildlife species, a minimal non-fragmented area of habitat or a larger area of partially fragmented habitat is required. Although habitat fragmentation has been directly documented in some areas (Burgess and Sharpe 198 1; Salwasser 1986), in the case study area most of the published information is about its complement — habitat loss. For example, Thompson (1982) in Alberta, Dancik et *al.* (1979) in Alberta, and Boateng (1984) in British Columbia all provide data on habitat loss. These examples offer indirect evidence of habitat fragmentation that is deleterious to wildlife species of closed forest canopy but advantageous to those that frequent forest edges. Westworth and Brusnyk (1984) have studied the latter in relation to pipeline rights-of-way in forested areas. Declines in waterfowl numbers with loss of wetland habitat are well documented (Environment Canada and United States Department of the Interior 1985). Rubec and Rump (1984) tabulated from the literature the net wetland loss from different areas in British Columbia, Alberta, Saskatchewan and Manitoba. As an overall estimate, Wildlife Habitat Canada (1985) considered that prairie wetlands are being destroyed at an average rate of 2 % per year. Westworth and Brusnyk (1983) have studied the influence of size and shape of remnant habitats on white-tailed deer populations. For less commercially important animal species and for plants it appears that very little is known about habitat fragmentation in the case study area (M. Dale, pers. corn.).

Changes in agricultural production in recent years have promoted certain practices that have contributed cumulatively to soil erosion: the extension of cultivated land and cropland; continuation of the practice of summer fallowing; reduced utilization of grasses and legumes in crop rotations; intensification of land use through larger farms and bigger machinery; expansion of monocropping and increased specialization (Senate Standing Committee on Agriculture, Fisheries and Forestry 1984).

The loss of soil by a water and wind erosion means loss of nutrients needed for plant growth and loss of organic matter with resulting reduction in water-holding capacity. A concurrent cumulative effect is siltation of natural surface drainage channels. In the prairie region, infrequent but intense summer rainfall storms are a significant cause of water erosion by sheet, rill and gully erosion. Rolling lands west of the Red River Valley, Manitoba, are a susceptible example, as are the lower foothills of Alberta, the Peace River region and the area of central Saskatchewan from Prince Albert to Yorkton (Simpson-Lewis et *al.* 1983).

Erosion from summerfallow fields is twice that from wheat in a wheat-fallow system, and a study in the Swift Current area of southwestern Saskatchewan revealed that summerfallow loses four to eight times more soil during snowmelt than stubble fields (Nicholaichuk and Read 1978). Recent trends towards reduction of summerfallow area and increasing use of minimum tillage or zero-tillage methods should reduce erosion. However, the overall amount of soil erosion is increasing in the Peace River area where further land clearing is occurring (Simpson-Lewis et *al.* 1983). On sandy soils in southern Manitoba where there are increases in wide-row corn and soybean crops, which afford little soil protection, soil erosion is also intensifying.

It is often the richest part of the soil that blows away; the all-important organic matter exists in small particles readily carried by the wind. The economic cost of topsoil loss is indicated by the fact that removal of 2.5 centimetres of topsoil from one hectare of dark brown soil takes away 160 tonnes of soil and enough nutrients to produce 1,235 bushels/hectare of wheat. Added to this loss is the removal of recently applied fertilizers.

Reduction in soil fertility has been partly shielded by increased yields derived from fertilizers, herbicides and improved crop varieties. However, these technological advances have not restored the cumulative net loss of organic biomass. Depletion of organic reserves below a critical portion of their original levels leads to instability in the soil system and to erosion hazard (Sanderson 1982), effects that have been made worse by drought conditions.

Significant areas of prairie soils now require nitrogen fertilizer *even* after being summerfallowed (Beaton 1980). Considerable loss in total organic matter has occurred cumulatively over time due to cultivation of prairie soils. The soil organic matter content of cultivated prairie soils declined by as much as 48% compared with native soils (Bentley and Leskiw 1984). McGill et al. (1981) determined that the percentage of soil organic matter losses from A horizons of prairie soils ranged from 41 %

on brown soils to 49% on black soils since cultivation began. Grey soils of forested areas along the northern edges of the case study area have suffered an average 36 % organic matter loss in the period of cultivation. Organic matter loss affects the ability of soil to hold moisture and leads to related problems of soil erosion, alteration of soil structure and spread of salinity. Cropping systems that include summerfallow leave the soil free of vegetation and well aerated for extended periods of time, leading to lower levels of soil organic storage, lower resistence to erosion and less structured stability (Simpson-Lewis et *al.* 1983) than is the case in grassland or in forage rotations. The situation has reached such proportions for certain areas that some soil scientists speak of rehabilitating the soil, not just conserving it.

Although nutrient loss by leaching is commonly associated with climates in which precipitation significantly exceeds evaporation, recent research has established that leaching of nitrates does occur in the semi-arid conditions of the prairies. Evidence from southwestern Saskatchewan shows that water and nitrates were being leached below the root zone of cereal crops in wet years (Campbell et *al.* 1985). Crop sequences that permitted the greatest loss of nitrate were the short two-year and three-year wheat-fallow rotations with no fertilizer additions. Even with wheat grown each year, some nitrate was lost in wet years. These recent findings suggest that leaching has been as much responsible for nitrate losses as erosion, based on growing season precipitation records. The latter indicated that 30 of the past 96 years had precipitation levels equal to or greater than the 243 millimetres received during the relatively wet year of the study (1982). These findings are an example of the kind of basic information needed to assess the cumulative changes in soil nutrient status. Serious concern is apparent for the natural nutrient balance of soils. In the prairie provinces in 1960-62, the nutrient uptake of the harvested crop was derived principally from the natural nutrient content of the soil. By 1982, this situation had changed dramatically (Bird and Rapport 1986).

There are indirect effects associated with the cumulative changes outlined above. Related problems such as acidification and soil compaction result from intensive farming practices that involve applications of fertilizer and other activities that requiring mechanized passage over the land. Soil acidification may be natural or it may be induced by factors such as fertilizer application, cropping system selected, soil management practices and industrial emissions. Use of nitrogen fertilizer and the presence of acid rain magnify acidity problems of soils (Bentley and Leskiw 1984) so that liming is increasingly recommended to maintain soil productivity. The use of lime on the prairies is a recent phenomenon due to the considerable use of nitrogen fertilizer in recent years. It has been estimated that from 1985 onwards, acidity induced by nitrogen fertilizer may require over 250,000 tonnes of lime per year to offset reduced yield from acidity influences in Alberta and northeastern British Columbia. However, the extent of liming may be limited by the costs required to mine, process, transport and apply lime, despite a lime freight assistance program instituted by the Alberta government (Bentley and Leskiw 1984; Bircham and Bruneau 1985).

Soil salinization is another cumulative effect associated with today's agricultural practices. It has long been known as a local problem, recognized in irrigation areas as a canal leakage problem. It is now recognized as a pressing dryland farming problem. The soluble salts, mainly magnesium sulphate, sodium sulphate and calcium sulphate, increase the osmotic pressure of the soil solution and interfere with plant uptake of water and nutrients. The plants are under water stress even in the presence of water. The patchy nature of the distribution of salinized soils makes it difficult to assess accurately the total acreage involved but there is no difficulty in identifying it as a cumulatively increasing hazard to crop production.

Some specialists (Henry 1986) view salinization as a water problem rather than a soil problem because many salinized soils are excellent if judged on all other criteria except salt concentration. Two prerequisites are necessary for saline soils to develop — a source of water, and significant periods of the year when evaporation exceeds the quantity of water entering the soil by precipitation or irrigation. Some soil salinity results from runoff water that moves laterally through the soil because of impermeable layers and then discharges in a lower slope position. Such areas exist in south-central Saskatchewan and parts of Alberta and Manitoba.

A common form of soil salinization results from groundwater discharge from bedrock and glacial aquifers that are under artesion pressure (Henry 1986). Such areas are common in Saskatchewan. In such cases, water enters, primarily through sloughs, to aquifers that provide rapid permeability and movement over long distances from the point of entrance. Where the aquifers become discontinuous, pressures provide an upward gradient that transports water and salts close to the surface and maintains a high water table by constant upward movement from the aquifers.

The wheat-fallow rotation system, so long expounded as a soil conservation measure, has contributed to the disruption of the water cycle so that salts found naturally in soils at some depth have been dissolved and brought to the surface layer where their presence rendered the soil infertile (Sanderson 1982). Rough estimates suggest that in some areas salinization may be spreading at a rate of up to 10 % per year (Bentley and Leskiw 1984). A recent overview of land degradation on the Canadian Prairies (PFRA 1983) concluded that salinization may be the cause of annual economic losses four to five times as great as the combined annual economic losses due to erosion, loss of nitrogen and acidification. This same organization acknowledges that the extensive practice of summer fallowing is by far the most important cause of soil degradation in the prairie provinces (PFRA 1983).

The last example of agriculturally related cumulative effects relates to the continuously increasing use of agricultural chemicals. The trend to minimum tillage or zero tillage farming methods is a stimulus to herbicide usage. Sales figures reveal that large quantities of insecticides, herbicides and fungicides are used annually in Canada. In 1977, sales in Canada of fungicides were $8 million, insecticides $21 million and herbicides $125 million. Reasonably accurate data are presented each year at the meeting of the Expert Committee on Weeds, but comprehensive data on quantities of insecticides, fungicides and herbicides used in Canada are not available. Statistics Canada data are presented in a way that protects the secrecy of company information; for example, data for several compounds are pooled or data are simply not given. Thus, an accurate assessment of the present and future role of pesticides in Western Canada is not possible (Hay 1980) and this presents a major challenge to cumulative effects assessments for agricultural chemicals.

R. Owens (pers. corn.) assembled the following information from records of chemicals put down by licensed applicators in Alberta in 1982. The rule of thumb that is generally accepted in the literature is that use of chemicals by licensed applicators accounts for about 10 % of total use.

Insecticides	**kg**
malathion	**6276**
chlorpyrifos	**4630**
dimethoate	**4046**
carbofuran	**2127**
diazinon	**1875**
carbaryl	**1418**
methomyl	**1118**
methoxychlor	**971**
trichlorfon	**614**
temephos	**589**
Total	**23,664 kg**
Total for all insecticides, involving 40 compounds	**25,526 kg**

Herbicides	**kg**
triallate	**185,589**
2,4-D	**161,161**
MCPA	**36,923**
trifluralin	**22,929**
picloram	**17,808**
bromoxynil	**10,147**
dicamba	**9,170**
diclofomethyl	**8,280**
difenzoquat	**7,764**
acrolein	**7,388**
Total	**467,159 kg**
Total for all herbicides, involving 50 compounds	**529,300 kg**

Fungicides	**kg**
carbathiin	**19,922**
benomyl	**2,570**
chlorothalonil	**1,329**
thiram	**1,275**
pentachlorophenol	**1,101**
Total	**26,197 kg**
Total for all fungicides, involving 19 compounds	**27,315 kg**

Using the 10% rule of thumb this means that 250 tonnes of insecticides, **270 tonnes of fungicides and 5,300** tonnes of herbicides were applied in Alberta in 1982. It is not known exactly where or when these chemicals were applied or how often any given field was sprayed.

Relationship to the Conceptual Framework for Cumulative Effects Assessment

The selective cumulative effects given attention in this case study reveal the central importance of the research component within the conceptual framework for cumulative effects (Figure 4). As outlined in the next section, habitat fragmentation is an example of a cumulative effect that has occurred because there is a weak ecosystem-research link (Figure 4), in the sense that so little is known about the size, shape, and distribution of habitat fragments needed to support particular species of wildlife.

In contrast, knowledge about soil erosion, topsoil losses, soil nutrient depletion and soil salinization is well advanced. In these cases, cumulative effects occur because activities along the ecosystem-management links of the conceptual framework (Figure 4) occur without full use of knowledge generated in the research component. In other words, although the research-ecosystem links (Figure 4) are strong, the research-management links (Figure 4) remain weak. These relationships to the conceptual framework are described in more detail in the next two sections.

