Reference Guide, Feasibility Study, and Overview of Institutions Interested in Cumulative Effects Assessment
Volume I

Reference Guide to Cumulative Effects Assessment in Canada

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A Manuscript Report Prepared for the
Canadian Environmental Assessment
Research Council
October 1988

NOTE TO READER

This volume is part of a three volume set as follows:

VOLUME I A REFERENCE GUIDE TO CUMULATIVE EFFECTS ASSESSMENT IN CANADA

By Patricia A. Lane, Ronald R. Wallace, Richard L. Johnson and David Bernard

VOLUME II FEASIBILITY STUDY IN CEARC CUMULATIVE EFFECTS ASSESSMENT (CEA) WETLANDS OF THE BOREAL AGRICULTURAL FRINGE OF THE PRAIRIE PROVINCES

By Ronald R. Wallace and Patricia Lane

VOLUME III OVERVIEW OF AGENCIES AND INSTITUTIONS INTERESTED IN CUMULATIVE EFFECTS ASSESSMENT AND MANAGEMENT

By Nicholas Sonntag, Patricia A. Lane, Ronald R. Wallace, Brian M. Marcotte and Stephen H. Janes

Please note that VOLUMES II and III are addenda to the main report (VOLUME I). VOLUMES II and III are available in xerox form upon special request to the Canadian Environmental Assessment and Research Council (CEARC) in Hull, Quebec.

October 1988

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PREFACE

The Canadian Environmental Assessment Research Council (CEARC) was established by the Government of Canada in 1984 to advise governments, and others, on possible improvements to environmental impact assessment. Through the leadership of CEARC, and other Canadian environmental assessment agencies, the assessment of cumulative effects (CEA) is recognized as essential to the maintenance and preservation of Canadian natural resources and environmental quality. This recognition implies a need for a broad approach and long-term solutions to cumulative effects in the scientific, social and institutional spheres of influence. This Reference Guide is the fourth in a series of CEA studies supported by CEARC (CEARC and U.S. NRC, 1986; Peterson et al., 1987; and Sonntag et al., 1987).

This first attempt by the Canadian Environmental Assessment Research Council to produce a detailed Reference Guide for Canada involved many individuals across Canada and the United States. The study team was constituted so that the various geographical regions of Canada would be adequately represented. Dr. Patricia A. Lane, P. Lane and Associates Limited (Halifax, Nova Scotia), and Dr. Ronald R. Wallace, Dominion Ecological Consulting Limited (Calgary, Alberta), served as co-project managers and were responsible for much of the writing. They also collected information on the Atlantic and Prairie Provinces, respectively. Dr. Wallace was the main author of Volume II concerning the Wetlands Feasibility Study (Wallace and Lane, 1988). Mr. David Bernard and Mr. Nicholas C. Sonntag of ESSA Limited (Vancouver, British Columbia) collected information on the Territories and British Columbia, and they were also responsible for summarizing the agencies interested in CEA and for compiling the CEA methods [Volume III (Sonntag et al., 1988) and Appendix 8.1 of Volume I, respectively]. Mr. Stephen H. Janes of Janes and Associates Limited (London, Ontario) was responsible for the Ontario region and for providing advice on jurisdictional and institutional considerations. Dr. Brian M. Marcotte and his student, Mr. Vidar Neuhof, of McGill University, conducted interviews and reported on CEA in Quebec.

ACKNOWLEDGEMENTS

Dr. Gordon Beanlands, Executive Secretary of CEARC, provided overall direction for the project as Scientific Authority. His insight into CEA in Canada and his encouragement greatly enhanced the Guide. He also provided excellent logistical support to the study team. Dr. Barry Sadler and Dr. Jon O'Riordan contributed invaluable advice as to the study direction and content. Dr. M. Husain Sadar and Mr. Robert Connelly, FEARO, Ottawa, also provided advice on the Guide and facilitated discussion on CEA with other FEARO-CEARC personnel.

The project greatly benefited from a Science Advisory Board which was established to ensure the proper balance and scientific content for the study. The Science Advisory Board consisted of the following individuals: Dr. Robert Rosen of Dalhousie University; Dr. Richard Levins of Harvard University; Mr. Richard Johnson, U.S. Fish and Wildlife Service: Ms. Sally deBecker of Pacific Gas and Electric Company; Mr. Earle Hickey of Environment Canada, Canadian Parks Service (Halifax, Nova Scotia); Mr. Bruce Turner, Canadian Wildlife Service; and Mr. Gary Stewart of Ducks Unlimited (both of Edmonton, Alberta). Mr. Turner and Mr. Stewart allowed the use of their unpublished data for the Wetlands Feasibility Study [Volume II (Wallace and Lane, 1988)]. The study team gratefully acknowledges the assistance of these individuals in offering suggestions on CEA, supplying reference materials, sharing their experiences in CEA, and reviewing our draft report.

Besides serving on the Science Advisory Board, Mr. Richard Johnson of the U.S. Fish and Wildlife Service (Fort Collins, Colorado) contributed greatly to the writing of the U.S. experience (Volume I, Appendix 7.3). He generously shared his considerable insight into CEA. Several of the ideas described in these sections were influenced considerably by communications with Dr. Carl Armour and Dr. Samuel Williamson of the U.S. Fish and Wildlife Service. Ms. Merle Peterson and Dr. Everett Peterson, Western Ecological Services Ltd. (Victoria, B.C.), advised us on their previous work in CEA and offered valuable suggestions on the draft report. They also provided the use of their office facilities while the team conducted meetings in Victoria.

Dr. Ted Manning of the Lands Directorate, Environment Canada (Ottawa), discussed CEA with us and provided reference material for the Wetlands Feasibility Study. Mr. John Donihee of Yellowknife, NWT, met with us to discuss CEA issues specific to his area and the overall regulatory considerations of CEA. Dr. Elizabeth Stull of the Argonne National Laboratory gave us advice on the theory of CEA and the description of the U.S. experience. Ms. Chantel Abou Debs prepared the French resume de l'exécutif on the final version of Volume I.

Approximately 80 other persons in government, academia and industry across Canada participated in the interviews. Each individual who contributed to these interviews is sincerely thanked for this important contribution to the Guide. These individuals are listed in Volume III (Sonntag et al., 1988).

The study team sincerely acknowledges the assistance and contributions from all the above-noted. While we acknowledge those significant contributions, the authors accept full responsibility for the comments in, and conclusions of, our report.

EXECUTIVE SUMMARY

There is a whole class of environmental problems that is presently not well treated by traditional environmental impact assessment methods and existing jurisdictional and institutional arrangements. Collectively these problems can be termed cumulative effects (CE). They can arise from multiple human activities in a given area or from multiple perturbations to the environment from a single activity. Cumulative effects can be characterized as occurring over spatially-extended areas greater than the size of the local ecosystem. Examples in Canada include long-range transport of atmospheric pollutants, global climate change, large water diversion projects, groundwater contamination from toxic chemicals, and habitat fragmentation. Probably every part of Canada is experiencing cumulative effects in one form or another.

Environmental impact assessment procedures and requirements in Canada are narrowly focussed upon single proponent, single development assessments. These are termed proponent-driven assessments. There is no effective assessment and management approach to regional patterns of environmental deterioration which may result from small incremental actions having no identifiable proponent or where there are so many proponents and human activities occurring that there is no way to assess their combined effects on the environment. These are termed ecosystem-driven assessments. Who assumes responsibility in such instances is a key question. Cumulative effects have ramifications beyond environmental deterioration per se. Broad-scale loss of environmental quality implies severe long-term economic losses and a restructured set of development opportunities, or lack of them, for Canada's future. The World Commission on Environment and Development (1987) has recently reported on the ramifications of cumulative effects on a global scale. Canada, as a country both rich and yet dependent on its natural resources for its continued prosperity, cannot permit cumulative effects to increase in an unchecked and unmanaged fashion if Canada is to have an effective sustainable development policy.

The objectives of the Guide are to provide a basic reference to cumulative effects problems in Canada, to describe the present conceptual thinking on the subject here and in the United States, and to present a methodological framework for conducting CBA. A way to categorize cumulative effects problems is also given.

Because the consideration of cumulative effects was placed in environmental regulations several years ago in the United States, Americans have conducted more CEA and developed more methodologies than Canadians. There are no CE regulations in Canada. In the U.S., a large number of federal and state agencies as well as a variety of proponents have been actively working on CEA methodologies. Many methods have been suggested, but the basic conclusion of the U.S. efforts is that cumulative effects assessment should be considered a process and not a single method.* The U.S. and Canadian experiences are summarized in Appendix 7.0. At different steps in the process, ,a variety of methods can be utilized. These are outlined in the Guide and annotated in Appendix 8.0.

The Guide is designed for the Canadian user. Beginning with a typology based upon proponent- and ecosystem-driven types of cumulative effects, the user is asked, "Do you need a cumulative effects assessment?" A decision tree helps the user to answer this question.

The user must then decide whether to use a top-down or bottom-up type of cumulative effects assessment. The Guide provides a 12 to 13 step process for either application. Essentially, the top-down approach is used for ecosystem-driven and the bottom-up for proponent-driven cumulative effects problems. Central to the conceptualization is the notion of feedback, and early determination of whether the key feedbacks occur with the human activities, the environmental changes they induce, the valued ecosystem components, or some combination of these. Feedbacks are very important in these complex systems. Feedbacks can be the cause of surprise and counterintuitive effects that foil management efforts. Feedbacks can also serve a valuable role in system control but only if we can understand and manage them appropriately.

The Reference Guide concludes with three sets of recommendations on further development of CEA in Canada. These include: (1) methodological considerations, (2). potential jurisdictional and institutional arrangements, and (3) the use of consensus-building techniques.

For the first set of recommendations, the main method suggested is loop analysis which centers on the evaluation of feedback relationships and their role in complex systems. Loop analysis involves qualitative network analysis and can be used by a non-mathematical assessor. The method can combine biophysical, socio-economic, jurisdictional and institutional variables in the same cause and effect network. This facilitates the elucidation of the system behaviour emanating from the interconnection of these disparate variables. In this section, we also recommend that the development of CEA will proceed most effectively if there is an iterative process between the improvement of the conceptual framework and its application in a case study format. Both top-down and bottom-up case studies are needed.

In the second set of recommendations, we suggest that there be some new federal initiatives for CEA in Canada. There needs to be an effective combination of regional planning and environmental assessment capabilities in a new type of environmental management. We suggest that five regional CEA boards be established across Canada and that they operate under federal mandate, to guide CEA efforts in their respective regions with an overall cohesive policy on sustainable development. These boards would handle both proponent-driven and ecosystem-driven types of CEA.

In the third set of recommendations, we discuss many cumulative effects problems centering on the joint use and sharing of environments and their resources. This inherently involves negotiation by all parties concerned to ensure the optimal use and least damage to these spatially extended systems.

The Guide also contains a glossary of acronyms and a large bibliography to direct the reader to more specialized areas of the cumulative effects literature. A feasibility study involving the wetlands of the boreal agricultural fringe of the Prairie Provinces is described in Volume II (Wallace and Lane, 1988). Both the biophysical and associated jurisdictional and institutional problems are discussed. Suggestions' are then given as to how the cumulative effects problem could be assessed using a top-down assessment process. In Volume III agencies and organizations interested in CEA in Canada are described (Sonntag et al., 1988).

1.0 INTRODUCTION

1.1 Cumulative Effects Assessment (CEA)

The purpose of this section is to define CEA and to provide an overview of why CEA is such a difficult subject area both conceptually and operationally. In addition, the importance of improving our ability to conduct, implement, and review CEAs is emphasized. Cumulative effects or impacts potentially affect every Canadian now and in the future. CEA is probably the most difficult and inherently complex problem facing environmental managers, regulators, and developers in managing our natural environments and resources. Effective management of cummulative effects in Canada is the key to a successful policy for sustainable development.

Traditional environmental impact assessment (EIA) usually centers on a single development planned by a single proponent in a circumscribed area, such as a local ecosystem, for a specified time period. In recent years, there has been growing dissatisfaction with this assessment process since many problems of environmental deterioration, resource management, and multi-user conflicts are broader in scope. The growing awareness of the serious long-term effects of acid rain, global warming, urbanization, accelerating loss of wetland habitats, large river diversions, large lake eutrophication, and species extinction have captured the attention of national and international decision makers. These are cumulative effects problems. Because EIAs have traditionally examined a single project and effects that can be directly traced to the project, there is no doubt that considerable environmental detrioration proceeds unrecognized and unchecked.

Cumulative effects assessment (CEA) is currently undergoing intense development in Canada and abroad to address the larger spatial and longer temporal scales for ecological, socio-economic, jurisdictional and institutional systems related to environmental deterioration. An increasing number of literature citations also demonstrates that CEA will have profound effects on how we conduct environmental assessments, influencing information requirements, data collection, analytical tools, environmental training and jurisdictional and institutional systems. Assessments will be increasingly of an interdisciplinary nature and will have to cross traditional jurisdictional boundaries. New assessment methodologies and institutional frameworks will be necessary for Canada to be able to conduct CEAs and manage CEs effectively. The significant challenge posed by cumulative environmental effects will test all levels of the scientific and environmental management communities, not just in Canada, but globally.

The problem of developing CEA is multifaceted. First, it is difficult to achieve consensus on the definition of cumulative effects (CE). Second, many small individual actions are not considered important in traditional EIA even though we now realize that their collective consequences can be severe on a regional scale. Third, the theory of cause and effect in spatially- and temporally-extended ecosystems is in its infancy, and what theory has been developed at the regional level in ecology, such as island biogeography, was not designed to answer EIA-type questions. Fourth, the existing jurisdictional frameworks are not equipped to deal with cumulative effects problems effectively. These frameworks have existed since Canada became a country and clearly predate the existence and identification of many cumulative effects problems. In addition, overworked environmental managers are limited by their disciplinary training, mandates, geographical jurisdictions and time constraints.

At present, there is no consensus on the definition of cumulative impacts. A working definition can be developed from a description of some possible types of cumulative impacts as follows (adopted from CEARC and U.S. NRC, 1986):

1) Cumulative impacts happen over a period of time when the same type of perturbation occurs with high frequency so that the separate perturbations are not damped out by the ecosystem (time-crowding). An example is a continuing incremental input such as acid deposition. This is essentially an example of a periodic input phenomenon.

2) Cumulative impacts happen in space when the same perturbation occurs in locations so close together that effects overlap spatially (space crowding). An example is the cyclical effects of forest clearcutting. This is a type of synergistic phenomenon.

3) Cumulative impacts occur from different types of perturbations (possibly from separate developments, activities, etc.) that affect similar environmental components if the spatial-temporal scales of the perturbations overlap sufficiently (compounding effects). This type of cumulative impact involves both periodic and synergistic inputs, and we define it as "combined".

It is now recognized that many diverse and remote factors may cause cumulative effects. For example, certain economic sectors may be directed, supported or controlled by governments, regulatory requirements, or jurisdictional factors in ways which synergistically cause long-term environmental degradation. The agricultural industry is a good case. Agricultural policies have provided subsidies, at virtually any cost, for an uncontrolled expansion of the agricultural base. These policies have caused additional and significant fragmentation of wetland habitats, serious soil erosion, and deterioration of aquatic systems through chemical contamination in runoff and siltation.

Cumulative effects are important because of their inherent multiplicative and nonlinear nature; combined effects represent a general example of this phenomenon. Many ecological relationships are essentially nonlinear, and these nonlinearities are magnified under many cumulative effects scenarios. Clearly, if cumulative effects are not addressed appropriately, there can be large prediction errors. Factor interaction is well known in toxicological studies at the individual level, but it is less well understood at the population and ecosystem levels.

Small Local Effects - Big Regional Problems

In 1982, Odum compared the problem of cumulative effects with the "tyranny of small decisions" as described by an economist, Alfred Kahn (National Research Council Committee, 1986). This concept calls attention to the fact that whenever numerous, small decisions affecting the environment are made independently, the incremental consequences of the decisions are usually not addressed nor are they recognized as being caused by discrete events. As a result, long-term or large-scale environmental perturbations have not been examined by traditional approaches to EIA nor are these problems, which are growing in significance, solvable by these methods. For instance, there are no scientific methods presently available which adequately assess cumulative effects quantitatively.

Theory of Cause and Effects in Spatially Extended Ecosystems

Whereas there is no consensus on the definition of cumulative effects, there is a general realization of the importance of recognizing them and being prepared to assess their significance in real world situations. As noted above, the pervasive nature of acid deposition on large biogeographical scales has called attention to the importance of this class of problem. As Canada becomes increasingly developed, areas larger than the size of the local ecosystem will continue to be affected both periodically and synergistically. As we develop improved conceptualizations of these spatially-extended ecosystems to predict and manage impacts, we will also need to develop new analytical tools to understand causal relationships correctly. Conceptualization will be an iterative process as analytical capability also improves. The environmental assessment community is now at a stage of discussing the issues and understanding the problems, but there is no universally established approach presently available and readily usable. If a generalized approach could be developed, then the whole field could progress quickly. Intensive theoretical development is necessary to expand the analysis of local ecosystems and singular developments into larger space and time scales for multiple developments and more intricate levels of causality that simultantously consider the biophysical and socio-economic aspects of the environment simultaneously.

In addition to the increased complexity of larger time and space scales and more intricate causality, there is also a more complex level of prediction required for CEA than for traditional impact assessment. In the latter, we wish to predict and compare system structure and behaviour with and without a particular development. Often the development can be described using engineering design criteria. With CEA, we will need to predict not only the future behaviour of systems with larger space and time scales but we also will be required to predict cumulative effects from developments not yet proposed but probable for a given region. This is necessary so that environmental planning is optimized over the long term and resources are not used on a first come, first served basis, which would close options for future development and resource use.

Resolving cumulative effects is not simply a problem of developing better analytical tools and improved understanding of spatially-extended and perturbed ecosystems. Equally important is the plethora of jurisdictional and institutional barriers that presently impede the identification and management of, cumulative effects. Hence, resolution of CEA in Canada will be significantly influenced by the solutions chosen for scientific, social and jurisdictional problems. While partial solutions in individual categories can be achieved, successful resolution of CEA problems is unlikely unless problems are addressed from an integrated perspective. Identifying workable solutions to the jurisdictional, institutional and procedural problems which impede implementation of environmental problem solving has only just begun to be addressed rigorously in Canada.

There is probably no single solution to all the types of environmental problems which may arise. The point, however, is that a solution to the existing jurisdictional dilemmas is presently being sought by several agencies. It is also clear that, while methodological problems for CEA may be identified and scientific approaches to resolve them instituted, the jurisdictional barriers may prevent, or at least frustrate, their optimal implementation. For example, we presently understand a great deal about the underlying causality and scientific aspects of impacts related to acidic deposition, but jurisdictional and institutional considerations have hindered the implementation of needed solutions.

As Peterson *et al.* (1987) pointed out, the structures of the existing environmental management agencies in Canada may be not capable of responding to, or identifying, 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."

This example of the multiplicity of jurisdictions and institutions failing to catch environmental problems of significance until they reach public awareness by threatening health, is compelling.

It is recognized that these types of agencies cannot be expected to respond to broader issues which extend through and beyond their collective jurisdictions. Indeed, in Canada the existing institutional arrangements tend toward. a fragmentation of interests and responsibilities regarding renewable resource management. No better example can be cited than the traditional struggles between forestry and fisheries interests and agencies. Harvested forest lands erode into, and degrade, fisheries habitat. Forest conservation and protection measures by aerial pesticide spraying against forest pests may directly affect aquatic species and nearby communities. Yet, no area wide management agencies are able to resolve, or perhaps even address, the wider issues of long-term management of the collective resources. Often, institutional arrangements preclude the open and objective resolution of such conflicts and leave little access for the average citizen, except through the costly and largely inefficient mechanism of the courts.

Similarly, societal attitudes toward the re-use (or non-use) of materials greatly amplifies the long-term, cumulative effects of seemingly insignificant, individual choices. Hence, economics, society and human attitudes all act, and interact, to produce cumulative effects on the receiving environment. This implies that effective solutions must address our fundamental attitudes toward the conservation and management of natural resources and environmental quality, and must be framed in policies that are cognizant of the interrelationships of environment, economics and society, that is, sustainable development. In short, CEA may be defined by environmental management techniques but cumulative effects can only be fundamentally and effectively addressed by much wider economic and social policy decisions. It is also essential that the management framework be designed for the extended spatial-temporal scales that are inherent in cumulative effects.

In any case, there has been no successful demonstration of legislative or institutional arrangements in Canada which has been able to cope adequately with, or regulate, the major long-term cumulative trends in environmental impacts at a national or regional scale. New legislative and institutional arrangements are urgently required as are the overall CEA conceptualization and approach that must underlie them.

1.2 Objectives of the Reference Guide

The objectives of the Reference Guide are as follows:

1) To motivate potential users to consider CEA-type problems and their solutions important for ensuring the quality of the Canadian environment,

2) To provide a basic reference of CEA terminology, concepts and references,

3) To present a holistic approach including a methodological framework for CEA and for organizing associated information,

4) To present an overview of major cumulative effects in the five geographical regions of Canada,

5) To give a brief review of the history and emerging theoretical framework for CEA in Canada and the United States using case studies,

6) To provide recommendations for future development of CEA in Canada,

7) To present a CEA feasibility study centering on wetland habitat fragmentation of the boreal agricultural fringe of the Canadian prairies (Volume II - Wallace and Lane, 1988). and

8) To summarize future collaborative potential for CEARC with other agencies and organizations interested in CEA in Canada (Volume III- Sonntag *et al.*, 1988).

1.3 Application of the Reference Guide

This Guide centers on the environmental aspects (mainly biophysical) of cumulative effects assessment. It was outside the Terms of Reference of the study to provide a complete methodological framework for the related socio-economic, institutional and jurisdictional areas. We do, however, point out many of the concerns in these latter areas throughout the text and illustrate how they relate to the biophysical considerations.

Human activities and developments are pervasive throughout much of the Canadian environment. Some types of impacts, such as those related to acidic deposition, may originate thousands of kilometres away from the affected area. In a strict sense, probably every square metre of the Canadian environment is cumulatively impacted. A single development, such as a power plant, can impact, in cumulative ways, on a local ecosystem through simultaneous chemical releases, thermal plumes, impingement and entrainment processes. Thus, a particular environmental component, like a larval stage of a valuable fish species, can experience multiple and cumulative effects via a single development in a local ecosystem as well as from multiple developments or other human activities located both inside and outside its watershed.

For the above reasons, it is necessary to focus this Reference Guide on the class of CEA problems beyond the level of a single development in a local ecosystem (which can be handled by traditional EIA procedures) and up to and including all of Canada. Thus, spatially-extended systems above the local ecosystem form the smallest unit, and all of Canada is the largest unit considered by the Guide. For example, we consider the role of worldwide climatic change within Canadian borders but the Guide does not extend beyond Canadian territorial boundaries to consider cumulative effects of climate change on the biosphere. Often, CEA problems will involve two or more jurisdictions although presence of multiple jurisdictions is not a prerequisite for CEA. We only briefly consider international jurisdictional overlaps, such as the management of the Great Lakes by the International Joint Commission, when such examples enhance description of potential methodologies and conceptual advances.

There is a wide variety of potential users of this Guide across Canada. In developing the Guide, we consulted personnel from several tiers of territorial, provincial and federal regulatory agencies, industry, academia, consulting companies, municipal government, and even several U.S. scientific and regulatory agencies. All expressed interest in obtaining and using the Guide. Obviously, it is difficult to provide a single guide that will simultaneously serve the field ecologist and the senior policymaker. They work on different aspects of CEA problems and have different types of training and perspectives. Each type of knowledge is important in the total approach to CEA, but the key point is that the knowledge and the needs for additional insight are different.

No one guide can be everything to all users, but, to slant the Guide to one type of user would necessitate neglecting many others. Therefore, we have chosed a compromise approach, but we have had to assume that readers have a basic understanding of how environmental impact assessments are conducted in

Canada according to federal and provincial procedures. For example, we have assumed the reader is familiar with, and has access to, FEAR0 assessment guides and Beanlands and Duinker's (1983) "An Ecological Framework for Environmental Impact Assessment in Canada". We have also assumed that readers will be familiar with such basic assessment methodologies as ad hoc, checklist, mapping and matrix approaches. Although we discuss several potential modeling approaches for CEA, we assume that readers do not have extensive mathematical and modeling experience or experience with multi-jurisdictional assessments for which no clear guidelines may exist.

As in any new developing field, the terminology of cumulative effects assessment is evolving rapidly. The literature contains a large number of terms and acronyms that are difficult to remember so we have included a glossary (Chapter 5.0) to assist the reader. We have also tried not to encumber the text with too many definitions. Each acronym is explained when it is first used. In Chapter 6.0, extensive literature references are provided so that the reader can follow-up his or her particular interests in CEA.

Eventually, it may be desirable to produce custom-designed reference guides for particular audiences or specific types of CEA problems. While CEA is developing so rapidly, however, it is beneficial to provide all interested parties with a common, generic information base.

2.0 CUMULATIVE EFFECTS ASSESSMENT -- AN OVERVIEW

2.1 Global Sustainable Development and Cumulative Effects

To date, Canada has not had an organized approach for recognizing, evaluating and managing cumulative effects. Overall, the focus on EIA has been narrow and proponent-driven. Types of proponents have also been limited. Recently, the Minister of the Environment called for review of the environmental assessment process in a Green Paper (PR-157). Although the changes suggested therein are needed, they still do not provide for an operative cumulative effects assessment and management (CEAM) framework. This means that many types of environmental problems will continue to slip through the assessment net. While EIA changes are being suggested is the opportune time to broaden our view of environmental problems and to plan more wisely for the future. The recent report of the World Commission on Environment and Development has provided a compelling rationale for combining long-term economic development and environmental management into an integrated framework or "blueprint for global survival". The Commission, however, did not supply this blueprint. Undoubtedly, the blueprint will be constructed and applied in many contexts throughout the world in the next few decades. If Canada is to manage her environments wisely, as well as be a full participant in promoting and implementing this global blueprint, then effective CEAM must be given priority. The large-scale environmental deterioration the World Commission refers to is, in essence, global cumulative effects. The blueprint is CEAM.

Creating the blueprint will involve conceptual innovation in integrating biophysical, socio-economic, and jurisdictional and institutional considerations on extended spatial-temporal scales into a holistic assessment and management framework. This framework will need to be applied in appropriate case studies that will iteratively lead to enhanced understanding. This will come about in part by combining aspects of impact assessment and ecological principles with aspects of regional planning and economic development in a novel manner. It is too early to envisage whether or not a new discipline will evolve, but it is a possibility. At the very least, a new thinking and a new determination to implement CEAM will have to emerge. They will have to be a form of goal-oriented planning where the goals are no longer the more simplistic, short-term economic ones of traditional regional planning and cost-benefit analysis. The goals must be environmentally based with clearly specified economic ramifications. The overall goal, of course, is long-term environmental sustainability which also includes an economic optimization. Environment and economics are inextricably linked in a fundamental way; all of our needs must be met from our environment. To achieve environmental sustainability, we need a new set of criteria that are conceptually sound, operationally measurable, and implementable in either existing or innovative jurisdictional and institutional arrangements.

This Reference Guide centers on a portion of the necessary blueprint for sustainable development, that is, the largely environmental and ecological components of the conceptual base. In this chapter, we first describe CEAM in Canada and how it relates to EIA and environmental planning. Next we discuss some of the institutional and jurisdictional barriers to effective CEAM in Canada. It was beyond the Terms of Reference to make detailed proposals for the elimination of these barriers. In this chapter, we also list the basic assumptions of the conceptual framework. Assumptions such as these should always be made explicit.

2.2 CEAM in Canada

As some of the following chapters will show, cumulative effects are very much a part of a pervasive deterioration to the Canadian environment. CEs affect overall environmental quality as well as many resource management issues. CEs have always been with us, and they will always be with us. As future increases in population and development occur, however, cumulative effects problems will become more apparent; and they will require better planning and management, especially on a regional to federal level.

Interestingly, some of the problems which result from cumulative effects have been defined for some time, although succeeding generations have approached their solution in different ways. The first National Parks in Canada were areas clearly identified then as national resources worthy of long-term protection and conservation. This recognition, originating in the 19th century,. of long-term degradative effects from development pressures, surely constitutes one of the clearest visions of a people's determination to offset cumulative effects. And yet, even that vision could not foresee the magnitude of the effects which were to be created by the industrial revolution, effects which transgress national and international boundaries far beyond the control of our present governmental apparatus.

Although CEA has been a part of environmental management and thinking in Canada, the more formalized conceptual development and plans for implementation are relatively new. Thus, attention is now focused on CEs in a way that has never occurred before in Canada.

The recent history of the CEAM concept can be traced, in part, by examining a few of the more recent and important events in this area. In 1982, Odum (1982) wrote an article pointing out that seldom are the combined consequences of many small, independent decisions affecting ecosystems given much attention. The following year, the U.S. National Research Council formed the Committee on Applications of Ecological Theory to Environmental Problems (CAETEP) which promptly initiated a series of case studies, some of which illustrated cumulative effects problems. These case studies were described in the book Ecological Knowledge and Environmental Problem-Solving (Orians et al., 1986). Meanwhile, CEARC was formed in 1984, and the members soon assigned CEA issues a high priority.

Lack of a universally accepted definition has been a problem for those trying to deal with cumulative effects. To help clarify the basic concept of CEA and to investigate related issues, a major workshop was held in Toronto in February 1985, sponsored by both CEARC and CAETEP. At this workshop, thirty participants, primarily researchers and environmental managers from Canada and the United States, described their perspectives on CEA, and proposed directions for both research and planning (CEARC and U.S. NRC, 1986).

