CUMULATIVE ENVIRONMENTAL EFFECTS:

A BINATIONAL PERSPECTIVE

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PREFACE

In April 1983, the U.S. National Research Council's (NRC) Board on Basic Biology formed the Committee on Applications of Ecological Theory to Environmental Problems (CAETEP). In January 1984, the Canadian Environmental Assessment Research Council (CEARC) was established by the Federal Minister of Environment to advise on research priorities in environmental assessment. Representatives of the two bodies attended each other's early meetings. They agreed that cumulative environmental effects were among the most important environmental assessment problems and in need of much more attention than they had been receiving.

Both groups felt that the concept of cumulative environmental effects and the basic issues involved should be clarified, that difficulties in understanding and managing them should be identified, and that recommendations were needed for scientific and management research on those topics. As a result, a workshop was held in Toronto on February 4-7, 1985. The 30 participants were drawn from both Canada and the United States, and represented a wide variety of disciplines. This volume contains the papers that served as a basis for the discussions at that workshop, a synopsis of the discussions, introductory and closing papers presented there, and the recommendations that issued from the workshop.

Although the material herein reflects the views of the workshop participants, and not necessarily those of NRC or CEARC or any sponsors, it will be used by NRC and CEARC. CEARC will use the material as a basis for the formulation of a specific research agenda in the science and management of cumulative effects; CAETEP has used it in the preparation of its report entitled "Applications of Ecological Knowledge to Environmental Problems"; and the material may be used to guide some future NRC activities.

Financial support for the workshop was provided by the Federal Environmental Assessment Review Office (FEARO), the United States Environmental Protection Agency, and the United States Department of Energy. The organizers of the workshop are most grateful to the participants, the members and staff of CEARC and CAETEP, and the sponsors.

Editorial Committee

INTRODUCTION

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

The purpose of the Toronto workshop was to explore these issues, to identify current scientific and management techniques of dealing with cumulative effects, and to recommend research and management priorities for improving the management of cumulative effects. The workshop organizers sent a letter to all participants, asking for contributions, and noting the shortcomings of environmental assessment that is focused on specific projects:

- It ignores the additive effects of repeated developments in the same ecological system, e.g., the effects of the loss of wetlands and disposal of toxic chemicals on fish habitats and productivity.

- It does not deal adequately with precedent-setting developments that stimulate other activities, especially in fragile environments.

- It ignores change in the behavior of ecological systems in response to increasing levels of perturbation, e.g., nonlinear functional relationships.

- It does not encourage the development of comprehensive environmental objectives that reflect the broad goals of society.

The workshop brought together some 30 participants with diverse scientific and management experience in environmental assessment, in recognition of the need to integrate science and management in solving cumulative assessment problems.

Scientific and management papers were prepared for each of the four major environmental systems — terrestrial, fresh water, marine, and atmospheric. Each paper was commented upon by two other workshop participants. Because the four environmental systems are interdependent, a keynote paper was commissioned to provide an overview of issues that affect all of them. The paper was not intended to be a complete synthesis of the other contributions — time did not permit that — its purpose was to point out some issues that might have been overlooked by the eight authors who initially worked independently.

The major emphasis in the workshop was on the natural sciences and their relationship with management and decision making; the social sciences were not well represented. Thus, the discussions and recommendations do not include the contributions that social scientists can make to improving the assessment and management of cumulative effects. This was a decision by the workshop organizers, to keep the scope and size of the workshop manageable. The solution to the problems caused by cumulative effects, however, will require the participation of social scientists.

Fred Roots's "Closing Remarks" is a summary developed during the workshop and presented at the end of the session. The essence of the discussions generated by the papers and comments on them is summarized by the editorial committee in the final two sections. The first is an attempt by the editorial committee to highlight major conclusions, and the second presents some recommendations for research and practice in environmental assessment to improve the management of cumulative effects.

OPENING DISCUSSION

CUMULATIVE EFFECTS: SETTING THE STAGE

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My task is to set a stage against which discussions of cumulative effects may be cast. The job is, on the one hand, made easy by the hard work performed by the authors of the eight papers. On the other hand, it is made difficult by the complex nature of the problem and by the fact that, not surprisingly, each author took his assignment literally and concentrated his attention on the particular environmental type he was asked to address, Thus, it falls to me to develop some conceptual threads that may help bridge the gaps between these individual efforts, I can only hope that my keynote does not turn out to be played in B flat minor but is, rather, in A major.

As pointed out by Clark (this volume), cumulative impacts are embodied in the pop-ecology expression "everything is connected to everything else." This concept is used in a variety of ways to support activist positions and it is widely accepted in popular views in North America about the environment. There is, of course, an element of truth to the assertion but, fortunately from the standpoint of both theoretical ecology and environmental management, not all connections are equally strong. If that were not the case, any hope of developing sound bases for ecological predictions would be vain. Our chances for success rest upon the fact (or hope) that the number of strong connections upon which we need to concentrate attention is a small enough number to be manageable, and that our insights will enable us to recognize which ones they are.

There is general agreement as to what we mean when we speak of cumulative impacts on the environment. Our concern centers on the fact that environmental perturbations often are repeated, such that their combined impacts are both more substantial than those of the individual events and, sometimes, of a qualitatively different nature. To the extent that this is true, the traditional methods of assessing the significance of development on a project-by-project basis may fail to predict and, hence, help us manage, cumulative effects.

Assessing cumulative impacts is more complex than assessing impacts of single projects. Thus a first step is to undertake an analysis designed to help us decide whether or not there is really a serious cumulative impact that needs to be considered. If not, so much the better. As pointed out by Clark, cumulative impacts are important when the frequency of occurrence of individual perturbations is high enough that the system has not recovered from the previous one at the time the next one arrives. Similarly, cumulative impacts occur when the distance between perturbations is such that individual effects have not declined to zero at the point where the effects of neighboring perturbations are no longer felt. Finally, cumulative impacts may arise when different types of perturbations cause similar environmental effects, provided that they fulfill the time and space criteria mentioned above. These general notions provide a suitable framework for analyzing cases to determine if a cumulative analysis is really needed. As the papers prepared for this workshop indicate very clearly, cumulative analysis is often required, but we should not automatically assume that this is the case without prior investigation.

SOURCES OF CHANGE THAT LEAD TO CUMULATIVE IMPACTS

It is useful to divide sources of perturbations of potential cumulative significance into two categories. The first, and the one which has received the bulk of attention so far, both generally and in the eight papers prepared for this workshop, is the addition of materials to the environment as a result of human activity. These added materials may conveniently be divided into two subcategories, chemicals and species of living organisms. Of these two, chemicals are the sole subject of the papers prepared for this workshop. Included are toxicants, nutrients, inert materials and chemical catalysts. All of them have the property that the quantity present in the environment is a direct function of the quantity added, adjusted by subsequent chemical interactions that modify those materials. The addition of species has the very different property that the numbers present may bear no relation to the numbers introduced, and the problem cannot be solved by stopping further additions. No laws prohibiting further introductions of rabbits into Australia or starlings to North America will have an appreciable effect on the impacts of those introductions.

Introduced species are a major source of environmental problems and, even though there is increasing awareness of the importance of reducing the flow of new species into the great biogeographical realms, the problem grows in magnitude. Indeed, solutions to other biological problems may have, as one of their components, deliberate introductions of still more foreign species. This occurs, for example, in pest control, agriculture and, most recently, with genetically engineered organisms. Indeed, the flow of species among biotic realms is so great that geologists may come to refer to the present period as the Homogocene.

Although the importance of introduced species is clear, I am unable to determine from evidence I have examined whether it really is a cumulative problem or whether it is best treated on a case by case basis. To frame the question differently, is the effect of the addition of more species to an ecosystem a nonlinear function of the number of introduced species already present? Should we be less worried about the first few introductions than about those occurring after the pool of exotics is already large? Or should we be more worried?

Cumulative impacts may also result from the removal of materials from the environment. The simplest cases of this phenomenon involve the harvesting of individual species of organisms, The effects of rates of harvest are seldom linearly related to population densities, and higher rates may propel the population into an alternative stable state. Such cumulative effects have been well studied in the population management literature, but they are often not considered cumulative effects even though management of renewable resources is basically cumulative effects management.

More complex cumulative effects due to removals of materials arise from alterations of habitats. This is almost exclusively a terrestrial and coastal problem. Human activities alter the mix of habitat types, making some types rare while increasing the frequency of other types. These alterations can and do have severe impacts on the organisms living in those patch types because of decreasing mean size of patches and increasing distances between patch types. The former results in higher extinction rates in patches and greater edge effects, both climatic and biological. The latter reduces colonization rates. For example, the increasing fractionation of the deciduous forests of eastern North America is leading to great reductions of populations of bird species with large territories or home ranges and of those species that require forest interiors (Anderson and Robbins 198 1; Forman, Galli and Leck 1976; Galli, Leck and Forman 1976). Surprisingly, a significant effect is due to the cowbird, an avian brood parasite which inhabits open country and only penetrates a short distance into forests to seek nests in which to lay its eggs. In small forest blocks a very high fraction of nests are vulnerable to cowbird parasitism.

Perhaps the most important single problem in biological conservation relates to our ability to preserve species in the face of habitat fragmentation. There is considerable debate about the details of the consequences of fragmentation (Diamond 1975; May 1975; Game 1980; Gilpin and Diamond 1980; Higgs 198 1; Margules, Higgs and Rafe 1982; Simberloff and Abele 1982; McCoy 1983; Harris 1984) and how best to respond to those effects when designing the sizes and shapes of reserves. There is, however, nearly universal agreement that the cumulative effects of fragmentation are important. This problem is of greatest importance in the terrestrial component of the earth because our perturbations of the atmosphere and oceans rarely produce comparable fragmentation effects. Nonetheless, this important topic receives only passing mention in the two workshop papers dealing with the terrestrial environment. More time devoted to consideration of this issue would be well spent.

PROCESSES THAT INFLUENCE THE NATURE OF CUMULATIVE IMPACTS

In one way or another, cumulative impacts are the result of the movement of materials. Here I examine the propensity of processes to concentrate or disperse materials added to the environment in order to provide a framework for anticipating where cumulative effects are likely to be the most severe.

Concentration

A number of processes lead to the concentration of materials, Most important of these are movements of the physical medium itself, such as atmospheric mixing and stratification, water currents, and downward movement of soil water. Other processes are relatively independent of movements of the medium itself. For example, chemical interactions cause flocculation and settling of suspended materials entering estuaries, and the settling of particles, living or dead, due to gravity. Knowledge of these movement patterns is the key to predicting where cumulative impacts are likely to be most severe and, hence, where they may need to be treated.

Living organisms, themselves, are responsible for considerable concentration of materials. Among these processes are aggregation and migration, trophic concentrations, metabolic alternations of materials which affect their solubility, transport and persistence, and, of course, reproduction.

Dispersal

Other processes, some of them the same as those leading to concentration of materials, are responsible for dispersing materials, either increasing or decreasing cumulative impacts, depending upon rates of dispersion in relation to sources and persistence of the materials in question. The complexity of spacial scales is such that attempts to solve local cumulative impacts by spreading the risk (solution by dilution) may transfer cumulative impacts to another scale; as when tall smoke stacks are used to meet local ambient air quality standards for pollutants.

A key component of an analysis of potential cumulative impacts in different environments should be a consideration of the types of processes leading to concentration and dispersal of materials, their relative strengths and rates, and how they may interact with one another. Such considerations are raised in several of the papers prepared for the workshop. I suggest that this theme may be worthy of deliberate attention in the workshop sessions.

HOW DO ENVIRONMENTAL DIFFERENCES INFLUENCE THE NATURE OF CUMULATIVE IMPACTS IN THEM?

One cannot read the eight papers prepared for this workshop without being struck by the diversity of ways in which the problems are framed. Some of these differences clearly represent the idiosyncracies of the authors, but many are a result of pervasive differences in the environments in which they have worked. Here I compare and contrast the four environmental types with respect to those features that appear to exert major influences on how cumulative impacts are manifest in them.

Atmosphere

The atmosphere is characterized by a lack of fixed physical structures. There are fronts, pressure cells, inversions, and boundary layers, but they change in position and may vanish for long periods of time. Moreover, the rate of global mixing is so high that materials emitted into the atmosphere can be carried to all parts of the globe in times short enough to be of relevance to cumulative impacts (Wallace and Hobbs 1977). As a result, a larger fraction of cumulative impact problems in the atmosphere are global in scale than is the case with other environments. Moreover, the usual solutions to dealing with local atmospheric problems inevitably lead to an expansion of the scale of their effects. In the atmosphere, processes of dispersal dominate those of concentration, but there are notable exceptions such as inversions and scavenging of particles by precipitation, that may lead to local concentrations of materials. Finally, the atmosphere is characterized by a relatively simple set of uses to which we put it. By and large, there is concensus about the values placed on the atmosphere within societies, even though there may be intersocietal differences. Canada and the Soviet Union may stand to gain from climatic changes induced by increased concentrations of atmospheric CO_2, while many countries at lower latitudes may be damaged. These differences, however, stem not from disagreements about the valued components of the atmosphere, but are a function of the spatial and temporal pattern of distribution of those benefits.

An important consequence of these characteristics of the atmosphere is that for a long time, modeling of effects has concentrated upon cumulative impacts. Most of the models being investigated today are regional to global in scale and cumulative in nature. I suspect that this is not so much a consequence of the fact that basic scientists have pioneered work on the global models, as suggested by Clark, but is founded in the very nature of the atmospheric system itself. This notion may be an appropriate subject for discussion and debate during the workshop.

Oceans

The oceans, like the atmosphere, lack fixed physical structures except at their boundaries, but significant constraints are imposed on their behavior by the positions of the continents and the sizes and shapes of the various oceanic basins. As a result, cumulative effects in the ocean tend to be more compartmentalized than those in the atmosphere. There is extensive mixing of water masses in the oceans, but many of the great and small circulation gyres in the oceans, in particular basins, retain water for long times. As well, the mixing provided by the deep ocean bottom currents is at such a slow rate that any cumulative effects will express themselves in time frames vastly different from those we use in modeling the atmosphere. Thus, in the oceans the relative balance between forces favoring concentration and forces favoring dispersal of materials are more evenly balanced overall and, depending upon the location, one or the other of these general processes may dominate.

Over much of the oceans human use is light and there are few conflicts over uses. Those that do arise primarily concern sharing of the harvests of renewable resources, not conflicts over how the oceans should be used. Along the coasts, however, where processes of concentration dominate, conflicting uses of marine resources become important for environmental managers. Development of aquaculture may interfere with recreational use of waters. Industrial developments displace spawning grounds. Toxic materials poison commercially valuable species. It is here that marine problems are most complex, and it is, accordingly, not surprising that treatment of estuaries dominates both of the papers on marine environments prepared for this workshop.

The undoubted importance of estuaries and the complexities of the problems they pose should not, however, divert us totally from consideration of potential global cumulative impacts in the marine environment. Preparation of a set of figures for the oceans comparable to those prepared for the atmosphere might be a profitable undertaking during the workshop and, if the preliminary efforts appear promising, they should be followed up after the workshop.

Fresh Waters

The world's fresh waters are bounded by very rigid barriers. The properties of lakes are profoundly determined by their sizes, shapes and the climates in which they are found. The behavior of added materials depends on the nature and extent of stratification of the waters, the residence times of water (turnover rates), and the chemistry of the inputs. Within lakes, processes that concentrate materials dominate over those that disperse materials, and the relative isolation of lakes from one another means that individual lakes can be, and usually are, considered as discrete units. The most appropriate scale for dealing with cumulative impacts is the individual lake and its immediate watershed.

Rivers are similarly bounded, except that they are connected by one-way flows of the medium and, hence, its contained materials. Materials entering flowing waters are dispersed when viewed from the perspective of the point of entry, but concentrated when viewed from the perspective of observers downstream. Rivers do have the capacity to purify themselves and whether or not there are cumulative impacts depends on the quantities of inputs, in particular, locations and distances between input sites. Dams, for example, produce a zone of nitrogen supersaturation immediately below them, but the flow of water quickly restores nitrogen levels to equilibrium with the atmosphere. On heavily developed rivers, however, flow distances between dams may be insufficient to restore normal nitrogen concentrations, leading to a condition of more or less permanent supersaturation over long stretches of the river.

Flowing waters are prime concentrators of materials, such that cumulative problems as perceived by limnologists are dominated by processes of concentration of materials. It is clear that the unit of consideration must normally be the watershed, or at least that part of it above the site of concern. This orientation is clearly reflected in the two papers prepared on fresh waters for this workshop.

Freshwater problems are strongly influenced by the multiple uses people make of lakes and rivers, many of which are in actual or potential conflict. One person's pollution is another's increase in production of some valued ecosystem component. Not surprisingly, a common frame of reference for dealing with cumulative impacts in these systems is known as "river basin management."

Terrestrial Environments

Of all environments, terrestrial ones are the most complex spatially and temporally. Spatial variation is expressed in the form of structures that are relatively persistent in time, such as soils, woody plants, and rock outcrops. Since the basic substrate is solid and not liquid or gaseous (although it does have components of both of those), movement of materials is highly restricted and many impacts, however severe, remain local in nature. As a result, much attention has been paid to dealing with cumulative impacts at a local level compared to the scale of, say, atmospheric problems.

Processes affecting concentration or dispersal of materials are very complex in terrestrial systems. Processes of soil chemistry result in leaching of materials through the substrate and into ground water; or, if precipitation is less, in their concentration in different layers in the soil, known as horizons (Jenny 1980). Many cumulative impacts find their appropriate focus in soil profiles, but this is a very unstudied environmental problem. If, however, the result is leaching, the problem becomes transferred to the aquatic sector.

It is in terrestrial environments that problems of deletions of materials and of creating different patterns of spatial heterogeneity become more important than they do in the other three major environmental types. It is also in terrestrial environments that the richness of different ways in which people use environments and, hence, what constitutes the valued ecosystem components, are greatest. Therefore, conflicts over land use are most severe. Indeed, cumulative impact management in terrestrial systems is, as stressed so clearly by Munro (this volume), in effect "land use management." Much time is spent arguing about which ecosystem components are most valued and, hence, which should receive special attention when changes in the mixes of uses are contemplated. Determining the appropriate boundaries of the problem is often very difficult. Baskerville (this volume) demonstrates that, left to their own devices, forest management practices may create cumulative problems on a scale much larger than those ever considered by the persons responsible for making those decisions. Munro stresses the important fact that there is no single land manager in charge. Politically we are organized such that the different valued ecosystem components are under the administration of different agencies, each charged with the protection and enhancement of their particular components. There is also complex ownership of land. It is no wonder that science and scientific information often have little to do with the ways in which these complex cumulative impact problems are approached and dealt with. Land use planners may well have "Atmospheric Scientist Envy." It remains to be seen if the procedures which have resulted in relative clarity in understanding of problems in that realm, can be successfully transplanted to the terrestrial realm.

Interchanges Between Environments

The organization chosen for this workshop, combined with the habitat-oriented ways with which environmental problems are usually dealt, results in underattention to problems of transfers of materials among environmental compartments. Indeed, universities are organized to reward investigators for confining their attention to events in the particular environments around which disciplines are often organized. Yet some of our most pervasive cumulative impact problems result from inter-environment transfers and some of them are, a *priori,* very nonobvious (Rudd 1964). It was not expected that applications of DDT to croplands in the Midwest would be a major contributor to reproductive failures of brown pelicans on the California coast. Therefore, discussion of exchanges of materials between environmental types will be an important component of this workshop.

THE MANAGEMENT OF CUMULATIVE IMPACTS

Several key components of the process of dealing with cumulative environmental impacts underlie the remarks in all of the management-oriented papers prepared for this workshop. I list them here for the purpose of providing a checklist that we might keep in mind as we discuss management problems in each of the four major environmental types.

Determining if Cumulative Impacts are Likely

Dealing with cumulative impact problems is much more difficult than dealing with project-specific impacts. We need to spend some time at the beginning to determine if cumulative impacts are likely, why they are likely and, hence, where they should be especially looked for. These were systematically set out for the atmosphere by Clark and are implicit in remarks in the other papers. Perhaps a more explicit treatment will help us focus our efforts.

Determining the Most Appropriate Warning Signals

Once the likelihood of cumulative impacts has been established, we need to initiate anticipatory monitoring systems designed to identify those effects so that corrective action can be undertaken in a timely manner. Monitoring has traditionally been either chemical or biological. Chemical monitoring is often favored because regulatory standards are cast in terms of concentrations of chemicals rather than on the presumed biological effects of those concentrations. The role of biological research was to provide scientific underpinnings for establishment of appropriate standards for concentrations of the chemicals.

There are, however, reasons for not relying exclusively upon chemical monitoring of materials because such monitoring does not provide useful information concerning how adequate the chemical standards are (Ward 1978; National Research Council 1979; Bromenshenk et *al*. 1985). Since most experiments used to determine standards are, in Baskerville's terminology, toy experiments, there are strong reasons for using living organisms to tell us whether or not the standards established as a result of those experiments are really appropriate in the more complex and variable field conditions to which they are actually intended to apply. The task is not an easy one, however. How do we decide the value of using unusually sensitive species, accumulator species that may be relatively resistant to the chemicals, or mixes of species so that competitive and predator-prey interactions are part of the monitoring program? Cairns (this volume) makes a strong case for using complex systems as the keystone of our monitoring program because they come closer to the real world whose protection is our ultimate goal. We may still conclude, in a number of instances, that unusually sensitive species tell us most of what we want to know and that we should continue to use them.

Undoing Cumulative Impacts

We are interested not only in reducing undesirable cumulative impacts in the future but also in undoing the undesirable effects that have already occurred. How can our knowledge of the processes leading to specific cumulative effects help us in the process of ecosystem restoration? Is restoration simply a matter of running things backward or do we need a new science of restoration? The European, and particularly British, experience, well advanced because of the relative scarcity of land, suggests that restoration must be viewed as a unique problem with its own theories and techniques (Bradshaw and Chadwick 1980). This may, however, be primarily a function of the peculiarities of terrestrial environments where alterations involve changes in long-lasting rigid structures and changes in habitat patches. In the more fluid environments, processes may be more reversible than they are on land, and it may suffice to simply reduce or eliminate undesired inputs to the systems and the problems will automatically solve themselves on time scales appropriate to the governing rate processes in the system. Whether we like it or not, management of cumulative impacts will involve many cases of shutting of doors after the horses are already out. The problem is knowing which of those doors are worth shutting and in which cases we really need to go chasing the horses.

Ignorance Has a Large Constituency

I close with an observation which has continually impressed me as I have dealt with environmental management problems. As scientists and managers we often assume that there is a common commitment to solving problems and to using the best available information and techniques to reach those commonly shared goals. However, because of conflicting interests over what are really the most valued ecosystems components, and the fact that debates on these issues are often highly public and involve strong commitments of people to particular positions, it often turns out that many participants have a vested interest in not knowing the answers and in keeping the debate at a high level of heat and ignorance. Any person who is strongly identified with a particular position, particularly when that position has resulted in the allocation of considerable resources to the outcome advocated by that position, has a strong vested interest in not finding out if that position is incorrect. Shortage of critical information is the best way to guard the sanctity of strongly held views, and this is as likely to be true for persons on the environmental side as on the developmental side of disputes. Therefore, although we are all dedicated to better problem solving, we need to be ever mindful that in the arena we have chosen to tackle, ignorance has a very large constituency. I predict this constituency to be large and healthy into the foreseeable future. Therefore, we should begin our discussions with expectations commensurate with the role that the facts and figures that will dominate our deliberations can be expected to play.

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TERRESTRIAL SYSTEMS

Scientific Perspective

SOME SCIENTIFIC ISSUES IN CUMULATIVE ENVIRONMENTAL IMPACT ASSESSMENT

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Forecasting environmental impact is difficult in the best of situations. It is particularly difficult against the background of inherently high variability in terrestrial systems. Terrestrial systems are characterized by extremely variable physical environments, both spatially and temporally. Not only do these environments influence the plant and animal communities, but the plant community can create significant local modification of the physical environment. Variability is the hallmark of terrestrial systems. This variability is pronounced in both the geographic and the temporal dimensions. Scientific approaches to impact assessment often flounder in this variability, either by failing to recognize it and becoming trivial, or by recognizing it without context and becoming anecdotal.

This paper expresses the opinion that there are two major issues to be faced in improving the scientific approach to cumulative impact assessment in terrestrial systems. First, scientific endeavours must be just that — scientific and rigorous. The essential concern here is bounding of the research and scientific interpretation at both the whole problem level and at the "piece" level. Second, impacts in biological systems accumulate in different ways. For research, or scientific measurement, to forecast or detect an accumulating impact, the protocol must be designed in a way that is appropriate to the manner in which the impact is accumulating. In the highly variable terrestrial environment, with the highly variable terrestrial systems, over both geographic area and time, cumulative environmental impact assessment requires scientific rigour if it is to be truly useful.

THE PROBLEM

In simplest terms, impact assessment involves the preparation and comparison of two forecasts of the future in a natural system. The first forecast is made to characterize how the system is expected to perform in the absence of perturbating development. The second forecast is made to characterize system performance as it is expected to respond to a specifically defined perturbation as a result of development. The difference between these two forecasts is the estimate of impact. Cumulative impact assessment is identical to environmental impact assessment, except that the bounding of forecasts with respect to geographic area, time, and variables included is broader with respect to cumulative impact assessment than it is with conventional environmental impact assessment.