Ecosystem and Research Components of the Selected Cumulative Effects

The biological consequences of habitat fragmentation are under active scientific debate. Habitat fragmentation has the effect of creating a metapopulation, which is a large regional population made up of many smaller populations of varied sizes, densities, and degrees of isolation from one another. The program to conserve a regional spotted owl population in mature and old-growth coniferous forests of Washington, Oregon and California (Salwasser 1986) is a well-documented example of management based on a knowledge of metapopulation genetics.

As habitat fragmentation continues, the list of species that are composed of metapopulations increases. Even more importantly, as recognized by CAETEP (1986), only recently has it been realized that such species cannot be protected against the threat of extinction by managing habitat for their local constituent populations. This recognition is the crucial first step toward maintaining the long-term viability of threatened species, but the scientific issues raised will not be easy to deal with, and the social and political steps required will not be easy to accomplish (CAETEP 1986). Unfortunately, the data needed for incorporation of metapopulation models into management guidelines is unavailable for most species.

Attempts to limit the cumulative effects associated with habitat fragmentation are hampered by a poorly developed research component. For most animal species, the minimal area of undisturbed habitat needed to support a given population is not known. Even less is known about the size, shape, distribution and proportion of total area of residual habitat fragments required for support of particular animal species. These information gaps must be closed if there are to be defensible remedial programs. For example, if land is to be purchased as "base habitat," it is desirable to know how much in total area, what sizes and shapes of parcels and what distances between parcels are necessary to sustain target populations. Similarly, when agricultural expansion is anticipated it is desirable to explain what land should be left undisturbed and why. There is a good illustration of this in progress at the present time. In the Big Ben area in northern Alberta, large blocks of land are being converted to agriculture piece by piece. The area supports moose populations of significant economic value and the region is considered to be of marginal agricultural capability. Alberta Fish and Wildlife would like to protect the moose populations but it cannot do so on the basis of specific habitat fragmentation criteria because information on the latter is unavailable.

In contrast to the unknown aspects of habitat fragmentation, improved soil management appears to be more dependent upon application of existing knowledge than upon research to generate new knowledge. There are, however, some exceptions to this generalization. In particular, the manner in which saline salts can be contained varies with their source and is dependent on basic knowledge of the problem. The Saskatchewan research by Henry and co-workers conducted between 1982 and 1985 on salinity caused by artesion pressure, rather than saline seeps, is illustrative of this point (Henry 1986).

Stewart (1985) stressed that remedies for soil conservation depend on a good research base, proven with experimental sites and then transferred to the producer. For many of the physical and chemical processes involved in cumulative soil changes, a good research base already exists. Technology transfer is a key component to be fostered by whatever means possible, with strategies co-ordinated around the farmer-producer. In the opinion of Stewart (1985), integration of this task is the combined responsibility of both federal and provincial governments through a proposed Land and Water Conservation Centre with a mandate to develop packages of information for farmers. Time frames of five to ten years would be needed for remedial measures to be successful. Technology transfer will have to be developed in the form of information packages for specific crops and conditions across the prairies. Some analysts have cautioned that to suggest that all that is needed is the application of existing knowledge would be misleading. In addition to the crucial educational aspects, there is also a need for identification of the full environmental effects and interrelationships in conservation issues, using a systems approach (Bentley and Leskiw 1984). A major impediment to cumulative effects management is that information on soil degradation has been very slow to be accepted by those who could take corrective action.

The federal government is considered to have prime responsibility for the long-term research required. However, on-farm delivery of information and assistance is better handled by provincial institutions. The federal PFRA program is an exception with its longstanding farm contacts but it could place more emphasis on soil conservation. Provincial governments bear the greatest responsibility for soil and water conservation and the major responsibility for land-use planning is left to local authorities. One noted problem is that planning authorities have responsibility for too small an area to cope with cumulative effects (Stewart 1985).

There are also outstanding information gaps in relation to agricultural use of pesticides. Even if there are not significant problems of persistence or bioaccumulation of the compounds, the effects of repeatedly removing susceptible species of animals and plants from the ecosystem are clearly cumulative and their consequences are not known. For example, what is the reaction and long-term effect upon birds, mammals and insect-pollinated plants of practices that repeatedly remove all insects from the ecosystem? Work is needed to assess the possibility of residue build-up over the long term and to predict what synergistic effects might occur (Environmental Council of Alberta 1985). Persistence of herbicides under prairie climate conditions, for example, is not well known.

The Management Component of the Selected Cumulative Effects

In relation to management of habitat fragmentation, several programs have been established to set aside parcels of land as "base habitat" for wildlife. The national parks are the largest in terms of area and effect, even though this is only one of their purposes. The Canadian Wildlife Service and the provincial governments have programs to purchase land for wildlife habitat and to encourage preservation of wildlife habitat on private land. Ducks Unlimited has purchased land for preservation of wetland breeding habitat for waterfowl and Wildlife Habitat Canada (1985) has a growing national program dedicated to the conservation, restoration and enhancement of wildlife habitat.

Other programs attempt to retard or prevent the process of further habitat fragmentation. For example, habitat goals are included in the Alberta document, Status *of the Fish and Wildlife Resource in Alberta* (Alberta Energy and Natural Resources 1984). Habitat preservation has been pursued with some success in the Eastern Slopes Region by the Alberta Government although not solely for wildlife objectives (Government of Alberta 1984). Similarly the use of land zoning for forestry (Green Zone) as opposed to agriculture (Yellow Zone) in Alberta has tended to preserve relatively large habitat fragments (Gordon 198 1). Regional land-use planning commissions have generally been receptive to proposals relating to wildlife habitat from the Alberta Fish and Wildlife Service (K. Ambrock, pers. corn.). However, support for efforts to preserve wildlife habitat is weak in comparison to that for expansion of the agricultural land base, even for its expansion into areas considered marginal for agriculture.

There has been intense conflict over whether prairie wetlands should be used for wildlife habitat or agriculture. The desire to expand the agricultural base has sometimes been encouraged by drought conditions. In May 1974 the Canadian Wildlife Service counted 1.5 million ponds in southern Alberta; in May 1984, during a dry year, fewer than 600,000 ponds were found

(Bailey 1986). A stimulus for this cumulative effect is that during dry years wetlands shrink or dry up, allowing cultivation. Once cultivated, such wetlands are rarely returned to a natural state and much wetland habitat critical to waterfowl production has been lost. Canadian Wildlife Service surveys indicate that in southern Alberta nearly half of all basins and over 90% of the margins of wetland basins have been impacted by agriculture (Bailey 1986).

Management of soil erosion is dependent upon application of presently available research results. For example, several management practices are available to control erosion and weeds, and to retain moisture and enhance fibre content; these include summerfallow, zero tillage, reduced tillage, chemical fallow and continuous cropping. The problem for farmers is to select the right land management procedure for the broad range of moisture, soil types and climatic conditions, quite apart from economic factors, and the costs and expertise required to select appropriate seed, fertilizer and herbicides. This is a problem to be considered not only at the regional level but also by individual farmers.

In agricultural areas, the key institutional and socio-economic feature is the exceptionally large number of small operations '(individual farms) involved in the regionally expressed cumulative effects. Even in forested portions of the case study area, a key institutional and socio-economic feature is that there are many managers involved in decision making. The latter circumstance is not unique to the case study area. Baskerville (1986a) has identified it as a major problem for forest management throughout Canada. In his words, "We are faced with a multiplicity of problems, in a multiplicity of forests, controlled by a multiplicity of managers." This complexity is compounded when one moves from a forest region to an interface zone where forest administration agencies compete with agriculturally oriented agencies for control of land-use decisions, and where many farmers depend on the forest industry for income from winter employment, as in the Peace River region.

Practices that result in the cumulative effects outlined here occur at the local level. However, the effects themselves are regional in scale; continuing deterioration of farmlands in the study area attests to the scale of the problem. Jurisdictions in place have not yet been able to act in an integrated manner for on-farm results. Bentley and Leskiw (1984) attribute this to several continuing problems: a lack of appropriate agricultural research to quantify the problems and to find practical solutions; insufficient demonstration and promotion of the practicality and proven economic benefits of known soil conserving and soil maintaining practices; persistence of boom-and-bust cycles that cause farmers to hesitate to invest in soil-conserving and maintenance practices, coupled with the uncertainties of return on the investment; and the reluctance of society to discipline those who abuse and misuse the land resource. Canada is unique among developed nations in that it has no clearly defined soil conservation legislation, but Rennie (1985) stressed that, even without such legislation, conservation of soils can be achieved by providing research, extension education and financial incentive programs to encourage better farming methods.

Conflicting government policies have been singled out as a barrier to concerted soil conservation practice (Senate Standing Committee on Agriculture, Fisheries and Forestry 1984). For example, the Canadian Wheat Board delivery quotas apply to all cultivated acres and several policies exist to promote grains as opposed to more diversified farm products. Kiel et *al.* (1972) also identified conflicting government subsidization programs. Examples of the latter include subsidies from one agency to encourage agricultural expansion by wetland drainage and concurrent subsidies from another agency to preserve or rehabilitate wetlands for waterfowl production. In Manitoba, land use in the agriculture-forest interface region is influenced by government programs many of which provide increased access, land drainage, and wildlife habitat conservation and development (Fox and Macenko 1985). Two such programs are the Manitoba Land Improvement Program of the Department of Agriculture and the Crown Land Classification Committee which has conducted several land-use studies to rationalize and allocate Crown land and natural resources. In general, government programs have encouraged conversions to single-use agricultural land from multiple-use forest land (commercial forest, trapping and hunting). On a more encouraging note, Mitchell (1984) points to two government initiatives to conserve wildlife habitat. These are the recent formation of Wildlife Habitat Canada, and passage of the Saskatchewan Critical Wildlife Habitat Protection Act of 1984. The latter restricts conversion to other uses of Crown lands designated as critical to wildlife welfare and survival.

Provincial governments of the four western provinces have acknowledged or declared as their policy a commitment to integrated resource planning as a basis for decision making. This approach is exemplified by the Alberta policy regarding the Eastern Slopes (Government of Alberta 1984). The Eastern Slopes are part of the Green Zone, that is, provincial public land managed primarily for forest production, watershed protection, recreation and other multiple uses, but excluding agricultural uses. Originally top priority was placed on watershed management and protection of the land through an eight-category zoning system with individual permitted and restricted uses. The multiple use zone is the largest, covering 65% of the Eastern Slopes. The original policy document formalized in 1977 gave a commitment to integrated resource planning and the 1984 revision has moved further to recognize the multiple pressures and demands for allocation of the resources of the Eastern Slopes. The revised policy specifically recognizes the need for the development of a strong tourist industry in the region in the next two decades and loosens restrictions on some land uses. Oil and gas exploration and domestic grazing are now permitted in the recreation zone. The revised policy is designed to be more flexible, although protection remains paramount. The focus is on regional objectives that are considered to be compatible with the intent of each zone.

Outside the agricultural areas, the general response to competition for land has been the promotion of multiple use, especially in forested areas, based on the argument that aggregate benefits are potentially greater than single-use benefits. However, aggregate benefits and the groups deriving such benefits are difficult to define, Weetman (1983) recognized this regarding multiple pressures on forest land and noted that most disagreements and misunderstandings concern the objectives of land use, which are set by society and which may require zoning land. Allowance for multiple regional objectives is apparent in the revised (1984) Alberta policy for resource management of the Eastern Slopes, yet the constraint of building policy in accord with the goals of the World Conservation Strategy is at the same time reflected in the recent Alberta conservation strategy (Public Advisory Committees 1986). These two documents reflect institutional efforts to mobilize public objectives and decisions within the constraints of a finite abundance of land resources and the desirable sustained yield of natural resources. These constraints are relatively new in North America, compared to Europe and parts of Asia where pressures for land uses have existed for longer.