Although proceedings of the Toronto workshop represent a binational perspective on CEA, the recommendations were not synthesized into a definite program of action. Thus, following the workshop, CEARC commissioned two studies to provide recommendations that would help in formulating a multi-year plan to 'guide Canadian research on CEAM. Together, these two studies (Peterson et al., 1987; Sonntag et al., 1987) defined the state of CEAM in Canada. More recently, CEARC synthesized these two reports into a draft research prospectus (CEARC, 1987) that outlines CEARC's multi-year research agenda on CEAM. The first priority on this agenda was to prepare a Reference Guide for individuals charged with preparing an assessment of cumulative environmental effects, which led to this report.

As Orians (1986) pointed out, to go beyond managing cumulative effects on a case-by-case basis, scientific and institutional approaches will both require restructuring. He added that considerable improvement in communications between scientists and managers will also be required. One step toward this new state of affairs is to develop a conceptual framework within which CEAs can be conducted.

In their reports to CEARC, both Sonntag et al. (1987) and Peterson et al. (1987) developed conceptual frameworks which they then used to evaluate and discuss cumulative effects case studies (several of which are described in Chapter 3.0). Taken together, these two reports offered several recommendations, including: development of research programs focusing on institutional and management aspects of CEA; evaluation of the usefulness of existing methods and analytical tools for CEA; and testing of the CEA concepts, framework, and methods in a feasibility study.

Using information from these two reports, CEARC is developing a conceptual framework for CEA. There are a number of common elements developed by the two study teams including: systems approach, specific choice of space and time bounds, consideration of selected ecosystem components, sensitivity to thresholds, and consensus. Each of these elements is discussed more fully below.

Although it is not a novel suggestion, it is important that any attempts at CEA adopt a systems approach. Without doing so, it is likely that the evaluation will fail to incorporate effects that accumulate over space or time just as early non-systems approaches (for example, EIA for individual projects) failed to recognize factors that we now recognize as contributing to our current environmental problems.

Likewise, selecting appropriate bounds on the spatial and temporal domain in which the analyses are carried out is important; until the bounds are selected, it is far too easy to focus attention on only some parts of the system rather than on the entire system. Equally important, choosing bounds gives investigators a rationale by which to make decisions on what to include and exclude in a given assessment.

A.- major step in making a CEA manageable is to accept that, although "everything in ecology is connected to everything else", not all connections are equally important (Orians, 1986). Consequently, only selected ecosystem components and processes need to be considered in CEA. Of course, selecting which components and processes are important is not a trivial task, but there are methods to assist in making these choices.

One area that clearly helps distinguish some types of CEAs from EIAs is consideration of ecosystem thresholds in the former. If CEA results are to be meaningful, some attempts will have to be made to determine what affect a given human action will have on an ecosystem,, relative to the internal thresholds of that system. Westman (1985) has pointed out the difference between thresholds inherent in a system and those affecting human values. This relatively new way of looking at impacts promises to assist not only in dealing with cumulative effects issues, but also with questions of significance that have long plagued individuals charged with conducting environmental assessments.

Finally, there is now a recognized need to develop a consensus on approach to CEAM in Canada among the various individuals and organizations involved either in controlling actions that cause cumulative effects, or in evaluating and deciding about the acceptability of these actions.

Our present system of environmental impact assessment addresses mostly single-proponent development and then often those developments which are largely funded by federal funds. A large number of activities that are currently ongoing in Canadian environments are not "caught in the assessment net", and they proceed unchecked. Especially troublesome is the problem of small incremental changes. At a fundamental level, the changes are not different from the biophysical and socio-economic ones found in traditional EIA. What is different is the larger spatial (and sometimes temporal) scales that translate into regional patterns of deterioration and a much reduced set of options for the future of any particular area in Canada. We cannot abate all change and all deterioration, but on a regional level we could certainly implement a much better cumulative effects assessment and planning system than we presently do. This should be done as soon as possible, and it is opportune that attention is presently focused on revision of the Federal Environmental Assessment and Review Office (FEARO) procedures and requirements.

At present, environmental planning is needed at both the provincial and federal levels. British Columbia, Alberta, Ontario and Quebec have formalized environmental and regional planning, but even these four provinces have no formalized frameworks to deal with CEs effectively. To date, mostly ad hoc responses to CEs have been the norm, and there have been few examples of CEA used in standard FEAR0 practices. Lane and Gillis (1988) did incorporate a simplified form of CEA in assessing the interaction of the proposed fixed link between New Brunswick and Prince Edward Island and twelve other types of human activities in the Northumberland Strait area.

In Canada, the legal and regulatory definitions which might be most relevant to the issue of cumulative impact assessments are not to be found within any single legislative base. Recent initiatives by Environment Canada for national environmental protection policy may, however, if passed by Parliament, begin to address such questions. The Canadian approach to CEA has tended to rely heavily on the co-operative nature of federal and provincial agencies in meeting the demands of elected officials for environmental protection through inter- and intra-agency initiatives. The new habitat protection provisions of the Canada Fisheries Act is a de facto recognition of the limits to enforcement actions under the Act and the need to adopt a broader perspective in co-ordinating essential ecological factors into renewable resource management. Fisheries and Oceans Canada has further pursued this initiative by formulating a policy on Arctic Marine Conservation Strategy and by implementing newer approaches to fish population management and protection on the east and west coasts of Canada.

The Lands Directorate of Environment Canada has also begun independent initiatives for research on broad scale land management practices. Their strategy paper "Toward Sustainable Land Use" (Manning, 1986) recognizes that the concept of sustained land use, "which maintains longer-term productivity and keeps open as many options as possible for future generations", is essential to the fabric of the nation. As Manning (1986) noted: "Land-use decisions are by their very nature long-term decisions".

This tacit recognition of the scope, extent and timing of development decisions entails an implicit understanding of CEAM. Unfortunately, management control is seriously undermined by the growing complexity and diversity in environmental management agencies. Ten provinces, two territories and a federal government, each having separate environmental legislative bases, present a significant challenge for any manager seeking recognition of, and action in, CEAM. There are some positive signs, however, which indicate that approaches to CEAM across this jurisdictional base may be possible. The Canadian Council for Resource and Environment Ministers (CCREM) has recently launched important studies on the nature of various jurisdictions with regard to regulations on environmental parameters. This basis for integration could be expanded into a "CEAM forum", under which consistent definitions and approaches are applied.

FEAR0 is another vehicle for potential recognition of CEA. A recent review by assessed the ability of FEAR0 to affect Canadian decision makers with long-term development decisions, and concluded that at the federal level, at least, the process had exerted a significant influence. Interestingly, the Lancaster Sound Planning Process grew from the recommendations of one EARP Panel. This Planning Process is, in effect, an attempt by federal agencies to deal with long-term influences of development and to recognize the need for cumulative effects management in a unique area of Canada. These positive initiatives and examples, however, cannot disguise the fact that in Canada there exists no single base for CEAM, although significant management and research initiatives have begun across Canada such as the International Joint Commission on Great Lakes Water Quality Agreement, Long Range Transport of Atmospheric Pollutants, and Alberta's Acid Deposition Research Program.

2.3 Jurisdictional, Institutional and Disciplinary Barriers to CRAM

While environmental concerns are key to establishing a workable framework for CEA, political institutional, jurisdictional and disciplinary factors must be recognized as exerting a formative influence on the development and implementation of CEA methods. Most of this Reference Guide deals with the ecological aspects of CEA. The purpose of this section is to illustrate that as we develop these facets of CEA, we cannot forget the jurisdictional and institutional problems that must be effectively resolved if we are to assess and manage cumulative effects successfully.

Peterson et al. (1987) dealt with the organizational and political aspects of the **management** component in a conceptual framework for CEA. Those authors noted:

> "... 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."

They further expanded this theme with appropriate reference to the democratic context within which CRAM must function if it is to be recognized and sustained:

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

These basic considerations are highly relevant to any discussion about the jurisdictional aspects which affect CRAM, as they underline the fundamental workings of the democratic process of which environmental management is but one component. Hence, the "interconnectedness" of the **political**-scientific-social system, which ultimately both produces and manages cumulative effects, must be recognized and carefully assessed if remedial processes are to be successfully implemented. At present, the existing institutions for environmental management are clearly oriented to. more traditional environmental impacts. These organizational "barriers" to CEA approaches in Canada are, in turn, reflections of the environmental and jurisdictional realities within the nation.

These traditional approaches assume government intervention either through regulation or by indirect, legislative control over resource allocation. Peterson et al. (1987) concluded that attempts to control cumulative impacts through **legal liability** are unlikely to be successful simply because of the enormous difficulty of attributing those effects to all the parties potentially contributing to them. In short, due process requires proof of causality and usually sets limits to liability in both time and space.

At the other extreme, cumulative effects defy the best efforts to co-ordinate and manage the plethora of government departments necessary to properly address them. Because of the pervasive nature of cumulative effects, almost every part of government is involved in one way or another. For example, the Department of Indian Affairs and Northern Development (DIAND) produced a large chart in 1982 which attempted, by traditional methodologies, to integrate and co-ordinate all of the departments needed for regulation of proposed oil and gas development in the Beaufort Sea (Peterson et al., 1987). The process used by DIAND included 20 different approval pathways, several reaching to Cabinet level, and 89 boxes indicating regulatory activities contributing to approval decisions. In addition to being unbelievably complex and virtually unworkable, such approaches may discourage developers, proponents or the public from taking environmental management seriously. At the very least, organizational co-ordination at this level of complexity may simply defeat any attempt to constructively address CEs.

Proponents are also reluctant to pursue CEA because their knowledge is limited to their own project. They do not believe they should develop assessment capabilities and be responsible for other projects in their area. They seek environmental approval on the independent merits of their own project and do not want to be constrained by impacts and perhaps wrongdoings of other developers.

Existing institutional structures further present barriers to CEA because any new arrangements must, by definition, be accommodated within the existing arrangements. In turn, these must either be included in existing legislative mandates for EIA or have new ones legislated. The latter becomes an increasingly difficult option, as evidenced by new federal requirements for regulatory impact statements to precede new legislative initiatives. Furthermore, many agencies such as the National Energy Board (NEB) have "quasi-environmental and socio-economic roles" which have a far more powerful legislative base through their hearings process than many environmental agencies such as DOE or FEARO. These latter agencies rarely, if ever, impose specific conditions, by law, on developments outside of existing regulatory compliance requirements. In addition to the institutional barriers to effective CEAM, proponents do not generally consider themselves required by law to address cumulative effects issues and, in fact, legitimize that perspective by "reductionist" approaches to the assembly of EIA (long-term, low-level effects are simply dismissed as being of "moderate" or "negligible" effect, as in the Beaufort Sea EIA)(Peterson et al., 1987).

The real dilemma environmental assessment faces is that a relatively mature and sophisticated procedural approach has emerged without the evolution of any clear-cut ability to integrate the management of the conditions or findings of the CEA research. In Ontario, the review process defined by legislation clearly sets the stage for CEAs and the regulatory body, in probing submissions, has extended its reviews and conditions of approval to reflect the CEA submission. A glaring weakness, however, continues to exist in the institutional system's inability to integrate and carry out the conditions or findings of the CEA. While the system for environmental review and regulation can spell out conditions, once the project is approved there are few cases where ongoing performance audits occur which can feed back adequate information into the regulatory system to carry out the assessment of cumulative effects.

Part of this deficiency lies in the narrow definition of the jurisdiction for these institutions responsible for carrying out EIAs and arranging the conditions required for the approval of individual projects. Part of the deficiency also can be traced to a fundamental characteristic of CEA findings in that one aspect of a proposal or one environmental condition can precipitate another hitherto unknown effect. Usually the triggering event or effect is well-known and its management well-defined. Cumulative or related effects, however, may not be perceived clearly until long after the triggering event, and there may be no provision available for management of the "surprises". In fact, there may be an absolute refusal of the affected institution to take any action.

While jurisdictional barriers often, and properly, attract much attention in discussions of CEAM, the question of inter-disciplinary problems often goes unaddressed. Each discipline of science (in environmental management) approaches problems from a distinct perspective, and it is this philosophical perspective which may shape subsequent conclusions and definitions of impact. (For example, see the comprehensive review of cost-benefit assessments in air and water pollution control questions in Freeman, 1982).

Engineers approach cost-benefit evaluations of water control structures from the perspective of initial capital cost versus the probability of loss of the structure. Frequency analysis of maximum probable events which could damage structures, however, ignore more subtle long-term effects such as habitat destruction or change (such as siltation/sedimentation effects). Hence, the initial definition of "cost" may fundamentally shape the eventual impact of projects so constructed. Moreover, the weight of the numerous factors shape the definition of "risk". For example, losses to habitat which might prove disastrous to wildlife populations might be judged an "acceptable risk" because of some advantage to humans. One need only examine the consequences and costs from the Bennett Dam in British Columbia as it affected the Peace-Athabasca Delta in Alberta to appreciate the magnitude of such losses. To be sure, the environmental costs of such engineering ventures are beginning to be quantified, but generally through legal remedy after the impacts have occurred. For example, refer to the comprehensive analysis of the Churchill-Nelson Diversion and associated impacts on the native fishery of northern Manitoba (Lehman, 1986). In cases such as these, the long-term "costs" of the engineering works to the renewable resource base may exceed the initial capital costs of the construction, when one considers total legal and compensation settlement costs.

2.4 Assumptions Implicit in Developing a CEAM Framework

In formulating a conceptual construct, whether it is an approach to CEA as given here, a formal mathematical model, or a statistical analysis, it is useful to list the assumptions. Five assumptions inherent in and fundamental to the CEA approach proposed in this Reference Guide are as follows:

1. Cumulative effects assessment is a complex systems problem. Science has traditionally not been very successful in solving complex systems problems. As our success has increased in solving simple problems, the relative proportion of complex system problems needing resolution has increased. General Systems Theory has provided an overview and approach to this type of problem, but not a detailed methodology (Weinberg, 1975). Science, for example, has been good at analyzing problems of small number systems. These systems have few components and few interactions between components. In engineering approaches where exact measures and complete functional descriptions are possible, small number problems can be solved. Population ecology essentially represents an analytical approach to such small number systems. Use of this approach at the ecosystem level, however, has been limited to theoretical or over-simplified models, a result of the near impossibility of obtaining measures of all the interaction rates and parameters needed for a functional, ecosystem-level model.

For large number systems, those that have a large number of components and many interactions, statistical analysis can be employed if randomness can be correctly assumed to apply and the system can be described by averages or mean values. The gas laws present an example where statistical analysis is applicable. Eighteenth century physicists at first tried to explain the position and velocity of each molecule of a container of gas in their enthusiasm to determine the fate of the universe. This quickly became impracticable as 10^{23} molecules of gas could be present in a single vessel and hence mean values were found useful in formulating the gas laws relating temperature, volume and pressure. Although ecosystems can have a large number of parts, there are not enough components to average them in a meaningful way. A fish is not dynamically or functionally equivalent to 10^{x} bacteria even though they may weigh the same. Thus, statistical approaches are useful in ecology only in certain restricted applications.

Between small and large number systems there are middle number systems, those that have intermediate numbers of components and intermediate levels of interconnection. These are the systems that have too many parts for pure analytical approaches to work and too few parts for statistical assumptions of average properties to be valid. As the number of components increases arithmetically in a system, the number of interactions increases geometrically. Scientists and social scientists have few reliable tools to deal with this middle level of complexity. For middle number systems, we find that the counterintuitive results of Lane and Levins (1977), the surprises of Holling (1982), and even the folklore wisdom of Murphy's Law apply. Murphy was reputed to have despaired over an inept aircraft technician when he stated, "Anything that can go wrong, will go wrong". CEA is a middle number system problem, and we cannot expect traditional methods to work well for it. Simplification, through the use of appropriate models, is needed if one is to solve problems inherent in middle number systems. CEA problems cannot be resolved with the reductionist, analytical approach used for small number systems or with the statistical approach used for large number systems.

--Fundamentally new conceptualization and methodologies need to be developed for CEA based on a more complicated form of causality than we are accustomed to using. Cause and effect and especially the causality emanating from feedback relationships is fundamental in CEA. For example, qualitative structures of causal inter-relationships of biophysical, socio-economic and management links are needed. Meaningful linking of the various disciplines is critical for successful CEA. Our impression is that the classical errors in managing whole systems have been made by ignoring interconnection, or not understanding the dynamics, of the whole. These were not errors in the detailed evaluation of individual links. In fact, traditional methods of analysis usually determine the effects of individual links in a system very well, but poorly determine the scope of a system to be studied, or how the parts fit together in the larger system.

2. Conducting a cumulative effects assessment is not "doing science". Although successful assessment is often very dependent on a good scientific information base, CEA and EIA are processes needed mainly for decision making. Thus, conducting a CEA or an EIA is not equivalent to "doing science". In many ways, the scientific method is a limited one. It is based on a reductionist thinking mode that has sometimes been carried to the absurd. Weinberg (1975) likened current science to a tool box. It has some very useful tools but they are not all good for all types of problems. Some of the recent attempts to make environmental assessment "scientific" have laudable motivations but are based on incorrect assumptions. Preston and Bedford (1987) in their recent review of CEA give the impression we should be attempting rigid experimentation, hypothesis-testing and quantification of statistical significance. For the most part, these are not even applicable concepts in CEA. To illustrate this point we describe two examples: the first illustrates the inappropriate use of the experimental approach in EIA and the second, the incorrect application of hypothesis-testing.

Example 1

Often a project or action is viewed as an experiment (National Research Council, 1986). The "experimental approach" in an assessment context is fraught with pitfalls and could even be described harshly as an approach which circumvents long-term environmental management goals. Lehman (1986) cited a case where a detailed South Indian Lake Impoundment study was conducted and later researchers examined long-term (and largely unanticipated) impacts in a post-study evaluation. The level of this lake was raised in a large-scale diversion of the Churchill River to supply hydroelectric power. A large number of impacts, many of which could be considered cumulative, resulted from the development. In particular, some of the cumulative effects with water quality and mercury contamination of fish were not anticipated.

This failure of EIA in the project-as-experiment approach caused the loss of the largest commercial freshwater fishery in northern Manitoba. Total catch eventually fell to one-third of its pre-impoundment size as operators abandoned the fishery (Lehman, 1986). The environmental consequences, and socio-economic impacts on the northern Native fishing industry, were severe and compensation-legal claims have already exceeded $2 million. These facts outline the perils of the "experimental" approach and point out the hidden costs which may be entailed by not striving for a CEA-type approach in major project decisions. The Native Peoples of South Indian Lake region suffered health risks and economic impacts. They did not even share in the scientific adventure. This project is a clear demonstration of the ethical and regulatory need to develop CEA methodologies in Canada and to ensure that they are properly applied.

A fundamental problem with CEA is the extreme complexity of assessments which may involve several projects affecting numerous environmental components over large time and geographic scales (Peterson et al., 1987). Because ecosystems are large and complex, it is usually impossible to do rigorous scientific experiments with valid experimental controls. Exceptions to this include the work accomplished at the Experimental Lakes Area by the Freshwater Institute and the long-term ecosystem studies at Hubbard Brook, New Hampshire. In the first example, valid experimental (whole-lake) manipulations have been accomplished with significant scientific benefits. These cases are rare in North America, but they provide rationale for long-term commitments to ecological field studies by institutions with significant scientific capabilities. Laboratory results concerning ecological processes can rarely be extrapolated with predictive, scientific confidence to field situations. As Lane and Levins (1977) concluded, physiological truth in the laboratory can equate to ecological myth in the field.

Example 2

A second example of applying the scientific method in an inappropriate way for CEAs is advocating hypothesis generation and testing for impact predictions. Hypothesis-testing is often recommended in Canadian EIAs, usually to be implemented in subsequent monitoring programs. For example, the Beaufort Sea Environmental Monitoring Programme (BEMP) centers upon generation of hypotheses, and testing them is central to the conceptual framework of BEMP.

Experimentation in ecological research generally leads to the application of inferential statistics in order to demonstrate treatment effects resulting from the experimental perturbation or alteration. The use of inferential statistics entails many explicit and implicit assumptions concerning experimental design, sampling, data frame, and the analysis and interpretation of the resulting data. A particularly important prerequisite for inferential statistics is true replication of treatments which many ecological studies and EIAs fail to provide (Hurlbert, 1984). For example, often studies which purport to satisfy this requirement in fact do not and thus commit what Hurlbert(1984) terms "pseudoreplication". This term can be defined as "the use of inferential statistics to test for treatment effects with data from experiments where either treatments are not replicated, though samples may be, or replicates are not statistically independent." Thus, pseudoreplication is replication of samples at some level other than the treatment unit, for example, blocks, sub-samples, etc.

While formulation of testable hypotheses and development of sound experimental designs suitable for statistical analysis are desirable goals, in practice they are not often achieved and the concept is not applicable to many assessment and monitoring situations. Major problems exist, then, in determining environmental change associated with anthropogenic activities for which inferential statistics can and cannot be applied and in developing new approaches to analyze existing and future data sets where inferential statistics are not appropriate. Almost sixty years ago, R.A. Fisher, the father of modern statistics, stated: "No one would now dream of testing a response to a treatment by comparing two plots, one treated and the other untreated" (Fisher and Wishart, 1930).

Yet, we continue to design expensive and even sophisticated assessments to generate hypotheses and monitoring programs to test these hypotheses that cannot be scrutinized statistically. Fisher developed inferential statistics for application to questions of experimental design. It is of vital importance to the EIA process in Canada to ensure not only that rigorous statistical methods are used where appropriate, but that other criteria be developed to consider those instances in which traditional statistical methods are not appropriate. This will obviate the subjection of well-intentioned assessments to criticism and invalidation on inappropriate statistical assumptions. The Experimental Lakes and Hubbard Brook Studies did not use inferential statistics to "test" for change.

3. Several steps in traditional environmental impact assessment have direct counterparts in cumulative effects assessment. The impacts and changes inherent in cumulative effects are not fundamentally different from those involved in more traditional types of environmental assessment in that all changes must eventually occur in a local ecosystem whether or not the ecosystem is predominately urban or wilderness. Changes can involve loss of reproductive potential of a species leading to local extinction, or decrease in water clarity leading to a decline in primary production in a lake. The "tyranny of small decisions" also teaches us that cumulative effects do not need to be profound locally: in fact, they can be very small. Thus, it is logical that many of the steps and analytical tools used in EIA will also be used in CEA. What is fundamentally different, however, between CEA and EIA, is the larger scale and often, complex pattern inherent in CEA as compared to EIA. The complexity of the pattern often arises from feedback relationships of cause and effect among the environmental components that occur on extended scales of space and time. For some CEA steps, such as bounding, only the scales of space and time substantively change; yet for other steps, fundamentally-different methods are needed such as cause and effect modeling. In the analyses of spatially-extended ecosystems, it is the indirect and community effects which often assume major importance in developing predictive assessments (Appendix 8.2). Hence, the theoretical requirements for fundamental advances in CEA demands that a more holistic approach to pattern be undertaken in contrast to EIA.

4. Cumulative effects assessment should be thought of as a process, not a method per se. CEA is a framework for linking the conceptualization of diverse types of information on fairly broad scales, with a central theme of cause and effect. Much of the U.S. work in CEA is now aimed at developing a process, not a particular method. As Appendix 7.3 demonstrates, the U.S. has completed a large number of case studies and has a large number of separate agencies working on CEA. Much of the CEA activity in the U.S. was motivated by specific references to cumulative effects in U.S. legislation. In Canada,

3.0 A FRAMEWORK FOR CUMULATIVE EFFECTS ASSESSMENT

Building upon the assumptions discussed in Section 2.4, a framework for CEA has been developed that involves the user first deciding whether or not there is a cumulative effects problem. Note that one of the major decision points is whether or not the impacts are expected to extend beyond the local ecosystem. We have assumed that one of the key CE distinguishing criteria separating CEA from EIA is the concept of the larger space and time scales inherent in CEA. Second, if there is a cumulative effects problem, the type of causality it entails must be identified. The subsequent ordering of the steps that should be followed in the CEA process is outlined. For each step, references are given to associated methods.

3.1 Is A Cumulative Effects Assessment Needed?

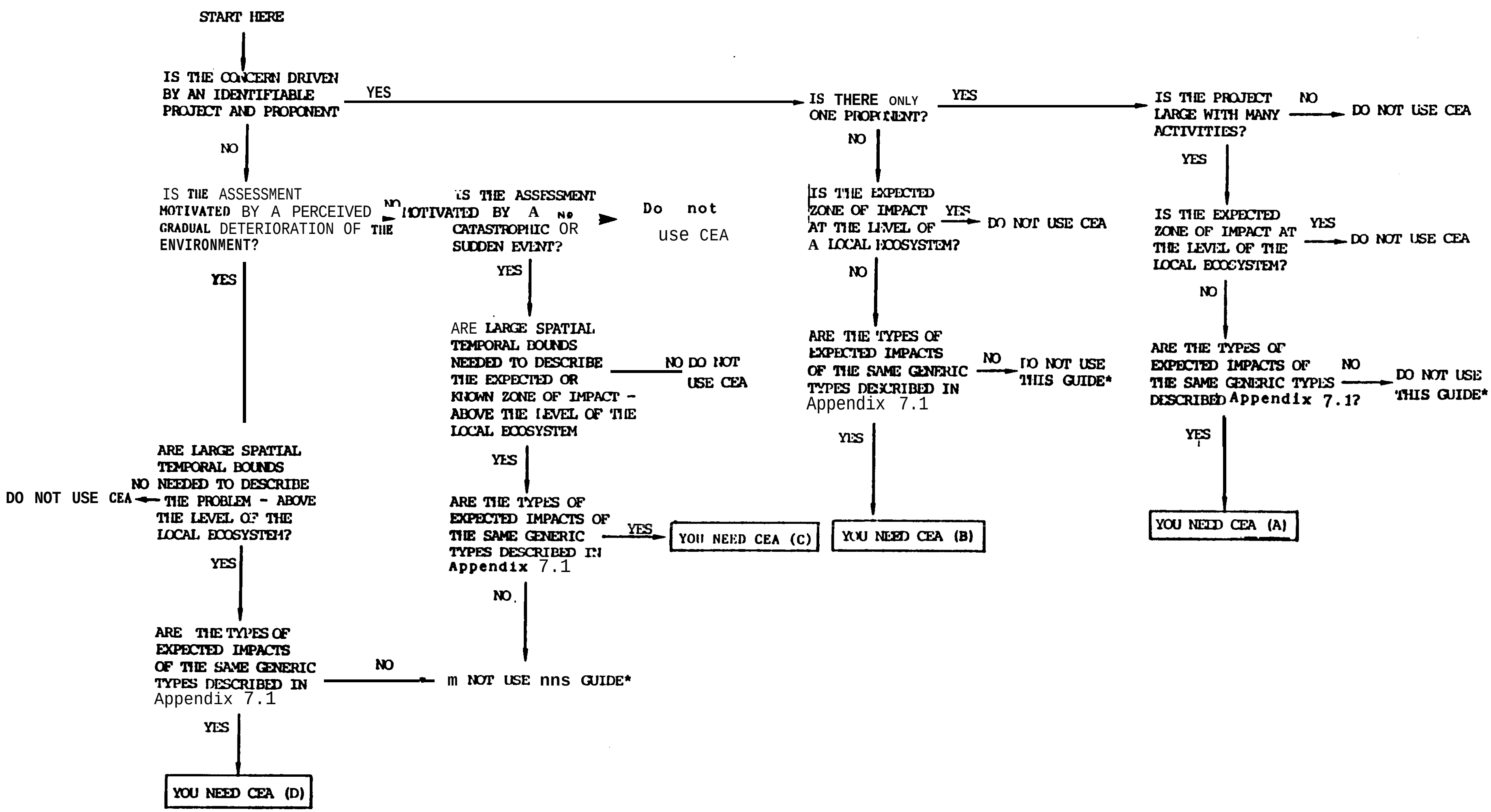
Use the decision tree outlined in Figure 3.1 for determining whether or not there is a cumulative assessment problem and whether or not this Guide will help to resolve it. The ends of the branches culminate in three basic kinds of decision: (1) Yes, use this Guide and the type of CEA problem is identified as Type A, B, C, D; (2) No, do not use this Guide: and (3) Perhaps this Guide will be useful. In the third case, there is a borderline example and it must be studied further before passing through the decision tree again. Often, careful* attention paid to Chapter 3.0 will help clarify whether or not borderline cases can be resolved using this Guide.

In Figure 3.2, the basic characteristics of the four types (A-D) of cumulative effects are described. For each type, the underlying mechanism can be periodic (time crowding),' synergistic (space crowding) or combined (both) as per the definition of CEs in Chapter 1.0.

The Type A cumulative effects problem involves a large project that has multiple activities and is proponent-driven. An example is the proposed expansion of the low level flying of NATO forces centered at Goose Bay, Labrador. The ecology must be studied at a regional level because the airplanes potentially affect an area much larger than the local ecosystem. Noise and acidifying emissions have been predicted to impact wildlife, aquatic resources, water quality and native peoples over large areas. With this type of CEA, (Type A), one would expect the impacts to radiate outward from the focus of the project, the Goose Bay airfield, as it undergoes major construction and operation activities during the expansion. The potentially affected impacted area is larger than many countries, and cumulative effects have already been observed resulting from the interaction of jet emissions and long-range transport of atmospheric pollutants (LRTAP). A FEAR0 panel has been convened to review the environmental impact statement (EIS) for this development.