In terms of scientific issues, management of a renewable resource is a very close analogue of environmental impact assessment. The manager of a renewable resource makes a forecast of system performance in the absence of any management interventions, and then makes a series of forecasts for specifically defined intervention regimes. Comparison of these forecasts with the no-intervention situation identifies the impact of each intervention regime, and based on this comparison, a management regime is chosen and implemented. In impact assessment, and in resource management, we must forecast impact. In management, the aim is to invoke certain impacts. In impact assessment, the aim is to limit certain impacts. In both resource management and impact assessment, the central form is that of a decision process, and a decision is always a choice between two or more forecasts that describe the futures which are expected to follow certain actions. Clearly, science cannot render the future certain, but these forecasts, that form the very basis of all environmental/management decisions, should have the strongest possible scientific base. The research that is necessary to improve impact assessment, and that is needed for resource management, is remarkably similar in form.

TWO CRUCIAL SCIENTIFIC ISSUES

From a scientific point of view the issues in cumulative impact assessment are essentially the same as in ordinary assessment. There are two crucially important scientific issues with respect to improving cumulative impact assessment. These are: achieving an appropriate design for quality research, and distinguishing different patterns in which impacts cumulate so that the research is properly aimed.

DESIGNING QUALITY RESEARCH

Achieving an appropriate design to ensure quality research is largely a matter of proper attention to problem definition and bounding, before research is undertaken. Failure to spend sufficient effort in placing research in context has all too frequently led to unhelpful science, and this problem is not restricted to environmental impact assessment. The bounding problem in terrestrial systems is similar to that in aquatic or marine systems; however, because of the highly variable nature of terrestrial systems, bounding specific pieces of research takes on added importance.

To put the scientific issue in the context of cumulative impact assessment, a very brief review of the bounding process in general is necessary. The first step in bounding a research study is to establish the geographic area that is the subject of the research, and to identify the units of subdivision (or lack thereof) of that total area. The point here is that geographic bound and the internal resolution sets the smallest unit of area for which interpretation is possible. In terrestrial systems, the climate varies from place to place, local climate can vary in terms of slope position and aspect, the nature of the plant cover itself influences the micro-climate of the community, and soils are variable from place to place, as is water availability. The plant community is determined by the result of all of these factors acting on the biological system; as a result the vegetative cover, both in species and structure, is highly variable from place to place. A research study can only speak to the piece of this melange that it has addressed. If a study characterizes a 1000 hectare area with no internal resolution of that area, then the study cannot be interpreted at the one hectare level — i.e., it can only express an average for the entire 1000 hectares.

Perhaps the only saving grace in this situation is that the basic process structure (photosynthesis, respiration, migration, etc.) is independent of geographic location, and bounding is a matter of establishing the appropriate interconnection of processes, and the manner in which the rates are controlled. In general, how a process works is independent of location, the rate of the process is dependent on location, and the linkages to other processes are somewhere in between. The most fundamental point, however, is that the sensitivity of performance in terrestrial systems to the various processes is not expected to be the same from place to place. Cumulative impact assessment must carefully bound with respect to geographic area, and define the nature of the subunits within that total area, so that sensitivity of forecasts to processes can be appropriately reflected in the overall assessment.

The second bounding issue is that of time horizon, and the size of the time steps taken in the forecast into the future towards that horizon. This is of course common to all forecasting problems, and with cumulative impact assessment the problem is no different.

The third problem is bounding which has to do with the identification of variables or components that will be used to characterize the natural system which is being examined with respect to impact. The issue here is which system components should be included (since it is impossible to include all of them) and what indicators, with what measures, should be used to characterize these components. You cannot make a scientific interpretation of a forecast with respect to factor X, if factor X was not a component of the forecast structure.

In these simple terms, bounding is a straightforward and normal part of good research. Since improper or inadequate bounding is frequently cited as the Achilles' heel of environmental impact research, let us examine briefly the difficulties of applying these simple and obvious rules. If one seeks to bound the problem of assessing the cumulative impact of acid rain on forest growth, the three simple steps are no longer simple. Indeed, much if not all of the confusion, with respect to the putative effects of acid rain on forest growth in eastern North America, is attributable to inadequate scientific attention to the bounding of research endeavours (Hare 1984). The acid rain problem covers millions of square kilometres including vegetational communities from prairie to boreal forest, and temporate mixed-wood forest. The impact has been accumulating over a long period of time, say in the order of a half century, and is continuing to accumulate now. The actual increments of acid rain occur daily, monthly, or yearly depending on the location of the plant community and climatological patterns. The response variable most commonly used is plant growth, which seems straightforward enough until one observes the plethora of indicators and measures of plant growth that abound in the literature.

How does one approach quality control in research into the impact of acid rain which accumulates on such a scale? Let us suppose for the moment that all the problems of bounding have been overcome, and that there is scientific agreement with respect to the total area under consideration, and to the smallest level of resolution within that geographic area; that the time span and time step are agreed to; and that the variables of the plant system to be used to characterize impact are agreed to. The classic research approach would be to match several geographic areas, and set up sampling systems appropriate to the agreed bounding. The acid rain would then be shut off for one half of the areas and the sampling continued, to provide the classic comparative experiment amenable to statistical analysis. Obviously, that is not possible. However, a close variant is attempted where areas with different acid rain loadings are used to mimic the "treatments." Note that in either of these cases, the two treatments are in different geographic areas, different plant communities, different soils, different local climates, perhaps different times, and different acid rain loading. We can rationalize that the differences are "small," but the differences are there. It is not surprising that attempts to approach the problem at this scale have wallowed in ambiguity.

There is, of course, a more incisive approach to the problem of researching the impact of acid rain on plant communities. A series of mist chambers can be used in which seedlings of appropriate species are grown under controlled regimes with respect to soil moisture, community structure, temperature, relative humidity, and of course acid rain loading. This procedure allows an unambiguous test with the most robust statistical procedures. What these tests show is the short-term difference between the plants growing in the environments of the different chambers, and not the cumulative impact of acid rain on the millions of square kilometres of highly variable forest.

This example illustrates the single biggest problem with research in cumulative impact assessment (or in resource management). Due to the spatial and temporal scales involved, we can never do truly rigorous scientific work with the real subject of interest. This leads us to create caricatures of the real problem, such as mist chambers, which are structured so that it is possible to do rigorous research. There is not much choice in this matter. It simply is not possible to introduce the levels of experimental control and system characterization that are essential to rigorous science at the level of the real-world problem, and it is therefore necessary to use caricatures of that larger real problem.

REAL, TOY, AND SCIENTIFIC RIGOUR

Sprague and Sprague (1976) offered an interesting perspective on the difficulties of doing research related to management level problems. Problems take one of two forms, real and toy. Real problems are those that exist in their real-world context, and their principal characteristics are large size, high spatial and temporal variability and general uncontrollability with respect to experimentation. The second group of problems are referred to as toy. Toy problems are the caricatures or models that we make of part or all of a real problem. Toy problems are characterized by being simple, small, clearly structured and well controlled with respect to experimentation. Similarly, they divided research approaches into real and toy categories. Real research is characterized by scientific rigour. This means a high level of control in well bounded situations with explicit measures and test protocols. There is a well-defined experimental approach and application of treatments to controlled subjects under controlled conditions with precise measurement and rigorous statistical analysis. Real research usually addresses cause/effect connections in a simple and direct manner. Toy research is characterized by observation of system states, which are the outcome of cause/effect connections, perhaps not even including measurement. From this, superficial analysis of system function is attempted from the outcomes, and in the absence of experimental control.

This characterization of research approaches and problem types allows four possible combinations. First, there is real research on toy problems. An example of this approach is the use of mist chambers to determine the impact of acid rain. The signal that a research paper is dealing with a toy problem is the appearance of such statements as "under constant temperature and relative humidity", "assuming the population structure is independent of harvesting" and other such statements that indicate the toyness, or abstraction, of the problem actually being researched. Second, there is toy research on real problems. This might be characterized by some of the more comprehensive efforts to assess the impact of acid rain on vegetation over large areas of forest where the messy nature of the problem is recognized, but maximum possible rigour is maintained.

Seldom, if ever, is it possible to do real research on a real problem. Sprague and Sprague concluded that in the rare cases where such research is possible, it certainly is not published, but rather is patented, or sold as a service. Finally, there is the possibility of toy research on toy problems. Environmental impact assessment has suffered more than its fair share of this sort of work, and this is the source of much of the most vehement public controversy surrounding impact assessment. In the acid rain context, an example of toy research on a toy problem might be an attempt to use small outdoor enclosures with covers to permit "control" of the amount of acid rain and the environment in which it is received. While such enclosures are outdoors and are therefore a subset of the "real" problem, they clearly do not represent the full variability of the real problem. Further, while covers might permit control of the amount of acid rain received, it is not possible to achieve the necessary rigour with respect to control of this and of other factors for a real research approach. The result would be flawed research and inadequate representation of the real problem, that is, toy research on a toy problem.

There is a potent message in the toy/real paradigm with respect to the use of science in environmental impact assessment in general, and in cumulative impact assessment in particular. Clearly, real research on toy problems is absolutely essential. These can be important building blocks for tackling the real problem if the toy problems are well constructed and bounded in the context of the real problem. Toy research on real problems is absolutely essential. This work can constitute integration of scientific understanding over the temporal and spatial bounds of the real problem if the scientific approach is rigorous. The key is to avoid toy research on toy problems, and to be honest about the extremely limited extent to which we can carry out real research on real problems. Do not underestimate the difficulties posed by existence of the latter two categories! Toy research on toy problems is the special domain of careerists, and invariably becomes part of the problem, and not part of the solution. It turns out to be very difficult for good scientists, who are by nature remote from the real problems, to recognize/admit/understand that their caricatures are not the real problem. Failure to recognize this can result in the caricatures not even being a useable part of the real problem.

FORMS OF CUMULATIVE IMPACT

The second major scientific issue, with respect to cumulative impact assessment, is how to distinguish between the various ways in which impacts can accumulate so that research can be aimed at the right target. In broad terms, there are three ways in which impacts could be cumulative in natural terrestrial systems. The first form of cumulative impact is that which results from a continuing incremental insult to the system. Acid rain might be a good example of such an insult. Here, each incremental loading of acid rain adds to the accumulated sum of previous increments over time. In such situations there is little loss or diminution of previous loading, so that the increments themselves do in fact become additive. In the acid rain example, while the occasional clean rain does not load the system further, it also does not purge the system of the accumulated effects. In these cases, the reaction of the biological system to the additive loading (i.e., the impact on the system) will also accumulate. The impact on the biological system may be either linear or non-linear with respect to the additive loadings, Similarly, incremental loading of an urban area with additional industrial plants is additive, and can result in either linear or non-linear impacts in the associated natural systems.

The second form of cumulative impact in natural systems is the situation where a single action or limited intervention results in alteration of the system structure, or system dynamics, such that the system itself accumulates the cause of an impact over time. An example of such an impact is available in the Cape Breton forests. Budworm-caused mortality has resulted in the loss of some 80% of the firs in these forests. The action of allowing the budworm to harvest this forest all at once, over a period of a few years, has set in motion a new accumulating effect which will have a delayed biological impact. The budworm harvest in this forest represents the largest cutover in modern times in this area, by far, and it has dramatically altered the age structure of the biological system. One outcome of this alteration is that there is now accumulating, in a very large area, an environment suitable for budworms in the future. There is a forest of essentially one age and one species type which over a period of some 40-60 years will reach a condition which once again will support/trigger another budworm outbreak. Thus, the cumulative impact could well be another insect outbreak. In the Nova Scotia case, the management choice has triggered an immediate change in forest structure which will continue to accumulate internally over time in the biological system, to result in a future impact. This form of accumulation is analogous to the delay between exposure to a carcinogenic agent and the onset of cancer. The initial loading incident may seem benign, but it is accumulated by the biological system into a form that becomes an impact much later in time.

A third form of cumulative impacts are those which accumulate by cycling over geographic space and time. An example here might be clearcutting in forests. Each year, as a portion of the forest is clearcut, it adds to the total of cutover area. However, cutovers are not static things and they always recover, although not necessarily to the “right” species. Thus, over time there is a dynamic balance between annual addition to the total of cutover by harvesting, and annual removals by plant succession. The effect of this is that the impact of clearcutting migrates across the geographic area through time.

Expanding this example to include the use of herbicides in plantations on cutovers might serve to clarify this situation. In a forest management unit of 500,000 hectares, some 10,000 hectares would be cut annually, in patches of about 200 hectares each. In the most intensive plantation scenario that is credible, some 40% of the annual cutover or 4,000 hectares is planted, and the remaining 60% or 6,000 hectares is allowed to regenerate naturally. Each plantation is treated with herbicides once or twice in the first six years of its life. In 50 years the forest would consist of 200,000 hectares of plantation in about 1,000 patches, and 300,000 hectares of natural forest stands in about 1,500 patches. The 200,000 hectares of plantation which have received herbicides will be in at least 1,000 different locations (each of about 200 hectares) scattered through the 2,500 patches of the 500,000 hectare forest. While environmental impact assessment of herbicides has traditionally concentrated on the local impact on a single hectare or a few square metres, an accumulating impact results from the fact that the herbicides alter the successional pattern over time where they are used, and that the location of their use migrates over the geographic area through time. Crop rotation agriculture and the migrating nature of light industry are other examples.

This categorization of cumulative impacts may not be all inclusive, and clearly is not mutually exclusive. The point in introducing it, however, is to illustrate that research approaches which do not recognize the different natures of cumulating impacts could fail to capture the real-world situation. In designing a scientific study, the nature of accumulation of impacts influences both geographic and temporal bounding, but particularly influences the indicators and measures that much be chosen in order to have a reasonable opportunity for scientific success. The problem in research design is perhaps simplest to illustrate in the case of the cumulating additive insults such as acid rain. Here the problem is one of detecting change (impact) in the biological system over long periods of time as a result of continuous acid rain loading. Real research in mist chambers can be of major assistance in determining whether the biological impact is likely to accumulate in a linear or non-linear manner. However, in the case of an impact which becomes embedded in the system structure or system dynamics and then accumulates within the system, conventional approaches to environmental impact research would fail to detect or forecast a problem. Impacts which accumulate literally within the system itself could very easily go unnoticed with conventional approaches to environmental impact assessment, since these tend to emphasize overall appearance of the system rather than its internal structure. The key here is to get an appropriate choice of indicators and measures. Finally, conventional research approaches, which concentrate on local effects or local impacts, will completely miss the accumulating impacts of things like clearcutting, which “cycle” over geographic space through time.

DO THESE ISSUES VARY WITH SCALE OF THE PROBLEM?

Two major scientific issues with respect to dealing with cumulative impact assessment in terrestrial systems are: how to achieve quality and rigour for research in problems that are so variable with respect to geographic area and time; and how to approach research of impacts that accumulate in different manners. Regardless of the scale of the problem, impact assessment, to be scientifically rigorous, must provide an explicitly based forecast of system performance without intervention, and an explicitly based forecast of system performance with intervention. Comparison of these forecasts is the basis of impact prediction and choice of action. That is the fundamental principle. The scientific issues do not vary so much from the micro to macro level. However, the practical difficulties of maintaining scientific rigour as you move from site-specific, to regional, to national problems, become immense.

Without the most careful and rigorous attention to scientific approach, there is a rather large chance that wrong (inadequate) impact assessment research will be carried out, particularly when the scale is large. The most important principle here is to design the research to suit the problem, rather than to suit a bureaucratically imposed framework, or data need. For example, if biological impacts accumulate from successive incremental additive insults of acid rain, then clearly research must address a relatively long time-horizon, with a relatively fine resolution or time step, if the impacts are to be detected and forecast reasonably in the context of the real problem. In this case, spatial pattern of the system may be less important, as long as differing loadings and species reactions are accounted for. On the other hand, if impacts in the biological system are accumulating as a result of some cycling insult such as clearcutting, then there is a need for a wide geographical area to be considered, and with a fine resolution of area within that total, in order to detect, and forecast, the relevant system dynamics. In this case, the time horizon and time steps may be of less importance. What is important here, is that bounding and research design be carried out in the context of the particular problem, whatever its scale and other characteristics. To be rigorous, each approach will have unique features that defy a “do it by the book” solution.

The main point of dealing with rigour in research approach and cumulative impacts at different scales, is that the real problem is qualitatively different as scale increases. As the real problem is seen differently, it is necessary to construct the toy problems used for real research so that they are most readily useable within the real problem context. Differences in the scale of the real problem, or in the nature of the accumulation, should lead to appropriate differences in the research approach. Failure to have the research match the problem in this manner leads to toy research on toy problems. Thus, the answer to the question “How do these issues vary with scale?” is that the issues themselves are the variation, as is the associated need for the scientific approach to vary, to maintain the maximum possible scientific rigour.

ARE CURRENT TECHNIQUES EFFECTIVE IN CIA?

This question defies an answer, since there is no convenient categorization of current techniques. However, some characteristics of the existing techniques in general need examination. Of particular interest here are techniques which attempt to predict environmental impacts themselves directly. These techniques are not rigorous science and inevitably result in great confusion in the environmental impact assessment process. The forecast of an impact necessarily implies that there exists forecasts of system behaviour, with and without intervention. Research claiming to identify impact which does not simultaneously characterize system performance without intervention and with intervention, is not credible science.

While the techniques of forecasting system performance for the determination of impact are variable, all have one thing in common. All forecasts are based on a characterization of system relationships. In some techniques this characterization is implicit, and therefore neither easily accessible to the reviewer nor scientifically rigorous. In others, the relationships are scientifically rigorous and explicit. It is a curious fact of human reaction that the wildest of implicit system relationship structures can go unchallenged, because they are unseen while the scientist who is rigorous enough to be explicit in stating his relationships literally invites challenge. Most problems in achieving an acceptable level of scientific quality in environmental impact assessment and in cumulative impact assessment in terrestrial systems stem from the way the system relationships are stated, or left unstated; that is, the degree to which system relationships in a forecast are left implicit, or are made explicit.

Explicitness of system relationships used in forecasts becomes crucial in bridging from the toy problems used for real research, to rigorous scientific analysis at the real problem level. When the system relationships are explicit the bridge from the toy problem to the real problem level can be relatively smooth. That is, it is relatively straightforward to embed the parts of the problem that have been researched, into the whole problem context. Scientific argument is the norm with respect to this bridging; it focuses on real statements, and is usually an intellectually constructive exercise. However, when the system relationships are left unstated, that is, when they are implicit, bridging from the toy problem to the real problem is a rocky road indeed. In the absence of a rigorously explicit framework, the toy problems that could be the potential building blocks of analysis simply float. Argument is non-productive largely because there is no focus, and there is a rather blind attempt to discover what the implied relationships really were. Such forecasts lack scientific rigour, and are seriously challenged in the scientific community, although their simplicity and easy understandability frequently make them popular with the media and the public.

In the broadest context, it is easier to identify what is missing in effectiveness of current approaches and techniques than to provide an overview of them. What is missing is any evidence of a systematic approach to avoid qualitative forecasts with implicit relationships, and the poor science that this implies,

HOW CAN CIA BE IMPROVED?

To the bystander not involved in environmental impact assessment, the attempts in that area to come to grips with real problems that are spread over geographic area and time have bordered on disaster. Having made that over-simple indictment I would follow with an equally over-simple prescription for better performance. What is needed most of all in cumulative impact forecasting is more scientific rigour. In preparing an analysis of a real problem from bits and pieces of research on toy problems, it is more important that all of the relationships are explicitly stated than that they be “right.” No one expects science to deliver the ultimate truth in these matters, but scientists at least expect that whatever relationships are used are expressed in a manner that renders them open to scientific discussion. Obviously, it is important to have relationships stated in the best possible form in terms of existing scientific evidence, but it is even more important that the statement be sufficiently explicit so that others can debate the statement rather than argue about what the “unstatement” really means.

The major necessity with respect to advancing the quality of cumulative impact assessment is open recognition by the players of the real situation. We will never be able to bring full scientific rigour to research on impact in the real problem categories. It is essential therefore, to recognize that the real/toy problem dichotomy exists, and to make the difference clear for others who use or interpret a forecast. Until the recognition of the real/toy dichotomy is openly made, we do not put sufficient effort on placing the real research we do on toy problems into a usable context. To return to the acid rain mist chamber example, this contextual problem can be extreme. We want to interpret the results of rigorously conducted experiments in mist chambers into a highly variable forest system with uneven canopies, of varying species, that result in wind eddys, differential loading of acid rain on different species, on different soils etc. The real problem is indeed monumental, but it is not necessarily intractable. If rigorous, real research is carried out on carefully constructed (toy) components of the real problem, it will be possible to greatly improve our analysis of the real system. It is equally important that we attempt research on the real problem itself in the most rigorous scientific manner possible, given the messy nature of real problems. That is, while recognizing that our research on the real problems is necessarily of a toy variety, we must make it the best possible research. The key here is to set up the research in a manner that uncovers what the components of the real problem are, and how they fit together. That is, the toy research on the real problem may not necessarily be aimed at determination of impact, but may rather be aimed at discovering system structure so that impact can be more credibly explored by research on toy components. Above all, we need major efforts on careful rigorous construction of real problems from toy parts to get consistent forecasts that are in a form amenable to scientific discussion.

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COMMENTARY I

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Although I shall cover some of the same problems as Gordon Baskerville, my emphasis will be quite different in several respects. First, I shall amplify his first point, that environmental impact assessment must be scientifically sound, rigorous, and quantitative, by stressing that it also must be able to make accurate predictions based on a knowledge of general ecological laws. Second, I shall not dwell on specific methods and approaches, because I am not sure that we even understand the problems well enough at this point to make wise decisions about which techniques to apply. Third, I shall emphasize that in order to predict with reasonable accuracy the long-term, cumulative effects of human activities on natural ecosystems, we require a quantitative, predictive understanding of the variables. and processes that interact to determine the structure and dynamics of complex ecological systems. Fourth, I shall briefly discuss two areas of general ecological research where substantial progress is essential in order to predict the effects of either natural or artificial perturbations. Finally, I shall mention some aspects of these general problems that are particularly relevant for terrestrial ecosystems.

ECOLOGICAL COMPLEXITY AND PREDICTABILITY

It is indisputable that most ecosystems are complex. Millions of species and billions of individual organisms inhabit the earth; hundreds of species and thousands of individuals occur in the small patches that constitute most ecologists' study areas. The multiplicity of interactions of all of these organisms with each other and with their inanimate environment defies the imagination, but it is these relationships that structure the living world, maintain its diversity, and determine its responses to natural and artificial perturbations.

I strongly believe that the only hope for developing a scientifically sound basis for assessing environmental impacts, especially long-term cumulative impacts, is to discover the general laws that govern the structure and dynamics of complex ecosystems. Some may argue that there are no such laws, or if there are, we will never acquire sufficient data and techniques to discover them. If this is so, I submit that this workshop is a waste of time, and the future of natural ecosystems and of man himself is even bleaker than most of us are prepared to believe. The effects of modern man on ecosystems are so large and pervasive, that only by predicting long-term, cumulative impacts, and by employing scientifically sound procedures to mitigate the most deleterious of these, can we hope to maintain a biosphere that will continue to support our existence.

There are two kinds of prediction, differing greatly in their logical and scientific bases, their power, and their practical applications. One kind is based solely on retrospective analysis of patterns in space or time. An example is my ability to predict, within two minutes, the time of sunrise tomorrow, based solely on my knowledge of what time the sun rose this morning, and of the tendency of the sun to rise every day within a minute or two of sunrise the previous morning. The other kind of prediction is based on knowing the relevant state variables and laws that determine the structure and dynamic behavior of the system. Thus, I could also predict the time of sunrise tomorrow with approximately equal accuracy based on a knowledge of my location on earth, and of the physical laws that dictate the movement of the earth relative to the sun. The latter prediction is much more powerful, however, because I do not require retrospective, site-specific information. Given the mathematical model that describes the movement of the sun relative to the earth, and the latitude and longitude, I can predict the time of sunrise tomorrow anywhere in the world.

It is this latter kind of prediction, based on scientific laws, that is required to make any but the most trivial assessment of environmental impact. Most ecosystems are so complex, and so variable in space and time, that the previous behavior of the system (or the behavior of a similar system in a different place) may frequently be inadequate to predict its response, even to natural changes within the range it has previously experienced. Yet, environmental impact assessment implies the ability to predict the response of an ecosystem to artificial perturbations that exceed the range of natural changes. In reality, most current environmental impact statements are entirely subjective estimations by "ecologists" of variable training and expertise, based on information of varying quality and relevance. Given the necessity and urgency of protecting the environment, even these assessments play an essential role. As professional scientists, however, we must recognize that most developed nations (including Canada and the United States) have laws for environmental protection that require a "technology," environmental impact assessment, that does not yet have a sound scientific basis.

Unfortunately, supplying the lacking scientific rigor is not simply a matter of technology — of applying existing basic scientific knowledge to practical problems. We require substantial progress in basic research to develop a rigorous basis for predicting the impact of ecological perturbations. The problems of obtaining and applying the necessary knowledge are particularly severe for two reasons. First, ecosystems are so complex that responses to perturbations are expressed on different spatial and temporal scales, and then these responses interact with each other to produce delayed, higher order effects. Important impacts can be indirect and cumulative, thus they are extremely difficult to predict. Second, as the human population has grown, it has increasingly subjected natural ecosystems to kinds and magnitudes of perturbations far beyond the range that these systems have ever experienced, and also beyond the range of the experimental manipulations tested by most ecologists. Terrestrial (and freshwater) ecosystems have special features that influence their susceptibility to artificial perturbations and affect their responses. These issues are discussed in the following sections.

INTERACTION NETWORKS

Traditional ecological theory is based largely on models in which species interact with each other and with their physical environment in a simple, pairwise fashion. Implicit in much community and ecosystem ecology is the assumption that it is possible to understand the structure and dynamics of complex, multispecies systems by putting together these basic units of pairwise interactions. The inadequacy of this approach has been revealed by recent theoretical and empirical studies. Theoretical studies have suggested that the dynamics of species populations are linked to other species and to factors in the physical environment by a complex network of interactions. A consequence of these networks is that both physical factors and species can have major indirect effects; species populations respond to chains of interactions in which physical factors and intermediary species comprise the multiple links. Compared to effects of direct, pairwise interactions, the outcomes through these indirect pathways can be substantially delayed in time, greater in magnitude, and opposite in sign (e.g., mutualistic rather than competitive).