With regard to regulation of urban expansion into agricultural lands, Audet and Le Henaff (1983) noted that in those provinces that introduced specific legislation to protect agricultural lands, such as British Columbia, Quebec and Newfoundland, the laws have proved effective mainly because they are linked with the municipal planning process. Manitoba and Alberta, through their respective planning acts, have provincial policies and guidelines on land use. Alberta's policies to conserve agricultural lands, and a sample regional plan policy are described by the Alberta Planning Board (1983). In Alberta's case, the guidelines serve as a framework for articulating specific subdivision regulations but have received criticism (Gordon 1981) as being inadequate to protect various land uses and objectives.

Implications of the Prairie Provinces Case Study for Cumulative Effects Assessment

The productivity of agricultural soils in the case study area has been seriously degraded by a combination of several cumulative effects involving potentially all four funtional pathways shown in Figure 2. These processes and the coincidence of severe drought in 1984 and 1985 have resulted in serious concern about the sustainability of the productivity of farmed land (Bentley and Leskiw 1984). The current difficulties of farming are seen as part of a larger problem involving threats to all renewable resources and the economic enterprises associated with them, according to a report prepared for the Canadian Environmental Advisory Council (J.S. Rowe, in Bentley and Leskiw 1985):

> Clearly, major environmental problems often grow *incrementally and imperceptibly from policies and practices that have appeared to be benign. Today such policies and practices in agriculture, as well as in other renewable resource fields, must be challenged before they work irreversible harm on Canada's environmental wealth.*

Rowe also identified the added impact of pressures of the market place for short-run economics as a major part of the problem relating to current soil degradation and land misuse:

> .... *farmers are encouraged if not compelled to adopt practices and cropping patterns that are inconsistent with long-run productivity. Since most farmers cannot survive if they ignore the short run in the interests of longer term gain, the unavoidable result is land use that conflicts with production* sustainability.

Wetlands, native grasslands, old-growth forests and prime agricultural lands are all examples that have been singled out for their susceptibility to "nibbling" losses which eventually accumulate to major losses (Robilliard 1986). The examples outlined in this case study area revealed two factors that hamper cumulative effects management: trends in environmental deterioration are extremely difficult to halt or reverse if they are the result of many small, dispersed sources, even if the trend or cumulative change is well-documented and widely understood; and because thresholds are poorly known and difficult to predict for small, dispersed sources of cumulative effects it is administratively and politically next to impossible to bring about corrective action.

Cultivated and grazed portions of the case study area are dominated by ecosystems in which there are greatly modified fluxes of energy and matter. The biological results of these modifications are no different in the case study area than they are for the general situation described by CAETEP (1986) in which energy flow patterns in ecosystems are diverted toward species of direct value to people and away from species with no current value. In this context, much of the difficulty in preserving species richness is related not to overexploitation of species, but to conversion of the ecosystems to uses that are incompatible with preservation of the community of species originally present.

The selected cumulative effects outlined in preceding sections lead to several conclusions. First, as noted by other analysts (Erckmann 1986; Munro 1986), cumulative effects from many small events cannot be managed by environmental impact assessment (EIA) procedures. The collective effect of many small decisions by many different operators, if it is manageable at all, can be handled best by economic incentives, to a certain extent by educational and extension programs, and very poorly by planning procedures as we know them today. The technique by which it might be accomplished will vary with different cumulative effects pathways, but it appears to be generally true for all the examples outlined in this case study that environmental planning and area assessments would be improved by deliberate incorporation of cumulative effects assessment criteria.

More specifically, habitat fragmentation is extremely difficult to prevent because it results from an exceptionally wide range of activities that, if they are regulated at all, are under the jurisdiction of a wide range of agencies; furthermore although provincial agencies may have a "habitat assessment section" or a "habitat protection section," prevention of habitat fragmentation is not a major goal or management criterion for any one agency in any of the prairie provinces. Furthermore, the effects of habitat fragmentation are not well understood, even by specialists in the subject, and this makes it very difficult to get public recognition of it as a problem.

Soil erosion, nutrient losses and salinization are processes that lead to a variety of direct and indirect cumulative effects. A key deterrent to management of these problems is the lack of planning authority over methods practiced by thousands of operators on privately owned lands. A major deterrent to assessment of the cumulative effects of agricultural chemicals is the absence of reliable data on amounts and persistence of these compounds released to the environment.

With the possible exception of agricultural chemical usage, none of the cumulative effects documented in this case study is seen as a threat to human health or safety; this circumstance results in a lack of political will to initiate corrective action.

CANADA'S MANAGEMENT OF CUMULATIVE EFFECTS ASSOCIATED WITH RADIATION HAZARDS

Cumulative Effects Pathways Involved

What effects of radiation can truly be classified as cumulative? One example is the repeated exposure of mine workers to radiation in underground mines, or to radioactive gases and particulates trapped in mine, mill or refinery facilities; such exposure leads to cumulative health effects and is an example of the interactive Pathway 2 shown in Figure 2. A similar type of cumulative effect from radiation hazards can occur when buildings are erected on waste rock or tailings containing above-normal concentrations of radioactive elements. The reality of this problem did not become generally accepted until residents of Port Hope, Ontario, began to suffer from health effects associated with exposure to radiation. They occupied houses that had been built on fill consisting of waste rock rich in radioactive elements. Radon gas emitted by the decaying elements had become trapped in the basements of these houses, leading to a similar situation to that occurring in poorly ventilated uranium mines and mills. The cumulative effect occurs through the assimilation into the human body of "radon daughters," radioactive products of the breakdown of radon.

It should be noted that this cumulative health effect occurs because of repeated exposure to risk of the same individuals. When waste rock or tailings are disposed of in the open, radon gas is unlikely to be trapped by buildings and will be carried away by the wind. Furthermore, repeated exposure of any individual is unlikely. Disposal of material with a low level of radioactive contamination has cumulative effects only in the sense that it makes a small contribution to the level of radioactivity in the atmosphere or water. Unless the quantities of waste are massively increased, this is unlikely to be significant in comparison to other sources. Low levels of radioactive isotopes in natural environments can, however, lead to cumulative effects through biomagnification (functional Pathway 2 of Figure 2). Canadian monitoring programs have not revealed this as a significant health problem to date. The Atomic Energy Control Board (AECB) is continuing monitoring studies, including monitoring studies of mothers' milk.

There is another radioactive waste problem that may have cumulative effects. No method for the disposal of waste with high levels of radioactivity has been generally accepted. One of the most frequently suggested methods is deep disposal in which the material is placed in storage areas within igneous rock formations (van Everdingen 1974). Subterranean movement of radioactive material can contaminate aquifers Or eventually reach surface waters. Material from more than one disposal site in the same region could contribute cumulatively to this effect. The problem is analagous to that experienced with deep disposal of non-radioactive hazardous chemicals.

Other releases of radioactivity still raise public concern because of their potential immediate effects. Examples are accidental releases from nuclear power facilities and those occurring as a result of accidents during transport of radioactive materials.

One of the reasons for public distrust of the nuclear industry and its regulators is its connection with nuclear weapons. That connection is inescapable. Another is the unfortunate use of the term "safe level" of exposure. Insofar as long-term effects are concerned, there is no such thing as a safe level because biological damage by radiation is a statistically random phenomenon in which the probability is never zero because of the existence of natural or "background" levels of radiation. What is possible is the definition of an acceptable level of risk, and this can be made comparable to that encountered in other industries.

Relationship to the Conceptual Framework for Cumulative Effects Assessment

There is a long history of activity dealing with the research-ecosystem links shown in Figure 4. Soon after the discovery of radioactivity it became evident that it could be immediately harmful to living organisms, including humans. Knowledge of longer term, but less immediately obvious, effects came more slowly. Although long-term effects could have been anticipated by a thoughtful observer, that did not occur — or if it did, the thoughtful observer remained unheard. When evidence of long-term effects appeared it took a long time for that knowledge to be accepted, and even longer to be assimilated, by those in a position to respond to the problem. When those responsible did become convinced of the reality of the problem, action was taken to deal with it.

There is also a considerable amount of Canadian experience in strengthening the research-management links (Figure 4). For example, exposure of workers to radiation in mines or to radioactive gases and particulates trapped in mine, mill or refinery facilities has been investigated by royal commissions in Ontario and British Columbia and has been the subject of many publications. Early attempts to deal with the problem were frustrated by uncertainties about which governments (federal or provincial) and which departments or agencies (AECB or Health and Welfare Canada) were responsible. Nevertheless, when the reality of the problem became generally accepted, effective measures were taken to improve protection against the hazard. AECB is at present proposing to further tighten exposure standards for workers in the nuclear industry and for the general public.

In relation to the management component of the conceptual framework (Figure 4), institutional arrangements for controlling the nuclear industry in Canada were in place as early as 1946, when AECB was established. However, AECB was established primarily to foster development of the nuclear industry and to control information and the security of nuclear facilities, It was equipped with powerful but vague legislation. Only as the process of problem recognition passed through its normal evolution, as outlined above, did AECB develop effective measures for dealing with the regulation of long-term radiation hazards. AECB has the power to control deep disposal of radioactive waste in Canada. So far no such disposal has been authorized, although AECB, the Department of Energy, Mines and Resources, and the nuclear industry have supported considerable research on the subject including the construction of two underground test facilities.

There is a complex institutional division of responsibility for overall regulation of nuclear hazards in Canada. The Atomic Energy Control Act makes the Atomic Energy Control Board broadly responsible for regulation of the nuclear industry in Canada (AECB Staff 1983). AECB licenses and regulates the operation of nuclear facilities and deals with nuclear civil liability and nuclear security. However, there are a number of areas of overlap with other governments and other departments of the Government of Canada. Cabinet has given Atomic Energy of Canada Ltd. special responsibility with respect to deep disposal of radioactive wastes. Environment Canada has responsibility for the Ocean Dumping Control Act which may also deal with radioactive waste. Health and Welfare Canada regulates the use of radioactive emitting devices in conjunction with AECB and has general responsibility for public health. Labour Canada and provincial departments responsible for health and labour are also concerned with the health and safety of workers in the nuclear industry, including uranium miners. The Canadian Transport Commission regulates rail transport and Transport Canada regulates air, sea and river transport of radioactive materials. AECB regulates their packaging. AECB also administers the international aspects of these matters, many of which are covered by treaties or agreements. Finally, it participates in the review of patent applications under the Patent Act.

This complex division of responsibility would, on the surface, appear to be an obstacle to effective assessment and control of cumulative effects, but in fact co-operative arrangements are in place to ensure that this does not happen, The latter has not always been the case. Before 1975 the division of responsibility for regulation of uranium mining between the federal and provincial governments appeared to contribute to a failure to adequately protect the health of mine workers. When the problem became evident, action was quickly taken to put inplace a co-operative regulatory program. Past problems have alerted those in authority to the need to anticipate cumulative effects. As a result AECB, in particular, has funded extensive research on potential problems. Its present research and development (AECB 1985) includes the following projects related to possible cumulative effects:

- aerosols and fission product transport;
- bioassay techniques for Saskatchewan mine and mill workers;
- stratified random sampling for radon daughter concentrations in mines;
- eight studies on personal radiation dosimeters;
- studies on water and electrostatic purification of underground air;
- solubility of airborne dust produced by nuclear facilities;
- studies of soil-plant and plant-animal transfers of radionuclides;
- determination of concentration factors in domesticated animals and wildlife;
- transfer of radionuclides from food to human milk;
- 10 studies on disposal of radioactive wastes; and
- 16 studies on health effects of exposure to radiation, most of which are either epidemiological or seek to determine how radioactive material enters the body and is retained.

Has Canada's control of cumulative effects of hard radiation been successful or not? The answer to this question is a matter of temperament. An optimist would say yes and a pessimist no. In the early days of the nuclear industry the answer was certainly no and a number of problems emerged. Now the answer is a fairly confident yes because the response to these problems has led to significant improvements in the regulatory and control system and in industrial practices.

Within Canada, the institutional arrangements and legal powers now in place to control radioactive hazards are more than adequate. All that is required is to make them work effectively by anticipating effects such as those that may arise from disposal of nuclear wastes deep within igneous rock formations, and by improving compliance and enforcement of regulation standards, especially in difficult areas such as management of abandoned mine facilities or transport of radioactive materials.