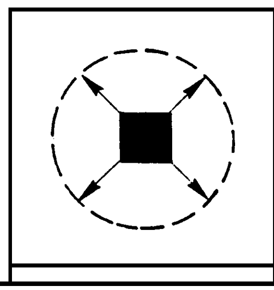
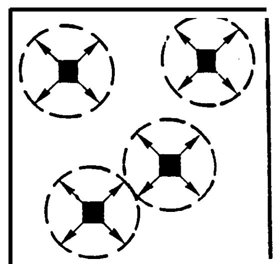
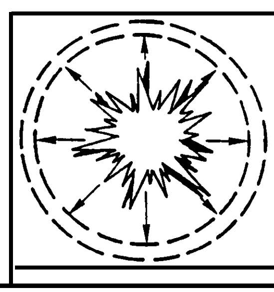
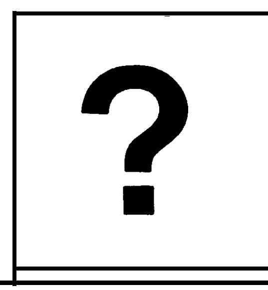
In the Type B CEA, we are concerned with multiple projects usually associated with multiple activities. The projects may or may not be of the same kind. With this type of CEA problem, impacts radiate out from the individual project foci and can interact with each other, resulting in a diffuse and often complex spatial pattern. Major waterways, estuaries and the Great Lakes provide a multitude of examples of Type B CEA problems. In this type of CEA,

Figure 3.1 Decision Tree for Answering the Question: Is a Cumulative Effects Assessment Needed?



* You may have a cumulative effects assessment requirement but you will need to be careful in evaluating whether or not your concern is close enough to the generic ones listed in Appendix 7.1 for this Guide to be applicable.

Figure 3.2 Basic Characteristics or the Four Types (A,B,C,D) of Cumulative Effects (CE). For Each Type (A-D), Cumulative Effects can be Periodic, Synergistic or Combined.

	Basic Spatial Pattern	
Primary Motivation	Identifiable Focus (Inductive)	Diffuse Pattern (Deductive)
Proponent Driven	**Type A** 1 Large Project Multiple Activities Cause of Perturbation 	**Type B** Multiple Projects Multiple Activities Cause of Perturbation 
Ecosystem Driven (No Identifiable Proponent)	**Type C** Catastrophic or Sudden Event (natural or anthropogenic origin) Cause of Perturbation 	**Type D** Broad Scale Environmental Deterioration (primary cause can be many small activities to one large one) Cause of Perturbation 

the same proponent may have been involved in more than one traditional assessment. Even if there have been multiple assessments of individual projects with the same proponent, however, the inter-relationships among the assessments have not been considered.

Type C and Type D CEAs lack identifiable proponents. These types of CEA are termed: "ecosystem-driven". In Type C, there has been a sudden and often catastrophic event. Examples include a large fire or other catastrophe where the causality is obvious. Perhaps the origin of the fire is not known but that the ecological destruction was related to a major fire is obvious. Another example occurred in Cape Breton, Nova Scotia, where spruce budworm populations reached epidemic proportions and destroyed large expanses of forest. Although the immediate causal link was obvious (namely, that the spruce budworm destroyed the forest), the underlying cause and effect and the role of humans have been more elusive factors. Controversy remains on whether or not spraying is the preferred management option. History suggests there may be long time scales of the order of decades related to these insect outbreaks.

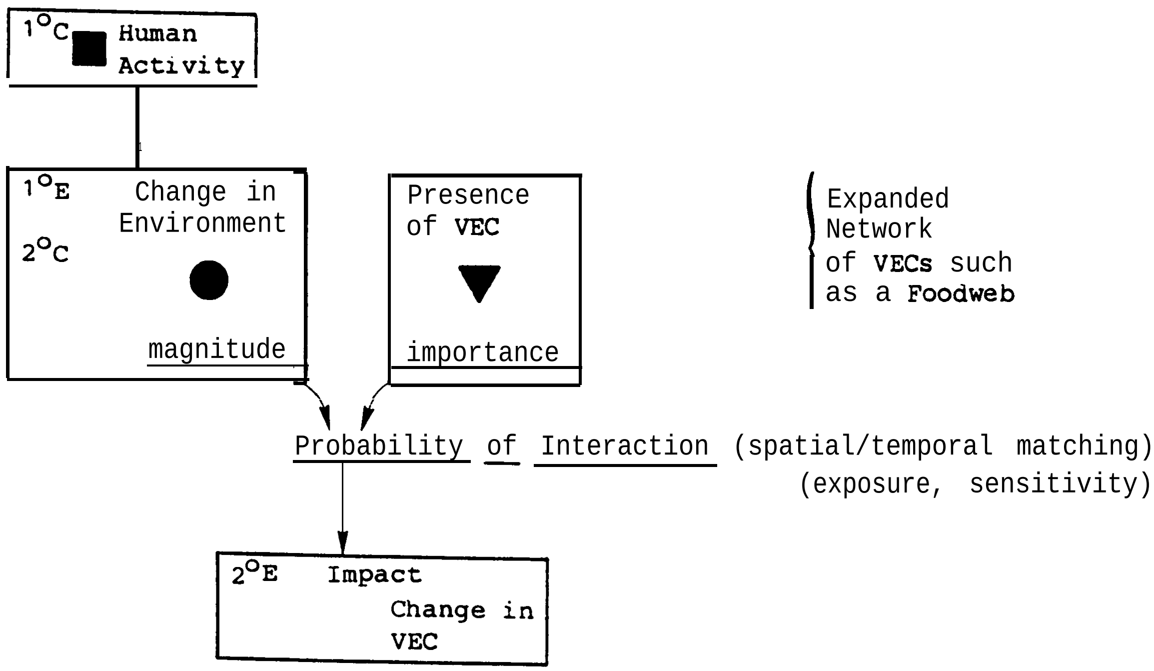
In Type D, there has been noticeable and broad-scale environmental deterioration. This deterioration might result from one or many human activities and developments, but usually the causality is unknown. In identifying the acidic deposition problem, for example, it was initially noticed on a large regional scale that many lakes that had supported fish populations in the past no longer supported fish, or that if fish existed in these environments, species diversity was much reduced and particular species had become locally extinct. It was later discovered that the fish were dying or failing to reproduce because of the low pH of the lake water which was subsequently linked to atmospheric emissions from industrial sources in central Canada and the U.S. As with the "proponent-driven" types of CEA, the "ecosystem-driven" types include very large spatial and temporal scales involving both an identifiable focus (Type C) and a diffuse pattern (Type D).

As with any characterization or typology of a set of complex problems, this separation of all CEA problems into four basic types is oversimplified. The typology holds for a large number of examples, but there will always be intermediate types. This typology, however, gives the assessor an initial point to identify and begin a cumulative effects assessment. As mentioned earlier, the fundamental tenets of cumulative effects assessment are: (1) that the causality is complex, and yet, it must be unraveled in an understandable way, and (2) the spatial-temporal scales and patterns are extended beyond that of the local ecosystem. Most assessors are not trained to understand causality on such extended spatial-temporal scales. In the next section, we build upon the four basic types of CEA given above and describe the basic networks of cause and effect associated with each type.

3.2 Characterizing the Type of Causality

In Figure 3.3, the conceptualization of cause and effect in traditional environmental impact assessment is illustrated. First, there is some sort of human activity and/or development which is termed the primary cause (1°C). This activity causes a primary change (1°E) in the environment. This change

Figure 3.3 Generalized Model of Environmental Impact.



Key:
1°C = first degree or primary cause
1°E = first degree or primary change
2°C = second degree or secondary cause
2°E = second effect or secondary change
VEC = Valued Ecosystem Component

in the environment, in turn, becomes a secondary cause (2°C) when it interacts with a Valued Ecosystem Component (VEC) to cause a secondary effect (2°E) which is an impacted VEC. In order for there to be an impact, there must be a change in the environment which interacts with a Valued Ecosystem Component to a sufficient degree to change the VEC in either a positive or negative way. [Note: throughout the Guide, we use the term Valued Ecosystem Component to indicate a broader range of environmental components (both biophysical and socio-economic) than intended by the originators of the concept (Beanlands and Duinker, 1983)]. They defined VECs as those components that would be identified in a social scoping. In the Guide, we include all components that have intrinsic value to humans, ecosystem integrity, etc.)

The causality portrayed in the model in Figure 3.3 is the simplest that can be described for traditional impact assessment, which is usually proponent-driven. Obviously, there is also some artificiality involved in this impact model. The delineation of the environmental changes from VECs is a human construct, not one of nature; thus, what might be a minor change in the environment to one assessor might be a major shift in a VEC to another assessor. In traditional impact assessment, however, this basic model has been used repeatedly. In some EIAs the impacted VEC is predicted without showing the intervening steps in the causal chain. In other assessments, a matrix might be used giving numerical scores to magnitude, importance and probability of impact. The degree to which the VEC will be affected by a change in the environment will depend on the overlap of spatial and temporal bounds, the degree of exposure of the VEC, and its sensitivity to the particular environmental change. Note that in this model, the causality is diagrammed as one-way and sequential. In an ecological system, the VEC and the environmental change would, themselves, be part of a more complicated form of causality. The VEC might be an important species, such as a salmon, which would be a component of a food web. Likewise, human activities are often interrelated in complex causal webs. To understand causality in ecological systems, it is always necessary to use models to simplify the essence of cause and effect. The key problem is to capture the essence of causality with a minimum of links. Lane (1986a,b) and Lane and Wright (1986) described how this could be done for a coastal marine community undergoing multiple perturbations (Appendix 8.2).

In Figure 3.4, each of the basic types of cumulative effects assessment problems are diagrammed using the reasoning in Figure 3.3. For each CEA Type (A-D) there are environmental changes and Valued Ecosystem Components, however, there are differences in the basic patterns of causality. For Types A and B, the flow of causality is from the left to the right of the page. For Type C, causality goes in both directions. The assessor may wish to deduce the primary cause of the catastrophe or predict the future effects. In Type D, most of the causality flows from the right to the left of the page. Essentially, when we reason from the specific to the general, or the parts to the whole, we are using inductive reasoning as shown for Types A and B. When we reason from the general to the specific, we employ deductive reasoning such as shown in Type D. Type C is an example of both inductive and deductive thinking since causality flows in both directions. Insofar as possible, all four types of CEA are illustrated using simple straight line causality.

Figure 3.4 Basic Types of Causality in Cumulative Effects Assessments. Types A and B Employ Inductive Reasoning and Type D Uses Deductive Reasoning. Type C Involves Both Inductive and Deductive Reasoning. ▼ Indicates where Assessment Begins.

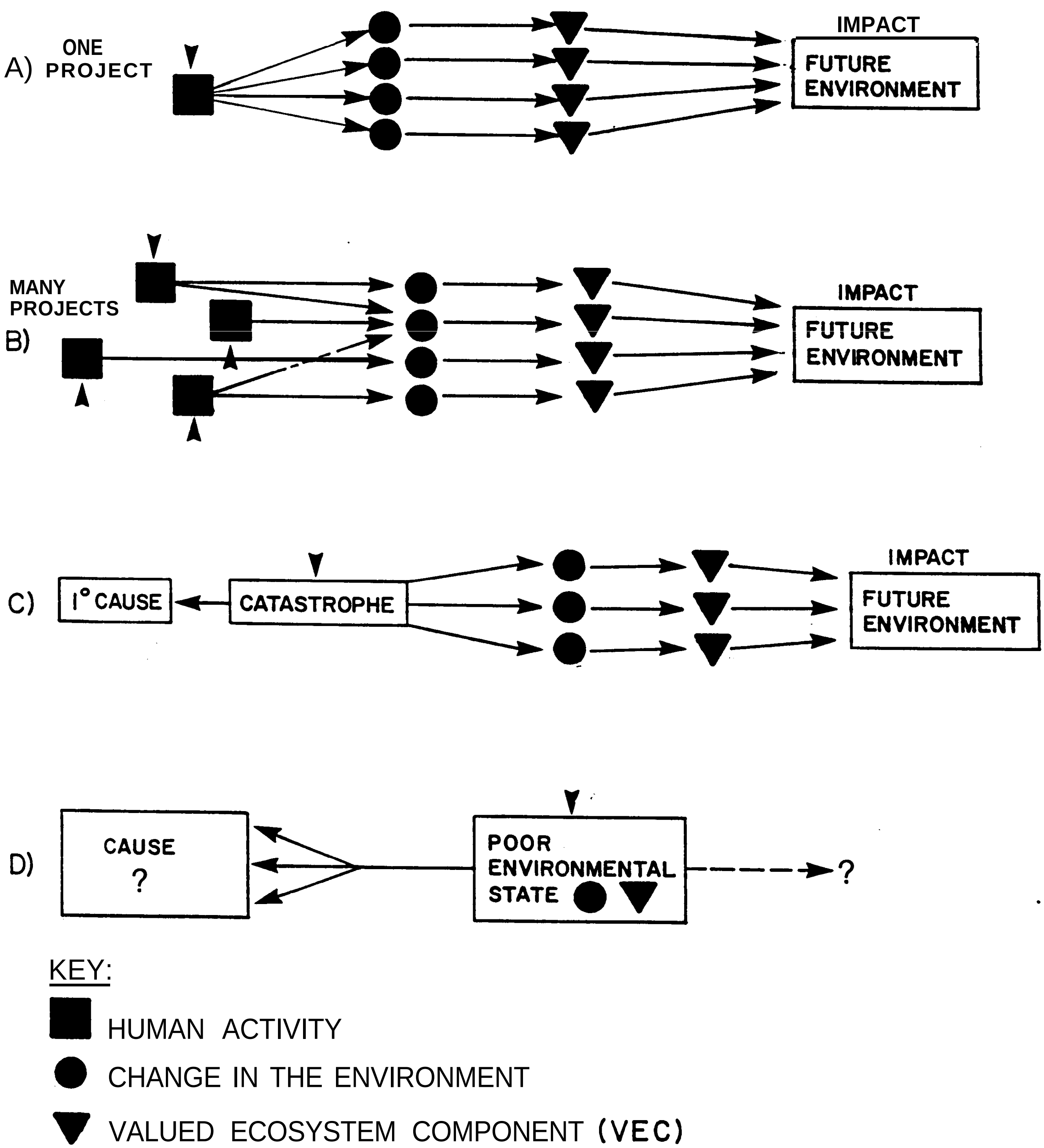
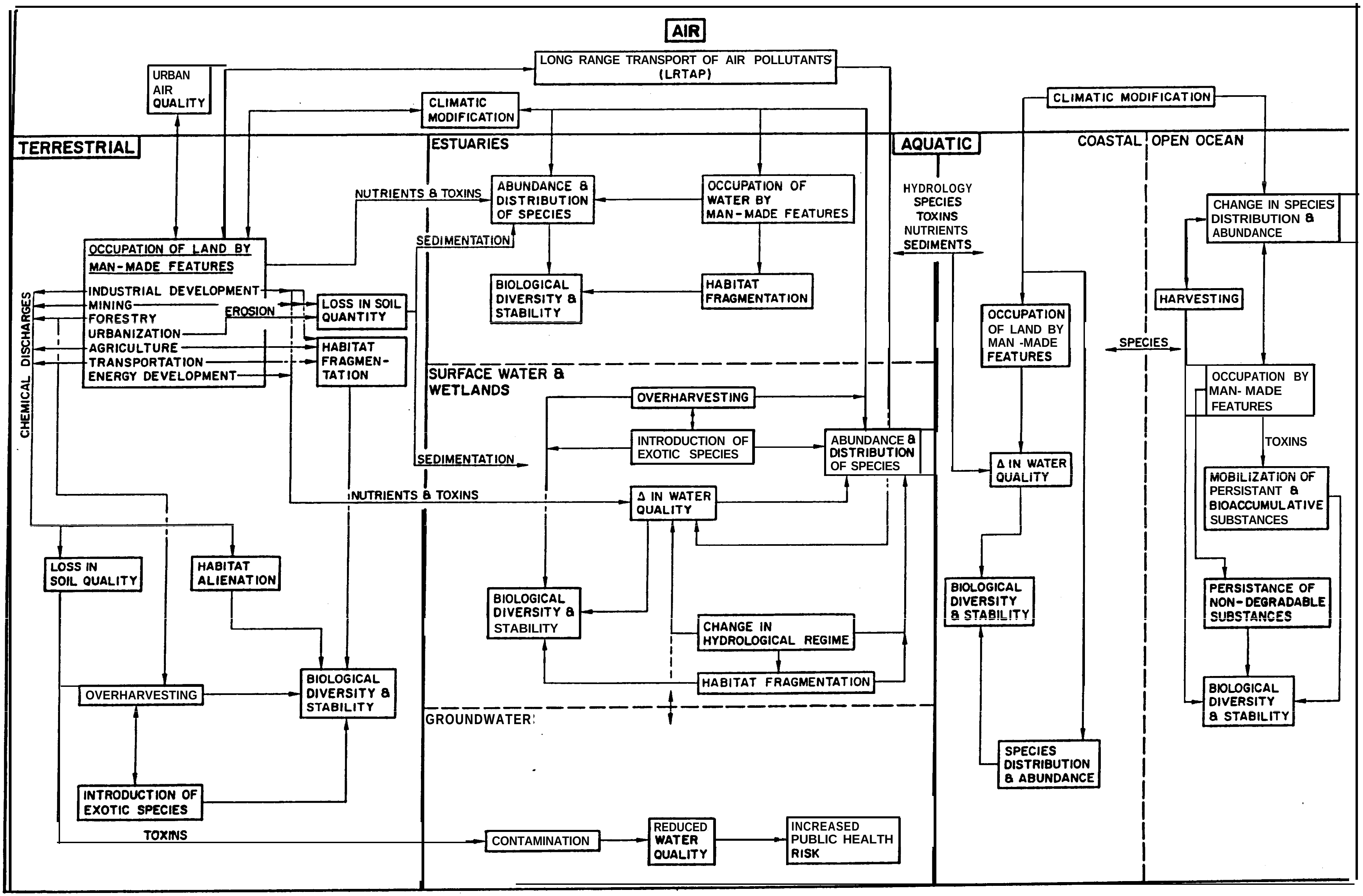


Figure 3.5 Interrelationships of Major Cumulative Effects Problems by Ecosystems as Idenified in Appendix 7.1.

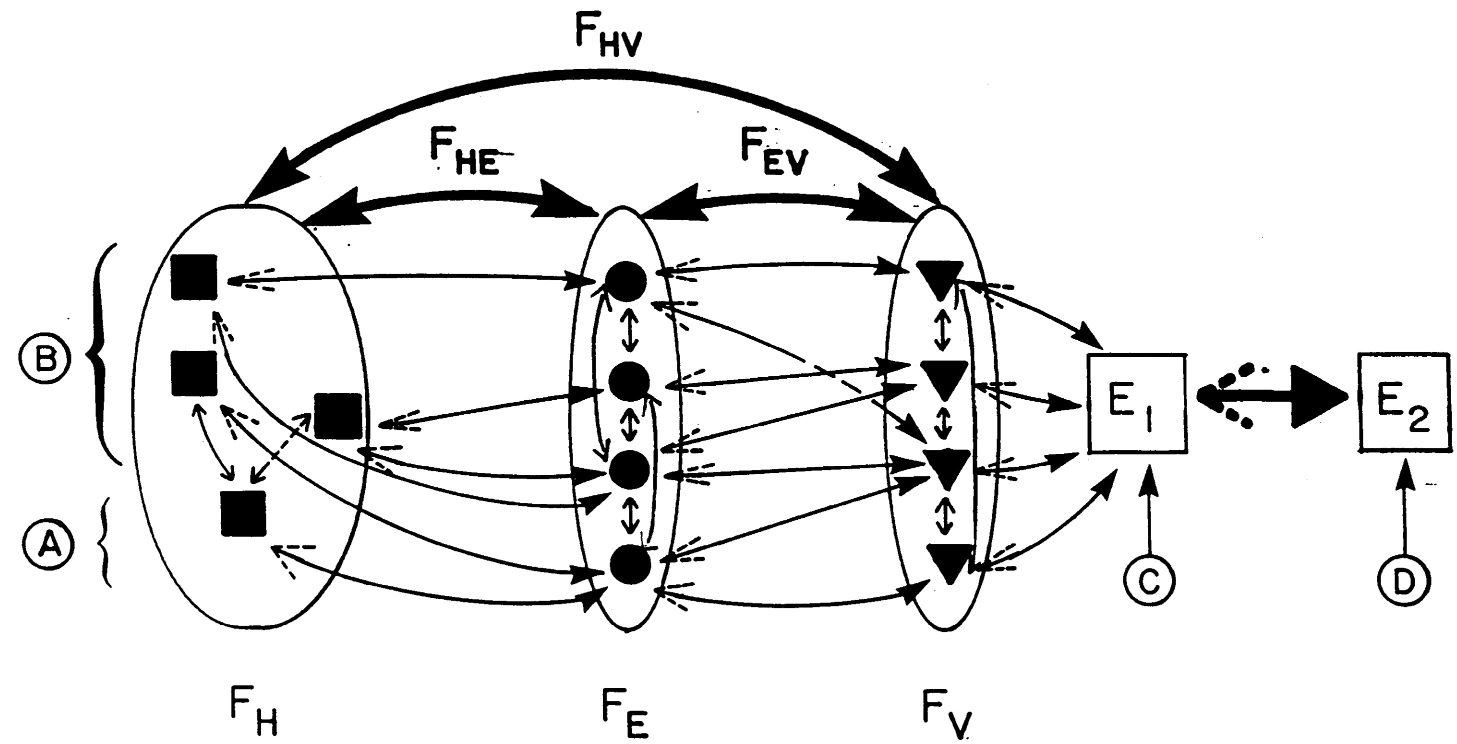


True causality in the natural world is seldom this simple. First, for any particular set of boundaries we would like to use in a CEA, there is probably more than one cumulative effects problem occurring. In Figure 3.5, the basic kinds of CE problem (described by region in Canada, in Appendix 7.1). are shown by interrelated ecosystems. Using this diagram, it is clear that a large number of CE problems potentially occur in the same space and time and contribute to overall environmental deterioration. If one chooses to complete an assessment only for area X on the acidic deposition problem, one may delete the causal links related to the Valued Ecosystem Components associated with other CE problems. Under particular circumstances this action is legitimate. For example, the deleted links might be considered to have a minimal effect, or logistical support might not be available for a larger assessment. It is always preferable, however, that the CE assessor carefully note what is and what is not being included in the assessment and determine if an omission will affect the final conclusions of the assessments.

In Figure 3.6, all four types of CEA (diagrammed in Figure 3.4) are combined into a single figure. It becomes clear that where the assessment begins in the pattern of causality differs with the four types of CEA problems. In Types A and B, the assessor starts with the human activities and developments and works forward to predict what will happen in the future. In Types C and D, the assessor works backward to determine the causes of the present state of the environment. Illustrated also in this figure are the locations of potential feedback (F) in the causal network. Feedback may be in terms of human activities (H), environmental changes (E), and Valued Ecosystem Components (V).

For example, F_H might arise from the interaction of the marketplace driven by the profit motive and an electric company's goal to supply cheap power. The company 'does not install scrubbers and its power plants release tons of acidified atmospheric pollutants (NO, and SO,). These emissions lead to changes in aquatic environments and initially a lowering of pH in lakes and rivers. Through F_E, the lowered pH valves change the solubility conditions for heavy metals such as aluminum. This causes aluminum to go into solution and become available to various groups of aquatic organisms. At high concentrations, aluminum is toxic to the organisms and can compound the existing stress related to the acidity. One of the VECs in this environment might be a sport fish species. Because of the change in pH and aluminum toxicity, competitive relationships might change among fish species in the foodweb. Lowered reproductive success of the VEC of interest, and concurrent, higher predation on its young from another fish species that was competitively superior to the sport fish would constitute F_V relationships. Indeed, most foodwebs have strong feedback relationships with and without the perturbations related to cumulative effects. As explained in the CEA framework assumptions (Section 2.4). the ecological mechanisms of the impact eventually operate at the level of the local ecosystem and can involve even lower levels of biological organization such as physiological, and behavioral and biochemical levels. What is different with acidic deposition, as compared to heavy metal toxicity or excess acidity shown for a single lake, is its large-scale spatial pattern which encompasses a large number of individual lakes.

Figure 3.6 Summary of Causality and Feedback for All Four Types (A-D) of Cumulative Effects. Solid Arrowheads Indicate Direction of Inductive Reasoning and Dotted Arrowheads Show the Direction of Deductive Reasoning.



■ HUMAN ACTIVITY

● CHANGE IN THE ENVIRONMENT

▼ VALUED ECOSYSTEM COMPONENT (VEC)

TYPE OF CUMULATIVE EFFECT

(A) 1 HUMAN ACTIVITY

B MULTIPLE HUMAN ACTIVITIES

C SUDDEN OR CATASTROPHIC EVENT

(D) DETERIORATION OF THE ENVIRONMENT

FEEDBACKS

F_H FEEDBACK AMONG HUMAN ACTIVITIES

F_E FEEDBACK AMONG ENVIRONMENTAL CHANGES

F_V FEEDBACK AMONG VECs

F_{HE} FEEDBACK AMONG HUMAN ACTIVITIES AND ENVIRONMENTAL CHANGES

F_{HV} FEEDBACK AMONG HUMAN ACTIVITIES AND VECs

F_{HV} FEEDBACK AMONG ENVIRONMENTAL CHANGES AND VECs

STATE OF THE ENVIRONMENT

E_1 STATE OF THE ENVIRONMENT AT TIME 1

E_2 STATE OF THE ENVIRONMENT AT TIME 2

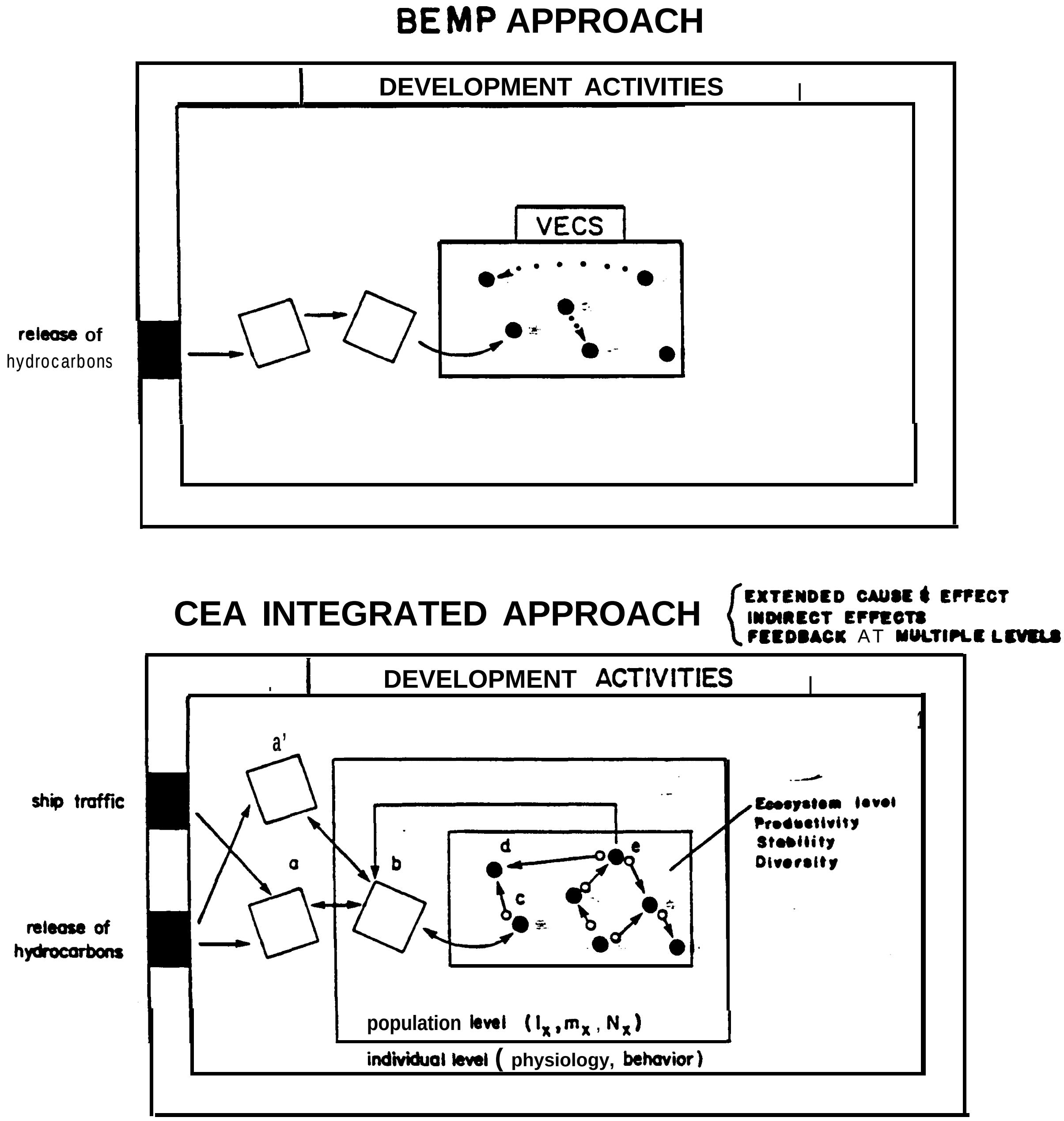
In addition to the feedback within human activities or environmental changes or VEC's, there are also feedback relationships between pairs of these components. Environmental managers might act to regulate a particular type of human activity or development as soon as environmental change is observed and before the VECs undergo a negative impact. Likewise, environmental changes can lead to changes in VECs that, in turn, change their behavior or physiological patterns which, in turn, lead to subsequent ecological change. When a VEC is noticeably affected, however, is usually the time when environmental managers influence human activities so as to lessen their negative consequences. These feedback links may be one- or two-way. They represent an important class of control mechanisms and options that might be available to the manager and regulator.