Empirical studies of natural ecosystems, especially experimental manipulations that have continued for many months or years, have supported most of these theoretical predictions. Much of my own current research is devoted to identifying the pathways of interaction that affect or are affected by species of seed-eating animals in a desert ecosystem. By means of experimental manipulations that have been sustained for almost eight years, we have found numerous pathways of at least two links (e.g., incorporating three or more species or physical factors). We have examples of direct predator-prey and competitive interactions that were reversed by indirect mutualistic effects, but only after delays of several years. Perhaps the most important message, however, is that many of the indirect effects were unexpected. Certainly we would never have predicted the multiple, long-term results of our manipulations from our knowledge of the direct, pairwise interactions.

It seems increasingly clear that many of the important characteristics of natural ecosystems, including their capacity to maintain high species diversity, and to be resilient to natural and artificial perturbations, must depend largely on the structure and dynamics of these networks of interactions. Thus, some of the important laws of ecosystem function must specify the properties of complex pathways of multiple interactions. Much additional research will be required, however, before the laws have been elucidated to the point that they can be used to predict the diverse ramifications of particular perturbations.

SPATIAL AND TEMPORAL SCALE

Another problem with developing a sound basis for prediction is the result of a different kind of complexity. Traditionally, ecologists have conducted their studies on spatial scales ranging from square meters to hectares, and on time scales ranging from days to years. The inadequacy of this restricted focus recently has become evident. Processes that operate on the spatial scales of continents, oceans, and even the entire earth, and on temporal scales of thousands and even millions of years, have major effects at all levels of ecological organization, from the abundance and distribution of individual species to geochemical cycles. The consequences of such large-scale phenomena for human impacts on the environment are now recognized, even though they are not yet well understood. Maintaining the grizzly bear in Yellowstone National Park, reducing acid rain in eastern North America, and restoring eroded soils on overgrazed rangelands in the Southwest are practical problems whose solutions are enormously difficult because of problems of scale. It is one thing to recognize these problems, and quite another to predict them in advance. Prediction is especially critical in these cases, however, because of the large-scale processes involved. Once they have been identified as major problems, they are usually enormously costly if not practically impossible to correct.

Furthermore, just because we can recognize some of these problems once they have become sufficiently severe, does not mean that we yet have any sound predictive understanding of these classes of phenomena. In fact, the phenomena are often extremely complex. They are usually not solely the result of large-scale processes, but of the interactions among a number of dynamic processes and state variables that exert their effects at different spatial and temporal scales. Effects of perturbations may be long delayed and may accumulate in unanticipated ways, because of the networks of multiple interactions.

Again, much additional research is needed. Ecologists have an unfortunate tradition of thinking we understand a level of organization because we have defined it operationally. Thus a population, community, or ecosystem is whatever an ecologist chooses to study. Even when these units have somewhat natural boundaries, and are essentially closed systems with respect to certain processes, they are open systems with respect to other processes that ultimately may affect the phenomenon of interest. For example, even though the U.S. Department of the Interior manages Yellowstone National Park on the assumption that it is a closed, natural ecosystem, this assumption is conspicuously violated for such important components as the atmosphere and the large mammal populations. As a result of human impacts on these elements outside the park, the park ecosystem is undergoing substantial long-term, cumulative changes. The only way to understand these kinds of phenomena is to expand the spatial and temporal scales of ecological research. To a large extent this will require breaking down the traditional boundaries between ecology and related disciplines, such as biogeography, evolutionary biology, climatology, and geology. The complexity of the problems will usually require more knowledge and tools than any single investigator possesses, and interdisciplinary collaboration will be required to make substantial progress.

TERRESTRIAL ECOSYSTEMS

Some of the special features of terrestrial ecosystems are particularly important for predicting cumulative environmental effects of human activities. Man is a terrestrial animal, and his exploding population has been sustained primarily by the exploitation of terrestrial resources. Natural ecosystems over an impressively large fraction of the earth's land surface, including the most productive habitats, have been destroyed to provide food, habitation, and minerals for the human population. Most of these changes have reduced primary productivity, caused major, potentially long-term changes in the local soil and water, and had effects beyond the boundaries of the exploited areas. Simultaneously, the relatively unaffected areas of native habitat have decreased in size, become spatially isolated, and been increasingly influenced by events outside their boundaries.

The relatively sedentary nature of many plants and animals, and the limited spatial scale of many physical processes on land, results in the impacts of some kinds of perturbations being concentrated within local regions, rather than being dispersed over a wide area. For example, species with limited dispersal may be permanently affected by local extinction. Chemical and radioactive pollutants may not be dispersed, and soil lost through local erosion may be replaced only after thousands of years of primary succession. Perennial plants, which are the predominant primary producers in terrestrial ecosystems, are long-lived and dispersed only passively as seeds. Thus, important biotic interactions may be highly localized initially, even though they may eventually have large cumulative effects over space and time. The spatial structure of terrestrial ecosystems thus affects the spatial and temporal scales on which complex networks of interaction are resolved. These problems of scale increase the potential severity of certain kinds of perturbations, and make their cumulative impacts more difficult to predict.

CONCLUSIONS

My overall message is one of unabashed skepticism about the present state of environmental impact assessment, but cautious optimism for the future. There is presently little sound scientific basis for making any but the most trivial predictions about the long-term, cumulative impacts of human perturbations. Major advances in basic ecological research are required to provide a sound basis for a technology of impact assessment and prediction. These advances will not come easily, because ecological systems are complex, major interdisciplinary research programs are needed, and public concern and government funding for ecology are limited. Nevertheless, ecological research has made great progress in the last few decades. Ecology has emerged as a rigorous science concerned with asking general questions, gathering quantitative data, building mathematical models, and testing them with appropriate experiments and statistical analyses. The discipline is beginning to acquire the information and tools required to elucidate the relationships among the multiple variables and processes that determine the structure and dynamics of complex ecological systems. Only when these relationships, the fundamental laws of ecology, have been discovered, will we have a sound scientific basis for predicting the cumulative environmental impacts of human activities.

COMMENTARY II

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The following are my responses to some of the issues raised in the eight papers submitted for discussion, amalgamated with a little of my own thinking on cumulative impact assessment. I totally agree with Baskerville's plea for more scientific rigor in impact assessment, and have very little to add to his discussion of how studies of "toy" problems should be integrated into head-on studies of large-scale "real" problems. I leave the specification of how this might best be accomplished to those more familiar with research in this area. I admit to several biases that will be apparent in the following comments.

First, to my mind, the issues of cumulative impact assessment and cumulative impact management are indivisible: cumulative impact assessment is only one tool for managing cumulative effects, which is our primary goal. By this I do not mean that research must slavishly follow the dictates of management, but only that by considering assessment in a management context we can identify the best ways that science can help solve the problem.

Second, in any kind of impact assessment we are trying to predict and detect changes that can be causally linked to some source(s); when we can make the connection, we call the changes effects. When the effects are valued as negative, we call them impacts, because what we deem now as a positive effect may in the future be seen as an impact. I believe we should be addressing ourselves to cumulative *effects* management. Only by doing so can we develop a balanced perspective for relating the tasks of prediction and management to the goals of society. Only by doing so can we examine the consequences of our efforts to "enhance" ecological systems and all that entails

Third, I am a terrestrial ecologist, and think of cumulative effects problems in terrestrial terms.

CATEGORIES OF CUMULATIVE EFFECTS IN TERRESTRIAL ENVIRONMENTS

As Baskerville points out, the design of research on cumulative effects must be appropriate to the ways that impacts accumulate. impacts may accumulate incrementally in a given area or system from repetitive perturbations from a variety of different sources, the classic example being nutrient and pollutant buildup in a lake. In spite of their many complexities, these problems are the easiest to conceptualize, if not to manage. Limnologists have often had some success, at least in making rough predictions of lake deterioration, although management success has usually depended on the existence of a comprehensive planning and control authority. However, this scenario is much more typical in aquatic than terrestrial environments, partly because the sins committed in the atmosphere and on land are usually visited upon the waters sooner or later. An often neglected example in this category is the cumulative effects of resource management decisions over time, e.g., inadvertent selection for small size or undesirable behavioral traits, or loss of genetic variability from failure to consider the consequences of harvesting practices on population structure. How frequently is this kind of cumulative effect occurring in non-managed populations? How can we detect it?

The accumulation of effects over increasingly large areas with time — such as the attrition of habitats, species, or ecosystems — is a common problem, and intimately related to one of the major long-term issues for terrestrial environments, fragmentation of ecosystems and species populations. What we see at any given time is a map of pieces of habitats of various sizes and spatial relations; in various stages of deterioration, rejuvenation, restoration, enhancement, or just ambiguous change; with activities in some pieces affecting conditions in others; and all changing in response to a plethora of factors. In this mosaic, over a long period, we see trends, shifts of direction, and step changes. How can we possibly deal with this complexity?

Without question, the only way to approach this problem is with research geared to a comprehensive planning effort based at a regional level. Perhaps the land use suitability and conservation strategy approaches outlined by Munro (this volume) would be a good start. Within such a framework could be integrated such considerations as the sensitivity of ecosystems to stress, the significance of particular ecological systems for the functioning of others, the concepts of rarity and abundance, and so on (Cooper and Zedler 1980). It is also conceivable that this approach could integrate the results of recent exciting, if preliminary and sometimes controversial, research into metapopulation analysis, patch dynamics, and island biogeography (e.g., Soulé and Wilcox 1980). The task of pulling this all together may be daunting, but I think something similar will inevitably be needed. The burning question here is to what extent we can deal effectively with the complex mosaic of changes that are occurring, without attempting to coordinate management of cumulative effects with stated goals and at a high administrative level. A goal-oriented approach to ecological planning is presented by Steiner and Brooks (1981), one based on resource allocation by Norton and Walker (1982), and one based on ecosystem sensitivity by Cooper and Zedler (1980).

Some actions can have a triggering or precedent-setting effect on future developments, ushering in a new set of environmental perturbations. For example, in construction of the road to Prudoe Bay, much consideration was given to problems with permafrost and caribou migration, but no real attention was given to the possible long-range changes in the patterns of activity on the North Slope that the existence of the road might initiate. Is this a cumulative impact? It differs from other cumulative effects trends primarily by the step-change in effects that dominate. What should be the input of ecologists to this sort of thing? Is this primarily a socio-political problem? Such actions certainly can lead to some-of our worst cumulative impact problems (e.g., massive soil erosion problems consequent to changes in farming technology). Baskerville's category of impacts that are embedded into a system only to show up in the future seems closely related to the triggering phenomenon.

UNCERTAINTY IN A COST/BENEFIT FRAMEWORK

Baskerville's point that scientists should make explicit the underlying assumptions in their arguments and process models is well taken. By communicating the bases of predictions, we both generate constructive discussion and analysis, and we provide decision makers with a means by which they can judge a prediction's reliability. On the other hand, to be too energetic in proclaiming our inability to predict effects in the face of overwhelming complexity, mind-boggling variability, and so on, can be counterproductive. This tactic may drum up a few dollars for research, but can have some negative consequences for our real goal here — to manage and control cumulative effects. We must ask how the nature of our scientific input influences management decision.

In the political climate surrounding most cumulative effects issues, scientific predictions of ecological effects influence management decisions to the greatest extent when the estimated magnitude of change is large, when the predictions are perceived as reliable, and when the costs attendant to the changes are perceived as being substantial. Obviously the only way to improve our predictive capability is to increase our knowledge and understanding through research and analysis, but in the short term, there are two ways to make the decision-making process a bit more likely to work in favor of the environment. First, take a little credit for our successes. This may be as important as specifying our limitations. This is not to say that we should pretend to know what we do not, but that we should admit that we do know something. There have even been a few smashing successes in prediction and control — the Lake Washington story being a classic example. Second, we can add a lot to the scope of perceived costs.

As Glantz and McKay (this volume) so eloquently point out, we only deem polluters liable when we can pin the responsibility on them with some assurance, and they can often evade the costs of managing the effects they cause. Clearly the "costs" in cumulative impact management are not only the financial costs of management, but also the costs borne by society as impacts accumulate. Some of these costs are obvious, because the effects occur close to the source, in space and time. Many cumulative impacts, however, are indirect and obscure. What are the long-term consequences of the continued attrition and fragmentation of ecological systems? The very important role that ecologists can play in this arena is to track down, reveal, and make clear the sundry and devious pathways by which the costs of continued perturbations come back to haunt society (we need only to discover them!). The matrix approach suggested by Clark (this volume) is an excellent start, but it is clear that to fill in such a matrix will require a great deal of coordinated research. Ultimately, cumulative impacts are always viewed within a cost /benefit framework, and the effectiveness of our management of cumulative impacts will improve only if we can develop a balanced framework for detailing and evaluating the often externalized costs of environmental deterioration.

THE RELATIONSHIP BETWEEN ENVIRONMENTAL IMPACT ASSESSMENT AND CUMULATIVE IMPACT ASSESSMENT

Both environmental impact assessment and cumulative impact assessment attempt to make a causal connection between some source(s) of perturbation and some environmental effect. In both cases, we are interested in predicting and measuring the amount of change that can be attributed to particular sources, and we wish to separate this increment from the amount of change due to other sources of variation, natural and human-induced. EIA is site-specific: CIA usually is not. Apart from obvious differences in the scale of the respective enterprises, CIA has one other feature that EIA normally does not. CIA is a form of pattern analysis, and cumulative effects management is the management of patterns. Much effort in CIA must go into the detection and analysis of trends, with the development of elaborate accounting procedures. In short, CIA needs some scientific input that EIA does not. In addition to a system for identifying trends in sources and effects, management of cumulative effects requires analytical tools for detecting critical thresholds — in effect, a warning system.

Practically speaking there is really no way that EIA, because of its site-specific, single development orientation, can do the job of CIA. However, there are several ways by which EIA can be incorporated into CIA. First, if all EIAs were conducted according to the standards set out by Beanlands and Duinker (1983), they could serve as a case file, an empirical base for models of cumulative effects. To do so, EIA would have to incorporate hypothesis testing and post-development audit of predictions. Second, regional coordination of EIAs could involve the allocation of generic studies to individual assessment responsibilities. Such studies could be designed by investigators working on cumulative effects, and could serve to improve not only our ability to do CIA, but also our ability to do future EIA. Studies could also be allocated to investigate the consequences of site variation and the like. Third, EIA could feed into and draw from regional ecological synthesis, as suggested by Cooper and Zedler (1980).

One of the major failings of EIA as a method for protecting the environment in the long term, is its inability to handle the consequences of multiple minor impacts, called the tyranny of small decisions (e.g., see Odum 1982). (EIA is often waived when impacts are expected to be small.) The design of EIA studies is usually inadequate for detecting any but the most serious effects (if follow-up studies are done at all), resulting in a high probability of making a type II error (concluding that an effect has not occurred when it has). The combined consequences of many such errors can be disastrous, yet this is how many land use decisions are made. Only some kind of regionally based scheme can deal with this problem, because it is unlikely that EIA can be upgraded to the extent that small effects can be detected. To ask that cumulative effects be dealt with only by EIA would make EIA an even more superficial "shotgun" affair than it already is.

A FEW QUESTIONS TO THINK ABOUT

- Can we really effectively control and manage cumulative effects without first establishing a comprehensive set of societal goals for protecting the environment?

- Do "breakthroughs" in managing cumulative effects occur only when comprehensive planning and control are instituted?

- How do we view "enhancement" of some ecological systems in the schemes of CIA? Is it an off-setting plus? Too much "enhancement" can wreak some very big changes in ecosystems.

- Is it always the best idea to try to maintain systems as they are, as we often do? When is this a bad idea?

- Do the difficulties encountered with increasing scale lie mostly in a failure to develop appropriately scaled management authority, or in our inability to predict effects at larger scales? How much better can we really predict at the EIA level than at the CIA level?

- Should the establishment of anticipatory monitoring be an essential part of any CIA program? How do we decide what to monitor, given the incredible variety of cumulative effects that occur? There are far fewer obvious Indicators of terrestrial environmental quality than there are for aquatic systems.

- If we need better interchange and communication between basic scientists and those tackling assessment problems head on, how do we achieve this?

- What can we offer local decision makers that will help them consider and deal with cumulative effects?

- What are the essential scientific components of a good CIA program, and how do we organize and coordinate them?

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Management Perspective

ENVIRONMENTAL IMPACT ASSESSMENT AS AN ELEMENT OF ENVIRONMENTAL MANAGEMENT

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The premise of this paper is that environmental management is a crucial requirement of any society. Environmental management is defined as the control and direction of human activities which have an effect upon the environment such that economic development is environmentally sound and sustainable. It must be guided by the need to work toward achieving the broad goals that society has agreed upon.

Environmental impact assessment (EIA) is an important element of environmental management, but it is questionable whether, in its present form at least, it should be the dominant element that it seems to be in a number of jurisdictions today. This paper examines some of the inadequacies of EIAs, the circumstances in which they are undertaken, and their relationship to other elements entering into development decision making, with particular reference to the requirements for effective management of the terrestrial environment. [1]

There is concern that EIAs as currently undertaken fail to take sufficient account of all the factors pertinent to development decision making (Emond 1981). Project- or site-specific EIAs may be too limited in terms of time, space or policy context. They may fail to reflect the significance of related events expected to occur in the future, or of ecologically linked consequences occurring at some distance from the project. Most significantly, however, they usually fail effectively to relate project costs and benefits to broad social goals (O'Riordan and Sewell 1981). EIAs must often be undertaken within a very limited period of time and, major decisions having been made, the terms of reference are often such that the scope of their recommendations is also very limited. These shortcomings result largely from the fact that EIAs are reactive rather than proactive. They are activities that are usually add-ons to planning processes already ongoing, rather than elements built-in to comprehensive, integrated development planning.

A somewhat different group of concerns is that changes in land use and technology associated with agriculture, forestry and urban development, activities that are centred in the terrestrial environment, are not usually the subject of EIAs. However, their long-term, cumulative impacts may be as significant as those of mega-projects.

It has been proposed that a more comprehensive concept of EIA, to be termed cumulative impact assessment, be developed as a remedy for some of the shortcomings mentioned. It is the purpose of this paper to contribute to that development, primarily by stressing the importance of a comprehensive policy context, and of the relationship between EIAs and land use planning.

REQUIREMENTS FOR MANAGEMENT OF THE TERRESTRIAL ENVIRONMENT

A first, necessary step is to consider the requirements for management of the terrestrial environment (the land*). The requirements will themselves be conditioned by what society has decided it wants. This question of social goals is of primary importance, and will be further dealt with below.

Defining the requirements is complicated by the fact that the land has so many managers, and can be put to so many uses. Private owners manage a small fraction of Canada's land surface, but it is the fraction that is most productive agriculturally, and is most densely populated. If food production is important, it is similarly important that this land be saved from significant degradation, and that it not be allowed to diminish in extent.

Private owners can decide to act in a wide variety of ways that will affect the land. They may log, clear natural vegetation, drain surfaces or subsurface water, level, cultivate, plant a host of different crops, irrigate, spray with herbicides or pesticides, put animals out to graze, hold them for fattening. They may extract minerals, hunt; allow the construction of

1 The environment is indivisible Emphasis on management of terrestrial environment is simply a matter of convenience in attempting to deal with a large and complex subject: it should not be allowed to obscure the numerous significant linkages between terrestrial. atmospheric, freshwater and marine environments Consider, for example, the relationship between soil erosion, water quality, and the welfare of anadromous fish; or the various effects of wetland drainage

2. "Land" is used here to refer to the land itself, the flora and fauna that it supports, and the minor surface waters that rest or flow upon it.

transmission lines, pipelines, roads or railways, or the erection of residential, commercial or industrial buildings. Each such action may be undertaken in a number of different ways, and with different types of equipment. For example, a field may be cultivated with a one-way disc or a no-till drill may be used; cultivation may be parallel to the contours or to the fence lines; land may or may not be summer fallowed. Herbicides or pesticides may be applied generally or selectively, at recommended rates or more intensively.

The owner's choice of action and the way in which the chosen action may be undertaken, are subject to varying degrees of control by municipal and provincial governments, less often by the federal government. Depending upon where the land is located, and what type of action is planned, control may take a number of different forms, for example, zoning for various uses, prescribing within certain areas activities considered to be harmful, or limiting the extent of exploitation. Some sorts of action, for example, most agricultural practices, are virtually uncontrolled.

While the private use of land is extremely important for environmental management, most of the land of Canada is Crown Land. Except north of 60°, it is owned by the provincial governments and its use is allocated by them. Crown land is usually allocated to what are termed the "less intensive" uses (e.g., forestry, grazing, hunting, mineral exploration and recreation). To varying degrees, these uses are controlled by the provincial governments. In most provinces, control by governments over the activities of both owners and lessees is exerted by a number of different agencies. They do not always work closely together, although coordination has improved considerably over the past decade. To the extent that the provincial governments do not control use of Crown Land, control is exerted by lessees such as ranchers, loggers or miners.

Thus there is no single manager of the terrestrial environment, but if there were, what would his responsibilities be, and what information would he require?

The task of the hypothetical manager of the terrestrial environment is to maximize the sustainable contribution of the land to the achievement of social goals. He will be largely concerned with the following sectors: agriculture, forestry, urban development, mining, industry, transportation and transmission, recreation, wildlife management and tourism. To undertake his task effectively, the manager will want to have information on the aggregate results of the use of all land within his jurisdiction, and on the specific effects of changes in the use of particular parcels of land.

Some such information will, or should be available in the basic data banks associated with land use planning systems; the balance will need to be acquired through EIA. The land manager's concern with respect to the effects of change in the environment will revolve around the following points:

- What areas of land are (or, as a consequence of a change in land use, will be) available for each of the foregoing sectors (on the basis of exclusive use or multiple use)?
- What is (or will be) the suitability of the land for its allocated use(s) or alternative uses?
- What is (or will be) its productivity? (Maximum productivity should not be thought of as the inevitable result of what economists term "highest use." In other words, the concept of productivity should not be based solely on economic criteria).
- What measures need to be adopted in order to safeguard (or restore, or enhance) its productivity?
- What contribution does the land make to the achievement of social goals — as presently used? — under alternative uses?

Much of the information that the manager needs can be provided by land suitability maps, maps showing present land use and resource inventories. For most of settled Canada, land has been classified according to its suitability for various uses (agriculture, forestry, recreation, groups of wildlife) by the Canada Land Inventory (CLI). The scale of classification is such that the CLI maps are eminently suitable for strategic planning. They can provide the basis for definition of a zoning system; along with resource inventories they can be the main datum upon which to establish targets for the future allocation of land to various uses.

The land manager also needs to understand the functioning of terrestrial ecosystems, in general terms and specifically in respect of lands for which changes in use may be considered. He should, for example, be able to predict the effect on the functioning of ecosystems within a watershed of various logging schemes that might be called for within it. Such schemes might include clearcutting of blocks of different shapes, sizes and locations; selective logging of trees of specified age classes; the use of differing sorts of equipment. Such information should be the product of carefully designed EIAs.

It is apparent that the land manager's task would be facilitated if there were in place a process for planning, monitoring and controlling land use, in which EIA would, as indicated, play an important part, and that would function in the circumstances of highly divided decision making described above (Holdgate 1984).

THE POLICY CONTEXT FOR EIAs

To consider the policy context of EIAs is to consider the manner in which EIAs should fit into a system of policy formulation, program planning and project design and implementation. The ideal construct would be a system something like Figure 1.

If such a system were employed for planning land use and resource development, all actions undertaken should contribute to the achievement of social goals and be compatible with the maintenance of environmental quality and conservation of resources.

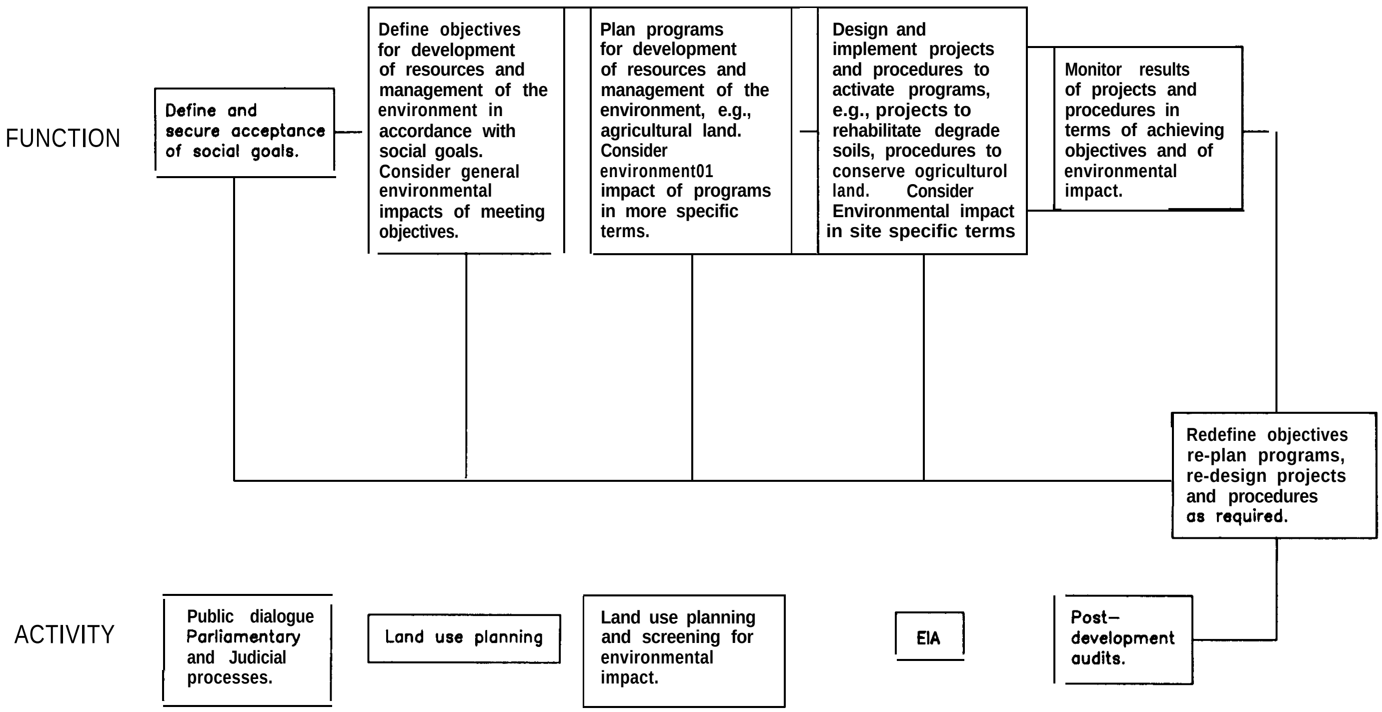

Figure 1. The policy context for EIAs: a system 01 policy formulation, program planning and project design and implementation

Why is such a comprehensive system needed? Why, in particular, should it be necessary to define social goals? The main reason is that, as the human population increases, and individual expectations for material goods rise, the demands that must be met by the land and renewable resources also grow. The decision that must be made should reflect our intention either to manage our environment so that it will provide for the future needs of society, or to allow unlimited exploitation for short-term gains. If we choose the broad goal of providing for the future, then we should decide what sort of future we want. By doing so, we will broadly define our common goals.