CANADA'S MANAGEMENT OF CUMULATIVE EFFECTS THROUGH THE GREAT LAKES WATER QUALITY AGREEMENT

Cumulative Effects Pathways Involved

The progressive deterioration of water quality in the Great Lakes was the result of compounding effects involving many processes, with the results being both additive (Pathway 3 of Figure 2) and interactive (Pathway 4). Eutrophication, largely through high loadings of phosphorus, and the addition of persistent toxic substances were the two main cumulative effects in the deterioration of Great Lakes water quality.

Relationship of the Conceptual Framework for Cumulative Effects Assessment

The agreement between Canada and the United States known as the Great Lakes Water Quality Agreement and the ensuing results of its mandate must be considered one of the major successes in cumulative effects management in Canada. This agreement is accompanied by one between Canada and Ontario (the only Canadian provincial jurisdiction that is a party) which defines the obligations of the two parties. Three key factors contributed to the success of this agreement: the scientific basis of the agreement focused on the Great Lakes Basin ecosystem; both Canada and Ontario were co-operatively committed to the agreement, having jointly negotiated its terms; and an important role was assigned to the International Joint Commission both in negotiating the agreement and in implementing it. The language of the agreement frequently emphasizes the ecosystem concept and the importance of controlling several cumulative impacts, such as eutrophication [Article VI, l(d), 1978] and persistent toxic substances [Article VI, l(k), 1978]. In other words, the research-ecosystem links (Figure 4) were well established and specific activities within the ecosystem-management links were set in motion to address the recognized problem.

The management approach was specific because research had yielded specific information about the ecosystem involved. For example, Annex 3 of the 1978 Agreement addresses "Control of Phosphorus," the purpose of which is to "minimize eutrophication problems." Specific target inputs of phosphorus, derived mainly from detergents, to each of the Great Lakes is specified in Annex 3, along with specific operating criteria and abatement strategies respecting municipal and industrial effluent treatment. The ensuing programs in both Canada and the United States to implement Annex 3 have brought about a remarkable reversal in the eutrophication of Lake Erie, once classified as "dead" by some environmentalists.

One of the important factors that contributed to the success of the phosphorus reduction program was the scientific understanding of the cause-and-effect relationships of the cumulative effect of phosphorus on microfloral viability. This factor can be generalized to other cumulative effects on water and air quality. That is, many of the effects that are attributable to specific chemical, physical or biological agents can be described in terms of quantitative dose-response relationships or physical-chemical models. In other words, the cause-effect relationships are amenable to quantification. For other cumulative effects for which cause-effect relationships are not as simple, the technical chances of success will be even more difficult and organizational arrangements will be even more important.

The Royal Society of Canada and the U.S. National Research Council have published a thorough analysis of these issues, including institutional arrangements, in anticipation of the IJC's detailed review of the Agreement scheduled for release in 1986 (NRC/RSC 1985).

SUMMARY OF CANADIAN CUMULATIVE EFFECTS EXPERIENCE IN RELATION TO CEARC'S INTERESTS

Unsuccessful management of cumulative effects can be a result of an inability to recognize a cumulative effects problem or, if it is recognized, an inability to take management steps to rectify it. The first circumstance implies inadequate attention to the research-ecosystem links (Figure 4) and the second implies inadequate attention to the links involving the management component. The portions of the Canadian examples that are considered to be successful have obviously overcome these two fundamental hurdles. Portions that have been less successful can be a result of any one of several barriers to successful cumulative effects management, the most frequent of which are already well documented in the literature as follows:

- mismatch between spatial boundaries of a cumulative effects problem and the jurisdictional area of the responsible regulatory body (Robilliard 1986);
- failure to realize that because cumulative effects occur within ecosystems they can rarely be understood or managed as simple factor-species relationships (Moore 1967);
- reluctance to accept unwelcome advice or evidence that a cumulative effect may be oncoming and vested interests in not knowing the answers to certain environmental problems (Orians 1986);
- excessive attention to habitat-oriented environmental studies instead of the required focus on transfers of materials between ecosystem compartments (Orians 1986);
- narrow specialization of researchers as a result of compartmentalization of university departments, with inadequate training in methods of dealing with interdisciplinary and multidisciplinary problems (Michaels 1986),
- lack of pre-disturbance baseline data because measurements of cumulative effects are often not initiated until a problem is well advanced (Hughes et *al*. 1980; Cronan 1983, 1985),
- pressure to produce rapid assessments that preclude cumulative effects measurements of before and after conditions (Kiell et al. 1986; Roots 1986);
- the inability of post-project monitoring by project developers to record changes associated with other projects in the area (Fox 1986; O'Riordan 1986),

The Canadian experiences outlined in Chapter 5 revealed a number of scientific and institutional factors that contributed to success in cumulative effects management including the following:

- Cumulative effects are more readily managed if there are determined efforts to achieve co-operative agreements in settings that possess complex divisions of jurisdictional responsibility, as demonstrated by Canada's system for control of nuclear radiation and the Great Lakes Water Quality Agreement.
- Cumulative effects have a greater chance of successful management if there are determined efforts to involve interested parties during the development of co-operative regulatory agreements, as demonstrated by actions of the Atomic Energy Control Board.

- Cumulative effects that directly threaten human life result in more successful management approaches (see actions of Atomic Energy Control Board) than do less threatening or less readily understood cumulative effects (see difficulties associated with recognition of habitat fragmentation as a problem).
- Cumulative effects that are a result of well-understood pathways, such as the cumulative effect of phosphorus additions to aquatic ecosystems, have an increased chance of successful management.

There are well-documented relationships between complexity of jurisdictional controls and the management of cumulative effects (CEARC and U.S. NRC 1986). It is important for CEARC to note, however, that such complexities do not automatically lead to inaction. The outline of Canada's handling of radiation hazards was deliberately selected as an example of successful management of cumulative effects in a setting of very complex jurisdictional involvement. It is not necessary for CEARC to gather more evidence that jurisdictional complexity can be an excuse for inaction but it is important to research the mechanisms or approaches that yield results in complex jurisdictional settings.

It is instructive to view two contrasting cumulative effects problems, control of nuclear radiation and control of habitat fragmentation, to reveal CEARC's potential role to improve institutional approaches for cumulative effects management. In the case of the nuclear industry, the controls of cumulative effects appear to be effective because the Atomic Energy Control Board has the authority to take any regulatory action that is necessary, but also has the good sense to involve other interested parties, both regulators and regulated, in a co-operative approach to common problems. Perhaps a contributing factor is the universal tendency to accept that effects that may directly threaten human life are of overriding importance, however low their probability of occurrence. One could speculate at some length on other reasons for the success of current arrangements, but to examine this more clearly CEARC might wish to seek representation on some of the interdepartmental committees that are instrumental in Canada's effective system for control of nuclear radiation.

Habitat fragmentation, outlined in this chapter as a cumulative effects problem, presents an instructive contrast to nuclear radiation for the following reasons: the effects of habitat fragmentation are much less well understood and, for this reason, it is difficult to get people to recognize it as a problem; a wider range of activities can contribute to habitat fragmentation; responsibility for regulating these activities is more widely dispersed; no single department or agency has reduction or prevention of habitat fragmentation as its major goal; and habitat fragmentation is not seen as a threat to human health or safety. Given these contrasts with the nuclear radiation example, it is not surprising that habitat fragmentation is a cumulative effect that has not been handled in a satisfactory way.

Agencies that have control over land use are the ones in the most immediate position to influence habitat fragmentation. In Canada these operate at the municipal or regional scale. However, at any time higher levels of government can intervene or take initiatives that override those at the local level. The Eastern Slopes Policy in Alberta (Government of Alberta 1984) is an example. In addition, government programs at a higher level can also influence local land use. Drainage projects supported by the Prairie Farm Rehabilitation Administration and energy-related development approvals by provincial governments fall into this category.

Notwithstanding these uncertainties, there are several things that CEARC could do to address the problem. As recommended in Chapter 7, CEARC could sponsor, or encourage sponsorship of, research into the nature, mode of action and consequences of the effects of habitat fragmentation. Dissemination of reliable information on the subject should raise awareness of the problem. Secondly, CEARC could attempt to organize meetings between representatives of the many agencies with responsibilities that bear on the issue. Results of the research projects could be presented at such meetings and proposals for specific actions in areas of major concern could be developed. The use of system models would be of assistance in this context, especially if these were also applied to the function of the regulatory systems of the various agencies as these bear on habitat fragmentation. This approach cannot guarantee success but it can ensure that the problem comes to the attention of decision makers.

The terms of reference for this review (Chapter 1) posed the following question: Can cumulative effects management be improved by contributions from regional environmental planning and area assessments? Based on case studies, our answer is yes; but the review focused more attention on the converse question: Can regional environmental planning and area assessments be improved by deliberate incorporation of cumulative effects assessment criteria? For this question, too, the answer was in the affirmative, based on information summarized by others (CEARC and U.S. NRC 1986) and outlined in the last two selected case studies in this chapter. The important point to note is that there are still advocates for each of two ways to look at cumulative effects assessment. The first is from the top downwards as in regional planning. The second is from the bottom upwards as in project-related assessments. These two alternative approaches were outlined briefly in Chapter 4.

Analyses already done by CEARC (CEARC and U.S. NRC 1986) and the present review reveal that cumulative effects assessment is not yet addressed properly by regional planning, nor can it be handled satisfactorily by environmental impact assessments (EIA) of individual projects. For this state of affairs, there appears to be two alternative course for improvement: a middle ground that integrates EIA and planning activities in a way that ensures cumulative effects are addressed; or development of an entirely different institutional context for cumulative effects assessment, distinct from EIA and regional planning. As indicated by the recommendations in Chapter 7, this review did not result in suggestions for distinctive institutional arrangements to be created for management and research into cumulative effects. The suggested approach is for CEARC to encourage analyses and research that would integrate and build upon the relative strengths of both a top-downwards and a bottom-upwards approach to cumulative effects management.

Some of the links between cumulative effects management and EIA were outlined in Chapter 4. If CEARC is to build upon these links it is important to recognize that the use of EIA for cumulative effects management could involve either of two major approaches — mediative or regulatory. At present, mediative and regulatory processes can be initiated outside of the context of EIA. For example, development of regulations under provisions of the Fisheries Act are done routinely by the Department of Fisheries and Oceans and these may or may not have been initiated by EIA work. Similarly, mediation processes have been conducted without the benefit of formal EIA processes. The point is that if EIA is to be made a more integral part of the decision-making processes, it will need to have an increased role in development of regional management plans. In this context, CEARC could exert an influence on federal and provincial agencies by exploring methods to better link EIA to the mediative and/or regulatory phases of decision making as now practiced in Canada. This could involve, among other things, encouragement by CEARC for the incorporation of EIA methodologies into mediative and regulatory phases of decision making. It is important that EIA be recognized as an early step that should precede the mediative or regulatory phases. Such an approach would encourage flexibility through continuing reviews of the regulatory standards adopted by the parties-at-interest and would also encourage re-evaluation of their effectiveness. This factor could be one of the single most important aspects for preventing serious cumulative impacts on a regional scale.

In summary, cumulative effects assessment has strong links with both environmental planning and environmental impact assessment. In recognition of such links, the recommendations in Chapter 7 are accompanied by comments on the significance of each recommendation for environmental impact assessment and for environmental planning. For this purpose, it is assumed that environmental impact assessment, as a formal process, is already becoming well recognized as an integral component of a more comprehensive planning and management process. As outlined by CEARC (1986), this assumption is not universally accepted, depending on the conceptual and institutional frameworks in which people are operating. The debate remains because, to many people, environmental impact assessment continues to be viewed as an "add-on"; others think that EIA must be an integral part of a project which, if truly accomplished, makes it environmental management rather than environmental assessment. This debate was not pursued in the present review; the important point is that cumulative effects assessment must be viewed in the broader context of EIA, whether the latter continues to operate as a somewhat independent process or whether EIA achieves its ultimate objective of linking natural systems, social values and development initiatives in an integrated planning process (CEARC 1986).