The concept of feedback and hence interconnection at extended spatial scales is the quintessential concept in cumulative effects assessment. The essence of conducting good cumulative effects assessments is to identify the locations and strengths of the key feedback relationships at the appropriate scale. This is not easy to do, and no precise prescription can be written that will guarantee success for every CEA. Much of the complexity, however, in CE is bound up in these extended feedback relationships. It is important to note that cumulative effects themselves are not fundamentally different from those effects that occur in local ecosystems: reproductive capacity may be diminished, feeding behavior may be altered, individuals may die, a lake may acidify, profit may decrease, a way of life might change irreversibly, or a social value may be lost. What is different are the patterns of these changes on a regional scale over longer periods of time. In addition, since many of these impacts are cumulative in a multiplicative way, there may be irreversible or sudden environmental damage before the environmental managers have time to respond appropriately. This is coupled with the fact that small changes locally, that are usually ignored, may have severe cumulative and regional consequences.

Failure to account for feedback even in its simplest form is evident in the way the Beaufort Environmental Monitoring Program (BEMP) was conceptualized (Figure 3.7). BEMP represents one of the most organized efforts to conduct assessment and develop rational monitoring plans on a regional level in Canada. In many ways, it has been a precedent-setting process. Although BEMP has been criticized for employing untestable hypotheses as the central theoretical construct in the program, BEMP can also be criticized for employing causal explanations that are too simplistic in framing hypotheses. Overall, BEMP is equivalent to a Type B cumulative effects problem. Multiple activities mostly related to oil and gas production in the Beaufort Sea are hypothesized through inductive reasoning to affect on a set of VECs. Approximately twenty hypotheses have been framed and are in use today.

In Figure 3.7, the BEMP conceptualization is compared to one that more realistically includes feedbacks. Most of the VECs identified are populations of aquatic organisms or higher organisms: mammals, birds and fish. All are interrelated in the aquatic foodweb. A set of hypotheses that predicts changes in isolated VECs that are in reality intimately interconnected cannot succeed. We know from network theory that even a single feedback loop

Figure 3.7 Comparison of BEMP Conceptual Approach to an Integrated One Centering Upon Feedback and the Ecological Heirarchy.



KEY:

- -DEVELOPMENT ACTIVITY
- ● – VALUED ECOSYSTEM COMPONENT (VEC)
- ❑ – CAUSAL STEP

FOR THE INTEGRATED APPROACH:

a – INDIVIDUAL LEVEL

b – POPULATION LEVEL

c -ECOSYSTEM LEVEL

strategically positioned in a network of cause and effect can lead to unexpected and even counterintuitive results (Lane and Levins, 1977).

Most environmental managers have an intuitive grasp of the counter-intuitive aspects of ecological systems. For example, pesticides kill insects in laboratory bottles but often fail to control them in nature. Why is this? It is not because we have observed an incorrect physiological response in the laboratory but, rather, the diverse feedbacks in ecological systems can result in an increase in pests where the physiology predicts a decrease. There are many ways this could happen. For example, the pesticide may have killed the predators which are slower growing than the prey pest of interest. Released from predation, the pest species may have increased in numbers even though some individuals were killed by the pesticide. Likewise, when nutrients enter a lake, there may be large blue-green algal blooms and subsequently, lowered concentrations of nutrients. In this case, the turnover rate of the nutrient pool has increased greatly whereas its concentration observed at a single time, has decreased. None of these ecological observations negate the physiology upon which they are based. In a complex system with feedback, however, many physiological truths become ecological myths (Lane and Levins, 1977).

These examples illustrate the importance of feedback in environmental systems. They also demonstrate that the choice of a suitable level of organization and scale to study an environmental observation or to predict impacts is all-important. An unsuitable choice leads to great difficulty in characterizing the minimal causality needed for understanding and predictive accuracy. Just as the physiological level is not appropriate to understand the local ecosystem, the local ecosystem is not adequate to understand events at a regional level. This is not to say that physiological information (in the first case) and local ecosystem understanding (in the second case) are not useful. Such understanding is not only useful but often necessary. What is emphasized, however, is that information at lower levels of organization and scale is often not sufficient to explain behavior at higher levels. If one knew everything about chemistry and physics it would still not be possible to write the equation for life. The essence of organization of living systems is not wholly contained within the sciences of chemistry and physics. Fundamentally different types of system behavior, that are not totally subsumed and apparent at lower levels, emerge at higher levels in a hierarchy.

3.3 Steps in the CEA Process

Because of the complexity of most CEA problems and because there are so many separate activities that must be conducted to complete a CEA, no single set of methods can be presented as the method for "doing cumulative effects assessment". More realistically, CEA should be thought of as a process of several steps. For each step, there may be several specific methods that could be employed. There is no single right method for any particular step. The process varies in the organization and ordering of steps for the four types of CEA. It is possible to discriminate two processes: one where the goal of the CEA is mostly a bottom-up, inductive reasoning process (Types A and B); the other where it is a top-down, largely deductive reasoning process (Types C and D). Note Types A-D were illustrated in Figure 3.2. The major steps for the bottom-up process are given in Table 3.1 and for the top-down process in Table 3.2. It is assumed before using either Table ***3.1 or 3.2,*** that Figure 3.1, the CEA decision tree, has been used and the assessor has reached one of the four terminal branches that states that the CEA Reference Guide for Type A, B, C, or D should be used. If any other terminal branches are reached, the assessor should not proceed in this Guide.

Step5in Table 3.1 and Step 6 in Table 3.2 relate the CEA diagram illustrated in Figure 3.6. Because this diagram summarizes all four types (A-D) of CEA problems, the diagram appears more complicated than it is. For types A and B use only the solid arrows, and for types C and D the dotted arrows. By constructing the diagram system understanding can be focused regardless of whether there is a single or several assessors. Alternative diagrams can be used if there is disagreement on the key casual links.

A detailed discussion of the other steps is not given here. Many are self-evident and logical extensions of steps used in traditional environmental impact assessment. In Volume II (Wallace and Lane, 1988) the cumulative effects problem of the prairie wetlands is described using the decision tree. It is a Type D problem and we illustrate how the CEA process can be applied. This concrete example is more helpful to the assessor than a hypothetical discussion of the steps. Since both the bottom-up and top-down processes have many steps in common, a single example such as the prairie wetlands can be used to illustrate both processes.

Both inductive and deductive thinking is used in understanding the natural world: neither mode is superior to the other. Scientists, for example, routinely use both. As a gross generalization, however, these changes that occur in the environment that are basically chemical (toxic chemical pollution in the Great Lakes) will necessitate a more complex set of feedback relationships for conceptualization than will those changes that are largely physical such as habitat fragmentation. Likewise, often those changes that are mainly of a physical nature can be indicated placed on maps more successfully than can chemical changes.

For the bottom-up process, where there is an identifiable proponent, development or set of developments, the initial scoping of Step 1 and the bounding of Step 2 could be greatly facilitated if there were formal arrangements for CEA in the federal regulatory and assessment practices. In the recommendations given in Chapter 5 .O, we suggest that there should be at least five CEA boards, one for each region of Canada. If such boards were formed, it is envisaged that they would have changing membership as the need arose, but the core membership would represent the best expertise available on the key CE problems of a particular region as well as the necessary blend of jurisdictional and institutional interests. One of the roles of the board would be to identify key cumulative effects problems and set regional environmental standards and monitoring programmes to ensure that CE were being monitored, managed and predicted adequately. Thus, there would be certain goals established by region and a system of environmental planning initiated. Jurisdictional and institutional arrangements would need to be adjusted to accommodate this initiative. When proponents wished to begin a new development, it could be screened against the backdrop of regional cumulative effects.

If there is not to be a formalized system nor identified regional goals for environmental quality and resource management, then it will be exceedingly difficult to have proponents account adequately for cumulative effects. First, it might not be in their interest to do so; and second, it would be difficult for them to have a sufficient regional overview and CE understanding to complete a satisfactory CEA even if they were motivated to do so. Usually for a proponent, the goal is to pass the regulatory hurdles and to pose no direct threat to the environment in spatial-temporal dimensions which are as small as and as circumscribed as possible. Other human activities impinging on that bounded area are given little direct consideration except insofar as they form part of the environmental description or if there is some direct way in which they might impede the development (both construction and operation). This process could be radically altered and improved with an integrated regional environmental planning and CEA process in effect. If there is not to be a formalized approach that integrates regional environmental planning and assessment capabilities successfully, it would appear that the best that could be achieved is a reactive approach that hastily organizes an ad hoc solution whenever a particular cumulative effect problem becomes intolerable.

Even disregarding the environmental damage that will result from continuing our present reactive approach, it is probable that if long-term economic indicators could be employed they would show the true economic cost related to CEs, then the political unit could be better motivated to combat CEs.

3.4 Selecting the Analytical Methods

For both the top-down and bottom-up CEA process, a selection of analytical methods for each step is given in Table 3.3. For some steps, there is only a single method listed; for other steps, several methods are given. Often the selection of a method will depend upon the logistical base available to the assessor. For many steps, in either the top-down or bottom-up process, a workshop or other collective format can be used to implement the method. In other steps, a single assessor might work alone. In Table 3.4, the logistical base using criteria of budget, data set, and intensity of assessment effort, is contrasted for space crowding (synergistic), time crowding (periodic) and combined types of CEA problems. In each category, the preferred methods are directly related to the degree of feedback in the system requiring characterization. For low feedback CE problems, usually less elaborate and less costly methods are needed. Loop analysis is the most appropriate method of characterizing high feedback CE problems. The method centers on the characterization of feedbacks and cause-effect pathways. If there are few data, then hypothetical loop models (Type 1) should be used; and if there is an appropriate data base, Type 2 models are recommended. An ecosystem 20-25 variables can contain thousands of pathways of effect and many hundreds of feedbacks. We know of no other method than enumerates these pathways and feedbacks in terms of ecologically meaningful predictions.

Table 3.5 contains a listing of the methods used in CEA by basic type. Relevant examples of each type are described in Appendix 8.1. Loop analysis is described individually in Appendix 8.2, because it is presently the best method for characterizing ecological feedback and it is not widely understood although there are approximately 40-50 references to it in the literature. In addition, several methods listed in Table 3.4 were developed in the United States and are also described in Appendix 7.3. For consensus building methods, see Section 4.3. References to all methods are listed in Chapter 6.0, Bibliography.

Table 3.1 Steps in a CEA for the Bottom-Up Process Needed for CEA Types A, B and Some Portions of C.

Figure 3.1 should be used to determine type of CEA problem before using this Table.

STEP	ACTIVITY
1	Scoping (define questions, issues, potential detail of analysis, CEA goals and logistical support).
2	Bounding (define universe of human activity, potential environmental change, VECs, institutional and jurisdictional boundaries).
3	Go through Figures 3.2 - 3.5 to establish common basis of understanding.
4	List human activities, environmental changes, and VECs.
5	Prepare a forward CEA diagram (solid arrows) in Figure 3.6.
6	Decide on the location and amount of feedback (F_H, F_E, F_V, F_{HE}, F_{HV}, F_{EV}) .
7	Decide on the CEA problem as one of space crowding (synergistic), time crowding (periodic), or combined (Table 3.4).
8	Select the analytical tools and perform the analysis to determine the predicted state(s) of the environment (Tables 3.3 and 3.4). (Characterize also the level of uncertainty associated with the predictions.)
9	Diagram predicted qualitative states.
10	Decide if the future states are acceptable, have potential to be mitigated, or are not acceptable and a way to alter causality in CEA diagram must be found.
11	Explore management options, design strategy, and make recommendations (including additional data collection, more sophisticated analysis, environmental effects monitoring, post project audits, socio-economic adjustments, institutional and jurisdictional adjustments, etc).
12	Repeat steps 4-12 if additional scenarios of potential human activities are hypothesized to occur in the future and decisions need to be made concerning equitable division of the regional ecosystem.

Table 3.2 Steps in a CEA for The Top-Down Process for CEA Types C and D.

Figure 3.1 should be used to determine type of CEA problem before using this Table. (Note: If you have a CEA Type C problem and the cause of the sudden event or catastrophe is well understood, you will need only the inductive approach described in Table 3.1.)

STEP	ACTIVITY
1	Scoping (define questions, issues, potential detail of analysis, CEA goals and logistical support).
2	Bounding (define spatial-temporal universe of concern for observed environmental deterioration, institutional and jurisdictional boundaries).
3	Go through Figures 3.2 - 3.5 to establish common basis of understanding.
4	Diagram known changes in qualitative state of human activities, environmental changes, and VECs.
5	List unacceptable and worrisome trends.
6	Prepare a backward CEA Diagram (dotted arrows in Figure 3.6).
7	Identify all human activities that should be included in the diagram and establish hypothetical links.
8	Decide on the location and amount of feedback (F_H, F_E, F_V, F_{HE}, F_{HV}, F_{EV}).
9	Decide on the CEA problem as one of space crowding (synergistic), time crowding (periodic), or combined (Table 3.4)
10	Select the analytical tool and perform the analysis to determine the causes of the observed environmental deterioration (Tables 3.3 and 3.4). (Characterize also the level of uncertainty associated with the causes.)
11	Explore management options, design strategy, and make recommendations (including additional data collection, more sophisticated analysis, environmental effects monitoring, postproject audits, socio-economic adjustments, institutional and jurisdictional adjustments).
12	If you have a Type D CEA problem assume corrective adjustments and prepare a forward CEA Diagram to project whether future states of the environment are predicted to be acceptable or not.
13	Repeat steps 7-13 if additional scenarios of potential human activities are hypothesized to occur in the future and if decisions need to be made concerning equitable division of the regional ecosystem.

Table 3.3 Some Suggested (Types) of Methods For Each Step in the CEA Process: Bottom-Up Approach, and Top-Down Approach. (Refer to Appendix 8.1 for a description of each type of method.)

Bottom-Up Approach

Step	Method
1	ad hoc
2	mapping, overlays, some simple models and calculations
3	use existing guide matrices and networks (Figures 3.2 - 3.4)
4	checklists
5	network (using existing guide format, Figure 3.5)
6	ad hoc networks, loop analysis
7	mapping, overlays, graphical methods, trend analysis
8	ad hoc mapping matrix, loop analysis, computer simulation
9	mapping, overlays, graphical methods, trend analysis
10	ad hoc
11	ad hoc, consensus building
12	same as steps 4-12 above

Top-Down Approach

Step	Method
1	ad hoc
2	mapping, overlays, some simple models and calculations
3	use existing guide matrices and networks (Figures 3.2 - 3.4)
4	checklists
5	checklists
6	network (using existing guide format, Figure 3.5)
7	checklist and network
8	ad hoc networks, loop analysis
9	mapping overlays, graphical methods, trend analysis
10	ad hoc, mapping matrix, loop analysis, computer simulation
11	ad hoc, concensus building
12	network (using existing guide format, Figure 3.5)
13	same as steps 7-13 above

Table 3.4 Selection of an Analytical Tool.

Once the CEA diagram is constructed as shown in Figure 3.6, levels of low and high feedback can be determined by the amount of interconnection in the diagram.

	Logistical Base			
	Short Term Effort, Low Budget, Small Data Set		Long Term Effort, High Budget, Large Data Set	
	Type A&B	Type C & D	Type A & B	Type C & D
1. <u>Space Crowding</u>	(ad hoc)	(ad hoc)		
Low Feedback	mapping cause/effect	mapping back step analysis cause/effect	geographic information system modeling	geographic information system modeling
High Feedback	loop analysis" (Type 1)	loop analysis (Type 1)	loop analysis (Type 2) computer simulation	loop analysis (Type 2) computer simulation
2. <u>Time Crowding</u>	(ad hoc)	(ad hoc)		
Low Feedback	cause/effect	trend analysis back step analysis cause/effect	forecasting risk analysis modeling	forecasting risk analysis modeling
High Feedback	loop analysis (Type 1)	loop analysis (Type 1)	loop analysis (Type 2) computer simulation	loop analysis (Type 2) computer simulation
3. <u>Combined</u>	(ad hoc)	(ad hoc)		
Low Feedback	trend analysis mapping cause/effect	back step analysis mapping trend analysis cause/effect	risk analysis modeling	risk analysis modeling
High Feedback	loop analysis (Type 1)	loop analysis (Type 1)	loop analysis (Type 2) computer simulation	loop analysis (Type 2) computer simulation

"Loop Analysis Types 1 and 2 are explained in Appendix 8.2

Table 3.5 Summary of References (l-9) Used in Appendix 8.1, Plus References for Three Additional Categories: Loop Analysis, Trend and Forecasting, and Risk Analysis Methods (10-12). References are listed in Chapter 6.0.

Method	Reference
1) ad hoc	- California Energy Commission, 1982. - Colorado Department of Health and U.S. Environmental Protection Agency, 1981. - Denver Research Institute and Resource Planning Associates, 1979. - Finsterbusch, K., 1977. - Hirst, S.M., 1984a,b. - Maryland Department of Natural Resources, 1982. - Reed, R.M., J.W. Webb and G.F. Cada, 1984. - Roy F. Weston, Inc., 1978.
2) checklists	- Armour, C.L., R.J. Fisher and J.W. Terrell, 1984 - Battelle Columbus Laboratories and Midwest Research Institute, 1979. - Bloom, S.A., 1980. - Canter, L.W., 1981. - Center for Wetland Resources, 1977. - Contant, C.K. and L. Ortalano, 1985. - Dames and Moore, Inc., 1981. - Dee, N., J.K. Baker, N.L. Drobny, K.M. Duke and D.C. Hanringer, 1972. - Everett, S.J., 1978. - Geppert, R.R., C.W. Lorenz and A.G. Larson, 1984. - Hydropower Assessment Steering Committee, 1983. - INTASA, 1981a,b. - Leopold, L.A., F.E. Clark, B.R. Hanshaw, and J.R. Balsley, 1971. - Mason, W.T., Jr., 1979. - Oscar, Larson, and Associates, no date. - Sassman, R.W. and R.M. Randall, 1977. - U.S. Army Corps of Engineers, 1980.
3) matrices	- Bloom, S.A., 1980. - Canter, L.W., 1981. - Contant, C.K. and L. Ortalano, 1985. - Dames and Moore, Inc., 1981. - Gilliland, M.W. and B.D. Clark, 1981. - INTASA, 1981a,b.

Table 3.5 (cont'd.)

Method	Reference
3) matrices (cont'd.)	- Kane, J., I. Vertinsky and W. Thompson, 1973. - Leopold, L.A., F.E. Clark, B.B. Hanshaw, and J.R. Balsley, 1971. - Roy F. Weston, Inc., 1978. - Sorenson, J.C., 1971. - Streeter, R., R. Moore, J.J. Skinner, S.G. Martin, T.L. Terrel, W. Klimstra, J.J. Tate and M.J. Nolde, 1979. - Yorke, T.A., 1978.
4) network	- Armour, C.L., R.J. Fisher and J.W. Terrell, 1984. - Armour, C.L., 1986a,b. - Bain, M.B., J.S. Irving, R.D. Olsen, E.A. Stull and G.W. Witmer, 1985a,b,c. - Canter, L.W., 1981. - Caswell, H., 1976. - Coullard, D., 1984. - Gilliland, M.W. and B.D. Clark, 1981. - Sorenson, J.C., 1971.
5) overlays	- Colorado Department of Health and U.S. Environmental Protection Agency Region VIII, 1981. - Dickert, T.G. and A.E. Tuttle, 1985 - Fabos, J.G., C.M. Greene and S.A. Joyner, Jr., 1978. - Kimball, T.C., A. Pate1 and G.A. Yoshioka, 1982. - Lumb, A.M., 1982a,b. - McHarg, I., 1969. - U.S. Department of Interior, Bureau of Land Management, 1977. - Winn, D.S. and K.R. Barber, 1985.
6) modeling procedures	- Boreman, J., C.P. Goodyear and S.W. Christensen, 1978. - Canter, B., 1986. - Caswell, H., 1976. - Center for Wetland Resources, 1977. - Coats, R.N. and T.O. Miller, 1981. - Contant, C.K. and L. Ortalano, 1985. - Darnell, R.M., 1973. - Everett, S.J., 1978. - Federal Energy Regulatory Commission, 1984.

4.0 CONCLUSIONS AND RECOMMENDATIONS FOR CEAM IN CANADA

Several conclusions and recommendations for the general CEA development in Canada are grouped below in three categories:

1) Development of CEA Approach and Process,
2) Jurisdictional and Institutional Concerns, and
3) Consensus Building.

4.1 Development of a CEA Approval and Process

Conclusion:

Developing a practical CEAM approach and process and finding ways to implement CEAM *may be the single best way to preserve environmental quality in Canada. It is feasible for Canada to develop its own CEA process and conceptual framework as described in this Guide. The ordering of the steps in the process relate largely to the CEA assessor's point of entry in the CE cause and effect network. The Guide essentially provides the broad outline of a practical CEA process; there is still much to do to supply the user with detailed, custom-designed methodologies for particular steps in the process. It is important that the process, individual methods and case studies (applications) develop in an integrated fashion. It would be desirable to develop a collaborative CE methodology with U.S. workers.

Recommendations:

1) Case Studies: There should be at least two case studies implemented that would typify the top-down and bottom-up CEA process outlined in the Guide. The wetlands of the boreal agricultural fringe of the Prairie Provinces problem discussed here as a Feasibility Study in Volume II (Wallace and Lane, 1988) is a top-down (ecosystem-driven) CEA problem with little ecological feedback through its dominant features of habitat fragmentation, hunting and natural predation, spatial patchiness and physical alteration. There are, however, some key feedback relationships at the socio-economic and institutional levels. In this study, population risk modeling would facilitate the meaningful integration of the diverse pieces of ecological data which could then be combined with causal network analysis of the socio-economic, institutional and jurisdictional valuables.

   The second case study should be a bottom-up (single to multiple) proponent-driven CEA problem that involves an important aquatic resource. This example should be characterized by chemical pollution which would involve ecotoxicological effects throughout the biological hierarchy (individual, population and ecosystem) resulting in diverse ecological feedbacks.

   It is important for both case studies, that multiple user groups are identified and that there is enough public interest involved to warrant giving major attention to the problem. One possibility for the aquatic study would be Georges Bank where there is presently a great deal of controversy surrounding hydrocarbon exploration. This example also has interesting jurisdictional and institutional ramifications. Another worthwhile example would be the plight of the Atlantic salmon in the Maritime Provinces in regard to acid deposition and other impacts.

2) Methodological Development: Intense development is needed to understand how causality and feedback operate in spatially and temporally extended regional ecosystems and to detail this understanding in a practical form for users. If we cannot learn to identify the strong feedbacks and basic qualitative structures of these systems, we will always be at the mercy of Murphy's Law (anything that can go wrong, will go wrong) and its corollary (the thing that can do the worst damage, will inevitably happen first). Murphy's Law is the downside of middle number system problems. Murphy's Law is applicable to many areas of human endeavor, and human activities within ecosystems have provided a long list of examples supporting its validity.

The basic qualitative structure must include the human activities, the environmental changes, the VECs and their feedback within and between these sets of components. In addition, the biophysical part of the structure cannot and should not be separated from the socio-economic, jurisdictional and institutional components. Key areas of feedback, points of natural and human control, as well as basic links may influence the dynamics of the system being assessed. A well-intentioned and even reasonable management edict positioned in a particular part of the network can actually lead to the deterioration rather than the improvement of the ecosystem or species the edict is meant to protect.

The main causal network technique (loop analysis) that is recommended is based upon feedback relationships among a set of interacting variables. Many other types of qualitative techniques can only represent one-way causality and thus much of the feedback needed to understand CE is ignored. Although loop analysis has been mainly developed for local ecosystem applications, its use should be extended to CE-type problems. Strongly quantitative modeling approaches should only be implemented after the qualitative structure and level of feedback are understood.

Once developed, loop models can be transformed into computer simulation models by a competent modeler. Loop analysis models have an advantage in that they can be used with and without data. Variables need not be in the same units. An environmental manager or a habitat protection law can be placed in the same network occupied by a caribou population without converting everything to grams of carbon or kilowatts of energy. These models can be used by the mathematically unsophisticated, and they are inexpensive. Loop models are also very helpful in guiding data collection and framing impact predictions. Most of the other methods listed in Chapter 3.0 need only minor revisions to be used in the CEA process.

3) Integration of Regional Planning and Assessment Capabilities: At present, regional environmental planning and environmental assessment capabilities are usually not possessed by a single individual to a sufficient degree to achieve successful integration of the two subject areas. Planners and ecologists often have very different academic backgrounds and types of professional experience. There needs to be a concerted effort to develop training programs for CEAM that are either totally new or that augment existing environmental studies programs in Canada. In addition, workshops are needed preferably focused upon case studies that will facilitate the integration of planners and assessment specialists. Results from these workshops and other collaborative efforts can be used to develop curriculum materials for a variety of purposes related to training and education for CEAM.

4) Logistical Considerations: First,.a software package for guiding a user through the CEA process and the basic qualitative modeling should be developed. Second, there should be improved and 'more organized information exchange between the developers of the CEA process in the United States and Canada. We have much to learn from each other.

4.2 Jurisdictional and Institutional Concerns

Conclusion:

The jurisdictional and institutional systems in Canada are not adequate to deal with the multitude of CEA problems identified in Chapter 3.0 and Appendix 7.1. Even when the regional ecology is well understood, the problem is not always solvable because of the jurisdictional and institutional barriers. The acid deposition problem is a good example of this. Any meaningful CEA process must contain steps that guide a user through a typology of these barriers and a set of options for dealing with them. This was outside the Terms of Reference of the present Reference Guide. An assessor needs to be able to identify the feedback associated with jurisdictional and institutional concerns that might enter the dynamics and qualitative structure of the ecosystem under assessment. New arrangements for CEAM should be explored at the federal and provincial levels.

Recommendations:'

1) Methodological Development: A separate study should be commissioned to develop the above typology and study potential feedbacks of jurisdictional and institutional actions with the environment including both its socio-economic and bio-physical components. Recommendations should be made to modify the Canadian CEA process to include steps to guide the user through the myriad of potential problems and management options. These recommendations should be tested in the case studies and improved as necessary.

2) New Arrangements: One reason that the U.S. workers have placed much more emphasis and effort on CEAM than have their Canadian counterparts is the fact that the U.S. included cumulative effects in key legislation

early in their EIA history. Although Canada may be behind the U.S. in formal efforts, we are still ahead in that we have fewer people, smaller CE problems, less bureaucracy and jurisdictional and institutional barriers than does the U.S. We should, however, strengthen and extend our current assessment and planning approach to ensure that CEs do not slip through undetected and unabated.

One way to achieve a CEAM process in Canada would be for FEAR0 to assume a coordinating role with five regional CEAM assessment boards for each of the five geographical regions of Canada (Atlantic Provinces, Quebec, Ontario, Prairie Provinces, and British Columbia and the Territories). The boards would have both federal and provincial representation. A modified form of the Regional Coordinating and Screening Committee might serve as a starting point.

At the federal level, there should be requirements that all proponents have their IEEs and EISs screened against a set of cumulative effects guidelines. P. Lane and Associates Limited/Washburn and Gillis and Associates Limited recently included a chapter on cumulative impact assessment for the Generic Initial Environmental Evaluation for the fixed link proposed between New Brunswick and Prince Edward Island (Lane and Gillis,1988). Twelve potential areas with cumulative effects were considered and analyzed. The FEAR0 coordinating committee for cumulative effects would need to develop the necessary training materials to implement proponent-driven CEA.

For ecosystem-driven CEA, each CEAM assessment board should serve as an early warning system for detecting CEs near threshold values. These boards could be a focal point for regional system description, data collection and monitoring, goal-oriented management objectives, identification of real or potential CEs, and recommendations for management, planning, and research. Generic templates and software packages as well as GIS systems could be developed as needed for all five CEA areas to facilitate the implementation of standardized CEA practices throughout Canada.

It is unlikely, especially for CEs arising from generalized ecosystem deterioration; that any single government agency (and certainly not proponents) will assume responsibility for the management of CEs if FEAR0 does not assume a lead role in developing and implementing new CEAM requirements.

4.3 Consensus Building

Conclusion:

Consensus building is an important part of successful CEAM. Consensus building is needed in several of the steps in the CEA process described in Chapter 3.0 such as setting of objectives and delimiting boundaries, agreeing on the monitoring of impacts and actions to be taken when thresholds are exceeded, and formulating new institutional and jurisdictional arrangements to ensure CEAM is operable in Canada.

Achievement of consensus among parties-at-interest involved in environmental disputes or negotiations has become an increasingly important objective for government agencies, and, in some cases, for proponents. In cumulative effects assessment, the decision makers often must determine the total carrying capacity of the environment for development and other human activity. This necessitates the resolution of multiple-user conflicts and the optimal allocation of environment among these users.

O'Riordan (1983) documented approaches to the consultative process as part of strategic planning for regional water resources in British Columbia. The use of public advisory groups as a component of the early strategic planning process was cited as a method to minimize future disputes. More recently, McGlennon and Susskind (1987) noted that the USEPA, finding 80% of all its new regulations being challenged in court, initiated a demonstration project to test the usefulness of negotiated rule-making.

These two examples at the regional planning stage and in the development of regulations, demonstrate the potential for application of consensus-building techniques across a broad spectrum of environmental issues. Jeffery (1987) explored the role and value of negotiation and mediation within the existing assessment/approval process in Ontario. The author contended that the negotiation/mediation process should not be allowed to reduce the authority of the regulatory/approval process set out in existing legislation and suggested that the most desirable role for this process is at the pre-hearing consultation stage.