The definition of environmental management given earlier demands that development be environmentally and socially sustainable. Therefore, if environmental management is to be an operational reality, broad social goals are needed to provide the framework within which development strategies and programs can be usefully formulated and assessed. It is clear also that social goals must take account of the requirements for sustainable resource use and continuing environmental quality, as well as community preferences with respect to the material, cultural and aesthetic benefits that development is expected to convey.

This presents some difficulties, because the process of goal setting is not usually an explicit one in Canada (Emond 1981), nor in many other developed countries. The nature of broad social goals can, however, often be inferred from legislation, government programs and political pronouncements, and it is one of the responsibilities of management to ensure, so far as possible, that the objectives and characteristics of projects are in harmony with social goals whether stated or inferred.

The manager's task would be simpler if social goals were defined more specifically, and the process of establishing them made more explicit. There are, however, substantially differing views on not only the nature of social goals, but also the desirability of articulating them in unequivocal terms. In respect to the nature of social goals, the problem arises because there is difficulty in harmonizing the desire for development that maximizes short-term gains (and thus responds to immediate concerns about maintaining living standards, creating employment and maximizing the return on investment), with the need for development that is sustainable in the long term. All that need be said about that issue is that it will become an increasingly difficult one, and we are more likely to progress by facing it than by evading it. As to the more fundamental question of the desirability of articulating social goals, there is a point of view that to define goals in other than the most general terms, is to create unwanted constraints that would close off political options, limit entrepreneurial initiative and the free functioning of the market economy, and stand in the way of economic growth. It is a matter of judgment whether such disadvantages are of sufficient substance to outweigh the benefits of rational and comprehensive planning.

It is encouraging that there are cases in Canada in which the need to undertake an environmental impact assessment has led to a much deeper and more extensive enquiry into all aspects of a project proposal, in the course of which the nature of the social goals of the groups likely to be affected by the project has become abundantly clear. This was the case in the Mackenzie Valley Pipeline Inquiry (Berger 1977) during the period 1974- 1977, and later in the Lancaster Sound Regional Study (Jacobs and Pallug 1983) 1979- 1983. The Environmental Assessment Panel that was established to consider a proposal to drill an exploratory well in Lancaster Sound concluded that a "meaningful assessment of exploratory drilling in Lancaster Sound could not be made in isolation from the broader issues that affect all uses of the area." It also recommended that "exploratory drillings be deferred until such time as the government has addressed the issue of the best use(s) of Lancaster Sound."

So, while the ideal planning system does not exist, nor, perhaps, is it soon likely to, there are precedents for an increasingly comprehensive approach to development that recognizes the importance of social goals. We should be encouraged by this, and work toward improvement of planning and more effective use of the system components that already exist.

One way of moving toward the adoption of a better planning system would be to prepare conservation strategies on the model of the World Conservation Strategy (IUCN 1984; 1980). Because of the division of responsibility for resource management in Canada, it is at the provincial level that the preparation of conservation strategies would be most useful. Preparing a Provincial Conservation Strategy (PCS) would, in fact, be an exercise in development planning of the most comprehensive sort, based on the goals of maintaining essential ecological processes and life-support systems, preserving genetic diversity, and ensuring the sustainable utilization of species and ecosystems. A PCS would clarify the present and projected natural resources situation in the province under prevailing social, economic and technological conditions. It would review all activities which have an effect on the status of natural resources, identifying obstacles to ensuring that natural resources provide a basis for sustainable development. A PCS would define the allocation of human and financial resources needed to achieve sustainable development. It would include a plan for monitoring the implementation of the strategy, and methods for its regular updating. The purpose of the PCS process would not be just to prepare a strategy, but to bring about an understanding of the interdependence between conservation and development.

Some steps have been taken in this direction. Groups interested in the preparation of PCSs have been established in British Columbia, Alberta and Ontario.

Referring to the federal level, the Minister of Environment said in 1981, "I am very happy to adopt this important document as a model for the development of federal government conservation strategies. It is an important step towards ensuring environmental quality and continuing growth and prosperity of our resource-based economy." (Environment Canada 198 1.) The federal government has its most significant impact on environmental management in the Northwest Territories. It is of considerable significance, therefore, that the Department of Indian and Northern Affairs (1982) took the lead in preparing as a draft discussion paper, "A Comprehensive Conservation Policy and Strategy for the Northwest Territories and Yukon." In 1984, the report of the Task Force on Northern Conservation called for the institution of a system of land use planning which seems likely to provide better guidelines for development, and a meaningful framework for EIAs. (Task Force on Northern Conservation 1984)

A strategic province-wide approach to land use planning would have the advantage of orderliness and comprehensiveness, and would tend to force the consideration of social goals. Public concerns about issues such as the loss of agricultural land to urban development, and mismanagement of forests, draw attention to the need for better management. However, they are usually the cause of recurring and unproductive confrontation unless they are examined at the strategic level. Specific environmental issues should therefore be used as opportunities to develop public awareness of the desirability of comprehensive planning.

The benefits of undertaking EIAs in a broader policy context are likely to become more apparent as we examine more closely what has already taken place. For most development projects in Canada, EIAs have been undertaken on the assumption that the project is in the public interest and will eventually proceed. To minimize adverse environmental impact, changes in siting or routing, in methods of construction and in operational regimes, may be recommended, but rarely is a project rejected on the grounds that too great an environmental cost would be incurred if it were to proceed. In the absence of any rigorous post-construction evaluations, it is not possible to assess the decisions that have been made — to determine if projects were indeed in the public interest, and if the modifications in design and construction aimed at mitigating adverse environmental impacts had the desired effects. It is a major priority to undertake audits of development projects: as a means of evaluating the decision-making process that led to their construction and operation, as a means of assessing the performance of projects in the light of their stated objectives, and finally, to provide a basis for comparing their actual environmental impacts with those that were predicted. Only by undertaking such audits will we be able to confirm whether decisions taken in the past were, in fact. properly aimed at achieving broad social goals.

Thus, the move by the Federal Environmental Assessment Review Office (FEARO) and Environment Canada to undertake environmental audits of development projects is most commendable. It is to be hoped that what may be revealed about the inadequacies of EIAs at both the technical and policy levels will provide the basis for improving the scientific basis of EIAs, and for establishing a more useful relationship between EIAs and the broader planning process.

LAND USE PLANNING AND THE ENVIRONMENTAL IMPACT OF CHANGES IN LAND USE AND LAND USE TECHNOLOGY

To focus more specifically on the problems of management of the terrestrial environment, it may be observed that the environmental impacts of changes in land use and land use technology associated with agriculture, forestry and urban development seem to have gone largely unassessed in advance of their occurrence. They have also received little attention in the literature devoted to environmental impact assessment. This is perhaps not surprising since most, though not all, of the changes are individually small, and their impacts become significant only as they accumulate beyond certain threshold values. Further, although EIA, quite properly, was not conceived as a substitute for land use planning, it is unfortunate that the close relationship between the two activities does not seem to have been widely recognized. Another reason for the lack of attention given to the environmental impacts associated with forestry and agriculture may lie in the fact that, during the period when the process of EIA was being developed, more attention was focused on pollution, with its implications for human health, than on such environmental perturbations as the removal of vegetative cover or the drainage of wetlands. Still another reason is that some, although again not all, of these sorts of changes take place without government support or, if they are supported by government, the support is dispersed over time and among a relatively large number of recipients. Changes in land use and technology associated with agriculture and forestry are not mega-projects, and they attract relatively little public attention.

It is unfortunate that all this should be so, since the effects on the environment of changes in land use, and in the practice of agriculture and forestry can be profound (Simpson-Lewis et al. 1979). A few examples will suffice. Drainage of wetlands in order to convert them to agricultural use may affect ground water supplies; it may change the hydrologic regime in associated watercourses; and it will eliminate the habitat for a large number of species of animals and plants, including many of direct economic value. The cutting of trees clearly has a significant effect on the habitats of numerous species of plants and animals; it also affects soils, and the extent of such effects is closely related to the types of equipment used for felling and removing trees. In addition, the condition of the soil, and the characteristics of vegetative cover in watersheds, have very significant effects upon the flow and quality of water. The side effects of the use of biocides and fertilizers as a means of increasing agricultural productivity are so familiar that they need not be detailed here.

The best known impacts of the changes in land use associated with urban and suburban development lie mainly in the stress placed on local ecosystems by the need to supply resources and to dispose of wastes. Another impact which can occur is the elimination of certain types of agriculture, such as fruit growing. This is not necessarily because all the suitable land has been converted, but because its extent becomes so limited that it is no longer possible to support the processing and marketing functions that are essential to its continuance.

It is quite clear that many conflicts of interest are reflected in the few examples just noted. It is equally clear, I should think, that they can be resolved only on the basis of a clear analysis of their environmental implications in relation to social goals. If the greatest flow of benefits is to be derived from use of the land, public interests will need to supercede private ones in many instances.

To ensure the best judgments about land use, land use planning and environmental impact assessment should become companion activities, associated in the comprehensive planning system described earlier. The former will contribute to the formulation of social goals and resource management objectives, and the latter will provide the detailed ecological information needed to consider specific issues and make decisions with respect to proposed changes.

LIMITS OF EIAs FOR CUMULATIVE ACTIVITIES

The concerns which are the theme of this workshop and the burden of this paper, are likely to be reflected in recommendations for broadening the scope of EIAs to ensure that they are sufficiently comprehensive to meet the needs of managers. Yet, if an EIA is to be a practical endeavour, it must be bounded in space and time. While “everything is related to everything else,” the significant impacts of projects do occur within spatial and temporal boundaries. If an EIA is to be manageable and its results comprehensible, these boundaries should be carefully defined. The most important, although by no means the only factors affecting boundary definition, are ecological. In addition, we may define boundaries, or criteria, of significance, and thereby additionally help limit EIAs to manageable proportions.

The discussion of defining boundaries in Beanlands and Duinker (1973), in particular, in reference to ecosystem components and ecological scoping, is useful and comprehensive, and there is little of a general nature that needs to be added. What may usefully be stressed is that, in the establishment of boundaries of whatever sort, judgment rather than precise measurement will predominate, and the results will reflect trade-offs and compromise among the factors affecting the dimensions of the study.

The question of significance arises in another fashion that does not seem to have received much attention, namely, with respect to the operation of the preliminary screening processes. Screening eliminates from further consideration projects considered to be of little environmental significance. The problem is that the possible cumulative effects of a number of such individually insignificant projects, or actions, are totally discounted. This is the situation in forestry and agriculture where numerous small and some not-so-small decisions, which obviously have a cumulative effect, are never assessed. While this is a problem that clearly needs attention, a solution calling for the assessment of each individual action would be impractical. The solution must lie in assessing the combined impact of a number of actions expected to take place over time, and in relating the assessment to the land use planning process.

For example, in respect to a tract of land that might be improved for agriculture by the eventual drainage of, say, 50- 100 semi-permanent potholes, an environmental assessment study should focus on the overall ecological effects of such action. It should also be designed to define the elements of courses of action that would yield long-term development benefits, while maintaining some benefits from wildlife and recreation.

The relationship between land use planning and EIA is clearly evident in the cases where proposed urban developments would encroach on high quality agricultural land. There is no need for EIAs to be undertaken for each proposal for subdivision. Overall plans based upon land suitability should provide primary guidance. EIA might be useful in cases at the margins, or where special considerations needed to be taken into account.

HOW TO IMPROVE EIAs (CIAs)

The foregoing discussion suggests a number of ways in which EIAs can be made more useful to the manager of terrestrial ecosystems.

Setting aside the question of the quality of the science that is applied to EIA, a most important topic discussed with admirable candour by Baskerville (this volume), the main point to be made is that EIAs should be seen as just one element of environmental management; they have an important place in the chain of goal setting, strategy formulation, program planning and project implementation (Holdgate 1984), but they do not by themselves provide adequate and comprehensive guidelines for development. At the same time the overall system for environmental management is poorly developed. Thus, the first group of recommendations of this paper is aimed at improving environmental management. The recommendations are to:

- encourage the definition of explicit social goals;
- establish or improve institutions and procedures, to take environmental considerations into account throughout the development planning process;
- recognize the close relationship between land use planning and EIAs, and provide an effective institutional linkage.

All these and other relevant actions could result from the preparation of provincial conservation strategies.

The second group of recommendations relates to the manager's need to have relevant information. The key to relevance is the identification of ecological relationships in both space and time. While judgment will need to be applied in bounding and screening EIAs, it can be effectively applied only if the ecological underpinning of environmental management and the potential significance of a series of similar activities, i.e., activities having a cumulative effect, is clearly understood. The recommendations are to:

- improve the basis for ecological understanding by ensuring that ecological base line studies are sufficiently extensive, and by carefully planned and sustained monitoring; and
- improve ecological understanding and the basis for project evaluation by undertaking post-development audits.

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COMMENTARY I

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I fundamentally agree with the discussion presented by David Munro. I hope to supplement his comments from a perspective based on environmental impact assessment (EIA) and regulatory work in the northeastern United States. Many of the examples presented concern wetland resources, but since wetlands may be grouped with either terrestrial or aquatic systems, they are relevant to this discussion.

Apparently the reactive rather than proactive role of EIAs is characteristic of Canada as well as the United States. This role is apparently a function of how EIAs are usually conducted. The party responsible for project development generally has primary responsibilities other than those necessary for comprehensive environmental assessment work. Furthermore, the EIA is frequently perceived as a barrier to pass prior to project implementation, rather than as a legitimate component of the entire decision-making process. Interagency and, more importantly, interdisciplinary coordination at the earliest stages of project planning could aid in avoiding these difficulties.

MANAGEMENT REQUIREMENTS

The disparate nature of private and public agency activities requires some mechanism for developing a common data base for all types of projects. Establishing baseline data collection requirements through zoning or permitting processes could give a resource manager the raw data from which to plan, monitor and control land use. Resource development organizations with more data collection capabilities (and presumably greater individual project impacts) could provide a higher order of compatible data.

Within the context of wetland resource management, Helfgott et a/. (1976) stated that the three steps in the administration and preservation of any natural ecosystem was to, “define, delineate, and regulate.” Munro’s hypothetical resource manager must fundamentally follow the same three steps. The goals to be achieved by resource management must be defined. The managed resources have to be identified, and then evaluated with regard to productivity and alternate use suitability. The delineation of resource utility and value derive directly from an understanding of the resource character and function. Regulation (management) should follow in accordance with the resultant information.

In wetland resource management, data have accumulated for both the functional value of the systems (Odum 1979) and the trend of resource losses. In both cases the identification (definition) of the resource and the development of a classification system were necessary prerequisites for effective management. Classification methods have evolved from the national system developed by Martin et *al.* (1953), to the hierarchical approach to national wetland classification finalized by Cowardin et *a/.* (1979). A primary purpose in both cases was to develop relatively uniform data bases for evaluating wetland trends throughout the United States. Although the wetland trends reported by Shaw and Fredine (1956) were incomplete, sufficient data was gathered to identify resource losses and heighten the awareness of the value of these resources. Indications of continued losses by Tiner (1984) have provided more refined data, and have shown the utility of the more accurate baseline data base being provided through the ongoing National Wetland Inventory.

POLICY CONTEXT FOR EIAs

If the maintenance of a resource base and environmental quality are components of defined social goals, EIAs should be an integral part of policy formulation and project design and implementation. The considerations for resource utilization, however, are not always objective. Trade-offs are frequently made on a relative scale, and in many cases economic, social, and environmental benefits and costs are unequally viewed from a long-term perspective (e.g., the 100-year design life of an impoundment). Furthermore, the impacts of various project components (economic, social, environmental) have concomitant impacts on each other. Therefore, it is generally the strength of the most acceptable data (weighted by agency agenda) which has the most influence in the decision-making process.

Broad social goals concerning environmental quality must unfortunately compete with other, equally compelling, social goals (e.g., shelter, employment). Two environmental goals may also conflict (waste treatment vs. habitat diversity). Inferences derived from governmental directives can therefore give conflicting signals regarding social priorities, Another complication is that many development agencies, in response to perceived environmental directives, may include environmental enhancement features which superficially “replace” or “enhance” natural resource values. Such project features could have two damaging impacts in that the destroyed resource vatues are not adequately replaced, yet the public perceives them to be. Mitigation policies must be closely managed and monitored to avoid such damage.

Although there is no mechanism comparable to the Provincial Conservation Strategy (PCS) in the United States, an amalgamation of state policies, under the guidance of federal mandates, could be a substitute. State-(or province-) oriented resource initiatives may especially require federal overseeing in regions where competition for resources between states or provinces is an issue, or where data uniformity is necessary for management effectiveness. For example, state-oriented wetland protection programs are not consistent throughout the United States. Among the states that have significant programs, the wetland data bases and management criteria are highly variable (Klein 1980; Kusler and Bedford 1976), and the program effectiveness is far from uniform (Rosenbaum 1980).

The focusing of attention on more immediate problem areas within the context of broad goals may be the most compelling means to evaluate cumulative environmental impacts. For example, the recognition of the declining environmental condition of the Chesapeake Bay (US EPA 1982; 1983) and coastal Louisiana (Craig et *al.* 1980; Boesch et *al.* 1983) have focused attention on chronic, cumulative effects of regional activities. The focus of attention on such a tangible example of resource degradation marshalls public concern and forces interstate (regional) cooperation.

In many cases in the United States, EIAs are undertaken after an active project decision has already taken place. In effect, the EIA becomes part of a rationalization process in which the general project dimensions are relatively constant, and the “no action” alternative is used as a straw man. A fundamental problem with many development-oriented EIAs therefore, is that the alternative analysis process is limited to a confined subset of potential problem solutions. Although initiatives have been developed in which interdisciplinary input is solicited at a relatively early stage in the decision-making process, the level of effectiveness of this project scoping is a function of how early in the process the input is provided, and how much time and energy is devoted to the process.

Munro’s recommendation for post-development project assessments appears to be an important means to monitor the effectiveness of development-oriented EIAs, while providing data for the development of cumulative impact studies. Since economic evaluations are frequently the initial driving forces for project development, the decision-making process is biased against the environmental evaluations which are added later in the process. An objective evaluation of the effectiveness of all project aspects to achieve program goals could conceivably bring economic and environmental evaluation criteria in better balance.

LAND USE PLANNING AND THE ENVIRONMENTAL IMPACT OF CHANGES IN LAND USE AND LAND USE TECHNOLOGY

Relatively little attention has been given in the EIA literature to activities which have an impact on the terrestrial environment. Most of the activities impacting the system are individually small, and the literature is perhaps biased toward the pollution-oriented studies concerning the aquatic and atmospheric media. Wetlands (which may be viewed as a terrestrial system component), however, have received some attention in the EIA literature (e.g., Darnell et al. 1976; Frederickson 1979; Schmal and Sanders 1978). Furthermore, profiles have been developed for many distinct wetland communities to broaden the knowledge base for natural resource decision making. The profiles serve as a consolidation of the scientific literature concerning the community function, value, characteristics, and help in assessing the impacts of development activities upon them (e.g., Wharton et *al.* 1982; Seliskar and Gallagher 1983). Cumulative studies could evolve from these data sources once the raw data from local site-specific projects are provided. Progress is underway in developing reporting procedures for these data.

The data base developed for wetland resources could serve as a template for the management of other systems. Literature reviews of generic impacts, community profiles, post development assessments and raw impact data would provide the basic ingredients for effective cumulative impact studies.

LIMITS OF EIAs FOR CUMULATIVE ACTIVITIES

At many agencies, projects are screened to eliminate from further consideration those which are considered to have minimal environmental impact. Unfortunately, the agency or individual that makes the determination is not always qualified to make that judgment. Furthermore, a conflict of interest may arise when the agency agenda and environmental requirements conflict. An added consideration is that, in cases where significant environmental impacts do result from a screened project, or when a cumulative impact threshold is exceeded, the quality control for a large set of decisions is called into question.

An interdisciplinary assessment of many small, individual actions may not be as impractical as first imagined. If review procedures are straightforward, and information requirements are enforced, reviews can be conducted and effectively. For example, a one-day review of wetland permits and EIAs held monthly in Virginia results in the screening of 25-50 small projects by experts from eight federal and state agencies.

With regard to the use of generic EIAs to project impacts or propose project alternatives, active use of post-development assessments is critical. Without some sort of measurement of the effectiveness of the preliminary environmental evaluations, recommendations based upon non-specific data will be resisted.

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COMMENTARY II

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Munro makes three fundamental and interconnected assumptions. The first is the relationship between environmental management and the goals of society. Second, the role of land use planning in environmental management and, third, the link between environmental impact assessment (EIA) and land use planning. Although these assumptions are woven throughout the text of the paper, in this critique they are explicitly discussed for ease of presentation.

It is almost axiomatic to say that environmental management should reflect the goals of society. Any system of management is designed to meet the goals of some agency, clientele or group. In general, the more limited and defined the goals, the more successful the system of management. With respect to environmental management, the "goals of society" are almost undefinable in a classical management sense. In a recent report, Thompson and McKay (1984) discuss the difficulties of applying management theory to environmental and resource problems. Their conclusions are relevant to this discussion.

Those authors define management to be "the setting of goals and the organizing and control of people, finances, time, equipment and knowledge to meet these goals." Management theory has developed based on experience in the manufacturing and marketing sectors, which involve relatively small systems with components which are easily quantifiable. In these man-made systems, most of the components are under the control of the managers, externalities can largely be ignored and tasks can be broken down into discrete units of activity with short and fixed time frames.

In contrast, they define environmental management as "the application of natural and social sciences to protect the natural environment, optimize the built and natural environment with respect to human benefits, and provide sound natural resource management." In contrast to the characteristics of traditional management theory, natural systems are large, complex, interactive, and not readily quantifiable. Some of the components move of their own accord in uncontrolled and unpredictable ways within time and space boundaries which are difficult to define. When you add to this the problem of determining the "goals of society" as your management objective, the fundamental utility of applying traditional management approaches and skills to environmental problems is called into question.

The second assumption in the paper by Munro is that of the role of land use planning in environmental management. There can be little argument that effective control of activities on land would significantly reduce environmental pollution and greatly assist the aims of conservationists. In many European countries the current generation has grown up with land use controls as applied through comprehensive land use policies or legislation. In contrast, land use planning does not seem to be a popular notion with either the politicians or the general public in North America. It seems that such interventions by governments run contrary to the "land ethic" which has evolved in the New World, whereby people feel strongly about their right to conduct their own activities on their own property. Much of this philosophy is reflected in law and government policies, and experience in both British Columbia and Newfoundland has shown the intensity of the belief in this *laissez-faire* attitude towards land. Politicians in both provinces experienced serious public opposition to the placing of restrictions on the sale and use of prime agricultural land.

This raises the question as to whether land use planning can ever be an effective way to manage the environment in North America. Furthermore, is there any evidence to indicate that national environmental quality is any better in western Europe, where land use planning has long been practiced, as opposed to North America with its emphasis on point source control of pollution?

The third major premise of the paper is that EIA is closely linked to land use planning — or should be. I believe that this offers one of the best ways to achieve some of the objectives of land use planning, if in a somewhat indirect way. The long-term control of human activities on some designated parcel of land, (i.e., a management unit) seems to be the best way to limit the cumulative effects of development. Since land use planning ***per se*** is somewhat difficult to implement in Canada for reasons mentioned above, it may be possible to gradually change and expand the role of EIA, an environmental planning tool which is more widely accepted.

For example, it is generally agreed that the current focus on individual development projects is too narrow to deal with cumulative effects. However, could this be somewhat overcome if each proposed project had to be assessed within the context of some pre-defined "land management unit"? These units would be established to reflect physical processes and/or large-scale ecological systems — for example, watersheds or selected coastlines — as well as jurisdictional boundaries of local authorities. Perhaps the EIS guidelines could define the management unit(s) involved or give criteria by which the boundaries could be established. A critical part of the EIS could then be assessing the extent to which the effects of development are already accumulating in the unit and the degree of control that authorities have had in managing the unit in the past. At this level, such an approach does not deal with the control of activities on individual parcels of land, but rather attempts to determine the integrated effects of combined land uses as a background against which to judge a proposed development project.