CHAPTER 6: THE MOST SIGNIFICANT CUMULATIVE EFFECTS ISSUES FACING CANADIANS

One of the hypotheses of interest to CEARC is that cumulative effects are having an increasingly significant impact on the quality of natural and social environments in Canada. The 1985 workshop, co-sponsored by CEARC, reached a clear consensus, in the affirmative, on this question. Roots (1986) summarized the workshop conclusions, in reference to both United States and Canada, as follows:

> The workshop was quite c/ear on this question. Failure to take cumulative effects properly into account is resulting in damage to the environment. The lack of *systematic attention to cumulative effects is leading to a potentially serious situation on a range of scales, in many p/aces, in both countries. The problems vary from "nibbling" at critical habitats, to unknown degrees of loading of environmental compartments with interacting chemicals, to ignorance of the severity and imminence of regional or global threats* [Emphasis ours].

It was suggested in an earlier section of this report, based partly on a recommendation by Clark (1986), that one of the most important roles for science in environmental impact assessment is to reduce as many apparently cumulative effects problems as possible to simple cases of single cause and single effect. That goal is reiterated here, although it is necessary to acknowledge one of its disadvantages. To identify cumulative effects issues facing Canadians on the basis of single causes and single effects would result in a list of hundreds of specific cumulative effects. For this review, it was necessary to focus on a few major groupings of environmental management issues, each of which contains within it dozens of specific processes that involve cumulative effects pathways.

In Canada, recent analyses of "stress on land" (Simpson-Lewis et *al.* 1983) emphasized several processes that contain additive or interactive cumulative effects. In that analysis, an exceptionally large number of identifiable stresses were grouped into a relatively small number of categories, based on two issues related to additions to the land and two related to subtractions from the land (Neimanis et *a/.* 1983). A similar level of generalization was used in the present review to compile a list of the most significant cumulative effects issues facing Canadians. Based on the present review, professional contacts made during the course of this review, and the experience of study team members, the many existing and potential cumulative effects issues facing Canadians were consolidated into 13 categories listed below. The list is not in any intended order of priority.

1. *Long-range transport of air pollutants (LRTAP):* This set of cumulative effects includes related phenomena such as acidic deposition, oxidants, and toxic or persistent chemicals, all of which are involved in atmospheric chemical transformation processes.

2. *Urban air quality and airshed saturation:* This set of cumulative effects involves management of the number, strength and distribution of a large variety of emission sources; an increasingly prominent issue, from an environmental and legal perspective, that is part of this set of cumulative effects centres around indoor air quality, including effects of primary and secondary exposure to cigarette smoke upon fòetal development and incidence of cancer.

3. *Mobiliza tion of persistent or bioaccumula ted substances:* This set of cumulative effects could involve either metals from the earth's crust or synthesis and subsequent dispersal of persistent toxic chemicals, especially xenobiotics; two distinct classes of end uses are involved with this set of cumulative effects: a) end uses in which release to the environment is uncotitrolled as in tetraethyl lead, PCBs or chlorofluorocarbons; or b) end uses in which the release is controlled; accidental, as in radionuclides; or unplanned, as in mercury mobilization as a result of hydro-electric reservoir projects.

4. *Cumulative effects associated with climatic modification:* This set of cumulative effects would be those brought about by changes to constituents of the atmosphere that alter its thermal or optical properties; this set of effects has no well-defined immediate impact but raises an important issue because of the long-term research required; potential cumulative effects of socio-economic importance include CO,-induced climatic changes, arctic haze, albedo changes, changes to the hydrologic cycle and water supply, and changes to length of the growing season.

5. *Occupation of /and by man-made features:* This set of cumulative effects results from the progressive increase in land area occupied by urban developments, roads, airstrips and other man-made features; the loss of pervious surface is a key trigger to the diverse cumulative effects associated with such land-use changes.

6. *Habitat alienation:* This set of cumulative effects results from repeated or continuous disturbances that make a habitat unpleasant or inhabitable even though there may have been no physical loss of habitat (habitat fragmentation); disturbances that can lead to habitat alienation include disturbances from noise and they can occur in atmospheric and aquatic media and in terrestrial, freshwater and marine habitats; an example of social cumulative effects within this category is the public concern for preservation of habitats that have not yet lost their wilderness character.

7. *Habitat fragmentation:* This set of cumulative effects results from changes in the area, relative proportions and relative distributions of vegetation/habitat types, as a result of a wide variety of land-use practices.

8. Losses of soil quality and quantity: This set of cumulative effects include losses of soil to wind and water erosion on shorelines and on the ground surface generally, loss of soil nutrients and soil organic matter, increased salinization and reduced soil productivity from physical or chemical changes associated with soil compaction or repeated use of fertilizers.

9. *Effects of use of agricultural, silvicultural and horticultural* chemicals: This set of cumulative effects include a wide variety of additive, bioaccumulative or synergistic pathways associated with use of insecticides, herbicides and fungicides; major knowledge gaps remain on questions of interactions between pesticides applied simultaneously or successively to ecosystems.

10. *Reduction of groundwater supplies and groundwater* contamination: This set of cumulative effects involves a large variety of potential toxic wastes that reach groundwater supplies by several possible avenues, both deliberate and accidental; salt-water intrusion as a result of groundwater removal is a locally significant cumulative effects issue; subsidence of soil surface due to groundwater removal is a related cumulative effect, although not yet evident as a significant issue in Canada.

11. *Increased sediment, chemical and thermal loading of freshwater and marine habitats:* This set of cumulative effects results from diverse activities that add to siltation of estuaries, streams and lakes, increasing amounts of sewage discharged directly to running waters and marine waters, lake acidification, and chronic heavy metal additions to marine waters and freshwaters.

12. Accelerating rates of renewable resource harvesting: This set of cumulative effects encompasses a range of issues related to conservation strategies and sustainable development based on renewable resources, including fish, mammals, birds and forests; maintenance and protection of rare or endangered species of plants and animals is included in this set of cumulative effects because the threat to such species is often the result of practices associated with the harvest of common, commercially important species; it is recognized, however, that management issues associated with rare or endangered species are different than the issues surrounding the management of commonly harvested species.

13. Long-term containment and disposal of toxic wastes: This set of cumulative effects needs to be recognized as a separate environmental management problem even though toxic wastes are a potential component of issues 1, 2, 3, 11 and 12 listed above; distinctive socio-economic, regulatory and technological issues accompany toxic waste management whether the cumulative effects are registered in atmospheric, terrestrial, marine or freshwater (surface and groundwater) media; waste management issues will be the context in which mediation, negotiation, insurance measures, and legal liability proceedings will point the way to new methods of managing cumulative effects.

It is important to explain why there is not one or more explicit socio-economic cumulative effects issues in the list above. One could list a separate socio-economic issue under a heading such as "progressive loss of amenities required for a high quality of life," under which noise pollution, deteriorating quality of drinking water, increased intake of allergenic food additives, loss of wilderness, reduced opportunities for certain outdoor recreational activities, and continued losses of rare plant and animal species would be considered. Such a separation of socio-economic concerns was avoided because an underlying theme of this review is that social and economic aspects are an integral part of all of the 13 listed issues.

It is notable that most of the listed issues involve social and economic impacts in the context of public health. However, another level of socio-economic questions enters into issues 5, 6, 7, 8 and 12, all of which deal with the way that we use the environment and its resources. In this context, there was a temptation to add another cumulative effects issue that focused on the economic forces driving people to live beyond the sustainable yield of renewable resources, in the sense referred to by the World Conservation Strategy (IUCN 1980). This important question was considered to be an integral part of those listed issues that involve the management and use of renewable resources. This suggested integration of the economic and biophysical aspects of sustainable development is not meant as a de-emphasis of the importance of the economic and social forces involved. The fact that there are forces that drive people to live beyond the sustainable yield of renewable resources is an issue that warrants special attention by CEARC to encourage the development of appropriate directed research.

CHAPTER 7: RECOMMENDATIONS

Recommendations in this section are grouped into three categories that relate to the links shown in the conceptual framework for cumulative effects assessment (Figure 4). The three key links are: ecosystem-management links; research-ecosystem links; and research-management links. Each recommendation is accompanied by a rationale, identification of the cumulative effects pathway involved (Figure 2), suggested steps for CEARC or others to implement the recommendation, significance of the recommendation for environmental impact assessment and/or environmental planning, and a suggested time frame for implementation of the recommendation. The latter is done in relation to three arbitrary time periods: measures that could be implemented now to improve cumulative effects management (referred to as "immediate"); measures that could be implemented in three to five years (referred to as "short-term"); and measures that require efforts exceeding five years duration (referred to as "long-term").

Several specific kinds of ecosystems that are of high priority for research into cumulative effects over the next 5-10 years are identified in the recommendations that follow. They include:

- a variety of ecosystems in which *habitat fragmentation* can be assessed in detail (Recommendation 4);
- at least one ecosystem to be studied to document the *stresses associated with degradation of the whole ecosystem* (Recommendation 5);
- studies of cumulative effects by documentation of ecological processes in several *disturbed ecosystems that are being rehabilitated* (Recommendation 6);
- at least one *ecosystem that is topographically suitable for testing of the 'bubble concept" to ajrshed management* (Recommendation 10);
- several *agricultural ecosystems suitable for assessment of cumulative effects of insecticides, herbicides and fungicides* (Recommendation 12); and
- encouragement of some *cellular-/eve/ cumulative effects research* to complement the predominant emphasis on ecosystem-level research (Recommendation 7*).*

RECOMMENDATIONS RELATED TO ECOSYSTEM-MANAGEMENT LINKS

RECOMMENDATION 1

CEARC needs to maintain a strong interest in the institutional aspects of cumulative effects assessment; one way to do so would be to sponsor detailed analyses and research designed to generate recommendations on how to improve institutional performance in each of the 13 sets of significant cumulative effects issues facing Canadians (Chapter 6).

Rationale for the recommendation — In Chapter 4 the points were made that: present arrangements for recognition Of cumulative effects and research into their mode of action seem to be at least acceptable and reasonably effective; and institutional arrangements for action to deal with cumulative effects are less satisfactory. It follows that recommendations should begin with identification of where the responsibility for action lies, and the type of arrangements necessary to ensure that the responsibility is discharged. Once this is in place, the responsibility for assessment and research will be inescapable.

A significant complicating factor is that the kind of arrangement that is most suitable depends on the nature of the cumulative effect, and how and where it occurs. For example, atmospheric and hydrospheric effects are likely to be widespread; terrestrial effects may or may not be more localized. Action to correct the cumulative effect of lead emissions on human health is likely to require quite different arrangements than programs to halt the deterioration of soils (Chapter 5).

A second complicating factor is that institutional arrangements cannot be proposed without taking into account existing arrangements. Each type of effect should be considered separately in the context of present institutions. Virtually all cumulative effects involve the mandates of more than one agency, department or government. The steps necessary to secure action on any interjurisdictional issue normally begin with a group representing all those with some responsibility for action. The recommendations of this group eventually lead to operational arrangements that can range from the informally consultative or advisory, to the creation of a new agency based on new legislation (Chapter 4). This pattern can be seen in some of the examples described in Chapter 5. The exception is where a group or single agency with appropriate powers to act already exists when the cumulative effect comes to notice.

Finally it should be stressed that appropriate institutional arrangements do not guarantee appropriate action, but they can increase the chances of success. The competence, values, loyalties and ambitions of the individuals involved in government programs, and the political considerations that come into play, are generally more influential than the type of institutional arrangement. Knowledge of how to make human organizations function more effectively is inadequate, and the knowledge that does exist is rarely applied.

The *cumulative effects pathways involved* are potentially any of Pathways 1, 2, 3 or 4 (Figure 2).