This view is interesting, as it suggests a parallel, or complementary, role for mediation as part of the existing regulatory process. Certainly, this has been the experience of the Alberta Energy Resources Conservation Board in seeking to resolve environmental issues between Syncrude and the Fort McKay Indian Band. In this latter case, there have been continuous negotiations carried out to identify, analyze and resolve long-term environmental issues, including cumulative effects.

The legal process, albeit somewhat confrontational, nonetheless constitutes a form of consensus-building, one with a defined (often binding) outcome. In Canada, the courts are less often used than in the U.S., because of the greater discretion embodied in our legislation and because the U.S. courts have usually taken a far more interventionist stance. The new Canadian Charter of Rights and Freedoms, however, may substantially alter this trend and may allow for more citizen input, through the legal process, into environmental regulation or decision-making. Sadler (1986a,b,c) noted:

> "Environmental mediation and negotiated agreements are generally viewed as supplements to regulatory and administrative procedures, rather than as an alternative to them. An important consideration thus becomes how best to tie these approaches to existing systems, for example, as preconditions for general approval or as requirements for the issuance of specific terms and licenses as development proceeds."

These types of concerns may imply a substantive need for the development of consensus-building techniques in cumulative effects assessment, at several levels:

1) Inter-governmental consensus

Clearly, more than any other environmental issues, cumulative effects embrace large areas, many jurisdictions and long time periods. The need for cooperation among Canadian and international governments will be a key factor in achieving success in this area.

2) Intra-governmental consensus

As noted above, the cooperation of a broad range of agencies will be vital to the successful implementation of CEA approaches. This will dictate cooperation between not just those agencies involved in environmentally-related resource management but also those with widely-differing, but applicable mandates, such as Revenue/Taxation.

3) Public cooperation

In order for CEA to evolve beyond the assessment state to implementative programs, an unprecedented degree of cooperation on the part of the public-at-large may be required. For instance, reclamation and preservation of regional wetlands will require the support of private landowners if any rehabilitative programs are to be successfully achieved. Once again, this implies a need for new mechanisms to facilitate public cooperation while providing, or devising techniques to give public incentives to do so.

For the reasons outlined above, CEA will clearly require new attention to, and methods for, the achievement of consensus within and between jurisdictions, governments and the public. These new initiatives will require careful examination in future, and strategies will have to be devised to ensure the cooperative recognition of CEA problems and to develop programs aimed at addressing them.

Recommendation:

A study should be undertaken to document the array of consensus building methods already in use and then, using this information, a practical methodology should be integrated into the Canadian CEAM process.

There is a direct application to the CEA process presented in Chapter 3.0 through a set of what is termed group methods that have been used to build consensus in CEA by the U.S. Fish and Wildlife Service and other U.S. agencies involved in CEA. These include: nominal group technique, back step analysis and FAST diagramming which are briefly described in Appendix 7.3. For any subsequent development of consensus-building techniques, the U.S. experience provides invaluable information and guidance for evaluating a variety of techniques and examples of potential applicability to the Canadian CEAM process.

5.0 GLOSSARY OF ACRONYMS*

AADC	Alberta Agriculture Development Corporation
ACE	Army Corps of Engineers, U.S. Department of Defense
AEAM	Adaptive Environmental Assessment and Management
AECB	Atomic Energy Control Board
AERCB	Alberta Energy Resources Conservation Board
AFS	American Fisheries Society
ANL	Argonne National Laboratory
BEMP	Beaufort Sea Environmental Monitoring Programme
BLH	Bottom Lands Hardwoods
BPA	Bonneville Power Administration
CAETEP	Committee on Applications of Ecological Theory to Environmental Problems (U.S.)
CCREM	Canadian Council of Resource and Environment Ministers
CE(s)	Cumulative Effect(s)
C/E	Cause/Effect Analysis
CIE	Cause and Effect Analysis
CEA(s)	Cumulative Effects Assessment(s)
CEAM	Cummulative Effects Assessment and Management
CEARC	Canadian Environmental Assessment Council
CEQ	Council for Environmental Quality (U.S.)
CI(s)	Cumulative Impact(s)
CIA	Cumulative Impact Assessment
CIAP	Cluster Impact Assessment Process (FERC)
CIP	Cumulative Impact Process (FWS)
CI Project	Cumulative Impact Project (NEC/FWS)
CPS	Collaborative Problem Solving (FWS)
CPT	Computer Planning Tool
CWA	Clean Water Act (U.S.)
CWS	Canadian Wildlife Service
DFO	Department of Fisheries and Oceans
DIAND	Department of Indian Affairs and Northern Development
DU	Ducks Unlimited
EA	Environmental Assessment
EARP	Environmental Assessment Review Process
ECAR	Ecosystem Component at Risk
ECON B	Economic Benefit Analysis
ECON I	Economic Impact Analysis
EEM	Environmental Effects Monitoring
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency (U.S.)
EPP	Environmental Protection Planning
EPS	Environmental Protection Service
ERA	Ecological Risk Assessment
FEAR0	Federal Environmental Assessment Review Office
FERC	Federal Energy Regulatory Commission (U.S.)
FRES	Fraser River Estuary Study
FWS	Fish and Wildlife Service (U.S. Dept. of Interior)

*Glossary also includes acronyms for Volumes II and III.

GL	Great Lakes
GLIMS	Great Lakes Information Management System
IB	Island Biogeography
IEE	Initial Environmental Evaluation
IJC	International Joint Commission
LAC	Least Acceptable Change
LIR	Legislative, Institutional and Regulatory Entities
LRTAP	Long Range Transport Atmospheric Pollution
NAWMP	North American Waterfowl Management Plan
NEB	National Energy Board
NEC	National Ecology Center (U.S. FWS)
NEPA	National Environmental Protection Act (U.S.)
NMFS	National Marine Fisheries Service (U.S. Department of Commerce)
NPS	National Park Service (U.S. Department of Interior)
NRC	National Research Council (U.S.)
NWT	North West Territories
ORP	Optional Risk Procedure
OTCR	The Ohio, Tennessee and Cumberland Rivers
OTS	Office of Toxic Substances
OWMC	Ontario Waste Management Corporation
PAR	Polyaromatic hydrocarbons
PG&E	Pacific Gas and Electric Company (U.S. - California)
POS	Plan of Study
RES	Recreation Economic Study
R&D	Research and Development
SAB	Scientific Advisory Board (CEA User's Guide)
SRES	School for Research and Environmental Studies, Dalhousie Univ.
TUNS	Technical University of Nova Scotia
UMRBC	Upper Mississippi River Basin Commission
UMRCC	Upper Mississippi River Conservation Committee
USDA	United States Department of Agriculture
USDE	United States Department of Energy
USDI	United States Department of Interior
USDOD	United States Department of Defence
USFS	United States Forest Services
VEC	Valued Ecosystem Component

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7.0 APPENDIX ON CANADIAN/U.S. EXPERIENCE

7.1 Overview of Cumulative Effects Problems in Canada

Cumulative effects problems observe no jurisdictional boundaries. Pollutants such as airborne contaminants from industrial stacks in the United States do not stop at the Canadian border nor is it possible to stop aqueous discharges from industrial manufacturing and/or processing from crossing provincial or territorial boundaries. It is difficult, therefore, to compartmentalize many CE problems to specific provinces or territories. Some CE problems, however, can be described generally in Canada by geographicregion and ecosystem type.

The purpose of this appendix is to give a broad overview of CE problems by geographical region in Canada: this appendix is not designed to present an exhaustive compilation of known and potential CE problems or to prioritize them. This review, however, presents enough detail on CE problems to enable the reader to visualize, in concrete terms, both the complexity of CE and the specific regional concerns of greatest immediate interest.

In the first section of this appendix, Canada is discussed in terms of the following five regions: (1) Atlantic Provinces (New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador), (2) Quebec, (3) Ontario, (4) Prairie Provinces (Alberta, Saskatchewan and Manitoba) and (5) British Columbia and the Territories. Interviews with environmental managers and EIA practitioners across Canada were useful in identifying specific cumulative effects problems on a regional basis. In addition, Peterson et al. (1987); GAIA, An Atlas of Planet Management (Myers, 1984); State of the Environment Report for Canada (Environment Canada, 1987a); and Environmental Quality in the Atlantic Region (Environment Canada, 1987b) were used. The latter is a recent update of the state of the environment in the Atlantic Provinces based on data collected by Environment Canada (1983). There were no other regional compendiums available.

7.1.1 Categories of CE Problems

Peterson et al. (1987) identified thirteen categories into which cumulative effects could be organized. This characterization is based on a review of a number of national and international papers and reports and professional experience. In addition to Peterson et al.'s basic typology, we list an additional three problems which can be considered relevant in a Canadian context (Table 7.1).

Regionally, cumulative effects problems differ depending on the overall intensity of human activity, and level and type of development occurring in each area. In the interviews, perception of cumulative effects problems differed for each region. Some CE problems, however, appear to be common to all regions of Canada. These include the mobilization of persistent and bioaccumulated substances and the long-term containment and disposal of toxic wastes. In addition to industrial and municipal discharge of toxic substances, metal mines dispose of an enormous quantity of solid wastes which may contain substances such as arsenic, cadmium, lead and mercury. Other CE problems such as the long-range transport of air pollutants affect only

Table 7.1 Cumulative Effects Problems (*) in Canada by Region.

CE PROBLEMS	Atlantic	Quebec	Ontario	Prairies	British Columbia	NWT and Yukon
	REGION					
1. Long-range transport of air pollutants and ecosystem acidification	•	•	•			
2. Urban air quality & airshed saturation					•	
3. Mobilization of persistent or bioaccumulated substances	•		*	*	*	*
4. Climatic modification	•		*	*	*	*
5. Occupation of land/ and water by man-made features			*	*	*	
6. Habitat alienation (aquatic and terrestrial)	*		*	•	•	
7. Habitat fragmentation (aquatic and terrestrial)	*		*	*	•	
8a. Decreases in soil quality		*	*	*		
8b. Decreases in soil quantity		*	*	*		
9. Use of agricultural, silvicultura and horticultural chemicals	•	*	*	*		
10a Reduction of groundwater supplies			*	•		
10b Groundwater contamination				•		
11. Increased sediment, chemical & thermal loading of freshwater and marine habitats.			•			
12. Accelerating rates of renewable resource harvesting	*		•		*	
13. Long-term containment & disposal of toxic wastes	*	*	•	•	*	
14. Activities and developments producing carcinogenic-teratogenic effects	*	?	?	?	?	
15. Loss of biological diversity	*		•	•		
16. Change in hydrological regimes of major rivers/estuaries.	*		*	•		

certain regions in Canada. Acid precipitation, for example, is a major concern to Ontario, Quebec and the Atlantic Provinces, but is not yet a big problem for the western Provinces although "Arctic haze" has been reported for the Territories. In the Atlantic Region, many CE problems are related to marine activities and developments. In the Prairie Region, CE problems are related to forestry and agricultural activities. Habitat fragmentation is probably being experienced in all provinces to a limited extent but is most serious in the Prairie Region where wetlands are being destroyed for agricultural uses.

There have been a number of scenarios proposed for the effects on climate and the atmosphere of anthropogenic pollutants discharged into the atmosphere. The general consensus is that the increasing amounts of CO, being discharged into the atmosphere will result in global warming by the end of the next century. Although the modeling of a climate system is complex and not all the forcing functions are known or understood, a number of models have been used based on the effects of an increase in CO,. Using this scenario the following impacts have been estimated assuming a doubling of atmospheric CO, concentration by the year 2085 (Healey and Wallace, 1987):

1) an increase in annual mean temperatures over Canada of about 2C° (ocean fringes) to 4C° (up to 6C° in Central Canada in winter),

2) a consequent reduced area and duration of snow and ice cover and arrival and disappearance of icepacks,

3) greater cloudiness as a result of the increase in oceanic surface temperature,

4) increases in the rate of evaporation,

5) a national increase of almost 150 mm in precipitation per year, but with marked changes in distribution,

6) changes in windspeed,

7) changes in vegetation growth rates and other characteristics and growing season,

8) increase in annual runoff rate at high latitudes, and

9) sea level rise (40-60 cm in the next century),

Many CE problems culminate in a loss of biological diversity. Projects, such as monocultural growing of forest tree species after clearcutting, introduction of exotic species (fish, mammals, plants) to an ecosystem, or major habitat changes that create unsuitable habitat for indigenous species, have the potential to affect adversely the distribution and numbers of species normally found in a particular habitat. These projects can have -major biological and economic implications.

7.1.2 Some Regional Examples

In the following sections selected examples of regional CE problems are discussed to illustrate the diversity and extent of CE problems in Canada.

Atlantic Provinces

All of the CE problems listed in Section 7.1.1 affect the Atlantic Region with varying degrees of intensity. CE problems especially relate to: (1) long-range transport of air pollutants resulting in acidification of lakes and rivers, (2) some forestry and agricultural practices, and (3) the overharvesting of freshwater and marine fisheries. Being primarily rural, the provinces in the Atlantic Region have not yet been seriously affected by urban-based pollutants such as motor vehicle emissions or urban expansion. Exceptions to this include the polyaromatic hydrocarbon (PAR) laden air emissions and aquatic effluents in Sydney, Nova Scotia, and the extensive flooding in Saint John's, Newfoundland, as a result of urbanization of the Waterford River watershed. Resource-based activities, both terrestrial and aquatic, have been the primary sources of CE problems to date.

There are a number of "hot spots" in the Atlantic Region where there are pollutant sources contributing to cumulative effects. These are areas where industries are the sources of both aqueous discharges of heavy metals and toxic chemical discharges, and acidic or carcinogenic air emissions. In addition, there are a number of large-scale projects that have the potential to create cumulative effects in the marine environment. These projects include the tidal power project on the Annapolis River, the proposed fixed link between New Brunswick and Prince Edward Island, NATO low level flying and air base expansion in Goose Bay, and offshore oil and gas exploration off the coasts of Newfoundland and Nova Scotia.

Climatic modification, although not now considered to be a critical problem in the Atlantic Region, has the potential to be serious in the long term. Climatic modification of the marine system can, for example, result in a change in fish distribution and abundance. If the associated sea level rise is as high as one metre, this could drastically alter the shape of coastlines and inundate many communities and coastal facilities (P. Lane and Associates Limited, 1988).

Quebec

The population of the Province of Quebec is primarily concentrated in the south, especially along the St. Lawrence River. CE problems identified through interviews with environmental managers and practitioners included: (1) chemical pollution in the St. Lawrence River, (2) accumulation of acid mining residues, (3) fertilizer, insecticide and herbicide accumulations, (4) soil and groundwater contamination from forestry and agricultural practices, (5) soil erosion, (6) acid rain, and (7) ozone contamination. In addition, the problems which have been ranked as most critical in Quebec include the long-range transport of air pollutants and ecosystem acidification, climatic modification, and mobilization of persistent and bioaccumulated substances.

Five CE problems are considered to be important now by the majority of persons interviewed. These included problems #1, 3, 8, 9, 11 and 13 (Table 7.1).

Major activities and developments which contribute to CE problems include the James Bay hydroelectric project, mining, forestry, and industrial and municipal pollution. There are 56,460 ha of land in Quebec that have been disturbed by mining. Most mines are located in the southern half of the province. Elements being mined include iron, tin, molybdenum, nickel, gold, silver, lead, and zinc. In addition to these mining activities which discharge toxic waste, municipal waste discharges have resulted in major outbreaks of the alga Gonyaulax excavata and subsequent paralytic shellfish poisoning in the St. Lawrence River.

The forests in southern Quebec have been severely defoliated by spruce budworm outbreaks. In 1982, 1.2 million ha of forests were sprayed with insecticides. Only one percent of this area was sprayed with bacterial insecticide. The remainder (99%) was sprayed with chemicals. All of the aerial spraying occurred in the lower St Lawrence River area and the Gaspe. The total forested area which has had trees killed by the spruce budworm in Quebec is 11,190,000 ha (Sterner and Davidson, 1983).

Ontario

CE problems which are of concern in this province relate to activities and developments associated with urbanization and industrialization in the south as well as mining and forestry in the north. In particular, the Great Lakes have been subjected to numerous studies to assess the impact from a number of mainly industrial pollutant sources on both the U.S. and Canadian side of the lakes. At present, the International Joint Commission is conducting a large multidisciplinary effort on fluctuating water levels in the Great Lakes.

Mining activities in heavily populated southern Ontario include non-toxic elements such as gypsum, salt, magnesium, and calcium. In central and northern Ontario, however, there are a number of metal mines (for example, iron, gold, copper, lead, tin, cadmium, and zinc). All of these mining activities have created substantial tailings areas where long-term rehabilitation is needed. In addition, the nickel ore smelter in Sudbury has been identified as a major contributor to the long-range transport of air pollutants. Emissions from this source together with the emissions from coal-fired electric generation stations constitute a major portion of Canada's contribution to the acid deposition problem of eastern North America.

Hazardous waste generation and its safe disposal are a particular concern in Ontario since this province generates over half of the hazardous wastes in Canada (Environment Canada, 1986). Of the 220 waste disposal sites in Ontario, approximately 50% are active. These sites are not considered to present a danger to health or to the environment at this time. Another concern in Ontario is the safe transportation of toxic and/or hazardous wastes by rail. There have been a number of toxic chemical spills in southern Ontario in recent years. The province has established regulations, and its Environment Protection Act tracks hazardous wastes from generation through to final disposal. In addition, the province has established the Ontario Waste

Management Corporation (OWMC) for the specific purpose of establishing a center with a comprehensive modern treatment technology. The selected site and technological proposals are now the subjects of a major environmental assessment submission under the province's Environmental Assessment Act.

Parts of Ontario are heavily populated, and the results of urbanization are now considered to be a major CEA issue. In particular, expansion of freeways, airports, and residential and industrial areas is considered to be rapid and extensive. Location of the rail system which conveys hazardous or dangerous goods in the vicinity of Metro Toronto is now the subject of a special task force. In addition, the safe disposal of solid wastes has become a major concern.

Prairie Provinces

The Prairie Provinces consist primarily of three ecozones: the boreal plain, boreal shield and the prairies. The types of cumulative effects which are considered to be important in these three provinces can, for the most part, be based on these ecozones. For example, the prairies are experiencing CE problems as a result of intensive agricultural practices which have changed the characteristics of the landscape. Drainage of wetlands, in particular, is a complex and serious problem, the ramifications of which have not been fully realized. Other problems such as reduced soil quality from compaction, erosion, improper fertilizer and chemical insecticide use, and salinization are also linked to the use of the area for agriculture.

The prairie ecozone is not extensively populated, but this is the most populated area of these provinces. The few major urban center do not contribute substantially to cumulative effects problems in this area. Farming practices, however, have dramatically altered the landscape both physically and in terms of wildlife habitat.

Forests in the western foothills of Alberta (the boreal plain) have been subjected to outbreaks of disease, insects and poor harvesting practices. There has, however, been limited chemical spraying in this area. Insects and disease are largely controlled through the encouragement of selective cutting and burning. Oil and gas exploration have also had an impact on the biophysical environment in the Prairie Provinces through the construction of pipelines, seismic activity, tar sands development, and drilling activity.

The northern areas of the Prairie Provinces (including the boreal shield) are the location of a number of major projects and activities related to mining, oil and gas exploration and hydroelectric power projects. In northern Manitoba, for example, the Churchill River is the site of a major hydroelectric project that has resulted in a number of environmental impacts on the fisheries in the reservoir. In addition to an increase in mercury concentrations in fish species (and thus a decline in the economic value of the stocks and an increase in the health risk associated with eating the fish), there has been a change in the distribution and abundance of fish. The latter has resulted in exploitation of lower quality fish stocks. There are similar impacts associated with the hydroelectric power project on the Peace River extending into Alberta.

British Columbia and the Territories

Like the Prairie Provinces, British Columbia and the Territories have few major centers of urbanization. In British Columbia, agriculture and urbanization are concentrated in valley bottoms in the southern portion of the province with the natural resource harvesting (forestry and fisheries) occurring along the coast and in the northern portion of the province. Forestry, particularly, has been an increasing concern in terms of habitat fragmentation and alienation. Associated with the destruction of virgin forests and unique habitats are the problems of erosion on steep slopes and loss of biological diversity and stability. There are also a number of hydroelectric power projects in the province which affect the quality of freshwater fisheries.

The Northwest Territories and the Yukon, in particular, have few CE problems which are considered critical at this time. Although there are major problems that can be associated with oil and gas exploration, and mining developments, these problems are localized. One potentially serious problem in the Northwest Territories and the Yukon, however, is the cumulative effects associated with climatic modification. This could drastically alter the Arctic ice regime, the extent of permafrost, and the mean annual air and water temperature. The latter has the potential to alter distribution and abundance of both marine mammals and fish, and terrestrial mammals and other vertebrates.

Although there are no major projects affecting the hydrological regimes in the North at this time, there is the possibility that the government of British Columbia will dam one of the key tributaries of the MacKenzie watershed for hydroelectric power production. This would probably have serious repercussions for waterfowl, fisheries, and the characteristics of wetlands along the MacKenzie River. Most of the problems associated with the North, such as mining activities, and oil and gas development, are localized and affect only a small proportion of the total area of the Territories.

In summary, environmental problems that have already resulted or could result, in cumulative effects are evident in most areas of Canada in varying degrees of intensity. The heavily populated areas have problems related to urbanization, manufacturing, and industrial activities. The Prairie and Maritime Provinces suffer from poor agricultural practices and extensive forestry. Northern developments and activities such as dams for hydroelectric power may be isolated but could have far-reaching effects on both the aquatic and terrestrial environments. As discussed earlier, CE problems are usually interconnected both spatially and temporally. Problems which occur on land have the potential to affect groundwater, surface water and marine water (estuaries and coastal areas). CE problems are complex. Often the effects of activities are noticed before the activities have been identified as creating environmental problems. The potential CE problems that have been identified in this section for each province and territory do not constitute a complete list of potential or existing environmental problems but give an indication of the seriousness and potential extent of cumulative effects in Canada.

7.1.3 Ecological Interrelationships of Cumulative Effects

Of the four basic kinds of environments (atmospheric, terrestrial, freshwater, and marine) and six subcategories of aquatic ecosystems (groundwater, surface water, wetlands, estuaries, coastal areas, and open ocean) almost all are associated with the 16 identified CE problems. As shown in Table 7.2, air (or atmosphere) is the least affected by these problems but airsheds are affected by some of the most serious impacts related to cumulative effects, such as atmospheric fallout from nuclear testing or accidents, long-range transport of air pollutants (LRTAP) resulting in ecosystem acidification, and urban air quality. Climatic modification resulting in increased temperatures in the atmosphere, in particular, has the potential for several long-term repercussions.

The terrestrial ecosystem has the potential to be affected by all CE problems with the exception of #11 which refers specifically to aquatic ecosystems. Of the freshwater components, groundwater is impacted by land developments which contribute to chemical contamination or reduction in groundwater supplies as a result of activities such as the draining of wetlands or other recharge areas; the application of toxic chemicals in the form of fertilizers, insecticides, and herbicides; or toxic discharges from industrial operations. Surface water systems and wetlands, like terrestrial ecosystems, have the potential to be affected by all types of identified CE problems. Atmospheric fallout, terrestrial runoff, and groundwater seepage of toxins can influence the quality and quantity of lakes, streams and wetlands.

Estuaries and coastal areas such as bays and inlets are susceptible to CE problems originating from air and land sources. Discharges from municipal sewage systems have the potential to create problems in terms of biological contamination of shellfish species and loss of recreation areas. Major population, centers tend to be located near or on estuaries; thus, these centers provide a number of pollutant sources. As these centers expand, the number, amount, and types of pollutants being discharged into the estuary grow exponentially.

7.2 Some Canadian Case Studies

The purpose of this section is not to catalogue case studies involving cumulative effects exhaustively; rather, by reviewing a few well-documented cases, to illustrate some of the methodological and jurisdictional issues associated with assessing effects of activities that result in cumulative changes to the environment. Overall, there are considerably fewer well-documented Canadian experiences in cumulative effects assessment than for traditional environmental impact assessment. In this section, particular attention is given to situations or issues already described by others.

7.2.1 Case Studies

The four Canadian case studies that follow are abridged versions of the originals presented by Sonntag et al. (1987) and Peterson et al. (1987).

Table 7.2 Ecosystems Affected by Cumulative Affects Problems (*)

CE Problems	ECOSYSTEM AFFECTED		Freshwater			Marine	
	Air	Terrestrial	Groundwater	Surface Water	Wetlands	Estuaries & Coastal	Open Ocean
1. Long-range **trans-**port of air **pollu-**tants and ecosystem acidification	•	•		•	*		
2. Urban/rural air quality **& airshed** saturation	*	•		•	?		
3. **Mobilization** of per-sistent or **bioaccumu-**lated substances		•		•	*	*	•
4. Climatic modifica-tion	*	•		?	?	•	•
5. Occupation of land or water by man-made features		•		*	*	•	•
6. Habitat alienation		*		•	*	•	•
7. Habitat **fragmenta-**tion		*		*	•	•	•
8a. **Decreases** in soil quality		*		•	•		
8b. **Decreases** in soil quantity		*		*	*	*	
9. Effects of use of agricultural, **silvi-**cultural, and horti-cultural chemicals		*		*	*	*	
10a. **Reduction** of groundwater supplies				*	*		
10b. **Groundwater** con-tamination				*	*		
11. **Increased** sedi-ment, chemical **&** thermal loading of freshwater and marine habitats.				*	*		
12. **Accelerating** rates of renewable resource harvesting				•	*		
13. **Long-term** con-tainment **&** disposal of toxic wastes				*	•	*	*
14. **Activities** and developments pro-ducing **carcenogenic-**teratogenic effects	•			*	•	*	*
15. **Loss** of biological diversity				•	*	*	*
16. **Change** in hydro-logical regimes of major rivers/estuaries.				•	*	*	
17. **Loss** in ecosystem stability				•	*		

Additional insights were derived from CEARC (1988) written after the other reports were submitted. The case studies are:

- Fraser River Estuary;
- New Brunswick Forest Management;
- Land-use Practices, Habitat Fragmentation, and Soil Changes in the Prairie Provinces; and
- Leaded Gasoline.

Some major methodological and jurisdictional issues raised by these cases are summarized at the end of the section.

Fraser River Estuary

This case study, reported by Sonntag et al. (1987), is useful for highlighting the role of regional planning in dealing with cumulative effects issues. The emphasis, therefore, is largely on institutional aspects of CEA.

The estuary of the Fraser River in British Columbia is part of a major ecological system, dominated by the Fraser River: that now includes one of Canada's major metropolitan areas. The Fraser River is renowned for its salmon runs, while it also supports the largest population of wintering waterfowl in Canada and is an important stopping point on the Pacific flyway for migrating birds. Human settlement has radically changed the lower Fraser Valley over the last fifty years: dyking channels the river; two-thirds of the original wetlands have been drained: and forests on the valley floor have been replaced by agriculture and urban development. Increasingly, commercial fishing fleets are sharing moorage with international trade and recreational boats, while industrial effluents, sewage, and run-off are discharged throughout the estuary. Such a scenario is almost guaranteed to result in a variety of cumulative effects, issues, and concerns.

From the Fraser case study, it becomes clear that much is known about the cumulative degradation or loss of ecosystems in the Fraser estuary and the factors contributing to this degradation.

Sonntag et al. (1987) discussed the institutional role that regional planning has played in initiating programs designed to control activities that result in cumulative effects, and they traced the evolution of regional planning programs and authorities in the lower Fraser River area. The authors also discussed how EIA helped develop the information base.

One specific example of how impact assessments have helped address cumulative effects in the Fraser estuary involves the proposal in the early 1970's to expand Vancouver International Airport onto Sturgeon Banks. This stimulated public concern for the cumulative consequences of developments in the estuary. As one of the first projects submitted to the federal Environmental Assessment and Review Process Office (EARP), the proposal led to intensive questioning of both the biophysical and socio-economic consequences of the project. It also stimulated similar questions about other developments in the estuary. These concerns resulted in several activities by government authorities. In 1977, the provincial Cabinet approved Order-in-Council 908 (requiring environmental impact assessments for developments outside the dykes), and the federal and provincial governments signed an agreement to undertake the Fraser River Estuary Study (FRES).

The FRES program, still continuing, was initiated to define the estuary management problem, to formulate management strategies, and to evaluate alternative institutional arrangements for ongoing management. While there have been notable successes in this program, it is also clear that major challenges await solutions. For instance, developing institutional responses is still a lengthy process, and ongoing political controversy and lack of political commitment to regional planning make the job more difficult just at a time when cumulative effects issues are becoming more numerous and difficult to predict. Success in dealing with these issues will, according to Sonntag et al. (1987), depend on continuing to learn how to integrate planning and impact assessment techniques and processes to provide a timely basis for action.

New Brunswick Forest Management

This case study, also reported in Sonntag et al. (1987), provides a good example of how poor environmental problem definition can delay the process of seeking and implementing a solution. New Brunswick has the largest proportion of forested land of any province in Canada. Economic development has traditionally involved exploitation of the forest resource to promote local and regional economic growth. Simultaneously, however, undesirable local ecological impacts from harvesting have resulted in regional degradation of the New Brunswick's forest industry.

Although many of the factors contributing to these cumulative effects were in operation since at least the 1950's, resource degradation was not recognized as a significant problem until the early 1970s when local industry began to evaluate why they *were* losing competitiveness in world trade. Simply stated, the problem resulted from the accumulation of consequences of many small-scale interventions by man and natural agents (for example, harvesting and budworm infestations) that occurred over approximately seventy years. The result was not only a product of poor quality (unusable species), but also a projected shortfall in the volume of raw material. Once it was agreed that maintaining the flow of quality material was the real problem, emphasis on designing and implementing long-term corrective measures soon followed (Regier and Baskerville, 1985).