The lack of consistency in approach to implementing EIA is both a constraint and an advantage. In this case, if EIA can be modified to take account of land use planning objectives, the inherent flexibility could be used to great advantage. The next major step would be to undertake environmental assessments of policies upon which the approaches to the uses of land and resources are based.

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FRESHWATER SYSTEMS

Scientific Perspective

FRESHWATER

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PREDICTING RESPONSE FROM ONE LEVEL OF BIOLOGICAL ORGANIZATION TO ANOTHER

Most predictions of cumulative impact (or even individual impacts) are based on single species tests. The assumption has been made that using representatives from different components of the food web and selecting the most sensitive species will protect the entire system. There is presently no scientific justification for several subsidiary assumptions: the most sensitive species in a laboratory test species is also a sensitive species in natural systems; the most sensitive species in natural systems can be adequately cultured in the laboratory; protection of the most sensitive species will also protect the functional attributes of complex systems; and the environmental realism of laboratory tests is sufficiently close to that of natural systems to permit extrapolations from one system to the other.

Scientific justification is weak for assuming that concentrations of chemical wastes or other environmental stressors tolerated by the "most sensitive species" in a limited test series of species, will automatically protect all desirable and essential environmental attributes at levels of biological organization up to and including ecosystems. Although this assumption seems intuitively unreasonable, little direct evidence exists to either refute or support this assertion. Circumstantial evidence commonly used by strong proponents of single species toxicity testing as the primary, or even sole, means of predicting risks and harm, is that these tests have been used for years in conjunction with various application factors, and that they seem to work quite well. This assertion may be true because the application factor may be sufficiently large to protect natural systems under almost any circumstances. Alternatively, application factors may only prevent the grossest and most visible environmental responses, such as fish kills and the like. The more subtle responses, such as altered nutrient spiralling or energy flow, are usually not measured. In fact, significant efforts at validation of the predictive value of single species tests in natural systems are exceedingly uncommon.

The number of commonly used freshwater test species is limited to about 20 species of fish and roughly the same number of invertebrates and algae. However, of these approximately 40 species, less than 10 are frequently used in the United States. The most commonly used species of freshwater fish are the fathead minnow, bluegill, sunfish, and rainbow trout. The most commonly used invertebrate is *Daphnia,* and the most commonly used species of algae is *Selanstrum*. While other species of fish, invertebrates, and algae are used, the five species just listed probably account for 80-90% of the species used in the toxicity tests carried out. Since even the five most commonly used species may sometimes have a comparatively broad response range (and the approximately 35 others even larger response ranges), one can only speculate about the total range of variability and response of the hundreds or thousands of species (including microorganisms) in a single freshwater ecosystem. Although the position of the test species response in terms of the total variability of hundreds of thousands of naturally occurring species is not substantiated by a significant data base, it is not unreasonable to assume that species easily cultured in the laboratory (an essential requirement for toxicity testing where only 10% mortality in the controls is allowed) are likely to be in the higher ranges. It is not unreasonable to assume that the easily cultured species tolerant of laboratory conditions might also be tolerant of environmental stressors. In any case, the sensitivity of commonly used test species relative to the enormously larger array of exposed species in natural systems should be the key to the development of appropriate application factors, since application factors are designed to account for variability not included in the test itself. When the relationship between the sensitivity of the naturally exposed organisms and the laboratory test organisms is not well documented, extrapolations will certainly lack precision. Under present circumstances, reliance on the use of the most sensitive test species in a small array of test species, and extrapolation to a larger number of species, does not seem scientifically justifiable.

A corollary to the previous discussion is that the most sensitive species in a natural system can be cultured in the laboratory. I am not accusing the persons who make this assumption of assuming that all sensitive species can be so cultured but rather that the assumption is made that representatives of the most sensitive species have been cultured in the laboratory, or can be. Again, there has been no validation of this hypothesis with scientifically justifiable evidence, despite the fact that such a hypothesis is a crucial, though usually unstated, assumption in the single species toxicity testing strategy. A caveat is appropriate here — there is no fixed relationship between sensitivity to toxicants and ease or difficulty of laboratory culture. There is evidence that some species (and life history stages of a single species) may be very sensitive to some toxicants and resistant to others, and *a priori* judgments of sensitivity based on either life history stage or taxonomic status will often be in error. We do know that only a small percentage of freshwater species has been taken through their entire life cycles in the laboratory, and that a larger number (but still small relative to the total number) can be kept alive in the laboratory for sufficient time to do toxicity tests in excess of 96 hours, particularly when one adds the requirement that mortality in the controls must be 10% or less. Without in any way denigrating the many Splendid contributions on relative sensitivity that have already been published, it is nevertheless a fact that only a tiny percentage of the total array of species has been tested with regard to sensitivity. Also, no working model permitting precise predictions in areas where no previous testing has occurred is available. This leads to a subsidiary but exceedingly important point (although to my knowledge it has never been explicitly stated): there seems to be a generally shared feeling that blocks to the understanding of how a system functions can be eliminated in a single masterful conceptual breakthrough as has happened in genetics, physics, chemistry, and a number of other disciplines. As a consequence, scientists search for the single, all-purpose, uniformly applicable toxicity test as knights searched for the Holy Grail in earlier times. The latest toxicity testing Holy Grail seems to be the *Ceriodaphnia* toxicity test. This is a very useful contribution but will not solve all the problems as some people in industry, regulatory agencies, and even academe hope. We seem to err on one side by saying ecosystems are so complex that they defy any meaningful understanding, or that one cannot possibly predict what will happen in ecosystems as a consequence of the introduction of a chemical or a particular course of action. At the other extreme we say that one or two simple tests involving a single species will enable us to predict everything. The "overawed by complexity" attitude is a paralyzing one, inhibiting constructive action. At the other extreme, dependence on a single species or a few tests with low environmental realism will inevitably cause serious problems when dealing with complex, highly variable and regionally differentiated systems. In that uncomfortable, intellectually unsatisfactory, middle ground lies the strategy, data, and information that will enable us to reduce risk but not eliminate it.

The third subsidiary assumption is that protection of the most sensitive species will also protect the functional attributes of complex systems. Since most single species toxicity tests use lethality thresholds, they are designed to reduce environmental concentrations of chemicals to that point where survival will be possible. It is well established that survival is possible for long periods of time even when function of a single species has been markedly impaired. Many types of evidence for both terrestrial and aquatic species support this survival versus function question. Recent acid rain studies on trees are probably the most widespread geographically. Even if more sensitive thresholds are used for single species (such as growth and reproductive success), no direct scientifically justifiable evidence ensures protection of ecosystem function if these single species attributes are protected. It is worth noting that proponents of single species toxicity testing as a sole means of estimating environmental hazard rarely explicitly state that ecosystem function will be protected; neither do they provide an explicit warning that ecosystem function is not protected. As a consequence, a substantial number of people outside the field assume that more protection is implied than is actually the case. In a recent commentary (Cairns 1984), I have speculated that if people were fully aware of the weaknesses of application factors used with single species toxicity tests, there would be ample justification for exploring the possibility of measuring critical ecosystem thresholds directly, rather than extrapolating them from single species tests. The argument over whether adequate methodology to do so is presently available (I believe it is) should not divert us from examining the basic issue: In the long term, are direct measurements of crucial ecosystem response thresholds scientifically defensible and possibly more cost-effective than the present strategy of extrapolating them from single species toxicity tests?

The fourth subsidiary assumption may in the long run prove to be a major determinant that will alter our toxicity testing strategy more than the argument over extrapolation from one level of biological organization to another. The toxicity testing strategy for protection of aquatic ecosystems was markedly influenced by the design of toxicity testing designed to protect humans — this was fairly well advanced when the aquatic field was in its infancy. A more profound and pervasive influence was that of the scientific method that called for the elimination of all variables except the one being tested, so that replicability of the experiment was enhanced. This drive to perfect replicability in laboratory toxicity testing for aquatic hazard evaluation resulted in very low environmental realism, because the latter was incompatible with a high degree of replicability. In short, we are trying to predict events in a highly dynamic complex system with enormous variability, from a simple laboratory system with little or no variability. The toxicity of mercury to fish would probably have been predicted accurately had the test been carried out in laboratory systems with mud, microorganisms, one or two trophic levels between them, and fish. In contrast, even 20/20 hindsight makes it difficult to devise a workable pre-use screening system that would have predicted eggshell thinning in raptors from the use of DDT. The need to couple environmental fate, transformation, partitioning, and the like for chemicals has lead to the use of more environmentally realistic laboratory test systems that very commonly include aquatic organisms (e.g., Cairns 1980). In some cases, correspondence between field and laboratory tests was quite heartening (e.g., Cairns and Cherry 1983); while in a number of others, correspondence has not been high (National Research Council 1981). In cases where correspondence between laboratory and field testing is quite high, the following conditions may be the major determinants: both field and laboratory measurements were at the same level of biological organization; a high degree of environmental realism existed for certain attributes (e.g., water quality) despite the fact that laboratory test containers did not resemble the natural environment very closely; all the test species used survived very well in the laboratory for the duration of the test, although the time involved represented only a small portion of the total life cycle. It is worth noting that in a new set of experiments carried out in our organization, a high correspondence occurred between laboratory and field testing at the single species level and at the community level when using microbial communities. (We have not yet used communities of higher organisms.)

NATURAL VARIABILITY VS STRESS RESPONSE

Commonly used methods for estimating environmental impact regularly reduce variability for all but one parameter. Where variability does occur, the practice of varying only one parameter at a time is customarily followed, despite the fact that natural systems do not function in this way. Regulatory measures have not addressed in any substantive way the distinction between a trend caused by stress, and an oscillating system for which the oscillations may not be apparent in a short time frame. Odum et *al.* (1979) state "It has been fairly common practice among ecologists to include any deviation from nominal, either positive or negative, under the heading of stress." Nominal state is defined in Odum's paper as the normal operating range, including expected variance. Earlier statements of the same view may be found in Esch et a/. (1975) and Barrett et *al.* (1976).

Nowhere does the failure to attempt to relate field and laboratory evidence show up more dramatically than in the failure to explicitly address the question of distinguishing between a pollutional trend and natural cycling or variability. Even the most superficial attempts to validate predictions based primarily on laboratory evidence would have run head-on into this question. The fact that it is rarely mentioned shows the enormous gap that exists between ecologists and laboratory toxicologists. To ecologists, discussions of natural variability would seem platitudinous, since natural variability is one of the commonly accepted pheonomena. Yet laboratory toxicologists have almost without exception failed to incorporate this widespread and generally acknowledged ecological phenomena into their investigations. Odum et *al.* (1979) note that an increase in variability is one of the frequent responses to stress, yet even ecologists have discarded certain field measurements because they are thought to be too highly variable. In fact, differences in variability rather than differences in averages or means might be the best measure of stress in natural systems. Environmental quality control will never be effective without a reliable means of directly determining environmental response to anthropogenic stress. Elsewhere (Cairns 1983), I have discussed the failure of pipe standards and technology-based standards. The only remaining alternative is receiving system standards based on biological/ecological responses. If biologists fail to address this question effectively, there will be a return to a combination of pipe and technology-based standards that have always had a greater appeal to engineers, chemists, and administrators. It is distressing to see ecologists squabbling over theoretical differences in responses and destroying public confidence in their methods. Even the least effective, crudest ecological methods are superior to pipe and technology-based standards for protecting the environment. Ecological methods are the only ones that have a feedback loop from the system being protected, based on ecological qualities.

MICRO SCALES AND MACRO SCALES

Micro (site-specific) and macro (regional, national, or international) scales have not been given serious attention in many assessment procedures. The best research in this regard is focused on chemical transformations of anthropogenic contaminants in laboratory microcosms or mesocosms and natural systems. A concomitant study of biological response is not presently available. Therefore, scientific justification for extrapolations at different scales is another component of the problem of extrapolation from one level of biological organization to another. Added to this, of course, is the justification of extrapolating from a small region to a large region, even when the ecosystem is "homogeneous."

Although some states (e.g., Michigan) have incorporated biological mixing zone authorization into their regulatory measures, the U.S. Environmental Protection Agency (USEPA) and other federal agencies have studiously avoided addressing this question in a substantive way. At the Second National Water Quality Meeting held in early 1984 at the Academy of Natural Sciences in Philadelphia, Pennsylvania (Cairns *in press*), I checked the audience reaction to the use of mixing zones as a means of validating predictions based primarily on laboratory evidence. Although the scientific soundness of this approach was generally accepted, there was a very strong negative reaction from three or four people who identified themselves as USEPA lawyers on the grounds that USEPA could not permit any damage to the environment, however limited. Since I distinguished between the engineering definition of a mixing zone (the zone where an introduced material is not completely mixed with the receiving water) and the biological definition (the zone where adverse biological effects occur), there seemed to be no doubt that even the most limited adverse effects were not acceptable under any circumstances. It seemed to me that scientific and social judgments were being mixed in arriving at the no-adverse-effects position. The responsibility of the scientific community is to determine the extent of the adverse effects within the mixing zone, and to estimate the probability of harm to the macrosystem from damage in the mixing zone (microsystem). An important component of this decision would be the determination of how many micro-components of an ecosystem could be damaged before the larger system showed substantive deterioration. The social component of the judgment would be whether micro-level damage could be tolerated if there were no evidence that there would be negative effects at the macro scale. A second component of this judgment would be whether the benefits to society of the proposed course of action would outweigh the ecological damage. Neither of these latter two are scientific decisions.

DIFFERENTIATING BETWEEN STRESS, SUBSIDY, AND PERTURBATION

Although Odum and others have called attention to this problem, there is little hard science on which to base distinctions between stress, subsidy, and perturbation. Scientific groups such as this should determine the importance of this area in terms of research priority, and design a scientifically sound research plan that will enable these distinctions to be made at specific sites in a variety of ecosystems. Differentiating these areas and making distinctions has not received much attention in academic journals covering the area of environmental science, or in regulatory measures.

Many years ago, Ruth Patrick (personal communication) was studying an industrial waste being discharged into the Gulf of Mexico. The waste stimulated the growth of a diatom that was extremely beneficial and, perhaps, essential to oyster production. There appeared to be no deleterious effects associated with this waste discharge. Thermal and chemical waste discharges that might be deleterious in some ecosystem might be subsidies in other ecosystems. Should industries that search out ecosystems where their waste discharges will be subsidies instead of detriments be rewarded and, if so, how? Carried one step further, should industries be rewarded in some fashion for examining a series of alternative sites for locating a new manufacturing plant and selecting the one where the ecological damage will be least? An industry making a contribution to the suspended solids load of a stream might cause appreciable damage in a high quality fishery where suspended solids were normally under 25 parts per million. The same discharge into the Kansas River near Lawrence where the suspended solids are regularly an order of magnitude higher would have far less effect. Similarly, a thermal discharge raising the ambient temperature only a few degrees might cause serious damage if the aquatic ecosystem were approaching a thermal threshold for commercially or recreationally important fish species, but the thermal discharge might be beneficial in a system where the temperature was not quite warm enough for a good warm water fishery and not cold enough for a good cold water fishery. To say that unexplored opportunities along these lines exist, is to understate the case. I am convinced that the adversary relationship that exists between industry, academe, environmental groups, and regulatory agencies will never lead to the development of cooperative management and quality control systems that are essential to the well-being of ecosystems. It is at least remotely possible that focusing on questions of subsidy will help foster a cooperative working relationship and shared goals that are so badly needed.

DETERMINING THE SUCCESS OF MITIGATION

There are a number of issues in this important area:

- How does one determine when the degradation caused by a cumulative impact has been arrested?
- If the stress is removed, will the ecosystem return to its original dynamic equilibrium condition without further intervention? If not, what form should this intervention take?
- If restoration of a damaged ecosystem to original condition is not possible, how does one select an alternative ecosystem that will be compatible with the other ecosystems to which it is linked?
- If a successful process similar to the one a damaged ecosystem had in its original stages of development is underway, should all further intervention (e.g., addition of species and nutrients) cease?

The degradation of a natural system does not necessarily cease when discharges into it or stress on it are eliminated. The disequilibrium produced by the cumulative impact of a variety of stresses may persist for a substantial period of time, or might even be permanent. A study of the South River in Virginia (Cairns 1982) at intervals after DuPont had undertaken a series of improvements in the waste treatment system, and a somewhat similar study on one of the forks of the Shenandoah River (Cairns 1982) showed rather rapid improvement in the biota inhabiting these rivers. Suppose, however, that improvements in waste treatment processes and reduction in total waste discharges into the river were not accompanied by immediate biological improvement. Does this mean that no improvement can be expected or that a new equilibrium condition has been attained that cannot be altered merely by reducing the stress on the system? If improvement is anticipated, how long should one wait for the evidence confirming this? A subsidiary question is: Are there some ways of predicting when the response will be immediate and when it will not? Relating the biological benefits to improvements in waste treatment is badly needed. Like it or not, cost/benefit ratios will be the basis for many judgments in times of economic hardship, and ecologists and toxicologists should be prepared with at least crude estimates of degree and quality of benefits. It is reassuring that polls indicate the public is willing to pay for these benefits, even in times of economic hardship. However, such willingness will probably not continue if the public has been "cheated" by inaccurate or overly optimistic predictions.

Magnuson et *al.* (1980) have explored the alternative directions ecosystem restoration might take following the removal or continuation of stress. Although they have made a Splendid contribution in identifying these options more clearly than I have ever seen done before, we badly need more substance in our predictive capability for determining the rate of return to original condition or the direction and rate toward a new equilibrium condition.

The selection of alternative ecosystems when restoration to original condition is not possible, provides a marvelous opportunity for both studies in theoretical ecology, and for improving damaged ecosystems so that, at the very least, the adverse impact on contiguous ecosystems is eliminated or reduced. If one views damaged ecosystems for their potential for ecological experiments on colonization processes and the like, all sorts of interesting experiments can be devised while, at the same time, enhancing ecosystem quality. The Hubbard Brook studies have provided an excellent model for this type of research (Likens 1985). They have not, however, explored in any depth the construction and management of alternative ecosystems (i.e., ecosystems of different quality than the ones damaged). Numerous examples exist, however, such as those covered by Bradshaw and Chadwick (1980) or Holdgate and Woodman (1978).

The present laws on rehabilitation of stripmined lands in the Commonwealth of Virginia require that after the initial regrading, reseeding, etc. has occurred, no management intervention shall occur for a five-year period. At the end of the five-year period, a judgment will be made by employees of the Commonwealth of Virginia on whether the rehabilitation was adequate. Since bonding is involved and, therefore, significant funds, the decisions will be closely watched. Unfortunately, this is too recent a development for any decisions to have yet been made. There are, to my knowledge, no similar restrictions on rehabilitation of aquatic ecosystems either in this state or others, although I have not made a major attempt to check this thoroughly. However, even if the successional processes are similar to those characteristic of the ecosystem when it originally developed, one can make a case for management intervention in the successional process during rehabilitation. Perhaps the successional process, though in the right direction, could be accelerated by appropriate management practices. This could be accomplished by introducing appropriate strains of colonizing species without waiting for natural processes to take care of this. Unquestionably, our knowledge is not adequate to always produce the desired results. As a consequence, all such plots should be treated as experimental, and the regulatory agencies and industries, as well as the academic community, have to recognize this in order to improve management and predictive capabilities. Rigid laws governing management practices are probably the result of a lack of confidence in the stewardship of the persons charged with rehabilitation. If such confidence could be increased, perhaps more flexibility would result and, therefore, a more rapid accumulation of useful information. Perhaps professional societies might take a hand in such studies to ensure that public confidence is higher than it is presently.

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COMMENTARY I

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Once again John Cairns has provided us with an interesting and thoughtful paper in which he makes some compelling arguments for doing things differently. Let us take, for example, two quotations:

> *Even the least effective, crudest ecological methods are superior to pipe and technology-based standards for protecting the environment. Ecological methods are the only ones that have a feedback loop from the system being protected, based on ecological qualities.*

> *In the long-term, are direct measurements of crucial ecosystem response thresholds scientifically defensible and possibly more cost-effective than the present stfategy of extrapolating them from single species toxicity tests?*

If one reflects on these two statements, and relates them to the way we now "regulate" those human activities that we see as having the potential to disrupt freshwater ecosystems, then I think it will be clear that Cairns has concluded that there is a need to change (or even revolutionize) some of our traditionai approaches. I believe he is right. Indeed there is absolutely no doubt in my mind that if anything, Cairns understates the problem. Furthermore the real tragedy is not so much that we are embarked on the wrong course, but that our collective ability to move in the directions reflected in Cairns's paper is rapidly being eroded.

Despite the clear and unequivocal evidence that the current approaches to freshwater management are woefully inadequate, the agencies and bureaucracies that now have this responsibility are controlled primarily by persons who are committed to pipe and technology-based standards. The people who are building the case for new approaches are often viewed as being impractical, or even as a threat to the status quo. In times of economic restraint, the option value of persons who are developing a better way is likely to be seen as being less important than protecting the existing policies, programs and dogma. In Canada one has only to look to the recent cuts in Environment Canada for a clear example of this tendency. The Canadian Wildlife Service, which, in my view, contains the most ecologically aware group of scientists in the Department, was reduced by about 22% and its ecotoxicology group was particularly hard hit. The decimation of the Canadian Wildlife program stands in marked contrast to the groups that focused on the pipe and technology-based standards.

The Canadian Wildlife Service had a herring gull program on the Great Lakes. Since the early seventies, a very small but dedicated group of scientists has been monitoring both the chemical residues in herring gull eggs, and the health of the herring gull colonies. One has only to look through recent reports of the Great Lakes Water Quality Board and those of the International Joint Commission to realize that the herring gull program was, beyond a doubt, our best measure of progress under the Great Lakes Water Quality Agreement of 1978. Without the information from this program we would have essentially no means of even hazarding a guess as to whether or not the toxic chemicals in the Great Lakes System are more or less of a hazard than they were in the early 1970s. People want to know whether it is safe to drink it, swim in it or eat the fish from it, and herring gulls make an excellent barometer because they do drink it, swim in it and eat the fish from it. Now figuratively speaking, it seems that we are to be left with little more than a hollow shell of what was once the center piece and flagship of our Great Lakes International Surveillance Program.

Other recent cuts further emphasize our retreat to pipe and technology-based standards. The National Research Council is terminating its Environmental Quality Secretariat, and the Canadian Toxicology Center that was to have been established at Guelph seems to have been lost. As of now (February 4, 1985) I see few reasons for optimism — in the short term. In the long term (probably decades) we will have no choice but to pay more attention to what we are doing to our environment. The extraordinary public support that is reflected in all public opinion surveys on environmental quality issues is heartening. Indeed this is one case where the public is clearly ahead of both the bureaucrats and the politicians.

This workshop is on cumulative impact assessment, and I would suggest that if we were able to assess the cumulative impact of the program cuts outlined above we would find that they will have a devastating effect on our collective long-term ability to manage the toxic substances issue. The loss of expertise, information, morale and momentum will certainly move us from a leadership role to a follower role, and will reinforce the outdated and inadequate approaches that we now have available. Where we will turn for that leadership I don't know, but I expect we will, as we have in the past, find much of it in two small European countries, Sweden and Norway, which seem to have developed a more mature understanding of the role of man in ecosystems. Their ability to address cumulative impact issues has enabled them to play a role out of all proportion to their population on such issues as mercury pollution, the fate and effects of DDT and the nature of acid rain.

Cairns outlines a number of things that have contributed to the present dilemma. The dominant role of the engineering and legal disciplines in shaping our environmental control mechanisms have, in my view, contributed to the development of regulatory approaches that can be administered, but often bear little relationship to what is going on in nature. The people who had some awareness of stress/response relationships as they relate to freshwater were, more often than not, called upon to fill in the "knowledge gaps" in the grand conceptual model, but they had very little real opportunity to influence that model. The basic problem faced by ecologists is that we cannot predict impacts at the ecosystem level with the degree of precision that is demanded by the regulatory models developed by our lawyer and engineer friends. Furthermore, let us not delude ourselves, we will never be able to develop the kind of precision that current approaches imply and demand.

Despite our inability to provide the level of detail that is demanded, we, collectively, have devoted an undue amount of our effort, particularly since the National Environmental Policy Act, trying to predict impact, while at the same time, almost ignoring the opportunity to assess what actually did happer-r. As a result, we have not capitalized on opportunities to improve our overall ability to predict the implications of alternate courses of action.

Cairns touches on a fundamental reason for this problem. The scientific method as taught to us in our universities is basically irrelevant, and perhaps even counter-productive when it is applied to ecosystem responses. We have, I would suggest, seriously incapacitated ourselves with Occam's razor. Occam's principle of parsimony may have been relevant to Newton's laws or even President Kennedy's decision to put a man on the moon, but it can be very inappropriate when addressing environmental modeling and decision making, or for that matter, President Nixon's war on cancer.

In my view many of us with ecological training have also succumbed to Occam's razor. In the search for precise, quantitative methods, we turned our backs on what the "naturalists" had to offer, and tried to develop cause/effect relationships that for the most part don't exist in the real world. These responses are, more often than not, a result of multiple causes that in turn are a result of chance or random events. In retrospect many of the early naturalists who were not so locked into linear thinking, were much wiser than we once thought. It is heartening to see that many logicians and mathematicians are now talking about fuzzy logic, and have journals like "Fuzzy Sets and Systems." As someone who has corne to see the world in shades of grey it is good to see that others are questioning the black/white, true/false features of the Aristotelian logic that is reflected in so much of western society.

At this point I would like to outline some of the experiences that have led me to conclude that the views expressed in Cairns's manuscript are sound.