Suggested steps for CEARC or others to implement the recommenda tjon — For selected topics from the list of most significant cumulative effects issues facing Canadians

(Chapter 6), CEARC should initiate or encourage others to undertake analyses that would ask the following questions and take the following steps in relation to immediate action programs:

- What governments, departments and agencies have legislative mandates that cover all aspects of a cumulative effect, the activities that cause it, and the activities that could avoid or mitigate it?
- Is there an existing organization that includes representatives of those agencies, which either already have or could be given responsibility?
- When the first two questions are answered, the next step is to select one of three alternative actions: a) the existing organization, with any necessary additions, should be asked to recommend what kind of arrangement of those described in Chapter 4 is the most appropriate to deal with the cumulative effect, regardless of existing arrangements; or b) a new group should be established to do the same; or c) an independent inquiry should be established to do the same. There is the risk that an existing group will wish to hold to the status quo and that recommendations from a new or outside group will be strongly resisted by present power-holders.
- A complementary step would be to initiate research directed at improvement of institutional performance in dealing with cumulative effects by using as test cases one or more of the existing groups with such responsibilities.
- An important element of the recommended analyses will be to identify criteria by which institutional arrangements can be adapted to recognize problems at the appropriate geographic scale; this implies the development of criteria to determine when it is or is not appropriate to establish umbrella organizations to manage cumulative effects.

Significance for EIA and environmental planning — This recommendation could bring about improvements in environmental planning by helping to direct attention to cumulative effects and by suggesting improved methods to deal with them. The recommendation is particularly important because it centers on how environmental planning and management is actually carried out and how it can be improved.

The *time frame for implementation* is short-term.

RECOMMENDATION 2

CEARC, planners, policy makers, environmental managers and interest groups seeking to secure action to manage cumulative effects should pay careful attention to planning and communications.

Rationale for the recommendation — The purpose of this recommendation is to emphasize that if action on cumulative effects is desired it is not sufficient to proclaim the nature and severity of the effects. Determined planning and proper communications are essential. In particular, there is a need to exercise knowledge of how human organizations function. Implementation of this recommendation is partly dependent upon the results of research directed at improvement of institutional performance in dealing with cumulative effects, proposed in Recommendation 1.

The *cumulative effects pathways involved* are potentially any of Pathways 1, 2, 3 or 4 (Figure 2).

Suggested steps for CEARC or others to implement the recommendation — The following tactical steps are necessary if an effective planning and communications system is to be put in place:

- Recognize the problem to be solved early, before it becomes too difficult to control or too politically divisive.
- Accept that a campaign will be necessary to secure support for, and later approval of, whatever is proposed.
- Precisely define the objectives which the proposed institutional arrangement and management program will be expected to attain,
- Choose the type of institutional arrangement most likely to accomplish the desired goals.
- Co-opt existing power-holders and possible competing or hostile groups,
- Provide sufficient authority to the responsible body, but not more than is essential to its effective performance.
- Build into the institutional arrangements accountability to the government of the day and to the general public.

The tactical steps suggested above could be considered by CEARC as the framework for assessment of the geographic scale (local versus regional) at which cumulative effects are managed. Most such management in Canada today is at the local level; tactical differences between local and regional approaches for a given cumulative effects problem have not yet been evaluated.

Significance for EIA and environmental planning — The goal of the work proposed here is to increase the probability that cumulative effects will be assessed and that cumulative effects management will be implemented. Both activities are parts of environmental planning and will have some bearing on EIAs and how they are conducted.

The *time frame for implementation* is short-term.

RECOMMENDATION 3

CEARC should initiate or encourage an evaluation that would focus specifically on the system linkages between the various phenomena that comprise the long-range transport of air pollutants (LRTAP), including acidic deposition, oxidants and toxic chemicals deposition, with emphasis on evaluation of the effectiveness of scientific and institutional treatment of the system linkages amongst the LRTAP components (sub-systems).

Rationale for the recommendation — There are several common features of acid rain and oxidants, including long-range transport from the same source regions, related chemistry, and possibility of synergistic effects (both in transformation and impact) especially in forest ecosystems. Despite these similarities, the acid rain and oxidants activities have been treated separately. In addition, it is likely that the toxic compounds involved are similarly transported and toxics have also been treated separately from the other two components.

LRTAP is an example of an interconnected system that has not been treated as such, to the detriment of the overall assessment process. The cumulative effects of these and other, as yet unidentified, phenomena will be appreciated and controlled only when LRTAP is addressed in an integrated way, taking into account the common features of these components and their individual and joint ecosystem functional pathways. A systems approach to LRTAP would identify the significant linkages and provide a model upon which to base the quantitative evaluation of ecosystem modification.

The "row summation" and "column summation" approaches to assessment of complex environmental perturbations proposed by Clark (1986), based on a synoptic perspective, is a valuable, but still rudimentary, conceptualization. A full-scale systems definition would connect each of the sources and valued components of Clark's Figure 5 by transfer functions, to use the socio-economic terminology, for each of the matrix elements. It should be noted that Clark's concept addresses only the additive pathways (1 and 3) shown in Figure 2 of the present report. The approach proposed here would also focus on synergistic processes (Pathway 4 of Figure 2).

There are additional reasons for monitoring scientific and institutional approaches currently used to assess air pollutants. For example, the lead-in-gasoline case study (Chapter 5) highlights a situation in which environmental impacts consequential to the use of unleaded gasoline were not assessed adequately. Specifically, the impacts of increased NO, and hydrocarbons and their acid rain and oxidants impacts were not addressed.

The *cumulative effects pathways involved* are Pathways 3 and 4 (Figure 2).

Suggested *steps for CEARC or others to implement the recommendation* — This recommendation, perhaps more than any other, provides the scope for CEARC to act in an interventionist, but constructive, role. The key step would be to observe and evaluate the process of LRTAP assessment already in progress.

Evaluation of procedures already underway would be instructive in itself and would offer the opportunity for intervention and mid-course correction to improve the practice of cumulative effects assessment in this important application.

Significance for EIA and environmental planning — Since LRTAP is a large-scale, transboundary phenomenon, the suggested evaluation would produce the practical basis for approaches to future problems of this sort in EIA. This activity would identify the planning time scales and co-ordination logistics that pertain to prevention or mitigation of such phenomena.

The *time frame for implementation* is immediate.

RECOMMENDATIONS RELATED TO RESEARCH-ECOSYSTEM LINKS

RECOMMENDATION 4

CEARC should consider a detailed analysis of one example of a cumulative effects pathway that combines the characteristics of significant knowledge gaps and institutional complexity because of widely dispersed causative factors; this combination of circumstances results in the most difficult form of cumulative effects to manage; habitat fragmentation is a candidate subject for such an analysis.

Rationale for the recommendation — As shown by the prairie provinces case study (Chapter 5), habitat fragmentation is a good example of a cumulative effect that occurs as a result of circumstances described by Robilliard (1986) as "nibbling." Erckmann (1986) also noted an inability to handle the consequences of multiple minor impacts and Munro (1986) identified forestry and agriculture as activities that are a result of many small decisions which, collectively, have a cumulative effect but which are never assessed.

Among terrestrial cumulative effects, habitat fragmentation in particular is poorly documented in Canada. Although there is considerable international literature on habitat fragmentation and alienation, and some on habituation, understanding has not advanced sufficiently well to allow informed decisions on whether action is required to counter many of the effects, let alone what that action should be. For example, the Alberta Government has an active program of acquiring land as a habitat base for economically important wildlife species (K. Ambrock, pers. corn.). In that program, two key questions are being asked: How much habitat is required to sustain populations of these species? How is the amount of required habitat influenced by various cumulative effects? Answers to these questions are not available.

Knowledge gaps about the significance of habitat fragmentation and its dispersed origins which prevent this form of cumulative change being brought into EIA procedures are the two key reasons that make this a high priority subject for a more detailed study.

The *cumulative* effects *pathways involved* are predominantly Pathways 1 and 3 (Figure 2).

Suggested *steps for CEARC and others to implement the recommendation* — Two specific research objectives are suggested below for consideration by CEARC. Where particular areas or species are selected for study they should be the most abundant or the most representative.

For habitat fragmentation a fundamental research need is to define properties of ecosystems useful in monitoring and analysing the effects of habitat fragmentation; this could involve, for example, properties of plant communities analagous to guild structural properties of animal communities. Applied research needs would involve use of such properties, and examination of the structure and composition of habitat fragments occupying various proportions of impacted areas. By means of historical and demographic studies, and real-time monitoring, there should also be attempts to determine the structural and compositional dynamics of those fragments. These suggested lines of research are specific examples of the CAETEP (1986) recommendation that research should be conducted to determine the types of indicators, thresholds, and environments most likely to be useful for assessing and managing different kinds of cumulative effects.

For habitat alientation, habituation and adaptation the emphasis should be on documentation of the degree to which these phenomena increase or decrease the effects of habitat fragmentation. To understand cumulative effects it is essential to know the extent to which conclusions reached by habitat fragmentation studies must be modified to account for the behavioural phenomena of alienation, habituation and adaptation.

Significance for EIA and environmental planning — There is already significant documentation to indicate that cumulative effects that occur as a result of many small unassessed events must be evaluated in the context of a comprehensive land-use planning process (Munro 1986) and that only some kind of regionally based scheme can deal with this problem, because it is unlikely that EIA can be upgraded to the extent that small effects can be detected (Erckmann 1986). For these reasons, the analysis recommended here is not likely to have a significant influence on the ways that environmental impact assessments will be conducted in the future. The main beneficiary of an imaginative analysis of habitat fragmentation, as a cumulative effects problem, will be the institutions responsible for environmental management and land-use planning.

The time frame *for implementation* is short-term and long-term.

RECOMMENDATION **5**

CEARC should promote at least one long-term study in a biophysical research subject that is fundamental to an understanding of cumulative effects, and which requires research of more than five years duration for its resolution; the objective would be for CEARC to sell the idea that certain cumulative effects questions will never be answered unless there are mechanisms to ensure that long-term financial support will be available when warranted.

Rationale for the recommendation — It was stressed at the 1985 cumulative effects workshop (Clark 1986) that traditional environmental impact assessment practice does not give adequate attention to the way that degradation of individual valued ecosystem components accumulate to cause an overall degradation of whole environmental systems. As an example of this concern, Bormann (1985) postulated that forest ecosystem decline as a result of air pollution may have some functional analogies with the situation faced by radiation biologists two decades ago, who found that biological effects of radiation were continuous and did not follow a threshold pattern as previously believed. If this were the case in a stressed forest ecosystem, small but continuous reductions in energy flow through the ecosystem might be linked to sudden declines in biotic capacity to regulate energy flow and biogeochemical cycles. As Odum (1985) has emphasized, when stress is detectable at the ecosystem level there is a real cause for concern, for it may signal a breakdown in homeostasis.

At least one recent analysis of techniques for managing stressed ecosystems (Loucks 1985) has come to the discouraging conclusion that neither the system-specific assessment nor a longer-framework assessment can be viewed as truly predictive, and neither can stand alone as a management approach. This uncertainty suggests that high priority must be given to long-term research on stress in ecosystems.

The *cumulative effects pathways involved* are potentially any of Pathways 1, 2, 3 or 4 (Figure 2).

Suggested steps for CEARC of others to implement the recommendation — The first step to implement this recommendation would be for CEARC to initiate a problem analysis to identify a specific cumulative cause-effect pathway that is functional and measurable at the ecosystem level. Several processes associated with acid rain would be appropriate subjects, although it may be preferable to focus on a different cumulative effect because acid rain is already the subject of considerable research. The cumulative effects issues summarized in Chapter 6 offer numerous other target subjects for long-term examination.

The long-term research objectives should focus specifically on the question posed by Clark (1986), namely how do degradations of individual valued ecosystem components accumulate to cause an overall degradation of whole environmental systems. Research on stress in ecosystems should include a broadened search for biological effects that act in a continuous fashion rather than in a threshold pattern. Equal emphasis should be given to a search for reliable early warning signals of ecosystem breakdown.

Once the long-term research objectives are defined, CEARC should initiate discussions with the National Science and Engineering Research Council (NSERC) or other appropriate funding agencies to promote the idea that certain research topics, essential to an understanding of cumulative projects, cannot be initiated without firm commitments that the research can be carried to its long-term conclusion.