From the description in Sonntag et al. (1987) it is unclear what ecological methods were used to analyze the cumulative effects problem in the New Brunswick forests. The authors, however, provided insights into the institutional mechanisms that were used to deal with the issues, once they were identified.

The projected shortfall in timber supply led the province to commission a forest resources study in 1974 (Province of New Brunswick, 1974). The resulting report advocated establishing a new forest management program and producing comprehensive guidelines for forest resource development. Moreover, new legislation was initiated to bring control of timber licenses under one agency, the Department of Natural Resources. In addition, in 1980, the province passed the Crown Lands and Forests Act to reallocate access to Crown timber (Province of New Brunswick, 1980). This Act has now made it possible for the provincial government to rigorously design and control forest management. The Act also provides incentives for silviculture to improve the wood supply situation. This case study shows that even in a province that demonstrated the ability to react positively and rapidly to a cumulative effects problem, there was still a lag of ten years in applying methods for the purpose of identifying and quantifying the nature and significance of the effects.

Changes in Land-use, Habitat, and Soils in the Prairies

This case study, as described by Peterson et al. (1987), focused on habitat fragmentation and soil changes that result from land use practices determined mainly by thousands of individual land owners. Of all the case studies, this is perhaps the best illustration of the "tyranny of small decisions". This case study has been treated as a CEA feasibility study in Volume II of this Guide (Wallace and Lane, 1988). The area of concern is the zone extending from the Peace River region of northeastern British Columbia across the northern fringe of the prairies to southeastern Manitoba. Along with agricultural areas, this zone also includes the forestry-agriculture interface along its northern and western edges. In this region most ecosystem disturbances are from less intensive land uses. Notable exceptions include urban areas, mining for oil sands and coal, and reservoirs.

The dominant institutional and socio-economic feature of this region is the exceptionally large number of individual farms, many of which are still family operations. Thus, the decision making process controlling land use practices and, hence, habitat fragmentation and soil changes, is highly decentralized. To assess effects of land use practices and agricultural chemical use on any given site is difficult; to evaluate the effects of these practices on a regional basis is even more difficult.

Peterson et al. (1987) discussed the fact that given these circumstances, standard EIA methods are inadequate. They discussed ways in which the problem could possibly be managed, and they suggested that economic incentives, educational and extension programs, and perhaps planning procedures might all be appropriate. Since few of the cumulative effects associated with agricultural practices are perceived as representing a serious or immediate threat to human health, neither public concern nor political will exists to force changes. Furthermore, many of the cumulative changes are difficult to detect. In the absence of data to document these changes, it is difficult for many of the decision makers to realize the need to change current land use practices.

Despite the fact that a wide range of provincial and federal agencies have interests and mandates to help in managing the land and soil resources, there seem to be few attempts to coordinate efforts. Furthermore, examples exist of programs administered by one agency actually helping to cause the effects that another is trying to resolve. Together, all the factors described above help prevent the discovery and application of solutions. Until leadership is forthcoming, it is likely that land use practices will continue to be guided more by economic forces than by the need to conserve land and soil resources.

Leaded Gasoline

In this case study by Peterson et al. (1987), cumulative effects associated with the use of leaded gasoline are examined in light of how the effects were first assessed, and then used in drafting legislation to control use of this product. Leaded gasoline use produces airborne emissions of particulate lead. Not only do these emissions result in elevated lead levels in the atmosphere, but lead concentration levels also increase in water, urban topsoil and dust, and in foods. Since lead is persistent in the environment and accumulates in animal tissues and water and plant cells, the possibility for cumulative effects is obvious. Because of continual exposure directly and through the food web, human lead levels are rising correspondingly.

As Peterson et al. (1987) pointed out, the regulatory actions in this case were initiated only after overwhelming scientific evidence had been collected demonstrating that cumulative effects had already occurred. This delay seems to have been related to the fact that even though scientific evidence linking cumulative doses with human responses was available, economic data played a much larger role in influencing legislation to control leaded fuels.

After studying this case in detail, Peterson et al. (1987) suggested that even though scientific methods may be applied for analyzing a cumulative effects problem, the results will not necessarily be used in efforts to solve the problem. Thus, an important point when evaluating the "effectiveness" of any method designed for assessing cumulative effects is whether the results will be understood, and used, by decision makers.

To deal effectively with problems such as leaded gasoline, all related environmental consequences of an activity will have to be assessed in an integrated, holistic environmental assessment. It seems likely that had such an assessment been done for lead in the 1920's, when anti-knock additives were first proposed, human health concerns would have indicated the unacceptability of discharging this substance into the atmosphere.

7.2.2 Some Conclusions

The four case' studies outlined above offer' insights into both the methodological and jurisdictional concerns associated with cumulative effects problems; these are summarized in the following paragraphs.

Recently, considerable attention has been devoted to the question of what methods and procedures are most appropriate for use in cumulative effects assessments. As the leaded gasoline case study illustrates above, there are reasons to suspect that the availability of appropriate methods or procedures is not the bottleneck preventing CEAs from being undertaken. Nevertheless, more advanced methods are required for use in CEA than in traditional EIA. For example, in cases where cumulative effects are associated with thresholds, methods for identifying and quantifying these thresholds are required. Likewise, difficulties in quantifying the rate and extent of soil degradation and loss are related, in part, to the lack of methods for carrying out such analyses. The paucity of methods for evaluating'the significance of losing part of an estuary, or a forest, or any ecosystem is likely to at least cause difficulty when attempting to assess cumulative effects.

Even if methods, such as those called for above, were available, they would
3 not only have to be used in CEA, but also interpreted by scientists and decision makers. This calls into question the issue of whether the overall framework that has been developed to date is adequate. The question of how to interpret results from CEA is not trivial. If methods used to measure cumulative effects are complex, then the results may be difficult to convey to decision makers. In such cases, it may be difficult to judge whether or not the CEA was worthwhile.

A frequently asked question surrounding cumulative effects issues is: "Who should accept responsibility for carrying out the assessment?" In the case of a typical development project requiring an EIA, it is generally accepted that the proponent will be held responsible for having the assessment prepared. It is much less clear who should carry out the assessment of cumulative effects of. for example, agricultural practices in the prairies or logging in New Brunswick.

Presumably, most, if not all, of our current government and social institutions were created to deal with problems that existed at the time of their creation. As new issues and problems emerged, mandates increasingly began to overlap. While admittedly oversimplistic, this helps explain some of the confusion over who is responsible for dealing with cumulative effects issues. In most cases no one existing institution is responsible for dealing with this issue, and it is often more complex than any one contemporary institution appears able to manage effectively. This is not an insoluble problem but its solution will require some changes in Canada's present assessment process or more likely, in institutional systems.
Since jurisdiction also implies responsibility, and responsibility is at the heart of all cumulative effects problems, who, for instance, is willing and able to take responsibility for evaluating cumulative assaults on the environment? Equally important, who will decide when a threshold has been reached or surpassed, and what to do about it?

Few of the issues that are currently regarded as examples of cumulative effects are truly new. Most have been known for some time under other names such as land use, habitat fragmentation, and soil degradation issues discussed for the prairies. Nearly all of these problems were well known in the 1930s. What prevented action then, as now, was not primarily a lack of understanding, but rather a lack of coordinated efforts to develop and implement solutions. Redesigning some institutions to remove jurisdictional barriers will be an important step toward promoting cooperation and joint problem-solving.

7.3 U.S. Experience In CEA

Since the late 1970's, the U.S. Council on Environmental Quality has included cumulative effects in regulatory policy. The National Environmental Policy Act (NEPA) is usually acknowledged for requiring cumulative impact (CI) assessments even though NEPA does not specifically mention cumulative impact (CI). (Note that cumulative impacts [CI) and effects [CE] are used interchangeably in this Guide although U.S. custom tends toward CI and Canadian custom toward CE). The Council of Environmental Quality has subsequently promulgated regulations that require consideration of CI for implementing the NEPA. In the last ten years, there has been an intensive effort in the U.S. to develop CEA methodologies which have often been applied in a case study format. Several state and federal agencies have been involved in these efforts as well as a number of major proponents. In particular, the U.S. Fish and Wildlife Service at Fort Collins, Colorado, has had a cumulative impacts research team in place for several years. It has been specifically charged with developing a cumulative effects process. In total, the CEA studies in the U.S. have been diverse in terms of philosophy, approach, type of ecosystem and perturbations, methodologies, format, conclusions and recommendations. These very disparate efforts are difficult to summarize succinctly. It is important for the reader, however, to be aware of this diversity and have a general guide to which groups are using which methodologies. With better liaison between U.S. and Canadian assessment efforts, more progress could be made on CEA in both countries. It is clear that careful review of U.S. efforts will provide cost and time savings here in Canada, and we should plan our CEA efforts with enhanced U.S.-Canadian liaison. Several references describe U.S. approaches to CEA and provide a useful context for the methodological techniques listed therein (Cline et al., 1983; Horak et al., 1983a,b).

7.3.1 Current Federal Agency Involvement in CEA

The current status of major federal agency work on cumulative effects in the U.S. is briefly summarized in Table 7.3. Each federal agency and its main CI activites are briefly described below. Individual states and private proponents are also taking an active interest in CEA, but these diverse efforts are difficult to summarize in a short space.

Bonneville Power Administration, USDE

Concern over cumulative effects resulting from hydroelectric projects in the Pacific Northwest has been increasing in recent years. The Northwest Power Planning Council adopted cumulative effects provisions in the Columbia River Basin Fish and Wildlife Program in 1982. In support of those provisions, Bonneville Power Administration (BPA) funded Argonne National Laboratory (ANL) to develop criteria and a method for assessing potential cumulative effects of hydroelectric developments on fish and wildlife (Bain, 1985,b,c). BPA also funded a study to develop and apply methods to evaluate the cumulative effects of twenty proposed small hydro projects on fisheries resources in the Swan River drainage of Montana. Economic as well as fisheries impacts were included in that study (Leathe, 1985).

Army Corps of Engineers, USDOD

The Army Corps of Engineers (ACE) developed procedures for analyzing cumulative impacts at a relatively early date (Dames and Moore, Inc., 1981). This resulted in a comprehensive and detailed handbook that reviewed the legal

Table 7.3 Involvement of U.S. Federal Agencies in Cumulative Impacts (CIs) Assessment

Agency	Major Methods	Case Study or Process	Principle References
Bonneville Power Admin. USDE	Habitat Analysis, Fish Populations, Economics, Hydrology	Swan River Drainage Montana Hydro-electric Development	Leathe et al., 1985
Army Corps Engineers USDOD	General CI Analysis Including Public Interest Review	Draft Handbook of CI methodology	Dames & Moore, Inc. ,1981
Environmental Protection Agency	1) Island Biogeography AEAM 2) Collaborative Ecological Risk Assessment	1) Bottomland Hardwoods 2) Process Development 3) Freshwater Wetlands	1) Gosselink & Lee, 1986 2) Preston & Bedford, 1887
Federal Energy Regulatory Comm USDE USDA	Cluster Impact Assessment Process	Salmon River and Snohomish River Hydroelectric Development	1) Bain et al., 1985a,b,c 2) U.S. FERC EIS.,1987
Forest Service USFS	General Process Framework	General Guidelines	1) USDA, 1981 2) USDA, 1984a,b 3) Salwasser & Samson, 1985
National Park Service USDI	1) CI Problem Solving 2) Least Acceptable Change	1) Glacier National Park 2) Denali & Other Parks 3) Alaska National Park	Raley et al., 1987
Fish and Wildlife Serv. USDI	General CI Problem Solving Process	1) Chesapeake Bay 2) Mobile Bay 3) Great Lakes, UMR 4) Upper Mississippi	1) Williamson et al., 1986 2) Armour et al., 1984

basis for cumulative impact (CI) assessments and describes CI assessment procedures needed to meet CE jurisdictional mandates. This includes physical, chemical and biological changes as well as economic, social and behavioural effects, because the ACE has responsibilities for balancing differences in public interest reviews. Both positive and negative impacts are discussed, as are direct, secondary, indirect, future, aggregating and growth-inducing effects.

ACE has not officially adopted the approaches outlined in the Dames and Moore Draft Handbook, and the Handbook is not generally available. Other documents by ACE (for instance, INTASA Inc., 1981a,b and Horak and Vlachos, 1984) have incorporated many of the recommendations made by Dames and Moore, Inc. The ACE has explicitly addressed CI as part of their extensive regulations for controlling certain activities in waters of the United States.

Environmental Protection Agency

The Environmental Protection Agency (EPA), in cooperation with the FWS, completed three workshops concerning ecological impacts in bottomland hardwoods. Cumulative impact was -not the intended purpose or direction of these workshops, but CI analysis became an important part of understanding the ecological implications of diverse activities occurring throughout large watersheds or river basins (Roelle et al., 1985; 1987). One subgroup argued that there are important levels of analysis (watershed, regional landscape) above the site-specific (local) ecosystem and, furthermore, that emerging scientific understanding of processes is sufficient to formulate regulations at these levels under the general heading of cumulative impacts. A basic approach was briefly outlined for several higher-level functions of bottomland hardwoods, such as maintenance of natural biotic diversity. A general landscape ecology approach to CI in bottomland hardwoods was also described as a result of this project (Gosselink and Lee, 1987).

EPA has a project connected with its Corvallis Environmental Laboratory to develop a sound scientific basis for investigation of cumulative effects on freshwater wetlands. A workshop was held in 1986 involving presentation of papers regarding cumulative effects on wetlands, and the proceedings are forthcoming. EPA is also working with the FWS to develop ecological risk assessment procedures that can be used to estimate biological thresholds. Two workshops have been conducted in this project, and reports are in preparation.

Federal Energy Regulatory Commission, USDE

The Federal Energy Regulatory Commission (FERC) has no specific regulations on cumulative impacts. The FERC can issue preliminary permits, licenses and exemptions on a case-by-case basis with no review of a particular project application in relation to other proposed projects in the same river basin. The Commission has stated, however, that it would honour the recommendations of relevant agencies when certain project impacts cannot be mitigated and residual impacts remain. Some of these involve cumulative effects.

In April, 1985, the FERC developed the cluster impact assessment procedure (CIAP) to evaluate the cumulative effects of multiple hydroelectric projects in river basins. The CIAP was applied to three pilot river basins, including two listed in the next section. The CIAP geographic areas of concern that could have adverse effects on target resources have been identified. FERC's current position is that CI studies are only needed when licensed projects are clustered in a river basin, not when they are dispersed.

Forest Service, USDA

The Forest Service (USFS) issued regulations supplementing NEPA-implementing procedures in 1981 stating that impacts may be direct, indirect or cumulative (USDA, 1981). In 1984, the USFS published a notice of proposed revisions of NEPA-implementing decisions, including a more distinct definition of CI (USDA, 1984a). Teams conducting environmental analysis must have the professional capability to identify and evaluate the potential direct, indirect and cumulative, social, economic, physical and biological effects of proposed actions and alternatives.

Guidelines for implementing cumulative effects analyses were provided in an unpublished report in 1984 (USDA, 1984b). The purpose of the report was to provide a framework of assumptions and principles that should be considered during CI analysis in forest planning. The process is generic, with criteria to be developed, and applied based on individual situations. The cumulative effects task force further elaborated a generalized process for use in forest planning for the American Forestry Society (AFS) (USDA, 1987; Salwasser and Samson, 1985). Process steps include CI description, spatial bounding, threshold descriptions, data collection, effect prediction, mitigation determination, and monitoring.

National Park Service, USDI

The National Park Service (NPS) 'develops master plans for each of the units under its jurisdiction. Unlike the Fish and Wildlife Service, NPS has strong jurisdictional authority over the natural resources it is responsible for protecting. CI studies on Glacier National Park in 1986 and Denali National Park in 1987 grew out of management planning activities. The NPS is currently developing a CI process based on limits to acceptable change (LAC) for trial use in Denali and other Alaska park units. These studies are briefly discussed in the next section.

U.S. Fish and Wildlife Service, USDI

The U.S. Fish and Wildlife Service (FWS) in 1982 funded a project entitled, "Methods for Determining Cumulative Effects of Coal Activities on Fish and Wildlife Resources". The overall goal of the study was to identify and summarize the state-of-the-art of biological assessment and monitor the cumulative effects of development on fish and wildlife populations and habitats. Three documents were developed and first reviewed by an interdisciplinary working group and later by attendees at a national workshop and a technical review session, both held in July, 1982.

The first document, "Fish and Wildlife and Cumulative Effects: Is There a Problem?" (Horak et al., 1983a), was developed primarily for policymakers and the public. It emphasized a non-technical discussion of the general cumulative impacts issue. A classification system was proposed to represent the broad range of cumulative impacts. Fish and wildlife may be affected by many projects of the same type, individual projects involving different types of activity, or the combined effects of two or more actions on various wildlife habitats and species.

The assessment of project impacts is viewed as part of a larger process for tracing the effects of change on biological, physical and social environments. Recommendations to improve CI assessments therefore emphasize the importance of cooperation among agencies and industries. Government agencies must become more familiar with the motivations and actions that industries follow in pursuit of their economic development objectives. In general, decision makers need to understand the goals, mandates and methods of other organizations if CIs are to be managed more effectively. It is further recommended that approaches which allow for a range of possible outcomes leading to decision making be examined through case studies, workshops or national conferences. Field biologists need training in the broader institutional setting of CI issues including terms, characteristics and methods for assessing cumulative impacts. Basic research on specific ecological functions and processes, and alternative institutional mechanisms was also recommended.

The second document, "Methodological Guidance for Assessing Cumulative Impacts on Fish and Wildlife" (Horak et al., 1983b), provided interim guidance for field biologists who must assess cumulative impacts. It focused on methods then available with potential utility in CI assessment.

A cumulative impacts research and development project was initiated in 1984 at the National Ecology Center (NEC) which is part of the USFWS in Fort Collins. The CI project was designed to follow some of the important recommendations made in the Horak et al. (1983a,b) work. In particular, a collaborative problem solving (CPS) approach is being used to develop cause and effect analyses to narrow the problem and establish causal pathways for more intensive research and management decisions. Collaboration vertically within organizations, among relevant disciplines and among institutions is stressed throughout the CI project. This can best be accomplished through interactive workshops conducted periodically through the design, development and implementation phases of the project.

The emerging FWS/NEC CI process is based on general problem solving approaches such as those described by the National Research Council Committee on the Application of Ecological Theory to Environmental Problems (1986). Familiar steps of problem definition, analysis, consideration of alternatives, and monitoring are used by project-specific work groups to organize a CI assessment. Flexibility in choosing specific approaches is essential because of highly variable legal, institutional and budgetary constraints. The approach is summarized in Table '7.4.

7.3.2 Case Studies

Table 7.5 lists case studies and projects which the cumulative impact project team of the U.S. Fish and Wildlife Service/National Ecology Center

Table 7.4 Collaborative Problem Solving Process (CPS)
(R. Johnson, pers. comm., FWS, Fort Collins, CO)

STEPS

1) Identify the Problem:
- o Conduct CPS workshops to:
  - identify the problem
  - establish preliminary cause and effects
  - bound time, space and concepts
  - match legal institutional and regulatory entities (LIR)

2) Develop Conceptual Hypothesis:
- o Determine CI classification
- o Determine methods or models
- o Conduct CPS workshop to:
  - finalize cause/effect understanding
  - design empirical analysis
  - assign work

3) Analyze Problem (test hypothesis):
- o Review literature and collect data
  - resource inventory, status and trends
  - LIR and socioeconomic considerations
- o Build and execute models and methods

4) State Results and Conclusions:
- 0 State results of empirical analysis
- o Relate and predict consequences for:
  - environmental management objective
  - LIR and socioeconomic policy implications

5) Make Recommendations and Process Revisions:
- o Evaluate study and results
- o Recommend use of study results
- o Recommend future work
  - technical methods
  - LIR and socio-economic considerations
- o Design monitoring and feedback evaluation system.

participated in or observed. It should only be viewed as representative of U.S. work in CEA, not an exhaustive list. We briefly elaborate on these studies in this section.

FWS/NEC CI Project

A collaborative problem solving (CPS) process is being used to develop and implement a cumulative impact assessment process for FWS/NEC. A brief description of recent FWS involvement in CI assessment, and the description of the CI process were provided in the previous section. We list that project again here in order to illustrate the breadth of applications addressed by the CI process, and to describe how various methods were used. Whereas in the previous section we described a specific CI assessment, in this one we discuss how the CI process is being developed.

Initially, traditional literature review procedures were employed. The FWS documents produced by Horack et al. (1983a,b) were the most useful references. Some conceptual underpinnings achieved in that study allowed for a temporary by-pass around definitions and typologies to provide recommendations for future work. An adaptive and cooperative approach utilizing more than one technique, heavily conditioned by institutional realities, was incorporated into the design of the FWS/NEC CI project. The Horack et al. (1983a,b) studies also provided justification for involving representatives of several organizational levels within the FWS, various scientific disciplines and diverse institutional interests in designing the project. The NEC director (then Leader of the Western Energy and Land Use Team, which NEC replaced), the Director of the Division of Biological Services, and the Director of Ecological Services were active in technical as well as management and administrative decisions all within FWS. All three of these leaders participated in a three-day CI project scoping meeting and attended a field supervisor's conference where CI was selected for discussion as a high priority issue in the FWS. This support by high level officials provided managerial expertise and policy relevant to the study design, contributed technical expertise, and legitimized the enthusiastic participation of others in the project.

Field biologists, field office supervisors and relevant regional office representatives also participated in these early meetings. Their participation contributed essential technical and pragmatic institutional expertise, began a training function and enhanced implementation opportunities through case studies. The general CI project was designed during these early meetings (Williamson et al., 1985).

Several methods used during problem identification and scoping for the CI project were later used in case studies and will be included in the menu of methods for various tasks in the general CI process. In particular, nominal group techniques (Delbecq et al., 1975) and cause/effect analysis (Armour et al., 1985; Williamson et al., 1986) have become valuable tools in cumulative problem solving-process (CPS).

Analysis in the CPS approach is dominated by the use of a case studies. These case studies may be viewed as addressing the implicit hypothesis that a CPS

Table 7.5 Case Studies and Projects which the Cumulative Impact Project Team of the U.S. Fish and Wildlife Service/National Ecology Centre have Participated in or Observed.

Case Studies and Projects	Type and Purpose	Institutional Jurisdiction	Scoping Method
FWS/NEC CI Project	-Process Development	-FWS -other agencies -science	-CI Process -cause/effect -nominal group technique
Ohio, Tennessee Cumberland Rivers	-Barge Traffic	-CI: -FWS, states, & other agencies	-Cause/effect
Bottomland Hardwoods	-Regulatory Policy -Process devel.	-EPA: CI, FWS, states, other agencies	-AEAM scoping meeting
Snohomish River	-Low-head hydros and -process devel.	-FERC FWS,NMFS,Tribes state & other	-FERC's CIAP
Salmon River	-Low-head hydro & process development	-FERC: FWS,NMFS,Tribes State & other	-FERC's CIAP
Chesapeake Bay	-Bay recovery plan	-EPA - FWS -private, state federal agencies	-CI process -cause/effect -nominal group technique
Mobile Bay	-Bay recovery	-CI: FWS -States, local	-cause/effect
Upper Mississippi River	-recreation Plan -barge traffic	-CI: FWS -UMR Basin Comm. inc. state & fed. agencies	-collaborative workshops
Ecological Risk Project	-process devel. -thresholds and	-EPA: FWS -Universities	-interagency meetings and

Table 7.5 (cont'd.)

Case Studies and Projects	Type and Purpose	Institutional Jurisdiction	Scoping Method
Great Lakes	-international resource project and planning	-FWS: -GLS coord. comm. included	-CI process
Glacier Park	-park master plan	-NPS -FWS -other agencies	-interagency meetings & correspondence
North Slope Alaska	-energy devel. -regulation	-FWS: USDI -State of Alaska -Oil firms -Public	-interagency meetings -cause/effect
National Parks, Alaska	-placer mining -process devel.	-NPS: EPA -FWS, state of Alaska	-interagency meetings and correspondence

approach, utilizing real world learning experience, can most easily lead to an effective CI assessment process (Table 7.4). The case studies (listed in Tables 7.3 and 7.5) are briefly discussed as observations or experiments in support of that implied assumption.

Ohio Tennessee and Cumberland Rivers

The Ohio, Tennessee and Cumberland Rivers (OTCR) case study was a very short-term project for the FWS/NEC CI project (CIP) team. The FWS Field Office in Cookville, Tennessee, prepared comments on CI permits regarding barge traffic on OTCR. The CIP team spent a total of two man-weeks assisting the field offices in developing and presenting a cursory cause/effect (C/E) analysis (only about two days were spent in actual C/E modeling). Most of the coordination for the work was accomplished by telephone and by mailing documents. Two CIP Team members from NEC attended an inter-agency working meeting in Cookville to provide briefings on the C/E model and learn more about the CI problem (Figure 7.1).

Information available from the C/E model was sufficient to meet the needs of ACE and the FWS field office in determining principal resources of concern, relevant perturbations and causal pathways. Collaboration between two field offices of the FWS was enhanced by the CI assessment. The major contribution of this project to the development of a general CI process was the successful use of C/E analysis over the short time frame and modestly funded project. The C/E model did not provide quantitative answers to detailed questions, but it did provide a mechanism for consensus between agencies about important variables to work with, and a framework for tracking potential effects of barge traffic on fish and wildlife resources.

Bottomland Hardwoods

The Bottomland Hardwoods (BLH) case study was completed with NEC facilitated modeling workshops through an inter-agency agreement between the FWS and ERA. The initial thrust of the study was toward agency policy development, not to develop CI processes or to assess CI. One member of the FWS/NEC cumulative impacts project team, however, was involved in the project, and CI assessment became a major issue during the course of the study. A scoping meeting and three workshops were managed by a modified adaptive environmental assessment and management (AEAM) process (Holling et al., 1978a,b). Simulation models were not constructed, but the general AEAM facilitated workshop approach was utilized to develop word models and data compilation regarding the functions and attributes, of bottomland hardwoods and 'the likely environmental implications of alternative BLH development actions.

A subgroup, established to consider CIs and methods to assess them, concluded that incremental analysis of site-specific development activities could not be accomplished effectively with the existing institutional-jurisdictional framework. Moreover, mechanisms for establishing ecological objectives for spatial areas that reflect cumulative effects were not available. One recommendation growing out of this work was that landscape ecology and island biogeography be used to assess CI (Gosselink and Lee, 1987).

This case study exhibited good collaboration within relevant units of EPA and between resource enhancement agencies. Representatives of permitting agencies and resource development interests were included in the workshops. Economists were invited to one of the workshops in an attempt to seek interdisciplinary strength for evaluating, identifying, and describing, important functions identified in the Bottomland Hardwood Case Study (Gosselink and Lee, 1987). The most important contribution of the BLH study to CI process development was the determination that although ecological goals are essential, they frequently are not available at scales that match CI problems. The description of landscape ecology and how it might be used in CI assessment is an important advancement.

Snohomish River and Salmon River

The Federal Energy Regulatory Commission (FERC) conducted two separate cumulative impact assessments as part of the NEPA-required regulatory compliance for licensing small hydroelectric projects. These studies were located in the Snohomish River Basin in Washington and the Salmon River Basin of Idaho where multiple hydroelectric projects were proposed.

The scoping meetings for each project followed the scoping process outlined in FERC's clustered impact assessment procedure (CIAP), which consisted of several interactive meetings between the study participants and federal and state natural resource agencies to develop the study scope, gather information, and evaluate the assessment methodology. The actual assessment of impact was carried out using a variant of the Argonne multiple matrix methodology (Bain et al., 1985a,b,c), developed by Argonne National Laboratory (ANL) who participated in the study with FERC.

The matrix-based approach was designed to accumulate impacts from the assessment of single-project effects. Target resources, such as fish or wildlife species, were identified and for each target resource, a number of resource components were identified which would be important to the target resource. For the Salmon River and Snohomish River studies, the impact of each project on each target resource component was assessed in terms of a numberical criterion. Assessments for all projects for a single resource component formed a matrix vector. A project by project matrix was then formed, in which were placed elements expressing whether the impacts of each possible pair of projects could interact in a nonlinear way. This matrix was called the interaction matrix; and, when the interaction matrix was multiplied by the vector of project impacts the cumulative impact of all projects on a resource component was estimated. Adding the cumulative impacts for all resource components for a single target resource resulted in an assessment of the cumulative impact of all projects on the target resource. Ecosystem effects, such as the relationship between eagles and salmon were entered into the analysis at the resource component level, salmon being a resource component for eagles.

The results of the cumulative effects assessments were used in the decision making process after examining the cumulative effects of all possible combinations of projects on each target resource. Since cumulative effects assessment de-emphasizes the significant single-project effects, project combinations in which highly significant single-project effects were present were flagged for special consideration. Project combinations which either were flagged or had high cumulative effects on any target resource were eliminated from consideration as a licensing scenario. The studies resulted in recommendations to the FERC commissioners for alternative licensing scenarios, and final EISs have been issued.

Collaboration of natural resource agencies in the cumulative assessment process was sought, but success was limited. The scoping and licensing process was generally unresponsive to agency concerns and review comments. Since new information regarding the projects could not be sought due to the time frame in which a decision was to be made, impacts were expressed in non-quantitative terms. This was unacceptable to several resource agencies. The use of evaluative criteria was very problematic and did not satisfy those agencies requesting impact quantification or those agencies opposed to impact quantification.. Whereas FERC took a large and new step toward collaboration and the assessment of cumulative impacts, the urgency and visibility of the study, and the importance of the resource under study, made collaboration and testing of the methodology very difficult.