The section "Predicting Response from One Level of Biological Organization to Another" took me back to the formative years of the Freshwater Institute. My speciality at that time was freshwater benthos, and I was particularly interested in the use of chronomids (non-biting midges) as indicators of ecosystem health. I started a culture of *Chironomus tentans*, and the reason for the choice was simple. This species was one of the few species of chironomid that could be cultured easily. It mated on contact and did not require a mating swarm, and hence one could keep a culture going indefinitely in the laboratory. That fact, and not its relevance and applicability to the real world, was the primary reason for selecting this species. Single species tests do have a useful role, but even at the best of times we delude ourselves if we assume that we can extrapolate laboratory tests, with confidence, to field conditions. Laboratory tests can and do provide us with useful insights, but the proof of the pudding can only be assessed after the event.

I note that Cairns has also had "mixing zone" discussions with lawyers from the United States Environmental Protection Agency (USEPA). The International Joint Commission was given a watchdog role under the Great Lakes Water Quality Agreement, and it is expected to assess progress and the degree of compliance with that Agreement. The parties to the Agreement are the Governments of the United States and Canada.

The Agreement contains a very enlightened political statement as to its purpose.

> *The pur-pose of the Parties is to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem. In order to achieve this purpose, the Par?ies agree to make a maximum effort to develop programs, practices and technology necessary for a better understanding of the Great Lakes Basin Ecosystem and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes System.*

The foundation of agreement was the specific objectives, mostly water quality objectives, and the commitment to designate limited use zones. This would have given us a statement of objectives, together with realistic targets, as to where the parties and jurisdictions were expected to meet these objectives. Along came the Clean Water Act and now it is illegal (according to USEPA lawyers) to have mixing zones. Consequently authorities now give temporary "permits" to pollute while at the same time insisting that mixing zones, by legal decree, don't really exist. Our dilemma is that we, at the Commission, can talk about the specific objectives applying at one end of the pipe, but we know that no one will take the alarm seriously until we have clear evidence that pollutants are crossing the international boundary, and that objectives are not being met at the boundary. I view the failure of the parties to openly and honestly designate limited use zones as a "smoke screen and mirrors'' exercise, that enables us to continue polluting, while at the same time insisting that the law does not permit damage. Therefore, there is no mixing zone and no pollution. I'm afraid that unless we can find ways of changing our laws and regulations so that they bear more relationship to what is going on in receiving waters, we are playing Alice in Wonderland, where croquet is played with flamingoes and words mean whatever Humpty Dumpty wants them to mean.

I am pleased to see the discussions on subsidies and mitigation. Most of us have been conditioned to think of only the negative implications of human interventions. The cumulative impact of numerous stresses on a freshwater ecosystem is very unlikely to result in additive responses. We are dealing with a world where 1 + 1 may equal 2, but it may just as well equal 0 or perhaps it may equal 10 or 100. For the most part, we simply go on treating each stress as something that is to be considered as being independent of other stresses.

Since 1970 I have been involved, in one way or another, with the mercury pollution issue in northwestern Ontario. The English-Wabigoon system is perhaps the most mercury-polluted freshwater system in the world, and since 1970 we have been watching the recovery of that system. Sometime in the mid-1970s I became convinced that as scientists, we had an opportunity to begin asking some very different questions of that system. Instead of trying to understand every detail, why not explore opportunities for deliberately intervening in that system to help accelerate the recovery process? After a great deal of lobbying, the governments of Canada and Ontario signed an agreement to explore amelioration possibilities, and in August of 1984 the final report was released. By the time the study was completed all the scientific team leaders had corne to believe that yes, there were simple cost effective things that we could do to help the recovery of the system. The cheapest, but politically inappropriate, way of intervening would be to add a small amount of selenium to the system. The area is selenium deficient and although selenium is an essential nutrient, there was no recommendation to add it to the system, due to its toxicity. The most effective approach seems to be to artificially increase the level of suspended clays in those areas where the problem is most acute. Tests in large enclosures demonstrated very clearly that modest increases in the concentrations of suspended clay particles dramatically decreased the rate of mercury uptake in biota.

One has only to speculate on the linkages between suspended sediments, eutrophication and toxic chemicals to begin to appreciate the potential for constructive intervention. I have no doubt that there are times when open-lake disposal of dredge spoil makes sense both economically, and as a means of reducing the impact of many toxic chemicals. The economic implications in the Great Lakes System are clearly very substantial.

There is no simple answer or easy route to developing an adequate means of assessing the cumulative impact of different seemingly unrelated stresses. There are, however, many things that we can do better. The following medical analogy is used because I consider that there are many good reasons for thinking of ecosystems as dynamic living systems, and we do often have a significant impact on the health of those systems. Some of the directions that seem apparent include the following:

- We need better thermometers. A doctor uses a thermometer to tell if a patient is sick. He doesn't use it to identify the illness or to diagnose the problem. Similarly we need to develop sensitive early-warning measures of ecosystem stress that will signal when an ecosystem is not healthy.

- We need better diagnostic tools. Once it is clear that an ecosystem is showing signs of stress we need more sophisticated ways of tracking down the cause or causes.

- We need better methods of restoring ecosystem health. There are times when it does make sense to intervene deliberately and constructively to restore, rehabilitate, and even enhance conditions in aquatic ecosystems. Surely we have now reached the stage where we can contemplate intervening when it is clear that something is wrong. Similarly, what is intrinsically wrong with intervening, with a view to preventing ecosystem deterioration?

- We ought to focus less of our overall effort on preparing detailed environmental impact statements. In many cases, we have become preoccupied with making detailed predictions without regard to assessing whether or not our predictions were anything more than a legal step to go through in order to influence a decision. If we were to step back from the detail, and consider the larger processes that are impacting on a given issue, we would probably be able to foresee more of the cumulative impacts of interacting processes, policies and programs.

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

If we focused more of our efforts on the above items, there would be much more reason to hope that we could eventually adopt a more adaptive approach to both ecosystem assessment and ecosystem management. In time we would also be able to understand, predict and respond appropriately to more of the cumulative impacts of our collective actions.

COMMENTARY II

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The writings of John Cairns have a ring of authenticity. He has been deeply involved as a scientist and advisor on all aspects of the subject addressed in his paper. His leadership in the United States is widely recognized and acclaimed. Personally I have learned from him, repeatedly.

With respect to cumulative impact assessment, or CIA, we may note that Cairns's paper is formulated within an American context. A preoccupation with the question of what is legally defensible is apparent in the paper, and reflects the fact that the judiciary plays such a powerful role in the American system of governance. In his paper, there is no clear distinction between assessing environmental impact as a scientific/technical activity, and setting or enforcing effluent and/or target loadings standards within a legal/management context. These functions have corne to be linked quite closely in the United States, — they do not yet appear to be closely linked in Canada. The focus of my comments is on CIA as a scientific/technical activity, but related particularly to ecosystem features of particular importance to humans.

Strong reliance on the judiciary, as in the United States, seems to impose a demand on science to be relevant to the law and its interpretive regulations, and to be quite precise. Experts on the scientific method have noted that various criteria of scientific excellence cannot all be maximized simultaneously. Thus a legal demand for special relevance and high precision may involve a sacrifice of realism, richness, robustness, simplicity, comprehensiveness, and so on. An overemphasis on precision within the law, and within the regulations, and the technical studies undertaken to satisfy the needs of the legal process, may compromise the primary purposes of an impact assessment. These purposes may be more closely related to the criteria of comprehensiveness and realism than to some prior specification of relevance and precision. Formalization of regulations may act to institutionalize a particular scientific approach, and thus, may act to reduce motivation for scientific advances. CIA in Canada should be formulated with the processes of Canadian governance in mind, in which case comprehensiveness and realism as criteria may rank higher than statistical precision and a legal-based criterion of relevance.

THE MEANING OF TERMS

The term "cumulative" is used in various ways by different authors in this workshop. Cairns appears to use it in three ways: cumulation of the effects, caused by one intervention, from the species level to the ecosystem level of organization; cumulation over time of the effects of one intervention on one species (or on one system); and cumulation of a number of influences caused by different interventions on one species (or on one system). My own experience relates mostly to effects of a variety of interventions as exhibited at the ecosystem level of organization, hence I will focus mostly on Cairns's third connotation. It happens that I consider this third connotation to be particularly relevant to the ecosystem approach as urged in the 1978 Great Lakes Water Quality Agreement.

Various terms have been used to characterize the interactions between humans (especially commercialized and industrialized humans) and the rest of the ecosystem in which they occur. Terms such as stress or stressor, perturbation, subsidy, loadings, removal, restructuring, — refer to human forces as they intervene in and affect the rest of the ecosystem. Effects on the rest of the ecosystem of such forces may be termed responses, impacts, strains or stresses.

The terms "stressor" and "stress," are coming to be used to denote a cause and an effect respectively. The usage follows that of Hans Selye (1974) with respect to analogous phenomena defined at the level of organismal physiology of mammals, e.g.: "We shall see that the diverse biochemical adaptive reactions used by our cells and organs are surprisingly similar, irrespective of the kind of aggressor faced. This consideration led one to conceive of physiological stress as a response to any type of demand made on the body." (Selye 1974). After Selye had used the terms for some time, he came to realize that his use of "stressor" and "stress" was roughly parallel to that of "stress" and "strain" respectively as used in the physical sciences. By then however, his use (or misuse) of the terms was already widely accepted, and he did not change them. Many ecologists have corne to use his terminology rather than that of the physical sciences. Personally I haven't yet fallen in line with Selye's usage, but John Cairns has done so. So as not to confuse the issue further, I will not use the terms "stressor" or "stress" further in this paper, but rather refer to the relevant "force" or "aggressor" as an "intervention" in the ecosystem.

INDICATOR SPECIES

Indicator species have long been used to provide both qualitative and quantitative characterizations of the state of an ecosystem, especially with respect to features of that state which relate to dominant societal concerns and interests with respect to such ecosystems. The Saproben system was developed in Europe with respect to gross organic pollution

(Hynes 1960); and many other indicator species schemata have been developed. They have been applied to monitor the effects of particular environmental interventions, and also (much less frequently), to diagnose the likely causes of particular degradational effects or symptoms. Legal standards have been devised in the United States that define what is acceptable in terms of presence or absence of particular indicator species. It is not surprising that environmental impacts have corne to be assessed particularly with respect to the impacts on indicator species.

As Cairns shows, there is a danger that indicator species corne to be seen as ends in themselves, and not as rather imperfect surrogates of the whole ecosystem. This unfortunate trend can be fostered if an additional step is taken in which the impact on the test species in a controlled, stereotyped laboratory setting is taken as a sufficient indication of what the impact will be on the whole ecosystem.

This trend toward excessive reliance on laboratory species as surrogates of integrated ecosystem features may be an example of over-emphasis on a criterion of legal relevance and statistical precision over the criteria of comprehensiveness and realism, in order to satisfy requirements of the legal process.

SYNDROMES

Almost regardless of the type of human interventions in freshwater ecosystems — as those interventions have been practiced conventionally, and provided that those interventions are relatively severe — a kind of general degradation syndrome (GDS) cornes to be exhibited by the impacted ecosystem. This GDS can be seen as roughly analogous to Selye's general adaptation syndrome (GAS), also called his biological stress syndrome (Selye 1974; Rapport et *al*. 1985). Selye's GAS is focused at the organismal level of mammals, while our GDS is focused on the ecosystem level. In the Great Lakes ecosystem, this GDS has been characterized as follows (Regier and Grima 1984; Francis et *al*. 1985):

> *The* major *ecological interventions associated with human uses as conventionally practiced, often act synergistically so as to exacerbate each other's adverse effects, sometimes independently, and seldom act antagonistically so as to cancel out adverse effects.*
>
> *The interventions, separately and jointly, act to alter the fish association from one that is dominated by large fish usually associated with the lake bottom and lake edge, to one characterized by small, short-lived mid-water species. A similar change happens with respect to vegetation; firmly rooted aquatic plants near shore originally, to dense suspensions of open-water plankton algae. Further, the association of relatively large benthic invertebrates directly on bottom (such as mussels and crayfish) is supplanted by small burrowing insects and worms (such as midge* larva *and sludge worms). Broadly similar changes occur in the flora and fauna of the wetlands and nearshore areas bordering these waters.*
>
> *With the above changes cornes an increased variability from year to year in abundance of particular species, especially of landings of different fish species by anglers and commercial fishermen. Fluctuations are also more pronounced in the species associations of wetland, ben thic and pelagic areas.*
>
> *The shift from large organisms associated with the edges and the bottom of the waterbody, to small organisms in the bottom mud and in mid-water is not accompanied by a great increase in the total biomass of living ma terial, certainly not of the most preferred species.*
>
> *Market and sport value per unit biomass is generally much lower with small mid-water fish species than with large bottom species, and processing costs are higher. Similarly, the aesthetic value to recreationists of the rooted plants nearshore, is higher than a mass of stringy algae or a peasoup-like mixture of suspended algae and pollutants.*
>
> *The overall effect on fisheries is that nearshore labour-intensive specialized fisheries (sport and commercial) tend to disappear, though highly mechanized, capital-intensive offshore enterprises may persist (if the combined stresses do not become excessive, and if the fish are not so contaminated as to become a health threat for those who would eat them). Yachtsmen may quickly sail from polluted marinas through the foul nearshore water to the attractive offshore waters. Beaches are posted as hazardous to health.*
>
> *The combined effect is one of debasement and destabilization of the system of the na tural environment and its renewable resources, with respect to the features of greatest value to humans.*

By and large, the effects of different interventions cumulate to drive the ecosystem further into the GDS. This is not to say that all symptoms of the different interventions (at intense levels of action) are similar; for example, extreme acidification of lakes does not appear to induce the major symptoms of the GDS.

From this empiric generalization concerning the GDS, it follows that a first-order approximation to the CIA of a proposed relatively severe intervention of a rather conventional kind (but not acidification) can be made from an armchair — the impact will exhibit at least some of the features of the general degradation syndrome sketched above.

From the armchair it should also be apparent that it will not be easy to specify, after the fact of an intervention where other interventions are also acting, what the detailed and comprehensive impact of a particular intervention will have been. Since human interventions as conventionally practiced are generally not "well-behaved," the overall interactive system of interventions and ecosystem effects may be quite turbulent. Synergisms may occur not only among the effects of human interventions, but also among them and rather unusual natural events that may occur coincidentally.

Trend need not be destiny, as Cairns implies, because severe interventions in freshwater ecosystems, as they have generally been practiced in the past, have caused a rather predictable general degradation syndrome. This does not mean that this must inevitably occur in the future. Perhaps at least some kinds of interventions can be engineered so as not to contribute to a GDS — better yet, they might be designed to mitigate or cancel out the effects of some other human interventions that contribute to a GDS.

MANION'S APPROACH

How might we transform an understanding of a GDS into a tool useful for predicting or assessing in detail the impacts of some intervention on a particular ecosystem already subject to a suite of human interventions, and also subject to a background of anomalies in the natural driving variables to which the ecosystem is subject? For a somewhat analogous problem with forests, Manion (1981) proposed that harmful influences be classified into three types: predisposing, inciting and contributing. The overall impact of a new "inciting" intervention should be assessed in the light of other "predisposing" or "contributing" deleterious conditions or influences acting concurrently.

Where one or more types of human intervention are already severe to the point where the GDS is apparent, Manion's analytical scheme may not add much. The additional intervention will likely intensify the GDS condition, i.e., it will make a mess messier. However, where the number of degrading influences are relatively few in number and not severe in intensity, Manion's scheme may be quite helpful.

In temperate freshwater systems, human interventions are imposed upon a marked seasonal cycle with their suite of anomalies. Several investigators are apparently developing versions of Markovian models to explicate the effects of human interventions on features and processes of the impacted ecosystems. (Examples of such models were presented at the Ecological Society of America meetings in Fort Collins, Colorado in August 1984). Manions scheme might be compatible with such Markovian models for the purposes of cumulative impact assessment where the interventions are few in number and not particularly severe.

We have used a kind of modified Markov approach, with a conceptual framework something like that of Manion, to assess impacts of somewhat different concurrent interventions (Shuter et *al.* 1980; 1985, the latter is a kind of "post-impact audit"). We assessed the impact of thermal loading (by Bruce A Plant of Ontario's Bruce Nuclear Complex on Lake Huron) on a local smallmouth bass fishery. The warmed water affected the bass in several ways, especially with respect to the annual recruitment of young bass and to the vulnerability of older bass to anglers. This led to an increase in the amount of effort expended by fishermen and the intensity of that effort. Thus we assessed the cumulative effect on the bass of several kinds of ecological effects associated directly and indirectly with the thermal loading, and then assessed our CIA with data from a period following initiation of the impact.

A BERTALANFFIAN PERSPECTIVE

The ecosystem perspective of many, if not most, ecologists is akin to Bertalanffy's General Systems Theory or GST (Bertalanffy 1950; Davidson 1983; Steedman and Regier 1985). Within Bertalanffy's GST as such, there is no immediate basis of support for the idea that the relative well-being of a particular species at one level of organization should be a good indicator of the relative well-being of an ecosystem in which many biotic and abiotic features and processes are integrated, at least to some extent. It may happen that a particular species plays a dominant role in the ecosystem, which would then constitute a special case within GST. Though dominant, the species nevertheless integrates key features of the whole ecosystem. The species may also be of particular interest and value to humans. Under such circumstances, the dominant species may serve as an indicator species and satisfy both criteria of relevance and realism — proper scientific work should lead to appropriate precision in any assessment.

In oligotrophic Canadian freshwaters, the salmonids may serve as appropriate integrative indicators, not only of their own well-being, but also of that of the ecosystems in which they occur (Maitland et *al.* 198 1). The lake trout has been proposed to serve this purpose in the Great Lakes (Ryder and Edwards 1985).

Steedman et *al.* (1985) have attempted to characterize Great Lakes ecosystems in a way that would facilitate work with cumulative impact assessment as it relates to a variety of degrading influences by humans. This approach relates to sensitive species (e.g., salmonids) as well as to sensitive habitats (e.g., centres of organization), all within a kind of Bertalanffian perspective.

COMPLEXITY

Just now in 1985, a problem in CIA is generating controversy in the Great Lakes research community. To what extent is eutrophication of the lower lakes or of some bays in the upper lakes due to increased loading of nutrient phosphates or due to suppression of large piscivorous fish? Nutrient loading controls in part the trophic status of lakes through its stimulative effect on primary production, and is thus a form of bottom-up control. Large piscivores prey on small plantivorous fish, and thus constitute a form of top-down control on the trophodynamic pyramid. Piscivorious fish were suppressed by intense fishing and predation by the invading sea lamprey, at about the time that loadings by phosphates increased. Some of the indicators of eutrophication, such as water clarity and intensity of primary production, were presumably affected cumulatively by all three of these major factors (plus some others) — as has long been known by the more informed aquatic ecologists.

To sort out the separate effects of these various interventions with scientific rigour, after the fact and in terms of causal mechanisms, is now virtually impossible. Considering natural background anomalies as stressful interventions, it becomes quite difficult to work out the causality of a single cultural intervention (if relatively severe), because it will likely act in a non-continuous manner through space and time. To sort out the causality of two types of cultural interventions initiated concurrently, perhaps interacting with each other and with the natural background of turbulence, may strain any research budget because of the complexity of the problem. Three or more cultural interventions, acting concurrently at a level of some severity, might better be treated as a simple problem since it will likely be intractable if treated as a complex problem. Some approach (e.g., a comparative approach) will need to be found to the theoretical and practical issues so that they can be addressed as a cumulative phenomenon, per se. This is not a new problem to science and practice — note Selye's GAS with respect to mammalian organisms and approaches to the socio-cultural conditions of human urban and rural slums. We are developing a somewhat comparable approach to the Toronto aquatic ecosystem as an "area of concern" due to the cumulative impacts of numerous interventions (Steedman et *al*. 1985). We suspect that complexity is in the eye of the beholder.

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Management Perspective

CUMULATIVE ASSESSMENT AND THE FRESHWATER ENVIRONMENT

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It is important at the outset of this paper to define the concept of cumulative impact assessment, the limitations of its application to the freshwater environment, and the reasons why there are difficulties in effectively managing such impacts. These issues are discussed in this short introduction before some case studies illustrating specific management questions are presented. [1]

The term "cumulative impact assessment" is generally understood to embrace the analysis, interpretation and management of the accumulation of impacts resulting from a number of individual developments on the environment. With reference to the freshwater environment, this definition conjures up problems arising from multiple hydro-electric dams on major river systems, or major diversions such as those in the American west to supply irrigation water to large-scale agricultural development. It can also include multiple discharges of liquid wastes into rivers or lakes, both from point sources such as industries or municipalities, or from non-point sources such as agricultural feedlots and septic tanks.

Baskerville (this volume) notes that cumulative impact may also occur as a result of a single action, which affects ecological systems in such a way that the systems themselves magnify project impacts. This paper considers the former concept of cumulative assessment primarily, though the issues associated with information needs discussed at the end of the paper could apply equally to the latter concept.

Another aspect of cumulative assessment should be considered, namely the analysis of impacts among watersheds in a defined geographical area. There is growing recognition that the term "integrated resources management" does not connote multiple resource use in every watershed; that somehow an appropriate balance can be struck between competing uses to serve all of society's diverse demands. Rather, integrated management can embrace the notion that some environmental systems can be designated to provide certain demands — say for water supply or high water quality — at the expense of conflicting uses. In water management, the rapidly increasing demands for water use in agriculture and industrial use compete with instream requirements to provide adequate habitat for fish, ample dilution for waste disposal, or more simply, maintenance of flows that are aesthetically pleasing. The combined result of all these demands often results in multiple conflicts in individual watersheds. It may be possible to make more purposeful allocations of water use, to serve competing demands among a number of watersheds by designating priority uses in each watershed.

A third aspect of cumulative assessment is that the natural environment recognizes few boundaries. The emphasis in this paper on the freshwater environment cannot exclude the real linkage with all other natural environmental systems — terrestrial, marine and atmospheric. As will be demonstrated in the case examples, water quality can be affected by riparian land uses, such as suburban development, agriculture and forestry. Rivers generally flow into the marine environment, so at the interface, namely estuaries, there are clearly close linkages between salt and freshwater systems and their dependent resources. Even the atmospheric environment is linked with freshwater through such problems as acid precipitation affecting productivity of lakes and streams. Cumulative assessment specifically deals with issues that compound over temporal and spatial boundaries; thus a distinction between water and these other environments is simply not realistic.

The fourth issue that influences effective management of cumulative impacts is that such impacts often cross jurisdictional responsibilities. When dealing with the environmental impacts of a single project, generally a single jurisdiction is in control of impact management, unless downstream effects cross provincial or national boundaries. In Canada, the major exception to this rule is the split jurisdiction of fish resources between federal and provincial governments, though in many cases, there are cooperative programs in place to deal with such problems. Cumulative impacts, by their inherent nature tend to involve various levels of government to such an extent, that no single authority can generally assume control. Thus even the traditional tools for management — research, inventory, monitoring and predictive analysis are difficult to organize and implement. Given that some cumulative impacts raise very complex ecological and social questions, the lack of an organized institutional approach to their management has

1 The thoughts contained in this paper are solely those of the author and do not necessarily reflect the policies or management priorities of the B.C. Ministry of Environment.

become a major constraint in the attainment of society's environmental goals.

In the balance of this paper, four case studies which involve cumulative impacts on the freshwater environment are described. Two of these consider water quality management — one in a major river — the Fraser River and estuary, and the second a major lake system in the Okanagan Valley. A third case analysis covers aspects of water supply allocation of hydro power on the Fraser and Peace Rivers, and the fourth looks at the question of cumulative assessments across watershed boundaries affecting multiple stream and lake systems. In all cases, emphasis is placed on institutional rather than scientific issues.

FRASER RIVER AND ESTUARY WATER QUALITY

On the surface, water quality management in the Lower Fraser River and estuary provides a classic example of cumulative impacts. The Fraser River flows through the southern edge of the Greater Vancouver metropolitan area, which in 1981 contained a total population of around 1.3 million, plus much of the manufacturing industrial base in British Columbia. In the Vancouver area, water is discharged into the river and estuary from three municipal sewage treatment plants, over 100 industrial outfalls, around 200 storm water outfalls, together with leachate from numerous landfills and log booming areas (Figures 1 and 2). The total quantity of these discharges amounts to approximately 2 million cubic metres per day, less than 1% of the average river flow of some 300 million cubic metres per day.

The jurisdiction for managing all these wastes is somewhat divided. The provincial government has primary responsibility to control point waste discharges. However, local government can control waste discharges within municipal boundaries, and the federal government, through its mandate to protect fish and fish habitats under the Fisheries Act, can act to limit waste discharges if it feels that fish are threatened. Given that the Fraser River contains the largest population of salmon of all provincial rivers, (approximately 12 million fish migrate upstream each fall, representing almost 25% of total salmon production in the province), the federal mandate is strong.

In light of the potential threat to environmental quality posed by these multiple discharges, plus other impacts on fish resources resulting from loss of habitat due to industrial and commercial development, the federal and provincial governments signed an Agreement in 1977 to develop a joint management plan for the estuary (Fraser River Estuary Study 1979). A major component of this plan was the analysis of waste discharges, trends in receiving water quality, and the establishment of water quality objectives.

WATER QUALITY CONDITIONS

The high flushing flows of the Fraser River cause ambient water quality in the main river channels to remain satisfactory for most uses. There is some oxygen depletion in backwaters or sloughs due primarily to poor flushing, and aggravated by log storage or leachates from landfilled material. The concentrations of heavy metals and organic compounds are also generally below acute toxicity criteria, though there is evidence of bio-accumulation of some toxic materials in some resident fish, but not the commercially important migrating salmon. However, sublethal effects of these contaminants have not been fully investigated. Fecal coliform levels in the beaches on the estuary itself lie generally within the criteria for water-based recreation, but exceed the limits for shellfish harvesting.