Significance for EIA and environmental planning — The long-term research proposed here would have no immediate significance for EIA, other than to reinforce the idea that there are certain kinds of cumulative effects questions that simply cannot be researched in the context and time frame of EIA as we know it today. If the research resulted in identification of early warning signals of ecosystem breakdown, such knowledge would be of obvious political and administrative value in environmental planning.

The time *frame for implementation* is long-term.

RECOMMENDATION 6

CEARC should ensure that some cumulative effects research focuses on functional relationships within severely disturbed ecosystems that are being rehabilitated.

Rationale *for the recommendation* — There is a current debate about ecosystem research in "undisturbed" and "disturbed" ecosystems. On one side of the debate are those who suggest that the most important research to be conducted in ecological reserves is to monitor change that is occurring in the absence of human-caused disturbances. By this rationale, the approach is to wait for change to take place, a strategy in keeping with the principle that a key feature of ecological reserves is their value as outdoor laboratories where only natural processes are allowed to operate (Rowe 1985).

On the other side of the debate are scientists who point out the consequences of most ecological research being done in relatively "undisturbed" ecosystems. They suggest that such an emphasis is much like studying human physiology using only healthy subjects. Such studies include only a small subset of possible reactions and mechanisms; they also provide little information on methods to cure the sick (Aber and Jordan 1985).

A recent report by CAETEP (1986) made a particularly important point about "disturbance-tolerant" species in the context of species diversity indexes. A large environmental change often leads to local extinction of many sensitive species and to the predominance of a few disturbance-tolerant species. Consequently, species diversity indexes have been used as measures of disturbance in a community. Such uses of diversity indexes have been controversial, because they have been applied with little regard for the functional changes that occur in disturbed ecosystems. Most of the complexities of the processes that change diversity are not captured in diversity indexes, which are appropriately used only when one can be confident that they reflect the behaviour of the system being measured.

In keeping with the suggestion by Orians (1986) that we are interested not only in reducing undesirable cumulative effects in the future but also in undoing undesirable effects that have already occurred, there are now compelling arguments that ecological studies centred around restoration techniques may provide a unifying link between theory and practice. The idea is that many ecological questions can be answered synthetically by reconstruction, rather than relying solely on the traditional approaches of description and dissection. This idea should be tested further by CEARC by directing some cumulative effects research toward functional relationships within disturbed ecosystems that are being rehabilitated.

This subject was referred to by Clark (1986) in a somewhat different context. He noted that ecosystems in general show substantial capacities to return to their previous condition after disturbance. Holling (1985) has also made the point that *most* impacts do not accumulate because most environmental systems are sufficiently resilient to absorb many perturbations. From these observations, Clark (1986) concluded that the scientifically important question is not whether things are connected in ecosystems, but rather which things are so tightly connected that they must be analysed jointly in environmental assessments. Cumulative effects research in disturbed, but recovering, ecosystems would offer new opportunities to identify variables that must be analysed jointly.

The *cumulative effects pathways involved* are predominantly Pathways 1, 3 and 4 (Figure 2).

Suggested *steps for CEARC or others to implement the recommendation* — This suggested topic is one for which CEARC's most appropriate role may be the promotion of a pilot study by some existing research agencies. Rehabilitation and habitat enhancement projects are underway, or have been planned, in several freshwater and terrestrial ecosystems in Canada; such project areas should be assessed for suitability for the cumulative effects research proposed here.

Studies on the reversals of cumulative effects in ecosystems that are recovering naturally or are being rehabilitated through specific management techniques need not be as multidisciplinary as other cumulative effects research is. The single cause – single effect approach advocated by Clark (1986) would be appropriate here.

Ultimately, it will be in CEARC's interest to publicize the reversibility of certain cumulative effects problems. The option to do that will be hastened by CEARC's early promotion of a pilot study of cumulative effects in disturbed, but recovering, ecosystems.

Significance for EIA and environmental planning — Because the recommended research may require some long-term studies, implementation of this recommendation would be of no immediate significance for EIA or environmental planning. Information on recovery rates and reversibilities of cumulative effects will ultimately be of value, however, for environmental planning and management.

The *time frame for implementation* is initially short-term, but some research results may require long-term study.

RECOMMENDATION 7

CEARC should initiate a detailed evaluation of several alternative avenues by which research data are gathered for intended application to cumulative effects assessment; a related objective would be to assess the relative attention being given to research at various levels of integration from cell to total ecosystem.

Rationale for the recommendation — The traditional reliance on environmental monitoring programs as a measure of ecosystem change needs additional evaluation because these programs generally do not provide the level and quality of data useful in experimental science. An intensive examination of specific components of ecosystems may provide data of greater value for assessment of cumulative effects than is the case with present monitoring programs. In Canada, the trend has been toward the establishment of large, centralized institutional centers of research. Each is limited by jurisdictional mandate and the inclination of the researchers. Use of large government agencies that carry out monitoring programs is one way to assemble data for cumulative effects assessment, but comparisons should be made with other avenues, such as smaller university laboratories, or research conducted in the private sector in relation to EIA.

The evaluation recommended above should give particular attention to the rigour needed for scientifically defensible forecasts (O'Riordan 1986). Notably, it is not only scientists who stress the need for scientific rigour; at the 1985 cumulative effects workshop (CEARC and U.S. NRC 1986) several participants with long experience as environmental managers made the same point. Baskerville (1986b) stressed that "what is needed most of all in cumulative impact forecasting is more scientific rigour." Examples in need of evaluation are techniques that attempt to predict environmental impacts themselves directly. The forecast of an impact necessarily implies that there exists forecasts of system behaviour, with and without intervention. As Baskerville (1986b) concluded, research that claims to identify impact without simultaneously characterizing system performance in the presence of and in the absence of intervention is not credible science. This point is important not only for scientific reasons because, as emphasized by Dayton (1986) and Policansky (1986), the effects of natural variability are less likely to be cumulative than are human-induced effects. Sadler (1986) also noted that the key to understanding cumulative effects rests, first, on being able to distinguish anthropogenic changes from natural variability within specified boundaries and, second, on being able to relate this to the stability and resilience of natural systems.

Biological systems function at many levels from the cell to the ecosystem and the search for measures of response to disturbances has ranged across this entire spectrum. Many analysts stress that pollution effects occur within ecosystems and that our emphasis must therefore be at that end of the hierarchy. The point was made in Chapter 3 that of the various levels of integration between cell and ecosystem, the three most defensible levels for rigorous scientific investigation were the ceil, the individual and the ecosystem (Rowe 1961). There is growing recognition of the importance of cellular and physiological measures of pollution effects. Responses at these levels in the biological hierarchy occur over short time-scales, from minutes to days, and have been shown to be very sensitive. Furthermore, studies of cellular processes come closest to tackling the features of animals and plants that are most intimately responsive to contaminants in the environment (Bayne 1985).

Although there are repeated reminders that cumulative effects occur within the context of ecosystems, cumulative effects research promoted by CEARC should not focus exclusively on studies at the ecosystem level; equal support should be given to research at the cellular level within organisms because it is there that dose-response relationships, thresholds and toxicological indices can be most accurately documented.

The *cumulative effects pathways involved* are potentially any of Pathways 1, 2, 3 or 4 (Figure 2).

Suggested steps for CEARC or others to implement the recommendation — This recommendation is not intended to undermine the value of ecosystem studies; in fact, other recommendations of this review identify ecosystem research that is essential for assessing cumulative effects. Therefore, CEARC need not encourage a debate on the relative merits of ecosystem-level research and cellular-level research. It is more important to acknowledge that both are needed.

Follow-up evaluation by CEARC should focus on an evaluation of the research avenues that are most productive for obtaining cumulative effects information at the cellular, individual organism and ecosystem level. This task is different than the well-worn debate over basic research versus applied research.

Specific comparisons of the value of research data for cumulative effects assessment, based on both scientific and socio-economic evaluative criteria, should be made for research carried out as: a) an integral part of a project-specific environmental impact assessment, such as the recent Eastern Arctic Marine Environmental Studies; b) separate ecosystem-based studies, such as the Experimental Lakes Area: or c) fundamental research supported by NSERC or other comparable funding sources.

The goal of such an evaluation is to provide information by which CEARC could advise NSERC, the Ministry of State for Science and Technology, and other federal departments involved with research funding on the types of research and the funding horizons (three-year, five-year, more than five-year) required to address the main cumulative effects issues facing Canadians.

Significance for EIA and environmental planning — The evaluation suggested above would clarify several conflicting opinions that now prevail about the role of EIA as a vehicle for scientific research. An evaluation conducted according to rigorous scientific and socio-economic criteria would help define the most appropriate avenues for obtaining the data needed for improved cumulative effects assessment.

The *time frame for implementation* is immediate for the evaluation phase; and short-term and long-term for a research agenda based on the recommendations of the evaluation.

RECOMMENDATION 8

CEARC should initiate or encourage research into the application of general systems concepts to the evaluation of ecosystem perturbations for potential cumulative effects.

Rationale for the recommendation — Application of ecological information relating to cumulative effects will be more effective if ecosystems are viewed as systems (Odum 197 1b), that is as networks of sources and sinks of energy flow, inter-connected by control elements and feedback loops.

The systems analysis approach is an essential basis for treating cumulative effects quantitatively. The representation of ecosystems by network diagrams provides a means of visualizing the system's interactions qualitatively. Such networks may also be represented as matrices (Clark 1986). Because of the complex nature of the interactions that cause cumulative effects, planners cannot be expected to analyse the potential for cumulative effects in detail at their current levels of expertise. Training in general systems approaches would strengthen their capability to ask the right questions about development scenarios. The development of generic systems models applied to ecosystem interactions is necessary to provide the analytical basis for understanding how cumulative ecosystem impacts may arise.

The cumulative *effects pathways involved* are predominantly Pathways 3 and 4 (Figure 2).

Suggested *steps for CEARC or others to implement the recommendation* — Education of prospective planners about the principles of ecosystem analysis is a key step for implementation of this recommendation. To assist this goal, CEARC could encourage an educational emphasis on the systems approach in existing training programs.

An important step is to develop relatively simple, generic systems models to be used for assessment and planning purposes. Descriptions of general system concepts by Weinberg (1975) and the overview of environmental systems analyses by Blau (1985) would aid implementation of this recommendation.

Significance for EIA and environmental planning — This recommendation would assist planners and organizational representatives responsible for EIA and cumulative effects assessment to develop an appreciation of how the environment's complexity may be reduced to an analysable scale. General systems thinking must permeate the EIA and planning communities. If this can be accomplished, the data inputs needed for scientifically defensible analyses will be more clearly defined for environmental planning organizations.

The *time frame for implementation* is long-term.

RECOMMENDATIONS RELATED TO RESEARCH-MANAGEMENT LINKS

RECOMMENDATION **9**

CEARC should encourage and support a search for mechanisms that would result in better linkages between epidemiological and environmental research,

Rationale for the recommendation — Medical researchers are not necessarily well trained in disciplines essential to environmental research. Similarly, environmental researchers are rarely involved in epidemiological research. Other barriers centre around the nature of data collection and retrieval. For instance, medical records are not easily accessible to environmental researchers. Even at an epidemiological level, existing records are not usually suitable for wider application. Further, bans regarding the confidentiality of health data limit access to those pertinent data that may be on file. The information flow between environmental and health professionals is very limited and these circumstances have hindered the necessary cumulative effects research into human health questions. For these reasons, it is recommended that CEARC investigate ways to obtain integrated data sets for circumstances in which environmental changes result in human health problems. A new approach is needed if there is to be better long-term assessment of cumulative effects in human populations.

As a guide for possible initiatives by CEARC there are some examples of initiatives taken to bridge the institutional and disciplinary gaps between medical and environmental researchers. The Medical Diagnostic Review Program of Alberta's Acid Deposition Research Program, initiated in 1985, is one good example of a special research program undertaken to assess human health effects of acid gas emissions in southern Alberta. Interestingly, special funds were allocated outside of existing institutional and research agencies to allow the university-based research team to undertake the research under contract. Funds for this program were allocated only after residents of the Pincher Creek region had complained of alleged health problems for decades. Significantly, EIA was not a part of the Medical Diagnostic Review in Alberta.