Chesapeake Bay

The Annapolis, Maryland, Field Office of the U.S. Fish and Wildlife Service (FWS) is conducting a CI assessment in connection with the Chesapeake Bay Restoration Plan. The general motivation for FWS involvement in this work was observed declines in waterfowl and fish populations in the Bay.

Many agencies are involved in this project. EPA has a primary role and has been emphasizing water quality in the Bay. The FWS is persuing an emphasis on living resources with the FWS/NEC CI problem-solving process. Two collaborative workshops have been conducted to define problems, identify important cause/effect relationships and develop action plans. Submerged aquatic vegetation is one of the key variables being addressed as a consequence of the cause/effect analyses. Attempts to enter the CI issue from a general problem statement, such as declining or unacceptable water quality, proved unsatifactory in this case study. Even as issues were narrowed from that point through cause/effect analysis, there was no clear progression toward species populations, habitats or geographical units that could be meaningfully investigated. When the Bay restoration issue was entered from a wildlife species and habitat approach, causes and consequences led more quickly to specific problems and remedial actions.

The FWS/NEC approach has not yet been accepted by a six agency organization working on the Bay Restoration Plan. This may be attributed to the lack of involvement of other agencies in designing the CI assessment. Other agencies and institutions have their own goals and mandates, and until a CI assessment fits those needs it will not likely be used. Agencies, including the FWS, are reluctant to adopt CI procedures because of uncertainties regarding precedent setting consequences of methods and decisions, lack of confidence in the methods used, and acceptability by Congress and other constituencies of the results of CI assessments.

Mobile Bay

Multiple impacts to wildlife have occurred over large temporal and spatial scales in Mobile Bay, Alabama. For example, a 40' deep and 400' wide navigation channel requires dredging maintenence now and may be expanded to 50' by 550' in the future. Part of the Bay would be filled with dredge material from the expansion project. Chemical contamination, and development of the Bay for industrial and urban uses also continue to contribute toward fish and wildlife habitat degradation and population reduction. The first objective of an FWS/NEC cumulative impact study in Mobile Bay was to improve the documentation of these continuing wildlife impacts through more careful trend analysis and CI assessment procedures. Strong institutional objectives and jurisdictions for protection of natural habitats are currently missing for Mobile Bay. A second objective therefore was to establish a forum where objectives for the Bay could be articulated and followed up. A research plan leading toward pragmatic decision making was also considered a requirement. Accomplishment of these two objectives could lead to an overall plan for resource enhancement for the Bay area.

A scoping meeting and a cause/effect workshop have been conducted by FWS/NEC. The cause/effect (C/E) model developed during the workshop emphasizes changes in Bay geometry, turbidity, contaminants and loss of submerged aquatic vegetation as key problem areas for fish and wildlife resources. Data to specify the C/E model more quantitatively are currently being developed. The objectives of subsequent workshops were to improve the C/E models and enhance interagency cooperation. Lessons so far include a recognition that CI assessment requires a new mindset that is difficult to acquire and maintain. Long and sometimes inefficient discussions are frustrating, but may be necessary when learning to use flexible problem-solving procedures to address complex problems. There are data shortfalls that are likely to persist, and analytical procedures are constrained by available information. Collaboration with other institutions and agencies is imperative but the lack of preconceived directions and perceived uncertainty of people who are trying to guide the CI assessment procedure may hinder broad and enthusiastic involvement of other interests. Stronger commitments to the CI process from all interested institutions is needed.

Upper Mississippi River Recreation Economics Study

The Upper Mississippi River Basin Commission (UMRBC) is comprised of five states and several federal agencies. The UMRBC recommended to congress that a Recreation Economic Study (RES) be conducted to estimate the value (economic benefits) and economic impact of recreation on the Upper Mississippi River. A long history of interaction between concerned organizations has established well-developed institutions including the UMRBC and the Upper Mississippi River Conservation Committee (UMRCC). This latter organization and the five states involved have strong preferences for emphasizing the economic impact elements of the RES established by Congress. Traditional CI cost/benefit studies do not emphasize economic impacts, however, and an impasse had developed regarding how the RES should be conducted. NEC/FWS joined a cooperative agreement with a ACE (St. Paul District) to develop a Plan of Study (POS) to guide the RES. Development of the POS was viewed as a CI project because of obvious CI elements connected with use of the Upper Mississippi River. For example, development of recreation facilities such as boat docks and water access may affect fish and wildlife resources as well as local and regional economies. Alternative uses of the river such as increased barge traffic, resulting from enlargement of locks and deepening of channels, would also have both economic and ecological implications. Impacts from such development activities could accumulate in either simply additive or highly interactive (synergistic) ways, and along numerous biological and institutional pathways.

A collaborative workshop was conducted by the CI project team of FWS/NEC. Economists, administrators, ecologists, and recreation planners representing state, federal, and regional institutions reached agreement on the relative importance of economic impact analysis and economic benefits, and made specific recommendations about which of several alternative economic analysis methods and data bases should be used in the RES. The results of that meeting led directly to a plan of study (POS) that has been accepted by the necessary parties and has begun to be implemented. The most significant reasons for that success are that a common starting ground had previously been established by the Congressional Act requiring an RES; the appropriate people attended the collaborative workshops, including disciplinary specialists (economists, recreation planners, and ecologists) who could resolve differences of substance or misunderstandings: and the format of the workshop had as its central method a clear, objective articulation of' the issues and achievement of consensus.

This case study also provides a good example of needed collaboration between various operational elements of the same organization or institution. For example, river activities that enhance recreation values may serve general natural resource enhancement purposes well, but some of those same activities are not neutral to the enhancement or preservation purposes of some specific fish and wildlife species. More positively, however, it was also concluded that the ,'activities of traditionally development-oriented agencies and organizations can be carried out to develop recreation resources and enhance wildlife as well as to improve barge traffic. This case includes a lesson that economic analysis may not always be hostile to ecological objectives, and in fact may at times justify natural resource enhancing objectives. Similarly, this case opens the issue that it is not just ecological impacts that can accumulate; the economic and social implications of alternative actions and policies may accumulate as well. Sometimes these non-ecological impacts will be an important part of cumulative impact assessment processes.

Ecological Risk Assessment

The Ecological Risk Assessment (ERA) Project is an interagency agreement between the FWS/NEC and the Office of Toxic Substances (OTS) of the Environmental Protection Agency (EPA). EPA is the major funder of the project, and is directing the project toward the development of pragmatic methods for use in reviewing new chemical compounds that are proposed for production and use. FWS interest in the work is primarily motivated by several CI studies suggesting that environmental or biological thresholds are needed before CI can be addressed. This is especially important when neither clear regulatory jurisdiction or societal objectives are available for the scale at which serious CIs are operating. In those cases, ERA might be used to estimate the probability that given target resources will decline beyond some (alternative) level as a result of proposed actions. Trade-offs between project benefits and the probability of negative environmental consequences may then be negotiated more honestly. When objectives are known, but dose-response functions are not, ERA may be used to estimate the probability that the goal will be precluded as a consequence of proposed actions.

A ecological risk assessment (ERA) colloquium was conducted in November, 1986 to design ERA procedures for OTS. Target resources used in regulatory processes are normally high level carnivores or economically important species, but many of the consequences of resource development or chemical production activities occur at much lower trophic levels. A principal objective of the colloquium therefore was to integrate models that are meant to explain cause and effect relationships at several biological levels. Three computer models were linked together to estimate the probability that a chosen species population would decline beyond some target level as a consequence of exposure to various concentrations of a chemical compound. A unique procedure termed the optional risk procedure (ORP) was also developed to aid decision makers in choosing which chemicals to study in greater detail.

Collaboration in this project was good between the FWS and EPA and the colloquium also included involvement of the regulated chemical industry. The most valuable interaction, however, was between OTS regulatory scientists who insured pragmatic utility in colloquium recommendations, and other scientists who used existing computer models to improve the regulatory decisions made in OTS. A conceptual paradigm was also developed that will improve the ecological models and decision support systems available at the colloquium. A follow-up workshop was held to incorporate the results of recommended research and development efforts completed since the colloquium. The optional risk procedures were improved during a subsequent meeting.

The major contribution of the ERA project to CI assessment was the development of a procedure for estimating thresholds and for observing how the consequences of perturbations approach those thresholds. The development of simplified graphics techniques in the ERA project will also be useful for making trade-offs and negotiating compromises in CI assessments. An ancillary contribution of the ERA project was to demonstrate that the collaborative problem solving approach being used to develop a CI process is achieving some success in developing ecological risk assessment procedures.

Fish and Wildlife Service CI Projects in Alaska

The U.S. Fish and Wildlife Service is developing a guidance manual for predicting and evaluating the impacts of proposed oil and gas developments on the North Slope of Alaska. A CI assessment was conducted as part of that project. It was found that inadequate coordination and planning between developers and insufficient guidelines from appropriate federal and state agencies made CI assessment difficult. The manual documents that secondary physical impacts, as indicated by increased thermokarst, are occurring at Prudhoe Bay. These impacts can be related to the primary direct impacts of road, pad and facility construction. In addition there are cumulative impacts of oil development on shorebirds at Prudhoe Bay. It was found that the density of breeding shorebird populations is affected by the density of oil field facilities.

Further development of Alaskan oil is anticipated, and FWS may apply the FWS/NEC CI process to those case studies in the future. The Alaskan oil development cases provide an opportunity to study CI from one type of development on a well-defined spatial scale and on relatively undisturbed fish and wildlife resources. The Prudhoe Bay study has already demonstrated how secondary effects can be managed in a CI assessment.

Great Lakes

Roughly half of all coal used to produce electricity in the U.S. is burned in the Great Lakes area, and half of the toxic waste sites identified so far by the Superfund are located there. It is believed' that the use of approximately 900 chemicals and heavy metals has led to reductions in wildlife populations. A CI study being initiated by the FWS/NEC project is addressing a small subset of Great Lakes problems over a restricted spatial scale. An initial FWS scoping meeting narrowed the scope of the study to the St. Clair and Detroit waterways. It is expected that the scope of work will be expanded if this initial project is successful.

Most of the fish and wildlife resource agencies of Michigan and Ontario will be involved in future meetings and workshops. An existing geographic information system (GIS), called the Great Lakes Information Management System (GLIMS), will be modified and converted from a mainframe to a microcomputer format. GIS data and other existing information from state, federal and regional institutions will also be utilized. Agreement will be sought regarding observed wildlife population decline, major causal pathways for those reductions, and feasible remedies. Quantitative proportions or numerical coefficents for cause/effect relationships have not been attempted.

Institutional mechanisms for making decisions and implementing actions seem available for many previous Great Lakes issues, and consensus developed through collaborative problem solving may be adequate for bringing about required changes in resource management, development and restoration policies. The Great Lakes CI study can contribute to general CI assessment knowledge by investigating the implicit hypothesis that a rich history of complex problems has led, through improved technical understanding, to the development of institutions capable of making broad scope decisions in a relatively short time. Investigating this hypothesis, through the Great Lakes CI study, can identify the adjustment mechanisms of institutions as they change to match complex problems that supercede common institutional jurisdictions. Research, development and policy can emphasize enhanced technical understanding with the expectation that appropriate institutional adjustments will follow. In that scenario, studies to illuminate how institutional capabilities and remedies evolved in the Great Lakes should be undertaken so that other interstate and international problems can benefit from that experience.

If no institutional mechanisms are found to design and implement solutions to CI problems in the Great Lakes, then an R&D emphasis should be directed toward careful studies of institutions and how they may be directly influenced toward more authority and accountability for problems and solutions beyond any current agency jurisdiction.

Glacier National Park

Fifty-six external threats to the ecology of Glacier National Park were identified in 1980. The North Fork Basin of the Flathead River was identified as being particularly sensitive to external land use activities. A problem analysis technique patterned after the FWS/NEC CI process was used to evaluate the cumulative effects of external activities on resources within this region of the Park (Raley et al., 1987).

A cause and effect (C/E) analysis was conducted during a three-day workshop held at Glacier National Park. A problem statement representing the environmental issues was identified, cause and effect. relationships were determined, and tasks to prevent or remedy the problem were defined. The C/E analysis allowed participants to take an unrestrained view of the situation, and models were able to address simultaneously many resources and concerns. This was viewed favourably by the National Park Service (NPS) analysts, because the North Fork Basin represented ecosystem-level problems that needed to be addressed.

The C/E analysis was judged by the NPS as being appropriate and useful for potential or chronic problem analysis, but perhaps too cumbersome for short-term analysis of acute and urgent problems. When problems arise requiring immediate action there may not be sufficient time to contact the necessary experts and arrange a meeting for collaborative problem solving.

The Glacier National Park study provides an example of CI assessment when agency goals are well established through a management plan, and single-agency jurisdiction is paramount.

Alaska National Parks

The NPS is developing a process to assess cumulative impacts of placer mining for gold in three NPS units in Alaska. These CI processes are needed in support of environmental impact statements, mineral management plans and park master plans. The NPS is in the very early stages of process development, and is currently investigating a modified version of the LAC process. No indexing or weighting of resources or impacts would be attempted, and explicit interactions between mining developments would be ignored. This process relies on avoidance of long-term impacts beyond LAC levels from any individual project, thereby frustrating measurement of the accumulation of negative impacts in excess of threshold levels. The LAC process is in the early stages of development, and decisions about its characteristics and implementation are pending.

8.0 APPENDIX ON CEA METHODOLOGIES

8.1 Annotated List of Potential CEA Methodologies

The following sections provide: (1) a brief description of nine methods for environmental impact assessment, (2) comments on the potential usefulness of each method type for cumulative effects assessment (CEA), and (3) a conceptual outline of the major steps involved in using each of the methods suitable for CEA.

Of the nine techniques for environmental impact assessment, the first eight were identified by Shopley and Fuggle (1984). The nine analytical methods are:

1) ad hoc,

2) checklists,

3) matrices,

4) networks,

5) mapping and overlays,

6) modeling,

7) weighting/evaluative methods,

8) adaptive procedures, and

9) biogeographic theory.

1. Ad Hoc

Overview

In this classification, ad hoc refers to those methods that rely primarily on expert judgement and do not structure the problem to make it amenable to systematic analysis. Included in this classification are guidelines that suggest possible impacts without recommending specific means for their measurement or evaluation. Another type of ad hoc analysis, "pure" expert judgement, is characterized by a process of assessment that cannot be replicated. Each expert's conclusions are based on a unique combination of experience, training and intuition. In some assessments this is the only required or possible approach. In other instances, when more scientific methods are available, it is not sufficient to rely on ad hoc methods.

Detailed Review

Commonly, ad hoc methods are not applicable outside of their originating agencies, and many other environmental impact assessment methods were developed due to dissatisfaction with these methods. Because ad hoc methods are considered inappropriate for most environmental assessments, it is unlikely that they will be applicable to the compounded difficulties associated with cumulative impact assessment. However, ad hoc methods can be useful for helping to organize information prior to applying other methods.

Ad hoc methods have been used to evaluate energy projects in California, Colorado, and Maryland as well as offshore oil and gas development. Because the stages associated with these methods vary greatly, no attempt was made to set forth an outline of the major steps.

2. **Checklists**

Overview

Checklists are standard lists of potential impacts associated with a particular type of project. Checklist methods are primarily for organizing information or ensuring no potential impact is overlooked. In one sense, checklists are a more formalized version of ad hoc approaches in that specific areas of impact are listed and instructions are supplied for impact identification and evaluation. More sophisticated checklists (Canter, 1977) include scaling checklists, in which the listed impacts are ranked in order of magnitude or severity, and weighting scaling checklists. In weighting scaling checklists numerous environmental parameters are weighted using the expert's judgement, and then an index is calculated to compare project alternatives (Stover, 1972).

Westman (1985) lists some of the problems with checklists when they are used as an impact assessment method: (1) they are too general or incomplete; (2) they do not illustrate interactions between effects; (3) the number of categories to be reviewed can be immense, thus distracting from the most significant impacts; and (4) the identification of effects is qualitative and subjective. Checklists make no attempt to assess impacts. Because of these limitations for environmental assessment, checklists are not likely to be very effective for cumulative impact assessment.

Detailed Review

For the most part, checklist methods offer little potential for cumulative impact assessment; nevertheless, they are useful for helping to organize information prior to applying other methods.

3. **Mapping and Overlays**

Overview

Shopley and Fuggle (1984) credit McHarg (1969) with original development of map overlays, although this method has also been used extensively by others (Lewis, 1976). An overlay is based on a set of transparent maps, each of which represents the spatial distribution of one environmental parameter such as susceptibility to erosion. Overlays are the fastest way to identify zones which have all of a given set of variables. To investigate the degree of associated impacts, any number of project alternatives can be located on the final map. The validity of the analysis is related to the type and number of parameters chosen. For a readable composite map, the number of parameters in a transparency overlay is limited to about ten.

These methods are used in at least two ways in cumulative impact assessment. One way is to use before and after maps to give a visual assessment of changes to the landscape. The other way is to combine mapping with an analysis of sensitive areas or ecological carrying capacity. When used in the latter manner, constraints on the level of development are set on the basis of limits determined by the location of sensitive areas and by assessments of carrying capacity. These methods are spatially oriented and are capable of clearly communicating the spatial aspects of cumulative impacts.

The limitations of mapping and overlay methods relate to lack of causal explanation of impact pathways and inability to predict population effects. As well, these methods are unable to deal with large numbers of variables and cannot differentially weigh the relative significance of different variables. However, some sophisticated versions can make predictions about potential habitat loss.

Geographic information systems (GIS) are an extension of the mapping/overlay concept using computer technology. GIS may also be linked with computer models.

Detailed Review

We evaluated three methods based on mapping or overlay techniques. In all cases mapping was combined with some other method for determining environmental sensitivity or carrying capacity for a given spatial area. Based on this information, limits were placed on the scale and type of development.

In developing the analysis in support of a general permit for the lower Colorado River, the U.S. Army Corps of Engineers, Los Angeles District (1982), conducted mapping and an inventory of environmental and cultural resources in each of a number of river segments. The resources considered included: water quality, aquatic biological resources, terrestrial and wetland resources, cultural resources, land use, demographic and socio-economic considerations, and recreation and public safety. Proposed general permit areas are delineated on the basis of calculated resource sensitivities/impact relationships over the entire river.

This method only partially satisfies the problem definition criterion. The main drawback is the lack of explicit consideration of the causal basis for cumulative impacts. While not a predictive tool, nor a tool for explicit aggregation of cumulative impacts, this method does consider and define thresholds for development in each of the river segments. The production of an atlas containing maps of environmental and cultural resources and designated development areas clearly aids in communicating results. Depending on the level of resolution required, information is relatively easily obtained: however, some river segments will have better information than others. If extensive resource inventories are required, or a detailed Geographic information system is necessary, this method would likely become costly. Regulatory agencies that normally participate in the review of permits may suggest that general permits do not ensure adequate protection from cumulative impacts.

Winn and Barber (1985) looked at the cumulative impacts on grizzly bears by linking a computer simulation model with a geographic information system. The geographic information allows production of computerized maps of grizzly bear habitat and concentrations of grizzly bears. By superimposing road and campsite developments, changes in the amount of habitat could be calculated. Habitat changes were then used to estimate impacts on grizzly bears. While this application is simplistic, linking mapping techniques to computer simulation modeling techniques may be applicable in a large number of cases.

This method has been used to assist in habitat management for grizzly bears in several U.S. federally managed areas including the greater Yellowstone ecosystem and the Shoshone National Forest. To use the method as described by the authors, it is necessary to have detailed geographic information on vegetation and locations of grizzly bear activity, as well as "displacement coefficients". Displacement coefficients refer to the degree to which a particular activity will result in avoidance behaviour on the part of grizzly bears.

This method only partially satisfies the criterion for defining cumulative impacts since it fails to explicitly consider the causal basis for cumulative impacts. This is partly due to the nature of the application described. This method also fails to satisfy the criterion as an assessment tool. However, the discussion of the method and the proposal to link a geographic information system with a computer simulation is of interest. The results are relatively easy to communicate. The method can be costly if computer needs for the geographic information system and the simulation models are great.

Dickert and Tuttle (1985) used information collected in field studies to determine sensitivity to erosion, relative effects of different types of land disturbance, and a "land disturbance target" to assess cumulative impacts in Elkhorn Slough, California. Target values were based on the amount of land available in low erosion zones or on maintaining sedimentation rates at long-term averages. Future projects will be evaluated based on whether they violate the defined targets. The analytical work supporting the method consisted of four components: hydrological assessment of runoff and sediment transport, field measurements of erosion and deposition resulting from various land uses throughout the basin, photogrammetric analysis of upland and wetland change spanning a fifty-year period, and measurement of site disturbance associated with dominant land use.

Dickert and Tuttle's method is designed to deal with cumulative effects problems in coastal wetlands. Although their case study involved work done at Elkhorn Slough, California, the authors suggest this method would be applicable to problems involving wildlife habitat, agricultural land conversion, visual quality, and geologic hazards. This method requires that the cumulative effect problem be visible on aerial photographs, and that a significant length of record be available.

Of the mapping methods, this method appears to be better at defining the causal basis for cumulative impacts, although there is limited consideration of the biological impacts. It explicitly considers thresholds and integrates impacts over space and time. It appears to be easy to communicate, especially through the use of aerial photographs. Obtaining a time series of aerial photographs may be costly or impossible, however.

4. Matrices

Overview

In this classification, we consider interaction matrices. An early example of this method is the Leopold matrix (Leopold et al., 1971). In a Leopold matrix, and its variants, the rows of the matrix correspond to project actions (for instance, flow alteration) while the columns represent environmental conditions (for example, water temperature). The impact associated with the action row and the environmental condition column is described in terms of its magnitude and significance. The Leopold matrix represented the first attempt to systematically relate project actions to changes in environmental conditions.

Leopold-type matrices have been criticized because they are only appropriate for identifying first order interactions. To overcome this deficiency, the extended component interaction matrix (Bisset, 1980) was developed. This method advocates development of a second matrix that accounts for second and higher order impacts by identifying relationships between the environmental components.

Most matrices were developed for specific applications, although the Leopold matrix itself is quite general. Early in an assessment, an interaction matrix could be built for a specific cumulative effects problem. In such a situation it would be a useful tool for identifying interactions between project activities and specific environmental components. It would also be useful for identifying interactions between environmental components. However, in terms of problem definition, matrices tend to overly simplify impact pathways. Also, they do not explicitly represent spatial or temporal considerations, nor do they adequately address synergistic impacts.

Thus, as an assessment tool, matrices can only provide qualitative predictions of the impact a specific action may have on a specific environmental component. Since no two action-component interactions on any one matrix can be precisely compared, attempts to integrate across activities or environmental components are difficult. In general, the technique is easy to use only if one has either knowledge of the assessment situation or expertise from similar situations. Also, because of the sheer size of a typical matrix covering virtually all project actions and affected environmental components, the matrix becomes cumbersome. Consequently, matrices are probably best used for the purpose for which they were designed: that is, as tools for preliminary analysis and screening in environmental impact assessment.

For cumulative impact assessment the usefulness of matrices is limited to helping determine the set of activities that may affect a given environmental component. If these techniques are to be used, it is necessary to develop a new matrix for each new application or to use a tried and true matrix for a similar application.

Detailed Review

For the most part, matrix methods offer little potential for cumulative impact assessment: nevertheless, they are useful for helping to organize information prior to applying other methods.

In Canada, the Federal Environmental Assessment Review Office (FEARO) published a guide for environmental screening (FEARO, 1978) that presented two sets of matrices designed to assist in identifying potential adverse effects associated with proposed projects. The matrices were designed to assess effects from single projects, and gave no explicit directions for evaluating a project in context with other developments and activities.

5. Networks

Overview

The stepped matrix technique, developed by Sorenson (1971) to display the possible consequences of land use along the California coastal zone, illustrates how the matrix approach evolves logically into network diagrams. Network diagrams can be constructed from matrices where matrix elements represent linkages between pairs of components. These network diagrams provide the mechanism for linking first and higher order impacts. System diagrams have been used by ecological modelers to represent the conceptual structure of models. In the context of environmental impact assessment, one group of modelers, for example, used a sophisticated network, or system diagram, to represent impact hypotheses (Everitt et al., 1986) which causally related project activities to target resources.

For problem definition, networks or systems diagrams overcome the limitations of matrices by accommodating higher order impacts. They are also far better at explicitly identifying the causal basis for impacts. In addition, they are well suited to identifying the interaction between a number of activities, components, and a single target resource. As an assessment tool they are capable of making qualitative predictions regarding the cumulative impact of a number of activities on a single target resource. They do not formally integrate, however, over the spatial and temporal dimensions, nor do they integrate across target resources. Networks and systems diagrams can be communicated well and are easy to develop using expert judgement. Scientific documentation of complex systems diagrams, however, requires time and money.

Detailed Review

We looked at three methods representative of this group. In general, these methods represent cumulative impacts as causal relationships embodied in a conceptual model. In some cases network diagrams are used, while in more sophisticated cases computer models are developed.

The stepped matrix approach of Sorenson (1971) is excellent for hierarchically describing the relationship between activities, impacts, and potential mitigation measures. It provides for linking many activities to a single impact category, while providing for limited detail on the important ecological relationships. This method, originally developed for coastal zone impact management, could be adapted for use in other situations.

The stepped matrix approach provides a combination of a stepped matrix and columns network which enables identification of:

1) land use effects,

2) causal factors (land alterations associated with land uses),

3) conditions (initial identifiable impacts of causal factors),

4) consequent conditions (changes induced by the initial conditions),

5) effects (ultimately produced by the consequent conditions), and

6) corrective actions or control measures (mitigation).

This method emphasizes interrelationships among 1-6 and includes impact risk and mitigation measures. This matrix network is the starting point for further examination of interrelationships, information indexing, forecasting, and evaluation. The stepped matrix approach can be computerized, allows for non-quantifiable impacts, and treats multiple-use issues.

The method partially satisfies the criterion for problem definition. In some applications, such as where temporal aspects were explicitly considered and impact pathways were clearly shown in network diagrams, the method should perform well at problem definition. Although the method describes qualitative interactions, it does not represent synergistic or aggregative impacts. The method also does not explicitly consider thresholds. It does, however, make qualitative predictions of cumulative impacts across activities. The method is easy to explain, and the matrices facilitate a clear exposition.

6. Weighting/Evaluative Methods

Overview

In Shopley and Fuggle's (1984) classification, evaluation methods ensure that impact assessment is based upon acceptable value judgements. Most of these methods involve the determination of scales and assignment of weights that reflect people's values or preferences. Therefore, these methods are best applied during the assessment of alternatives, especially when choices are being made between alternatives. Westman (1985) provides a good description of various types of evaluation methods.

Evaluation methods must normally be linked with other methods (Lewis, 1976) and are applied after the impacts have been analyzed. These methods are not used to make predictions about impact magnitudes, as measured by changes in levels of target resources. A simple evaluation method would compare impact levels with some predetermined standard or threshold. More sophisticated methods for weighting the relative significance of various impacts aggregate them into indices that can then be used for comparing alternatives. These are the only methods that attempt to integrate across a number of impact dimensions or target resources. In most cases, the methods will determine that alternative A is preferable to alternative B; they cannot, however, indicate whether either alternative is good or bad.

Detailed Review

We have evaluated two methods that compare alteratives based on weighing preferences or expert judgement. These methods assume that information is available on the measurement of impact for a given project or alternative. Their strength is that they aggregate over a number of different impact dimensions to give an overall index or rating that can be used to compare alternatives.

Anderson (1981) proposed a general method involving evaluation of preferences between various groups which he calls "affected publics". Consistent scales are constructed to measure each of the impact dimensions. Relative weights are then assigned by the various publics to each of the impact dimensions. Using these weights and measurement scales, an index is constructed for each public and each alternative. In the full method, weights are assigned to each of the publics and then an overall index or score is assigned to represent the aggregate public preference for each alternative. This method relies completely on subjective judgement, and any applicant must decide who has a legitimate right to weigh one environmental resource against another, or trade off one affected public against another.

The key concept in Anderson's method is called commensuration. Commensuration is the process of determining what impact on one dimension is equivalent to a given impact on another dimension, or what impact on one public is equivalent to a given impact on another public. The detailed steps in the method are:

1) identification of impacted publics,

2) identification of issues (for instance, dimensions of impact using checklists, and ordering of dimensions in terms of importance),

3) measuring values in terms of functional curves (public representatives judge the functional forms), and

4) measuring weights (weight judgements are the basis for commensuration in the first step of the cascade, one weight per dimension per public; weights are measured by ratio scales).

Full commensuration is achieved in two cascaded steps: (1) across dimensions within each public, and (2) across publics. Within each public, commensuration yields the average evaluation of each alternative on each dimension, and the average evaluation by the public of the overall value of the future with and without the project. Commensuration also incorporates the value of mitigative measures for each project alternative. If a single best alternative is still not apparent, then the problem of trading off one public's loss for another public's gain is addressed via a single "trade-off dimension". The method employs various equations, aggregations and weighted summing techniques, and deals with equity, uncertainty, and utility.

To be effective, commensuration requires that representatives of the publics be determined. As with most methods of this type, Anderson's method offers little guidance on how to choose these representatives. The method assumes that the cumulative impacts on target resources have been determined. The method allows for integration across the impact dimension (target resources), something that few of the other methods are capable of doing. The results should be relatively easy to communicate, although they may not be acceptable to those looking for a more scientific basis for assessment of cumulative effects. In cases where the issues are well-defined and the number of affected publics is small, this method could help evaluate alternatives if used by a skilled practitioner. In most applications, however, the method would likely prove unsatisfactory, especially where a wide range of interests must be accommodated.