The major sources of waste are the municipal sewage treatment plants (STP), storm sewers and industrial outfalls. At present, the municipal plants have primary treatment. Installations of secondary treatment at the major plants - Annacis and Lulu Island — would reduce total loading of most contaminants of the river by 20-25%, but would cost at least $90 million (capital $198 1). Acquisition of land for sludge disposal would be extra. Controlling storm sewer discharges would reduce loadings by an additional 15-20%, but would cost at least another $35 million (preliminary estimate). These capital costs of some $130 million also have to be placed in context with the estimated $150-200 million required over the next five years to resolve the problems of solid waste disposal for the greater metropolitan area.

There are other means for controlling waste discharges that are now being considered by the provincial government. One is to place more emphasis on source control to prevent industry from discharging toxic material directly to municipal sewers. This however, will require a companion program to develop a facility for the safe disposal of sludges associated with such wastes. Studies are underway to identify a secure landfill in the dry interior of the province. A second approach is to strengthen enforcement of regulations under the provincial Waste Management Act, to prevent discharges that exceed pollution control objectives, or are discharged under unregulated conditions.

A third is to undertake a more thoughtful monitoring program. The analysts preparing the water quality assessment under the Federal-Provincial Agreement sifted through some 35,000 measurements of waste discharge data, and some 55,000 measurements of water quality (mainly chemistry) in the river itself (Fraser River Estuary Study 1979). Yet important gaps were evident in this massive data base, such as: no continuous monitoring of storm water outflows (all data quoted above are based on estimates and extrapolations from other municipalities); no algal bioassays to assess concentrations of contaminants at different trophic levels in the river; no detailed analysis of the mixing plume of the Annacis Island STP influenced by the saltwater wedge from the sea and the variability of downstream flows in the river; no adequate data on quality and quantity of leachates from landfills diverted to the Annacis Island STP; and no specific analysis of sublethal effects of toxic contaminants on fish in the river.

Many of these data gaps now have begun to be addressed through individual case studies conducted by the B.C. Ministry of Environment, and through a joint monitoring program proposal prepared by the federal, provincial and local government officials. However, the major questions have yet to

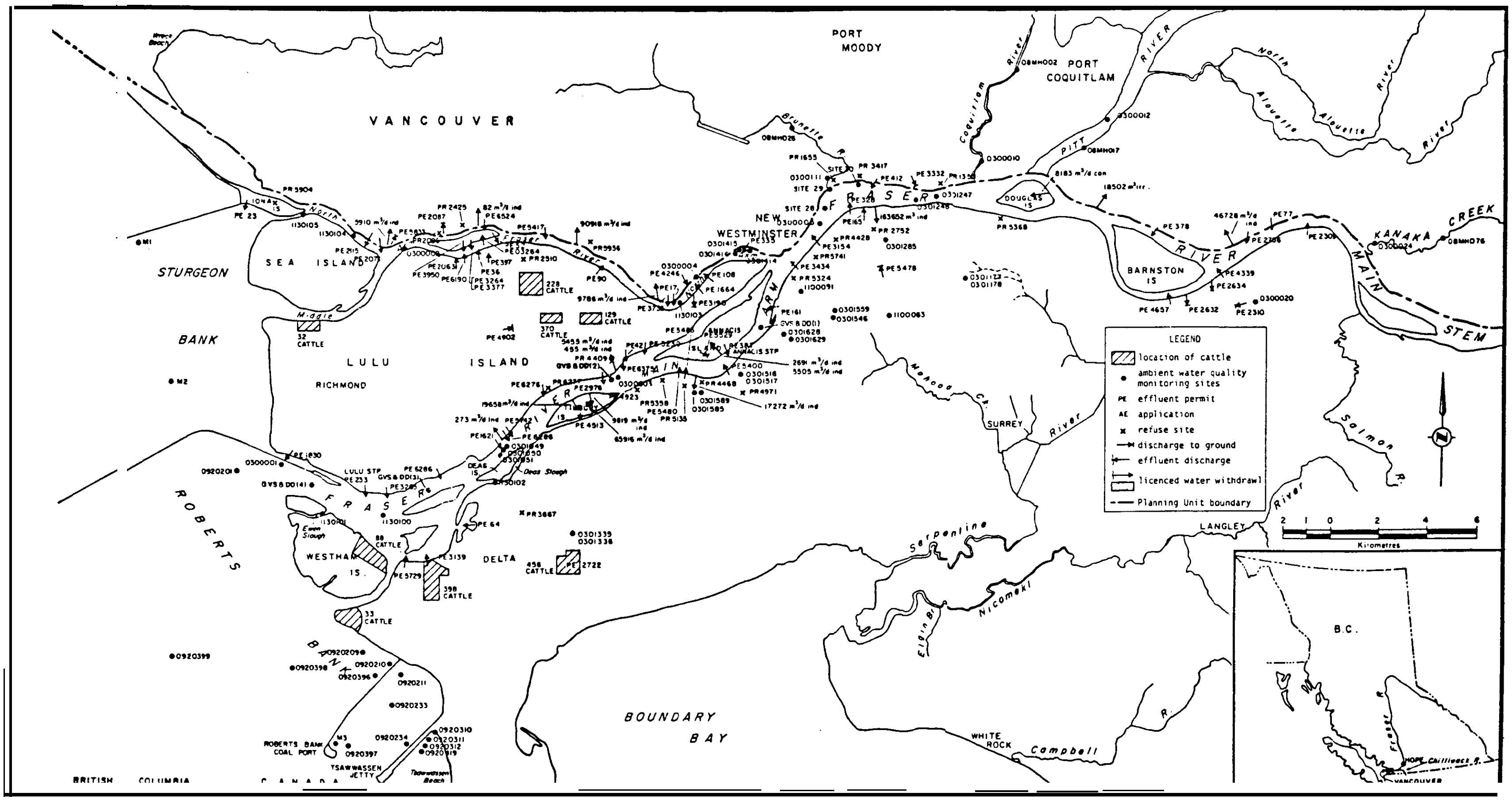

Figure 1. Locations of sites discharging effluents, ambient water quality monitoring sites and licensed water withdrawals, Fraser River downstream from Kanaka Creek.

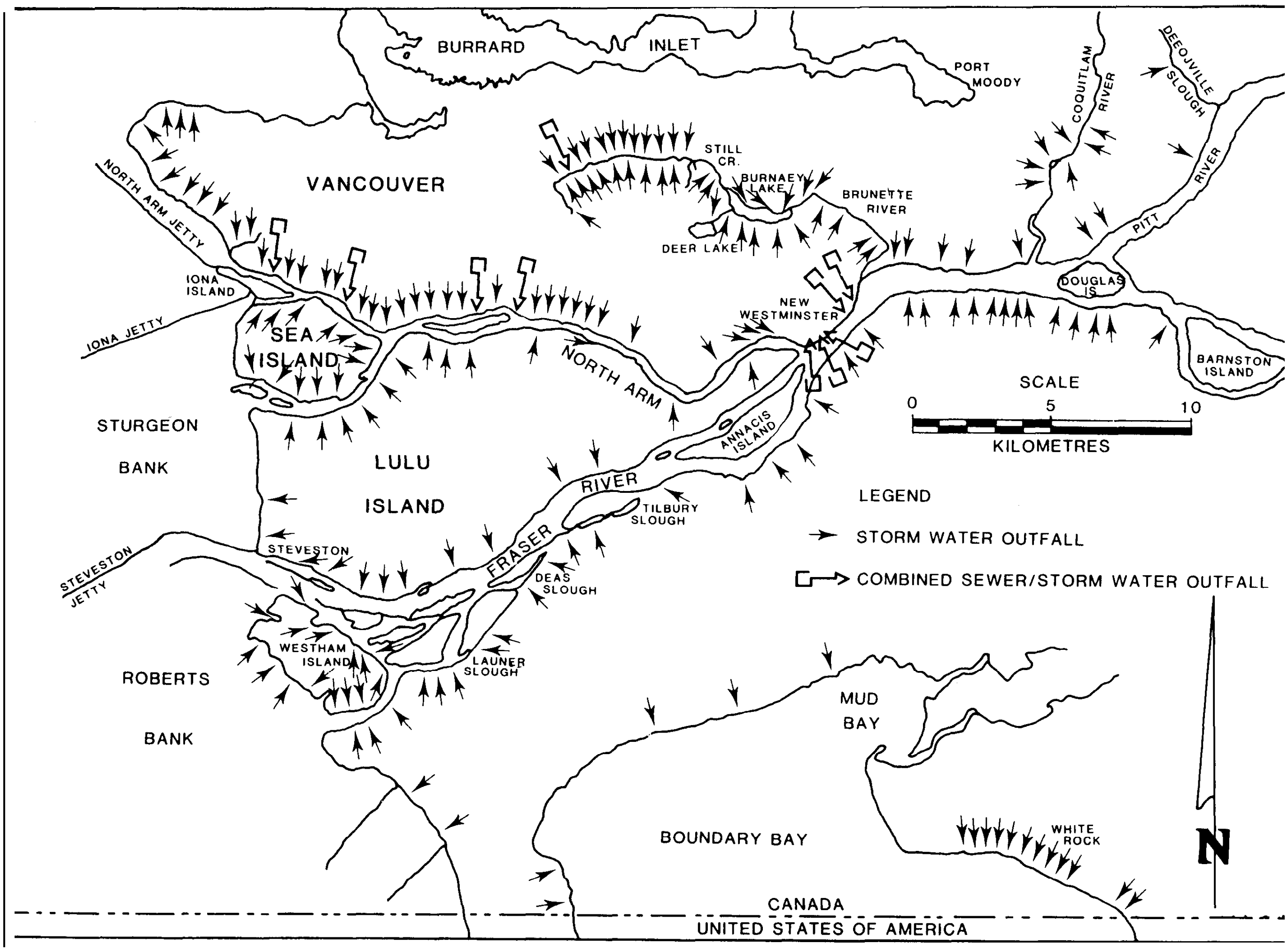

Figure 2. Location of Storm Sewer Outfalls

be answered: What is the risk of sublethal effects of contamination on aquatic biota, and potentially the highly valued salmon resource? Can the high cost of waste management controls be justified in light of this uncertainty and competing demands for expenditures, and what are the most cost-effective experimental research projects that can be undertaken to reduce the level of uncertainty regarding the long-term effects of changes in water quality on aquatic ecosystems? We will return to these questions at the end of the paper.

OKANAGAN VALLEY WATER QUALITY

The Okanagan basin lakes, like the Lower Fraser River, receive effluent from numerous point and non-point sources causing some of them to become eutrophic due to high nutrient loadings (Figure 3). Lake enrichment has resulted in a number of algal blooms on recreational beaches, and provided a nutritious base for aquatic weed growth in many of the shallower arms of Okanagan Lake. As a significant portion of the local economy is totally dependent on tourism and recreational development, which in turn is dependent on maintenance of adequate water quality, public concern over deteriorating water quality has been intense over the past decade.

This public concern led to the development of a comprehensive basin plan under a Federal-Provincial Agreement between 1969-1973. Subsequently, a number of recommendations of the plan were implemented, and results of this program reviewed in 1982. The major findings arising from this review concerned waste loadings and water quality.

Waste Loadings

Between 1970 and 1984 there was a decrease in total phosphorus loadings to the basin lakes due largely to improved sewage treatment at all of the municipal outfalls

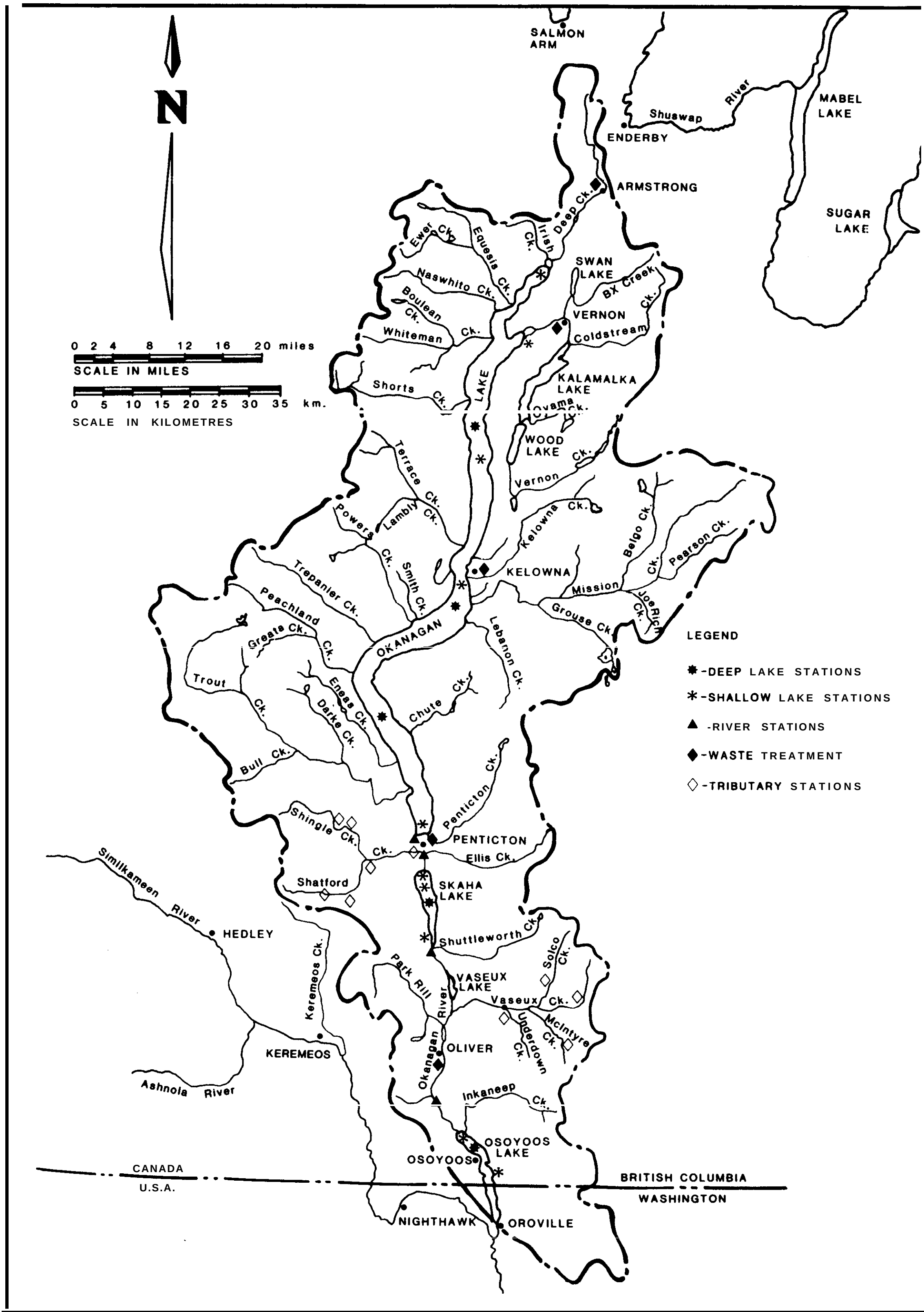

Figure 3. Location of Water Quality Monitoring Stations in the Okanagan Valley

(Table 1). However, phosphorus loadings from non-point sources (mainly septic tank fields and agricultural feedlots) have increased significantly over the same period.

TABLE 1

Comparison of Total Phosphorus Discharges from Various Sources, 1970 and 1984.

	1970 (kg/annum)	1984 (kg/annum)
Municipal Discharges	54,500	19,000
Non-point (controllable)	11,130	30,180
Non-point (uncontrollable)	45,900	38,100
	111,530	87,280

Sources: Okanagan Basin Implementation Agreement Report, 1982. Ministry of Environment estimates.

Water Quality

The current quality of the major basin lakes is portrayed in Table 2. Kalamalka and the main body of Okanagan Lake remain oligotrophic, but varying levels of elevated phosphorus are found in Ellison, Wood, shallow arms of Okanagan, Skaha and Osoyoos Lakes. Table 2 also indicates how the spring total phosphorus concentrations have changed over the past 10 years.

TABLE 2
Comparison of Spring Total Phosphorus Concentrations in Okanagan Basin Lakes 1970- 1980

Lake	Total P Concentration (mg/ 1) 1970171	1977	1978	1979	1980	Classification in 1980
Wood	—	68.5	91.0	54.7	84.0	Mildly eutrophic
Kalamalka	—	5.0	6.5	7.0	9.8	Oligotrophic
Okanagan (Central)	10.8	8.5	4.5	9.5	7.0	Oligotrophic
Skaha	20.7	11.0	18.0	22.8	24.5	Mesotrophic
osoyoos	22.8	21.0	23.5	17.3	21.3	Mesotrophic

Source: Okanagan Basin Implementation Agreement Report, 1982.

Water quality does not appear to have deteriorated significantly even though the population has roughly doubled over the decade. The fluctuation of concentrations in the smaller lakes, Skaha and Osoyoos, is partially due to changes in hydrologic conditions between years, since flushing rates in these lakes are high. Longer-term monitoring is required to understand the relationship between changes in nutrient loading and hydrologic conditions.

Three major questions continue to hang over the future management of water quality in the Okanagan basin. The first relates to understanding the system linkages between lakes and their differential flushing time. Kalamalka and Okanagan Lakes have relatively long residence times[2] — approximately 70 years, thus if they should become eutrophic, it could take a long time to reverse the trend. The lower basin lakes, Skaha and Osyoos, experience rapid flushing (residence times of one year or less). However, should Okanagan Lake turn eutrophic, the nutrient loadings into these lower basin lakes would be so large that no level of waste control could reverse the trend towards increased eutrophication. Similarly Wood Lake, upstream from Kalamalka Lake, is eutrophic and poses a threat to Kalamalka Lake. Thus the key question is how much nutrient loading Okanagan and Kalamalka can receive before they become eutrophic. This answer is unknown at present.

The second question concerns the gradual build-up of nutrients from non-point sources. There has been a rapid growth of subdivisions served by septic tanks in communities not tied into municipal sewer systems. Sewage disposal from septic tanks is regulated under the Provincial Health Act rather than the Waste Management Act (for discharges under 22.7 m^3/day). However, the Ministry of Health has taken the position that its primary management concern is the protection of public health, and has thus far not agreed to include nutrient removal specifically within its regulations. Even if the regulations were changed to meet guidelines prepared by the Okanagan Basin Implementation Board, their implementation would rely on the cooperation of the Ministry of Municipal Affairs to direct local government to incorporate these into municipal by-laws, and to the federal Department of Indian Affairs to encourage their application on Indian Reserve lands. Runoff from agricultural feedlots is an additional and increasingly important source of nutrient loadings to streams and lakes.

The third question, like that posed for the Fraser River, relates to the issue of financing waste management measures. The provincial government provides financial assistance to municipalities under the Sewerage Facilities Assistance Act, but under its recent restraint policy the amount of monies available to an individual municipality is limited, and the proportion of capital costs covered by the province has been switched from 75 % to 25 %.

The Waste Management Act (1982) provides municipalities an opportunity to develop waste management plans. Such a plan remains a discretionary measure, but could enable municipalities to tie in surrounding rural areas presently serviced by septic tanks, if these are part of their community expansion plan. However, such waste management plans would, at best, only provide coordinated treatment for nodes of population around the lakes. The B.C. Ministry of Environment potentially has the authority to coordinate the waste management plans of various municipalities to control nutrient loadings at or below the levels required to maintain water quality in Okanagan Lake within the oligotrophic range. However, local

2 Residence time is the length of time required completely to exchange water in the lake.

government cooperation is also required to provide financing. The 1973 Okanagan Basin Study report recommended that the three Regional Districts (a level of local government) that embrace the Okanagan Basin be combined into one for the purposes of facilitating financing and coordinating municipal treatment upgrading, but this recommendation was not acted upon.

In summary, the management of water quality in the Okanagan basin poses some complex ecological, socio-economic and institutional questions.

- What are the 'safe' levels of nutrient loadings that can be assimilated by the basin lakes?
- What level of water quality will residents and tourists accept in the lakes; will people grow accustomed to occasional algal blooms and aquatic weed growth?
- What are the most cost-effective measures for controlling nutrient loadings, both from residential/municipal development and through controls on agricultural and forestry land uses?
- How much is society willing to pay to control wastes, given the uncertainty of their impact on the water quality environment?
- Can an overall waste management strategy be developed that covers the entire valley — will downstream residents be willing to pay for waste management controls in upstream municipalities?

HYDRO POWER PROJECT DEVELOPMENT ON THE FRASER-PEACE RIVER

Both the Fraser and Peace Rivers have considerable hydropower potential, which has been subject to detailed analysis (Fraser River Joint Advisory Board 1968; Mackenzie River Basin Committee 1981). However, actual development on the Fraser River has been limited to a few relatively small-scale projects on tributary streams, because of the river's highly productive salmon resource. The only major development is the Alcan 800 MW project on the Nechako River, a tributary to the Fraser, built in the 1950s to power the aluminium complex at Kitimat. Such is the importance of the Fraser salmon resource that the federal Department of Fisheries successfully obtained an injunction from the B.C. Supreme Court to require Alcan to release flows sufficient to protect spawning sockeye salmon.

The Peace River, lacking valuable fish resources to counterbalance the economic importance of hydro power, has witnessed the development of two major projects in British Columbia (Williston and Site One), with a third (Site C) given approval-in-principle, subject to improved markets for electrical energy. Alberta also has an interest in developing hydro power but, recognizing the cumulative effects of B.C. hydro power production, is reluctant to commit its resources until it can negotiate an agreement on water flows across the border (Figure 4).

This broader question of jurisdictional controls on downstream impacts of major development was a major issue in the Mackenzie River Basin Study (1981). The Committee that undertook this study recommended that the jurisdictions involved (B.C., Alberta, Northwest Territories) negotiate an agreement,

> *Through which transboundary water management issues such as minimum flows, flow regulations and water quality can be addressed at jurisdictional boundary crossing points in the Mackenzie River Basin and which establishes a permanent Board to implement the provisions of the Agreement.*

To date no such agreement has been negotiated, though it has been the subject of considerable debate by policy analysts (Sadler 1984). Though the current economic recession has greatly reduced the immediacy of the potential developments for hydro power, there remain many unknowns about the effects of such proposals on the complex ecosystems of the Peace-Mackenzie systems, ice regimes, water quality and navigation. A decade ago, the damming of the Peace River to create Williston Lake had a significant impact on the downstream ecology of the Peace-Athabasca delta, a sequence of events that was not predicted at the time (Peace-Athabasca Delta Project Group 1973). In addition to these complex ecological issues are related questions on economics of power production with varying levels of upstream controls, and on the native people's claims to resource and land entitlements.

CUMULATIVE ASSESSMENTS BETWEEN WATERSHEDS

Major project developments are not the only ones that create significant cumulative impacts on freshwater systems. More insidious are the many small-scale actions that gradually build up impacts over time and space into major problems. Examples abound in British Columbia. Attrition of fish habitats in streams and estuaries occurs due to logging, water withdrawals and other streambank disturbances. One such example is the proposal by CN Rail to expand its track capacity over the next decade by twin tracking approximately 700 km of its route from near the Alberta border to Vancouver. Much of this track parallels various rivers (Figure 5), and will involve a large number of encroachments affecting flow velocities in these rivers and their tributaries. The total impact of such actions on fish migration, rearing, holding and spawning is unknown, although the decision is made and construction is underway for the first phase. An Environmental Assessment Panel established by the federal government has begun to look into the cumulative impacts, perhaps the first example of a public inquiry into cumulative assessment in Canada (Federal Environmental Assessment Review Office 1983). Other examples include conflicts between logging and domestic water supplies in the small, steep watersheds in central British Columbia; increased drainage problems in urbanising watersheds around Vancouver; increased natural hazard events (floods, slides) due to forestry, mining and other such developments in small watersheds.