This private sector – university study arrangement, funded by the province of Alberta, deserves serious consideration for possible applications elsewhere in Canada. The use of such approaches to research should be tested for a greater variety of cumulative effects problems that have human health connotations.

The *cumulative effects pathways involved* are predominantly Pathways 2 and 4 (Figure 2).

Suggested steps for CEARC of others to implement the recommendation — Three steps that could be initiated or promoted by CEARC are:

- Environmental-epidemiological data banks for Canada: Compatibilities of the types of data accumulated by epidemiological and environmental researchers should be investigated with a view to making basic data retrievable to a broad spectrum of researchers. Mechanisms and procedures to access medical data by non-medical personnel need to be developed. Similarly, environmental data sources must be presented in a manner useful to medical researchers. The traditional concepts of "data banks" may not suffice here. Perhaps special systems need to be recommended for each specific epidemiological study undertaken for environmental pollutants. The Alberta program referred to above could be instructive for future researchers.

- Epidemiological research centres: Currently, most epidemiologists are unfamiliar with EIA processes in Canada and the approaches used by environmental researchers. Only in exceptional cases are scientists from the various disciplines collaborative. Environmental epidemiological research is in its infancy in Canada, as it is in the rest of the world. Only few examples exist of detailed studies and these, such as the Bhopal incident, are usually related to catastrophic events.

CEARC could improve this situation by directing attention to deficiencies noted above and by recommending the allocation of special funding to epidemiological research centres to address environmental research. In general, CEARC should encourage the incorporation of epidemiological techniques into existing EIA mechanisms in Canada. CEARC could also set out a listing of probable long-term research topics upon which epidemiological investigations could be based. Any significant bridging of medical and environmental research communities would be a major contribution.

- Epidemiological data and decision making: A major deficiency in existing EIA mechanisms in Canada is that decision makers rarely are provided with an epidemiological perspective in relation to cumulative effects. The debate over smoking and cancer or use of asbestos are examples that demonstrate the time that can elapse between problem definition and regulatory decisions. In these examples, several decades elapsed before actions were taken to protect the public. Such delays do not contribute to the prevention of medical problems that are rooted in environmental conditions.

Whether by special funding for specific research projects or through long-term application of research programs, or both, CEARC could have a major role in identifying potential centres of excellence in developing environmental epidemiological research. CEARC could be a catalyst in this important area for research and could monitor progress within several distinct categories of environmental problems. Undoubtedly, this would be a major undertaking in time and funds. However, the problems addressed have significance to a wide spectrum of Canadians. A key role for CEARC could be to oversee the identification of appropriate problems to research under this heading. In cases where real needs for health protection have been acknowledged, CEARC could act as facilitator of workshops to define methodologies to be employed.

Significance *for EIA* and environmental planning — EIA has only lightly touched upon the definition of long-term medical problems resulting from major development proposals. In general, the EIA-epidemiological interface is in its infancy. This is unfortunate, since the public is judged to be far more concerned about long-term cumulative health effects than strictly environmental impacts. Improvement of the situation appears to be dependent on a far more active role for governmental health departments in the EIA process in Canada and in detailed medical monitoring of environmentally recognized cumulative effects.

The long-term monitoring of areas of known medical hazard is greatly overlooked in the process of environmental assessment. For instance, man-made changes in freshwater input rates to Hudson Bay and James Bay (Prinsenberg 1980) are thought to be associated with increased mobilization of mercury into the marine environment. The links to increased mercury burdens in marine wildlife and in Inuit are already established (Wheatley 1979; Eaton and Farant 1982). A long-term, integrated monitoring system, involving both environmental and medical variables, is required to properly assess the epidemiological consequences of such processes.

The time *frame for implementation* is long-term.

RECOMMENDATION **10**

CEARC should encourage the initiation of at least one cumulative effects study that is well suited to integration of scientific and socio-economic aspects at the research stage; a candidate topic is research into the applicability of the "bubble concept" to airshed management for the control of atmospheric cumulative effects in Canada.

Rationale *for the* recommendation — Airshed management programs based on the concept of an enclosed air space, or "bubble," have recently been developed to apportion permitted emissions among existing or proposed sources in a regional or single-site development area. Application of the concept has ranged in scale from extended urban-industrial developments to multiple emission points within a single plant. The concept is most highly developed in California where, under the state's Clean Air Act, the entire state is partitioned into airsheds or air management districts.

Regional air quality management units have also been defined for several parts of the northeastern United States, for several urban areas in Ontario and for the cities of Vancouver and Montreal. The management units address areas defined by topographic or economic development characteristics that attempt to define "airsheds" analogous to watersheds, which are semi-independent in nature.

Whether the "bubble" approach correctly alleviates cumulative effects has yet to be demonstrated for areas other than those that are topographically distinct basins, such as the Vancouver and lower mainland region of British Columbia. The Greater Vancouver Regional District and the B.C. Ministry of the Environment are currently developing a plan, on the scale of the lower mainland, to control emissions that form photochemical oxidants, a reasonably well-understood cumulative effect. Whether the airshed management approach enhances the control of cumulative effects remains to be demonstrated.

The *cumulative effects pathways involved* are predominantly Pathways 3 and 4 (Figure 2).

Suggested steps for CEARC or others to implement the recommendation — Unlike most of the other recommendations in this report, which tend to ignore the contributors to cumulative effects by focusing on the roles of administrators, regulators, planners and scientists, this topic would lend itself to integrated involvement of those who are subject to regulation Evaluation of this concept would provide an excellent opportunity to integrate socio-economic considerations with technological criteria for air quality management. This suggested integration implies that this recommended project would give CEARC the opportunity to invite industry and other "contributors" to the studied cumulative effect to be involved in the integrated research approach.

This subject also lends itself to a comparative analysis of various alternatives for cumulative effects management, including approaches based on regulation, mediation, and economic incentives. A pilot study in a Canadian urban area would provide the basis for both evaluation of this concept and its development.

Significance for EIA and environmental planning — *The* development of airshed management principles, involving socio-economic as well as scientific aspects, would enhance the capability of planners to allocate acceptable emissions more effectively, and less arbitrarily, than at present.

The time frame for implementation is short-term.

RECOMMENDATION **11**

CEARC should encourage a comprehensive examination of existing regulatory standards in Canada to assess their effectiveness in preventing cumulative, deleterious impacts.

Rationale for the recommendation — This state-of-the-art review lead to the conclusion that present regulatory standards in Canada would not, by themselves, ensure the successful management of cumulative effects. For example, long-term effluent standards are rarely based on cumulative impact assessments. Generally, acute lethal or other short-term criteria are employed. Many other examples exist of such short-term regulatory measures becoming an interactive subset of long-term cumulative effects. Hamilton (1986) addressed this problem with the following recommendation:

> *We ought to place less reliance on regulation as a means of sustaining the long-term viability of our freshwater ecosystems. The current approach of regulation with very little follow-up results in a very flexible situation that is probably in no one's best interests.*

The basic problem is that the existing "end of pipe" regulatory structures tend to ignore the impacted ecosystems, Conservation and protection strategies are overly restrictive once placed within the regulatory agenda. In the words of Hamilton (1986), "technology-based" standards have little relation to "ecosystem-based" standards.

A central problem in addressing cumulative effects rests with the definition of the term in reference to time scales. Time must be specified before any meaningful comparative analyses can be attempted. For example, for those interested in cumulative effects in groundwater systems, it is important to recognize the slow rate of movement of groundwater in comparison with movement of water over the land surface or in the atmosphere.

The *cumulative effects pathways involved* are potentially any of Pathways 1, 2, 3 or 4 (Figure 2).

Suggested steps for CEARC *and others to implement the recommendation* — CEARC should plan its future work in a way that would benefit from ecosystem-based research initiatives that have already been successfully employed. For instance, the Experimental Lakes Area of the Department of Fisheries and Oceans has fundamentally assisted government agencies across North America to develop phosphorus regulations and standards for protection of lakes. Experimental data from this study area are also an integral part of the documentation of long-term cumulative effects of acidification of lakes in the Canadian Shield.

Linkages between such long-term ecosystem studies and regulatory agencies needs to be more fully elaborated. Such studies should be investigated to search for mechanisms to insert their conclusions into ongoing EIA research. Presently, the regulatory and research communities tend to operate in isolation, partly because at least three separate activities are involved: EIA planning and research; regulatory standards and enforcement; and long-term ecosystem research. It is recommended that CEARC search for mechanisms to integrate these separate processes and to incorporate the findings of long-term research into existing standards.

In this context, it may be most appropriate for CEARC to function mainly as a facilitator, with the major effort, currently underway by the Canadian Council of Resource and Environment Ministers (CCREM), to be accelerated.

Significance for EIA and environmental planning — The implementation of EIA in Canada, across the numerous jurisdictions, lacks uniformity of approach and application. A comprehensive assessment of standards for environmental regulations would provide a more visible basis for inter-jurisdictional comparisons of enforcement, compliance and the resulting levels of environmental protection. Such information would, in turn, provide valuable points of reference for future EIA work, particularly where EIA requires the incorporation of regulatory standards.

The *time frame for implementation* is short-term.

RECOMMENDATION **12**

CEARC should focus its attention on new approaches to pesticide-related research that has been difficult to undertake to date because of insufficient data to verify the assumed cumulative effects problem.

Rationale for recommendation — As outlined in the prairie provinces case study (Chapter 5) a major deterrent to cumulative effects assessment in relation to insecticides, herbicides and fungicides is the absence of reliable data on amounts of these compounds being released to the environment. Research into cumulative effects of agricultural uses of insecticides, herbicides and fungicides has been handicapped by such lack of data, and it is a subject for which important advances could be facilitated by CEARC.

Although organophosphate insecticides and selective herbicides are advertised as non-persistent, and are certainly less persistent than are many organochloride insecticides, there are not adequate data on the usage or effects of use either on a routine basis or when pest outbreaks disrupt the routine.

This suggested research topic would provide an excellent opportunity to focus on the two interactive cumulative effects pathways (Pathways 2 and 4 in Figure 2, involving magnification and synergistic effects, respectively) which tend to receive less attention than additive cumulative effects (Pathways 1 and 3 in Figure 2).

The cumulative effects pathways involved are predominantly Pathways 1, 2 and 4 (Figure 2).

Suggested steps for *CEARC or others to implement the recommendation* — Although insecticides, herbicides and fungicides are well understood as individual compounds and in terms of their effects on target organisms, there are major knowledge gaps about overall quantities of these compounds applied on a regional basis in Canada, effects of repeated applications, and interactive effects of simultaneous occurrence of two or more agricultural chemicals. If CEARC initiates an analysis of this problem, the first step would be a more detailed definition of the knowledge gaps than was possible in the present review.

Specific research objectives to consider in any follow-up research promoted by CEARC include the following suggested steps:

- determine the frequency of application and dosage of pesticides and herbicides used on a district basis over a period of years to give some idea of the extent of the problem; at present such data are not available or not accessible;
- examine residues in soil and biota for evidence of accumulation and bioaccumulation; this would require a long-term monitoring program similar to some now in progress; and
- undertake an ecosystem monitoring system to determine the effects of repeated spraying, regardless of accumulation. Ideally this should be experimental and comparative, but it is unlikely that controlled spraying can be carried out over a large enough area to be representative. In the natural situation spraying is occurring over a significant proportion of a very large area. There is presently very little information on the ecosystem effects when large populations of insects, and many plant species, are repeatedly removed from a target area over a long period.

Significance for EIA and environmental planning — The purpose of the recommended work is to discover whether cumulative effects exist and, if so, how severe they are. Such information is essential input to both EIA and environmental planning if either or both of these processes are to be used to ensure that agricultural chemical usage is not leading to deleterious cumulative impacts.

The *time frame for implementation* is long-term.

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