Bain <u>et</u> <u>al</u>. (1985a) propose a method for evaluating alternative project configurations. Their method does not involve trade-offs between publics but rather trade-offs between target resources. The method has a stronger biological basis since it considers key components affecting the impact dimensions. The methodological advance associated with this method is that it allows for interaction between individual projects. This method is explicitly designed to identify cumulative effects over a number of hydroelectric projects proposed in any given river basin.

A key aspect of this method is identification of target resources and components. There are three stages to the method:

1) analysis, in which possible interactions between projects are identified;

2) evaluation, in which a subset of configurations is selected for more detailed evaluation; and

3) documentation, in which the projected impacts are summarized.

The authors suggest using a workshop approach at this stage.

Next, three main types of information must be assembled: (1) component impact values, (2) weights for each impact value, and (3) interaction values. Component impact values are numerical ratings of the impact that each project would have on each target resource component. Weight values refer to a set of weights used when combining component impact values. Interaction values are coefficients to express the interactive effect of each pair of projects on each component. Each of these three types of information is derived from expert judgement.

This method is used after the environmental impacts associated with each proposed project have been independently analyzed. While it partially satisfies the problem definition criterion' it does not identify the causal basis of impacts, and it considers many of the factors that contribute to impacts on target resources. It is ecologically weak, however, and does not adequately address thresholds. As well it does not predict cumulative impacts; it compares alternative combinations of developments. There are three key limitations for the use of this method: (1) availability and thoroughness of information produced for individual EISs; (2) availability of qualified experts; and (3) the credibility of the experts. The method relies heavily on expert judgement and asks experts to make trade-offs and identify interactions in ways that run counter to normally accepted scientific approaches.

7. Mocieling

Overview

Matrices and networks are types of models. They represent the conceptual structure or linkages between the various parts (activities, environmental components, target resources) of a system under study. While conceptual models are necessary to define the problem' they are basically limited to indicating that "x will affect y", or to asserting that activity "a" will cause a minor, moderate, or major impact on species "y".

To move beyond the conceptual level requires quantification. To quantify we must transform the conceptual model into a mathematical model. Mathematical models allow for explicit definition of relationships by allowing the user to specify the shapes of curves that represent the linkages between "x" and "y". For example, we can develop dose-response models for fish toxicity, and we can develop elaborate statistical models for assessing air quality. A special class of mathematical models' such as computer simulation models, are designed for the dynamic representation of ecological systems. When used for impact assessment, computer simulation models can make projections of potential impacts over time. These projections are based on a dynamic representation of the relationships between project activities and the ecological systems under study. Such models are especially well suited to accommodating interactions. Some sophisticated mathematical or computer models can represent synergistic impacts: however, most cannot. Computer simulation models require rigorous problem definition. The conceptual structure of the model, regardless of how it is represented, must be logically consistent. Building the conceptual structure for a computer simulation model appears to be an excellent way to define the cumulative impact problem. For assessment' all mathematical models can be used to make quantitative predictions. Of course, the accuracy of predictions is highly dependent on the quality of the data and on the validity of the model. The structure of ecological simulation models is such that integration over activity, and spatial and temporal dimensions is easily accomplished. Major concerns with computer models are often focused on the potential for high costs, questions about the accuracy of their predictions, and resistance by some people to accept their use.

Detailed Review

Cause and effect modeling techniques are an excellent method for representing ecological relationships between activities and their potential impacts (Armour and Williamson, 1986; Everitt et al. 1986). Armour and Williamson (1986) describe a five step method consisting of:

1) stipulating a clear problem statement,

2) categorizing causes of the problem,

3) modeling causes of the problem,

4) categorizing effects of the problem, and

5) modeling effects.

When the modeling is completed, causes and effects are linked in a logical network design. These networks provide for causal analysis of the cumulative impacts of multiple actions (causes). The method is an efficient and effective way of categorizing, classifying, and ordering information and ideas into cause and effect relationships. Stipulation of a clear problem statement focusses effort. By constructing network diagrams with groups of experts, the potential cumulative impacts of activities are revealed. The descriptive nature of the networks, however, often does not provide a basis for prediction.

This method appears appropriate for the problem definition phase of cumulative impact assessments. Little attention is paid to spatial and temporal aspects, however, and it appears difficult to represent synergistic impacts. Modeling also provides little guidance on how to assess cumulative impacts. In general, models appear easy to communicate, and they are cost effective to use. Since a model is based on expert judgement it requires little information; however, in a formal assessment a model could be criticized if causes and effects are not carefully documented. In field experiences with models (including barge traffic on the Tennessee River, habitat degradation in Chesapeake Bay, and degradation of Mobile Bay habitat) this method has been generally well received by both the U.S. Fish and Wildlife Service and the U.S. Army Corps of Engineers.

Computer simulation models, like those at the core of the adaptive procedure of Holling (1978a,b), are essential for full development of complex networks and models. Use of simulation allows for integration of impacts over space, time, and activities, as well as providing mechanisms for quantifying thresholds and key ecological processes. Because Holling (1978a,b) is reviewed as an adaptive method, it is not discussed here.

8. Adaptive Procedures

Overview

In the strict sense of the definition, these are not methods but are procedures, or sets of steps, for performing an impact assessment. Adaptive procedures become necessary when no single method is capable of handling all aspects of impact assessment. Within adaptive procedures various combinations of the other seven methods are employed, as needed, at different steps in the procedure.

Detailed Review

Five adaptive procedures that have some potential for use in cumulative impact assessment are:

- Dames & Moore, Inc. (1981)

The most complete set of steps for cumulative impact assessment is outlined in a handbook developed by Dames & Moore, Inc. (1981) to aid the U.S. Army Corps of Engineers personnel in assessment of cumulative impacts of permit activities. First, the proposed activities are identified and the environment characterized. Next, the level of analysis and the assessment approach are chosen.

The approach that relates to the assessment of biological effects proceeds through the following steps:

1) identifying effects, using network diagrams:

2) quantifying the likelihood, magnitude, spatial extent, and duration of the effects;

3) determining the significance of the effects; and

4) assessing the ecosystem-level effects.

Each of these steps has a number of detailed substeps. For example, assessment of ecosystem effects has ten substeps, including determining whether synergistic effects are present and whether or not tolerance levels of specific organisms will be exceeded.

In principle, if one followed all the steps and had the tools and resources to conduct the recommended analyses, an excellent cumulative impacts assessment could be done. This method appears excellent for both description and problem definition. As an assessment tool it has potential, for it explicitly instructs users to take account of thresholds, synergistic relationships, and other key ecosystem properties. Its predictive capabilities and ability to integrate across activities and spatial, temporal, and impact dimensions are, however, dependent on the specific method chosen. Because the approach relies on complex sets of specific steps and can include relatively sophisticated methods, it is difficult to understand and use. For simpler applications, information should be relatively easy to obtain; for more complex applications, the information demands and sophistication of techniques required make this a costly and time consuming method. Given limitations of time and money, it would likely be impractical to use the complete version of this approach. The selection of the method to use at each step is critical, and if approaches like Dames & Moore, Inc. (1981) are to be useful, more guidance is needed on the appropriate method for each step.

- Horak et al. (1983a,b)

Horak et al. (1983a,b) offer a ten step procedure recommended for cumulative impact assessment. These authors emphasize that there is no single method that has been developed to specifically address cumulative impacts; thus, their procedure includes a specific step to decide on the appropriate techniques to be used. The ten steps are:

1) examine premises and assumptions that underly the cumulative impact assessment;

2) identify and analyze development actions:

3) characterize arena (overview of environmental resources and adequacy of existing data);

4) scope (determine spatial, political and temporal boundaries);

5) map spatial characteristics;

6) establish the assessment approach and specific techniques;

7) determine characteristics and significance of impacts;

8) assess potential ecosystem effects;

9) derive some "impression for overall fundamental changes or transformations"; and

10) consider subsequent steps for monitoring and reassessment.

They emphasize the need to clearly define premises and assumptions upon which the cumulative impact assessment is to be based. This is necessary because of the confusion that currently exists about cumulative impact assessment and how it should be conducted. Their approach also highlights the importance of selecting the appropriate method; in fact, they make this an explicit step following the problem definition phase.

This procedure is good at defining project activities and the spatial and temporal aspects of the problem. It does not provide specific details on how the methods are to be used. Therefore, it is difficult to know how the approach will perform for cumulative impact assessment. Nevertheless, it does emphasize many of the key attributes of cumulative impact assessments for fish and wildlife.

- Adaptive Environmental Assessment and Management

As already noted, many adaptive procedures do not specify which methods are most appropriate at each step, or how the choice is to be made. One major exception is adaptive environmental assessment and management (AEAM) procedures (Holling, 1978a,b). AEAM uses computer simulation modeling methods in workshops and develops ecological simulation models which then serve as the focal point for the effects assessment.

Holling (1978a,b) advocated simulation modeling workshops as a mechanism to focus and coordinate the assessment team. Whereas the Dames & Moore Inc., (1981) approach outlines steps with little guidance on how accomplish them, Holling suggests that many of the steps can be accomplished by construction of models. Because this approach is based on the principles of systems ecology, and often uses simulation modeling, it is possible to incorporate relationships representing complex interactions and thresholds into the models. The procedure also emphasizes the use of expert opinion, facilitated workshops, and modeling to analyze environmental impacts. It was developed to promote understanding and integration of environmental, economic, and social issues into policy level decisions concerning design and implementation. It should be applied throughout the project development cycle by iterations of modeling or policy analysis workshops alternating with periods of data acquisition, research, and model refinement.

Through computer simulation modeling and other systems analysis techniques, the process: (1) emphasizes interdisciplinary communication; (2) limits the scope of the assessment to key factors; (3) explicitly states assumptions; (4) rapidly synthesizes existing pertinent information and identifies important data gaps; (5) describes integrated system behaviour; and (6) identifies alternatives and promotes collaborative selection. The process is coordinated by a group of four to six facilitator/modelers trained in the techniques of group dynamics, policy analysis, systems analysis, and computer simulation modeling.

Being an ecologically-based approach designed to construct models, AEAM is good at problem definition. The approach formally recognizes the importance of identifying specific project activities, specifying spatial and temporal aspects of the problem, identifying major linkages between system components, and it represents synergistic relationships mathematically. As an assessment tool it has the ability to integrate across activities, as well as spatial and temporal dimensions. It also makes quantitative projections of impact, and can be used to help determine where critical ecosystem thresholds might occur.

Although graphic representation of results helps in communication, it is unlikely that the analytical detail can be communicated to decision makers and lay persons. Models can be constructed based on expert judgement, but obtaining reliable data and validating models is difficult and time-consuming. This approach has had numerous applications in various aspects of environmental assessment (Environment Canada, 1982); generally the response has been favourable, especially when there has been a high degree of participation.

- U.S. Army Corps of Engineers (1983)

The U.S. Army Corps of Engineers (1983) guide to analysis of significance explores ways to define significant impact. The procedures that are advocated examine thresholds in determination of significance. Significance analysis is seen as part of the overall environmental impact assessment process and has five steps:

1) identify which resources are significant,

2) predict changes in resources,

3) define the magnitude and scale of resource changes,

4) judge the significance of resource changes, and

5) determine the consequences of impact significance.

These five steps are to be preceded by a project description, an assessment of environmental inter-relationships, determination of region-of-influence (for instance, spatial considerations), assessment of the data base adequacy, and description of the environmental setting. The approach concentrates on identifying significant resources (Step 1), judging the significance of changes (Step 4), and determining the consequences to significant impacts (Step 5). The guide itself provides a discussion of questions that need to be answered in the analysis of significance for threatened and endangered species, wetland habitats, unique habitats, fish, mammals, and birds as well as for physical, such as water quality, and cultural, such as Native Indian concerns, resources.

The U.S. Army Corps of Engineers' (1983) approach provides little specific detail on how to define the problem, except that it appears to be based on an understanding of ecological relationships and it tends to define significance in terms of thresholds. Depending on the tools used to determine the magnitude and scale of effects, it may also be predictive. The approach does not explicitly state how cumulative impacts will be integrated over activities, space, time, and impact dimensions. The procedure is relatively straightforward, should be easy to communicate, could be cost-effective in cases where information is readily available; and there is little uncertainty.

- Contant (1984a,b)

Contant (1984a,b) advocates a carrying capacity study as a major part of procedures to forecast and analyze cumulative impacts. In this approach, carrying capacity is taken to mean the maximum level of growth in an area that is consistent with socially acceptable levels of environmental quality and public welfare. A successful carrying capacity study requires agreement on whose values are considered in determining acceptable growth levels, environmental quality, and public welfare.

The procedure, designed for the Corps of Engineers permit process, involves specific steps to predict and monitor project impacts. Steps in the carrying capacity study are:

1) identify the area for investigation through scoping of activities and critical problems,

2) define the geographic boundaries of the study area,

3) determine the limiting factors and related growth activities,

4) determine the acceptable level of the potential limiting factor,

5) devise a growth variable,

6) make assumptions about future types of development,

7) devise relationships between activities and growth variables, and

8) determine the overall carrying capacity in terms of growth variables.

Different procedures are recommended, depending on the degree of impact and whether or not project impacts are at or near the environmental carrying capacity.

If the scientific and technical aspects of the carrying capacity study are strongly based on ecological considerations, this procedure could be very valuable for problem definition. The procedure emphasizes determination of a threshold upon which to base approval, and the carrying capacity study must make a prediction (most likely quantitative). The concept of carrying capacity is attractive to people, but explanation of the details and assumptions of the assessment may lead to misunderstandings. As well, carrying capacity information may be difficult to obtain and will likely require a costly study. There seems to be disagreement over who should pay for a carrying capacity study; there is reluctance on the part of both regulators and proponents to bear the costs of such studies.

- Summary

Neither the U.S. Army Corps of Engineers (1983) nor Contant (1984a,b) offer a procedure as systematic and comprehensive as those outlined by Holling (1978a,b), Dames & Moore, Inc. (1981), and Horak et al (1983a,b). Both the U.S. Army Corps of Engineers (1983) and Contant (1984a,b), however, focus attention on an important question that cumulative impact assessments must answer: How should carrying capacity be apportioned among projects, and at what point should development be curtailed?

In general, adaptive procedures are considered to be the best approach to addressing cumulative impacts, for they are designed to make the best use of existing methods, available expertise, and information. Their major drawback is that they are time consuming, may be costly, and require considerable coordination of people and tasks. This may make their implementation difficult. It is clear, however, that these approaches are a response to the complexity and difficulties that people have encountered in assessing cumulative impacts.

9. Biogeographic Theory

Overview

The developing theory of island biogeography (IB), and its associated species-area relationships, offers a possible method for making predictions concerning species losses from isolated patches of ecosystems as a function of incremental encroachments. Such a method would be of obvious value in assessing cumulative effects.

Detailed Review

To date, there appear to have been few attempts to use IB theory in CEA procedures. Nevertheless, island biogeography has been used to describe species losses associated with habitat fragmentation, particularly in forests (for example, Harris, 1984). As well, a computer model has been developed that allows simulation of fragmentation effects on resident species. In this case, species fates were modeled using a species-by-species approach, similar to that described by Gilpin and Diamond (1980; 1982) as "molecular".

Using IB theory to help assess cumulative effects requires that certain types of information be available. For example, island size, isolation from potential sources of colonists, dispersal abilities, dispersal abilities of the species, and population densities. The use of this information for many species and locations will undoubtedly hamper use of this method.

8.2 Description of Loop Analysis

Loop analysis is a qualitative, network technique that is based on feedback relationships. It is a signed digraph type of network analysis. It can be used to predict the changes in standing crops (levels) and turnover rates of the set of variables as they respond to parameter change or forcing from the environment external to the network. The method is based upon the concept of feedback which can be defined as the effect of a variable upon itself acting through intervening variables. Thus, loop analysis differs markedly from most of the network techniques described in Appendix 8.1 which involve straight line causality and little or no predictive capability. Loop analysis is essentially a top-down type of modeling approach in that it deals with the whole structure of the system of interest and allows the assessor to ask what effect does the system have on a particular variable as it is positioned in the network. It also differs markedly from traditional computer simulation techniques in its whole-system focus and proportionally lower effort spent in quantification. In computer simulation, the approach is usually reductionistic, the model is built one link and one variable at a time and much of the total effort is spent on constructing sophisticated differential or different equations, parameter fitting, and model calibration. With loop analysis!, the investigator asks: What is the overall structure of the system of interest? Is it stable? What effects will a change in a particular variable have on the rest of the network? Where are the key control links? Where can stability be enhanced? Once the qualitative structure of the system is understood, it then makes sense to quantify it.

The diagram approach to network analysis has been developed out of engineering (Mason, 1978; Mason, 1952; Lorens, 1956) with varying degrees of development and application in ecology (Saila and Parrish, 1972; Levins, 1973; Hill, 1975). Levins' technique, termed "loop analysis", has been subjected to field tests in freshwater ecosystems (Lane and Levins, 1977; Briand and McCauley, 1978; McCauley and Briand, 1979) and for marine ecosystems (Lane, 1986a,b; Lane and Wright, 1986).

Loop analysis employs signed digraphs to represent networks of interacting variables. The technique allows deduction, from routine monitoring data, of the important variables and interactions in a complex system, such as a coastal marine community. Loop analysis provides a methodology for analysis of systems based on qualitative representations of variable interactions. These are equivalent to the signs of the first partial derivatives of the coupled differential equations describing the system. The models derived from periodic sampling data indicate the dominant variables and interactions, and the predominant driving force (parameter input), for each sampling period. Once the network is constructed, the effects of a parameter input can be assessed in terms of directed changes in standing crops and turnover rates of all variables. Patterns of correlation can be predicted, and the most sensitive components in regard to environmental impact can be identified.

By comparing the theoretical field data, it is possible to construct a restricted set of loop diagrams that represent the system under study. Once the correct representation is determined, the pathways producing the directed changes can be extracted, examined and subjected to a more quantitative form of analysis using standard modeling techniques. Lane (1982; 1986a,b) and Lane and Collins (1985) have used loop analysis for data sets from marine field studies and mesocosm experiments. Lane and Wright (1986) discussed the theoretical basis of the technique.

In the following pages three examples of loop analysis are given. The first is a Type 1, hypothetical loop model not based on data. The second is a Type 2, data-based model using a large routine monitoring data set and the third example (Type 1) illustrates how a hypothetical environmental regulator becomes a co-variable with ecological components.

Advantages of Loop Analysis in Comparison to Quantitative Techniques

A few of the advantages of loop analysis are as follows:

- The qualitative approach gives a high priority to the understanding of whole systems. The models are robust in that they do not depend on precise measurement but mostly on directions of effect.

  Many different types of variables at all levels of scale can be included in one diagram and there is no need to standardize everything into a single unit such as kilocalories of energy or carbon. Variables can be included which cannot be measured. Human actions such as management decisions or institutions such as regulatory agencies can be diagrammed with algae and grizzly bears.

Qualitative results are more transferable among ecosystems and new information gained about a given ecosystem can be applied to another area without expensive time-consuming detours to collect additional data.

Loop analysis also provides a good guide as to what to measure and serves as a design for future analysis. Interpretation of a loop diagram yields important predictions about particular variables in the network, identifies an omitted variable or link and generates testable hypotheses. Data sets are not used to correct equations or achieve better-fitting parameters, but rather to find new ways to look at systems and to find new variables of interest even if they are abstract and impractical to measure. In subsequent research, there can be more selection in collecting the missing information and the "measure everything" approach does not have to be invoked.

Loop diagrams also serve an important role in assessing environmental impact. Besides the valuable predictions they give, they also provide a useful focal point that is understandable to ecological managers who are trying to make decisions about an environmental problem or proposed development.

There is a great economy of effort and resources for the amount of information gained in conducting qualitative analysis. If the techniques were developed to their fullest potential, millions of dollars could be saved in unnecessary data collection and impact assessment costs. Because these methods are holistic and enable the investigator to determine the qualitative structure of the ecosystem, understanding of cause and effect is facilitated thereby making much of the contemporary "brute force" data collection obsolete and wasteful. In addition, loop analysis fits into contemporary assessment procedures well. With an adequate set of instructions (procedural manual), government agencies and consulting firms could greatly improve their assessment techniques at less expense and with more understanding of both the impacts and the ecosystems. Note that this manual does not presently exist but it could be developed.

Example of Multiple Effects of a Power Plant on an Aquatic Ecosystem Using Type 1 Loop Analysis (Hypothetical Model)

Parameter inputs or perturbations to ecological networks are represented by + or - inputs to one or more variables in the network. Natural parameter inputs might include such events as a change in salinity or temperature or an increase in a predator (fish) not included in the diagram, whereas human perturbations include such events as (1) introduction of oil or toxic chemicals; (2) nutrient enrichment, (3) thermal pollution and (4) predation phenomena. The latter category includes fishing, environmental alterations, impingement and entrainment processes among others. One major use of loop analysis is to assume a parameter input is entering one or more variables and then predict that there will be changes in the standing crops and turnover rates of the variables as well as correlation patterns of these changes and associated levels of variation. Thus, it becomes critically important to determine the relative strengths of natural versus man-made parameter changes for a particular system. For example, how many times has a major industrial polluter gotten "off the hook" by demonstrating there is perturbation in the environment from natural causes. With loop analysis, not only can we predict effects but we can also work backwards: by knowing responses of ecosystems we can identify which variables are the sites of major parameter input. By evaluating the environment and known sources of perturbation by humans, it is often possible to determine which may be more important and whether they are yielding synergistic or antagonistic forces on the ecosystem in question.

In Figure 8.1, a generalized loop diagram is presented for a marine community located near a power plant. In marine ecosystems, we have found that nutrient addition is often an important parameter input that occurs naturally, for example, under spring bloom conditions. With human influences on an ecosystem, there are often multiple simultaneous effects. A power plant will discharge excess heat into the water which will have a positive effect on some algal species (I) and will also have a positive effect on nutrient addition perhaps through enhanced remineralization by bacteria.

At the same time, the mechanical action on the flow of water throughout the cooling system will cause substantial impingement and entrainment of herbivores (H), fish larvae (F,) and adult fish (F,). Thus, a single power plant can simultaneously cause five parameter inputs to the ecosystem. In this example, these inputs enhance each other and lead to less N, more I, less E, H, F_1 and F_a when parameter inputs at I and F_1 predominate (see Table 8.1).

Example of a Data Based (Type 2) Loop Analysis of a Marine Pelagic Community.

To date, loop analysis has been routinely applied to large data sets describing marine pelagic communities (Figure 8.2). These data sets are similar to those collected in biological monitoring programs for purposes of environmental impact assessment. In fitting loop models to data, one of the first procedures involves grouping the raw variables into loop variables. Rare, infrequent species are deleted because there is too little information to characterize them. The data frame involving changes in abundances over time is then transformed into a qualitative data matrix by determining percent relative change of each variable from one sampling period to the next. The loop models are fitted by hand and then checked by computer. A loop model is often finished even though there is not perfect agreement between its predictions and the data. If subsequent attempts to fit it would result in a loss in biological realism, then realism is given priority over accuracy.

A set of loop models is summarized by variables and links to determine the dominant or core network of the ecosystem. The core diagram is a network formed from the most prevalent variables and linkages in a set of individual models. Although a loop diagram for a single date can appear to have missing links, the core structure for an annual cycle or set of diagrams represents

Figure 8-1. Generalized loop diagram of a marine community located near a power plant. The power plant produces parameter effects of heat and impingement. Variables include nutrients (N), edible algae (E), inedible algae (I), zooplankton herbivore (H), larval fish (F,) and adult fish (F,).

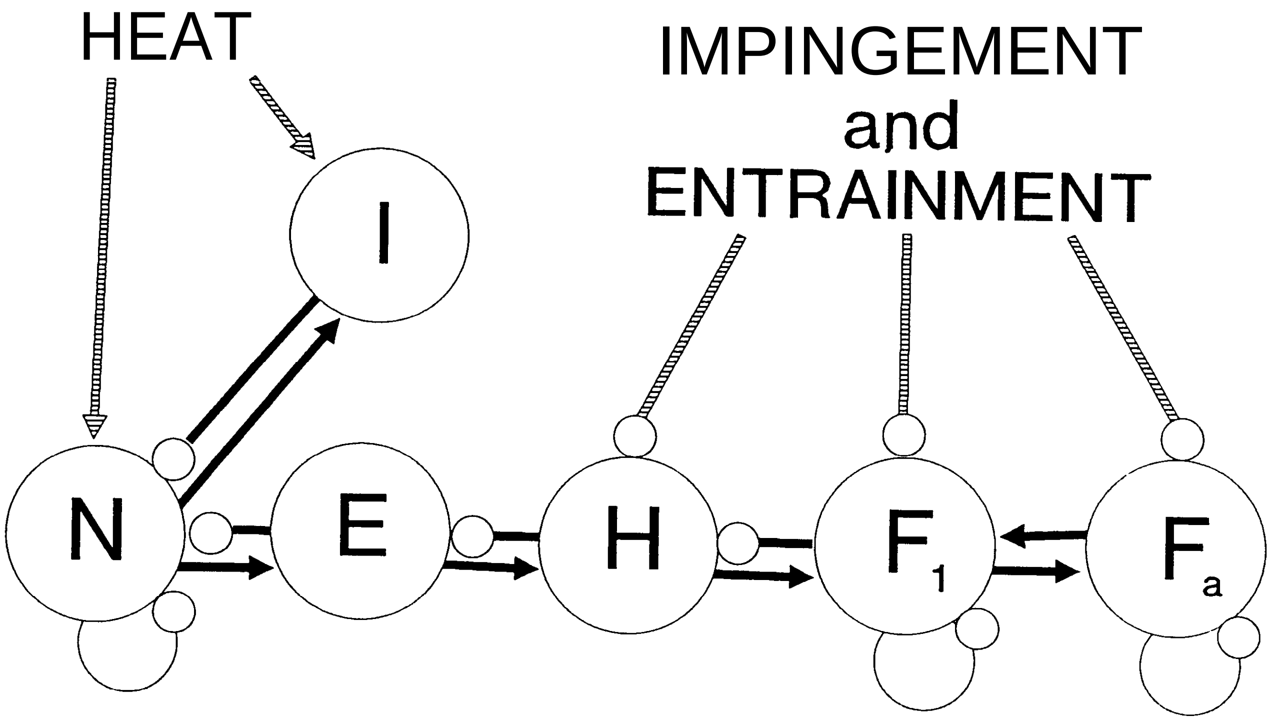
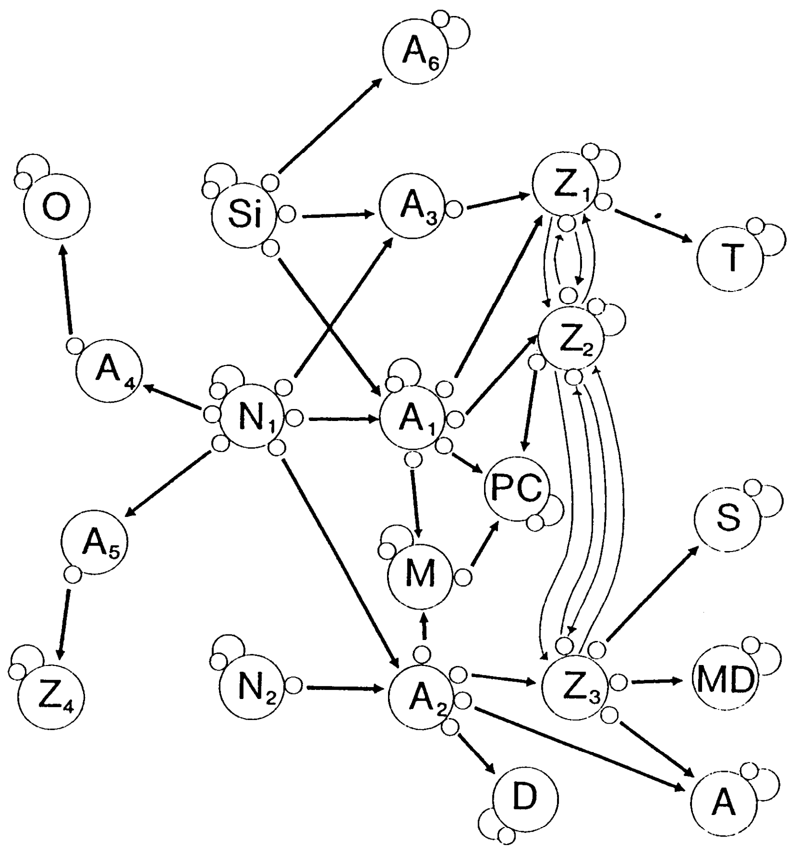


Figure 8-2. Composite marine core diagram for pelagic zone of Western Atlantic.



Key:

Si = silica
N_1 = inorganic N/P ratio
N_2 = organic nutrient pool
A_1 = diatoms
A_2 = dinoflagellates
A, = luxury consuming diatoms
A_4 = microflagellates
A_5 = monads and miscellaneous algae
A_6 = silica-flagellates
Z_1 = adult copepods, group 1
Z_2 = immature copepods
Z_3 = adult copepods, group 2

Z_4 = cladocerans
0 = tunicates (<u>Oikapleurasp.</u>)
M = mollusc larvae
PC = polychaete and barnacle immatures
D = decapod larvae
T = ctenophores
L = laurellibranch veligers
S = chaetognaths (<u>Sagitta</u> spp.)
MD = hydromedusae
A = anemone larvae'

Figure 8.3. Two alternative models of regulation of fishing industry (I) and of fish population (F) by regulatory agency (X).