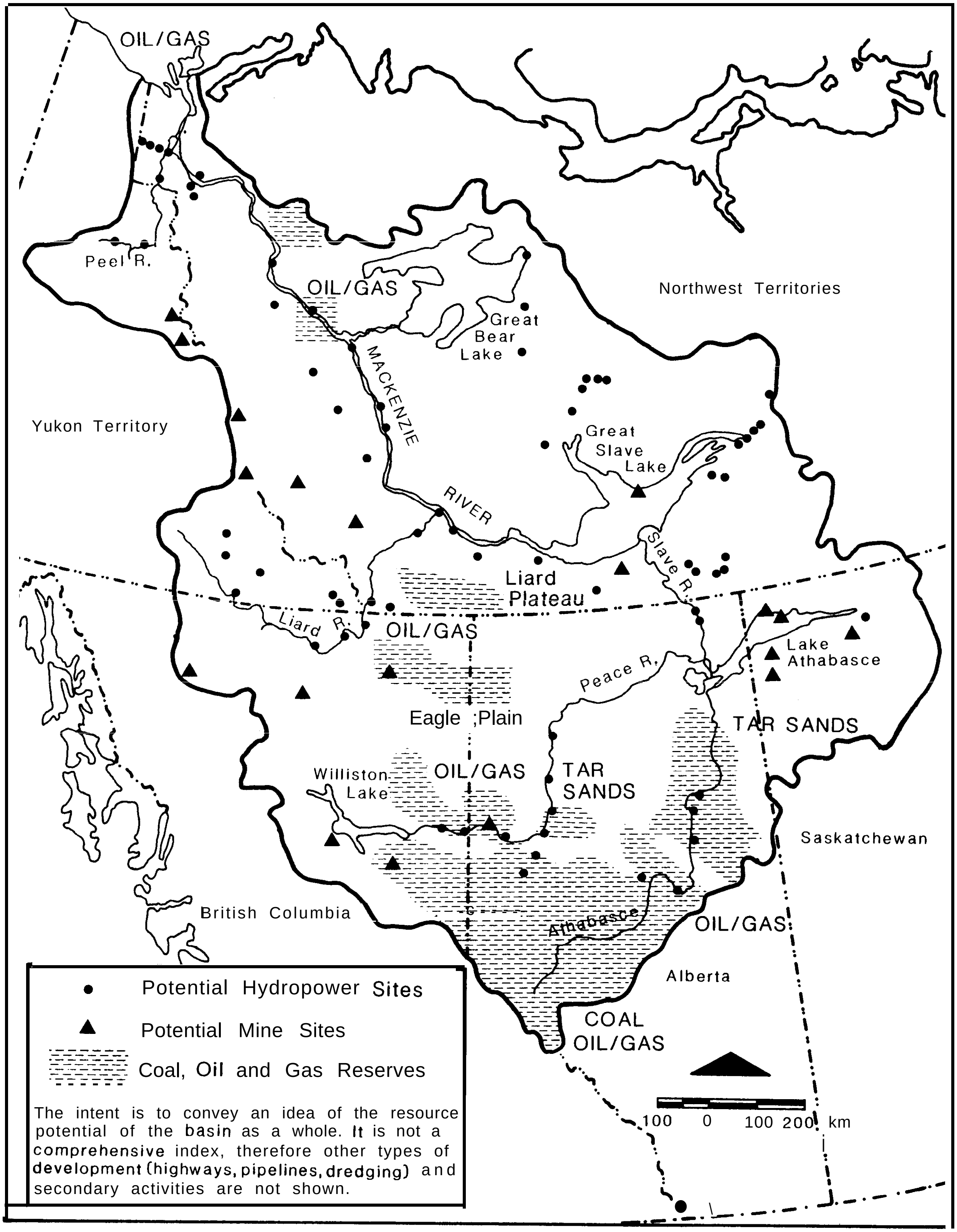

Figure 4. Selected development opportunities in the Mackenzie River Basin

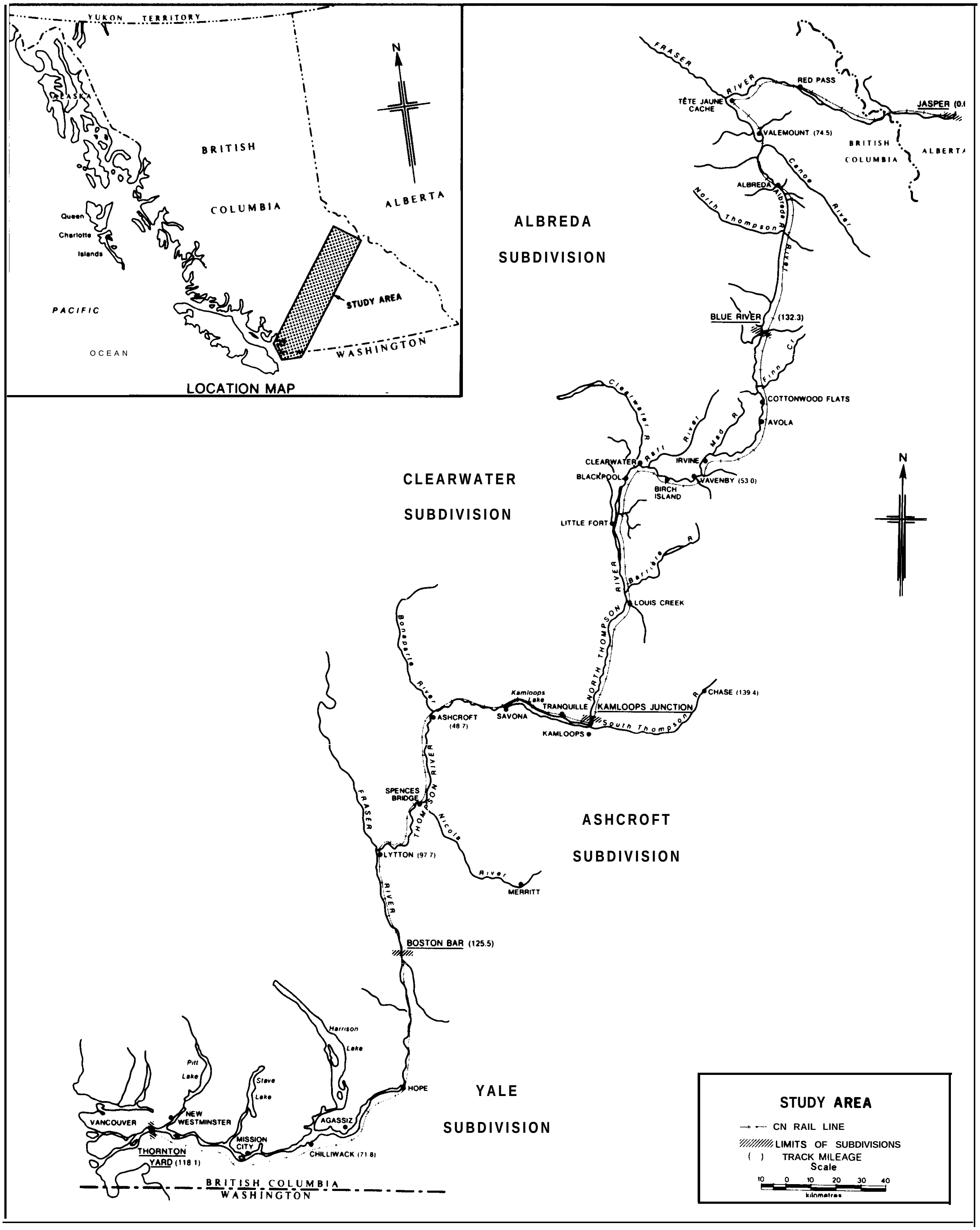

Figure 5. CN Railway line proposed for twin tracking, British Columbia

Most of these issues raise questions similar to those posed earlier in this paper, namely: inadequacy of information relating cause and effect; split jurisdictional responsibilities for managing water; land and related resources; lack of development of clear policies and plans which guide decision making on the allocation of water resources between competing interests; and the role of the public in influencing decisions. Before outlining some specific recommendations on a research agenda designed to improve both management and understanding of cumulative assessments, a few general observations resulting from the above examples are in order.

SOME OBSERVATIONS ON CUMULATIVE ASSESSMENT

Changing Role of Impact Assessment

For the past 15-20 years, environmental management has been dominated by the single-project environmental assessment process. The weaknesses of this paradigm have been touched upon here and elsewhere (Bardach and Pugliaresi 1977). This has resulted in a gradual shift to regional environmental assessments (James et *al*. 1983) and cumulative assessments. These trends themselves may be, in fact, leading to a broader concept, one that considers environmental management as an integral component of economic and social policy at a national and international level. The International Union for the Conservation of Nature (1980) in its World Conservation Strategy, has called for a reorientation of all resource management practices in favour of sustainable utilization of all living resources, and the protection of rights of minority cultures. The World Resources Institute also stressed the need to rely on nature's "income," not the depletion of its "capital." Considered in this context, many of the major environmental issues such as acid precipitation, escalating use of toxic chemicals, large-scale agri-businesses with their extensive consumption of pesticides, fertilizers, surface and groundwater resources are creatures of current economic and social policies. At some point, a fundamental evaluation of such policies will be necessary to resolve some of the substantive problems of cumulative environmental impacts.

The shift from reactive single-project assessments to anticipatory regional and international strategic analysis will have profound effects on institutional arrangements, information requirements and analytical tools. In the case of freshwater environments, several attempts have been made in this direction through strategic basin planning (O'Riordan 1981), and the recently released plan for the South Saskatchewan River (Alberta Environment 1984). Many improvements to these models are required to make their outputs practical, timely and implementable (Mitchell 1983). As such broadly-based plans affect social as well as ecological systems, opportunities for public input are required. This process can also greatly expand the time and costs for developing acceptable policies with which to place project development in context.

Changing Management Strategies

Broadening the scope of environmental analysis has raised questions concerning the adequacy of existing regulatory procedures. In the case of water quality, increasing attention is being given to some mixed model of economic and regulatory controls (Oates 1984). If attention is switched to the sustainability of the environmental resources, and information on the relationship between waste discharge and ambient water quality can be improved, it may be possible to develop the concept of transferable discharge permits. One such scheme is now being implemented on the Fox River in Wisconsin (O'Neill et *al*. 1983). Most analysts agree that some form of regulation is necessary to control hazardous wastes, the impacts of which are either unknown or potentially lethal. However, the super-imposition of discharge fees could reduce the overall costs of waste treatment, and might enable some regional waste management problems to become financially feasible through transfer payments.

Decision-Making Mechanisms

There appears to be two quite divergent trends in the structure of decision-making institutions. One thrust is towards centralization in an attempt to internalize the effects of decisions. The creation of Regional Water Authorities in Britain with responsibilities for managing both water supply and water quality, and also having financial clout, typifies such a shift. This model tends to reduce the need for public input and to some extent, local government involvement.

A second thrust is towards decentralization, where locally elected representatives have direct say in management of resources. There is considerable debate amongst policy analysts regarding the appropriate institutional structures to deal with equity and efficiency principles. Some local involvement in resource decision-making bodies may fail to pick up the broader environmental issues associated with cumulative assessment. The issues raised in the section on impacts among watersheds arise in most part from divided jurisdictional responsibilities for managing water and related resources.

One means of dealing with this dichotomy is through the development of environmental mediation techniques (Bacaw and Wheeler 1984). Decisions based on negotiations can be more adaptive than those proposed by centralized institutions. Much has yet to be learnt to develop such procedures where national or international issues of the sustainability of environmental systems can be considered as a context for making local development decisions. For example, some system of mediation will be required if major developments are to occur on the Peace-Athabasca and Mackenzie system.

Information Systems

Perhaps the most important constraint to effective mechanisms for environmental assessment is the development of suitable information. Baskerville (this volume) notes that the major challenge to scientists is to develop an objective understanding of ecological processes across an expanded time and spatial boundary. Based on the case examples cited earlier in this paper, it is clear that too much emphasis has been placed on descriptive rather than predictive information. There remains a lack of critical information on key cause and effect relationships such as sublethal effects of toxic wastes on aquatic resources, eutrophication processes in large lakes, and specific effects of changes in flow and temperature on fish productivity. Yet in most of these studies, there is no shortage of descriptive inventory data (Dorcey and Hall 1981).

There is considerable debate about how such predictive analyses can be improved. Ridler (1982) argues that empirical theory (i.e., observing and codifying cause and effect relationships through experimental design) may be more practical and cost-effective than analytical approaches. Some biological and most sociological systems behaviours are simply not predictable through analytical modelling. Baskerville and Cairns in companion documents to this workshop argue that some empirical analyses can provide misleading results. There appears to be a need to develop an unambiguous theory to define what is scientifically predictable and what is not.

Cornford et *al*. (1985) have attempted to develop a framework for information systems development, as shown in Figure 6.

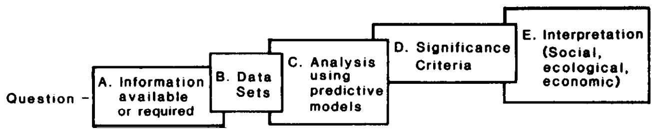

Figure 6.

First, the right questions on cause and effect relationships must be formulated and considered in appropriate spatial and temporal boundaries. Data sets should be checked to ensure that they are of adequate quality (accuracy, consistency) to provide sufficient confidence in results. In some cases, only a broad range of confidence is required, whereas in other cases (e.g., highly valuable resources at risk), more accurate analytical tools are required. Throughout the process, significance criteria should be specified to determine the relative importance of the issues/questions based on the value of ecological systems to society. In this way, environmental and social assessments become closely interrelated (Larkin 1984).

DEVELOPING A RESEARCH AGENDA

With these four issues as a general background, the following recommendations are made to strengthen the role of cumulative assessment in environmental management. It is recommended that there should be:

Information Systems

- more emphasis given to developing knowledge on process and predicting impacts;
- development of practical criteria for determining when intuitive deduction rather than objective scientific analysis is adequate for decision making;
- more emphasis on empirical analysis using experimental design tied-in with post-project monitoring;
- encouragement of institutional arrangements for undertaking long-term research into cumulative assessment and identification of sources of funding;

Policy Planning

- a critical review of the utility and contents of regional policies and river basin plans to improve their effectiveness in providing a context for cumulative assessment prior to decision making;
- identification of the linkages between waste discharges, assimilative capacity and water quality objective to determine total loadings allowable in watersheds and/or lakes;

Decision-Making Structures

- examination of the practicality of introducing economic incentives to improve decisions on water use and waste discharges within watersheds and river basins;
- development of bargaining and mediation processes to improve problem resolution associated with cumulative assessment;
- identification of institutional structures and responsibilities suitable for negotiating cumulative project assessments, both national and international;
- identification of mechanisms for providing input from local government and public interests to decisions that involve regional, national or international concerns;
- strengthening of decision-making processes that link water, land and air management.

Update

In the summer of 1985 the provincial government announced that the Okanagan Valley was considered an environmentally sensitive area. It allocated $26 million over three years to develop and implement priority components of a regional waste management strategy for the Okanagan. This includes the immediate upgrading of all municipal waste treatment plants to remove a minimum of 95% phosphorus by 1988 and a development of a specific program of controls on non-joint discharges required to achieve water quality objectives established for all Valley lakes. The cost-sharing formula of 25 % provincial, 75% local contribution for municipal waste treatment facilities remains in force elsewhere in the province but has been reversed in the Okanagan Valley in recognition of this "sensitive area" designation.

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COMMENTARY I

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O'Riordan's paper provides us with a description of several excellent water management cases that illustrate the nature of cumulative impacts resulting from developing and using water resources. He has also used these cases to provide a basis for suggesting some valuable lines of research inquiry. Before offering specific comments on the paper, I believe it would be helpful to specify the premises that underlie my views about managing resources involving cumulative impacts.

- The ultimate objective of resource management is, to the extent practicable, to maximize net benefits to society, taking into account potential cumulative impacts.

- In order to meet the needs of resource management, impact assessment must deal with the following kinds of impact situations:

— impacts of a single development or single resource use;

— the accumulated impacts of multiple developments or multiple uses of a single resource or biophysically interrelated resources;

— the accumulated impacts of developments or uses of two or more resources that are biophysically unrelated.

This last category of impacts may arise, for example, when a single community is impacted by a hydro-electric project and an unrelated mineral development.

- There are two major technical aspects of cumulative impact assessment. One aspect is concerned with measuring the cumulative physical and biological effects, and the other is concerned with translating these effects into estimates of social consequences.

- The prediction of the physical and biological effects of a resource use is destined to remain far from precise. Uncertainty will always be a feature of such assessments.

- The effects of physical and biological impacts upon people (i.e., social consequences) are even more difficult to predict than the cumulative biophysical impacts themselves, in part because of the complexity of the systems involved, and in part because they depend upon the preferences and priorities of the people affected, which are difficult to ascertain.

- In the final analysis, resource management that takes into account cumulative impacts entails the weighing of public preferences and priorities, as determined by the public's knowledge of prospective cumulative impacts and their perceptions of the uncertainties that remain. Cumulative impact assessment therefore involves three elements:

— estimation of physical and biological impacts;

— estimation of the effects of physical and biological impact upon social systems;

— evaluation of the impacts, both biophysical and social, in light of public preferences and priorities.

- Since this third element cannot be done technically, the final stage of cumulative impact assessment must be a social process of decision making that ideally will, by its nature, arrive at decisions that reflect a balancing of preferences among those affected.

- Once a cumulative impact assessment has been completed, implementation by government may involve:

— direct regulation of the resource user;

— use of incentives to motivate the kind and level of use desired;

— undertaking a new government action program or alteration of an existing one.

COMMENTS ON O'RIORDAN'S PAPER

These comments apply specifically to O'Riordan's proposed research agenda.

First, I agree that more emphasis should be placed on prediction and less on descriptive information. I suspect that current emphasis on description stems from a shortage of knowledge about how to make reliable prediction of cumulative impacts.

Second, I can see the value of experimental work to determine physical and biological effects of resource development and use. With regard to social effects, it will seldom be practicable to undertake useful experimental work. My emphasis would be upon O'Riordan's point that more emphasis should be placed on post-project monitoring. My observation is that development organizations have little interest in monitoring previous situations. Such studies must, therefore, not be dependent on support from these organizations, but should be independently financed.

Third, we certainly need to assess the implications of many existing policies and plans for dealing with cumulative impacts. Numerous examples can be identified of existing policies that tend to frustrate cumulative impact assessment and follow-up action — e.g., ground water law in much of Canada and the

United States, the effects of timber harvesting on wildlife, and laws governing mineral exploration and development in both countries.

Fourth, in general I agree with O'Riordan's emphasis upon the importance of decision-making structures. They pose a critical problem in securing valid cumulative impact assessments, and in instituting socially desirable management actions. Yet, this problem tends to be neglected because of the difficulty of bringing about institutional change. In the section which follows, I define the nature of the public decision-making problem as I perceive it, and suggest a line of enquiry that I believe will aid in dealing with it.

DECISION-MAKING ARRANGEMENTS

The design of decision-making arrangements for resource management has two difficult aspects that overshadow all others. One is the development of decision-making arrangements that are capable of embracing the variety of significant considerations that bear upon the choice of a decision. The other aspect is that of structuring the rights and obligations of individuals and organizations, and designing processes that will lead to an evaluation of all relevant information in light of public preferences and priorities, to arrive at a socially optimal decision.

Weighing Significant Considerations

Existing governmental organization structures preclude or inhibit consideration of all significant considerations, including cumulative impacts. This is due to the fact that a single agency is often responsible for only one resource use, and because impacts may be generated in one jurisdiction but affect one or more other jurisdictions. For example, a pollution control agency may regulate waste discharge to a river, while a forestry agency may determine whether timber harvesting practices will be allowed to degrade water quality in the same river. In this same example, the resulting water quality degradation may be caused by activities in one jurisdiction, but impacts may be felt in one or more downstream jurisdictions. One set of cumulative impacts may, therefore, affect a local, a regional, and a provincial jurisdiction; more than one provincial jurisdiction; federal jurisdictional responsibilities; or another nation. Existing institutional arrangements are seldom capable of dealing effectively with these inter-organizational and inter-jurisdictional impact problems.

Evaluating Impacts in Light of Public Preferences and Priorities

This is part of the impact assessment process, but there is no technical basis for carrying it out. It can only be done through involvement of representatives of a range of public interests in the decision process. While various techniques have been utilized, and valiant efforts have been made, public involvement has either not been utilized, or has not been utilized effectively in most decision making concerned with resource management.

RECOMMENDATIONS

There is a large body of political science and decision-making literature that has a direct bearing upon the foregoing difficulties, some of it going back to the 18th and 19th centuries. Part of this literature is concerned with the normative democratic principles which are presumed to underlie governmental institutions in both the United States and Canada, and which often are not applied in current designs of resource management institutions. The other part of this literature is concerned with the behaviour of organizations and individuals involved in decision-making processes.

The insights which this literature provides have not been fully utilized because those most concerned with resource management appear to have little interest in the scholarly literature on public decision-making processes, and because the existing system is resistant to change due to vested interests in the current distribution of power and influence which application of these insights would alter.

I recommend that this literature be reviewed, and used as the basis for developing a suitable framework for evaluating resource management institutions and decision processes. The initial draft of this framework should be critiqued by political scientists, sociologists and psychologists who are familiar with the fields involved. From this review should emerge a solid framework for use in making a critical evaluation of existing resource management institutions. When this task is completed, the next step would be to use the framework in evaluating institutional arrangements in a number of areas, such as the Fraser River estuary. Application of the framework in a few cases may lead in turn to its improvement. The result should be the provision of a tool to guide the development of resource management institutions that are capable of making and implementing cumulative impact assessments.

As is evident from the foregoing comments, I feel that the specific research items on decision-making structures that O'Riordan has recommended cannot be undertaken in a productive fashion until we have pinned down a solid theoretical foundation for evaluating existing structures and designing new ones. Once this foundation is developed, the specific research items he has suggested can be fruitfully addressed.

ADDITIONAL READING

There follows a few illustrative references to some useful literature on public decision making that has a bearing upon cumulative impact assessment.

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COMMENTARY II

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The theme paper in this section serves the intended purpose well by providing a useful point of departure for workshop discussion. It exemplifies the policy and institutional considerations associated with cumulative assessment of freshwater systems; it contains a useful set of observations on trends related to this emerging form of impact analysis and management; and it concludes with a checklist of issues for further attention. Only in this latter area are there grounds for general reservations about the approach taken. The research directions and applications of the recommendations drafted for strengthening the management of cumulative impacts are not always readily apparent, and in some cases, notably in the section on decision-making structures, become quite oblique. This is not to say the concluding prescriptions are without merit, just that they require further translation to become statements of management-linked research requirements and priorities.

In this commentary, accordingly, the discussion will be aimed firstly at consolidating, secondly at extending, and thirdly at the research specifications of certain lines of analysis in the theme paper. This approach is based and will expand upon three premises:

- there is strong evidence of cumulative deterioration of river, lake and wetland systems from the impacts of development;
- the scale and character of these problems imply adjustments in strategies and institutions which may become quite substantial over the longer term; and
- applied research on (as well as within) the process of management can help, provided this is properly targeted on the knowledge needed for making decisions on mitigation, rehabilitation and enhancement.

The problem of accumulating impacts on natural systems is a contemporary variant of "the tragedy of the commons."[1] It may be considered, in a general sense, as the quantum sum of the ecological changes induced by man's use of land, water, marine and atmospheric resources. While the fact that environmental impacts are increasing in magnitude, complexity and frequency seems beyond doubt,[2] the implications of what this means remain subject to a wide latitude of interpretation.[3] The assumptions we hold regarding the contributions of science and the capabilities of management exert an important bearing on judgments on this matter, (Suzuki 1985) i.e., whether we are taxing regional (or global) carrying capabilities and approaching thresholds worth worrying about.

From the standpoint of assessment and management, cumulative effects may be regarded as the "second generation" of problems for analysis and remedy. Under scrutiny is whether and how these questions differ from conventional or site and project-specific impact assessment, and thus require a restructuring of the prevailing approach.[4] To consider this question as a basis for developing a revised agenda for research, it will be worthwhile to review and then restate certain elements of the problem.

As noted in the theme paper, the term cumulative effects carries different connotations. It can refer to the additive downstream effects associated with a major hydro project, especially one which is precedent setting and may stimulate or eventually lead to a range of secondary developments. The uncertainty inherent in this situation sets well known difficulties for impact assessment, especially where unanticipated changes in sensitive ecosystems results from the primary development. A further variant of this problem is engineering projects which combine several dams in sequence or space along a major river (e.g., the lower Columbia River), or inter-basin diversions on a regional scale (e.g., the James Bay project). In classic form, however, cumulative impacts accrue from multiple sources of development and/or discharge, whether combined incrementally or in a non-linear manner. Key instances occur when such interactions threaten or induce impairment or loss of valued resources. These may involve physical depletion of the basic resource (e.g., falling water tables in the Ogalalla aquifer), as well as the water quality and aquatic habitat changes documented in the theme paper.

1. Hardin's thesis of infringement of the commons has a remorseless logic. In question, now as then. is its role as prophecy, bearing in mind the social and institutional assumptions that underlie the argument.

2. The authoritative works on this subject remain Thomas (1956), and Darling and Milton (1966). An elegant update is by A. Goudie (198 1).

3. Contrast, for example. the pessimistic forecasts of planetary survival, circa Earth Day 1970. with the more optimistic viewpoint implicit today. The prevailing complacency. of course, is not without challenge; as shown, for example, by the Council on Environmental Quality (1980).

4. Scientific and policy-institutional critiques of EIA are numerous. The former leads to a search for greater rigour, though a more radical approach is to question the paradigm of prediction. Cf: Beanlands and Duinker (1983). Boothroyd and Rees (1984). The emphasis in procedural reform is on placing EIA in the appropriate decision-making context. A relevant sampling of the literature is contained in Sadler (1985) and Weibe (1983).

The enjoining thread of discussion is the difficulty of understanding and tracking the way a multi-variate complex of ecological relationships change across space and over time. Much of interest on this subject is contained in the scientific paper in the accompanying session. It appears to be extremely difficult to estimate or predict cumulative impacts for regionally differentiated systems because of the discontinuities between cause and effect.[5] Quantitative correlations can seldom be established. The key to understanding cumulative effects, however, clearly rests on being able first, to determine anthropogenic changes from natural variability within specified boundaries, and second, to relate this to the stability and resilience of natural systems. Cornford et *al.*, (1985) for example, have proposed "mass balance" as a means of approach to cumulative environmental assessment of multiple-source impacts.[6] A comparison with other frameworks, which can give approximate estimates of the order of risk from cumulative effects, represents a useful exercise for applied research. Explicit consideration should be given to their linkages with ecological concepts (such as stress, subsidy and perturbation referred to in Cairns's paper), and with conservation principles (such as sustainable development referred to in O'Riordan's paper).

Case studies represent an immediate means of developing management perspectives on cumulative impact. They should be informed by, and contribute to, longer term research and trend monitoring designed to build the body of process knowledge for understanding cause and effect. Establishing and testing hypotheses is the sine *qua non* for applied as well as basic research. Applied studies, ideally, should be tied to experimental management, i.e., exploit the fact that decisions and actions must be taken to ameliorate, offset or reverse cumulative effects (Dorcey and Hall 1981). This is what I call *targeted* research. Put simply, it makes a researchvalue out of a management necessity; given that environmental decisions are largely driven by development applications and in connection with multiple source discharges or alterations, they tend to be made routinely and unrelatedly. Research design in such cases can lead to new functional knowledge to improve decision making.

Aquatic systems which function as pressure points for development will be of immediate interest for targeted research. The examples illustrated in the theme paper are relevant, because they display different levels of tolerance to stress. Lakes, by definition, are natural sediment traps, and tend to be more vulnerable to nutrient loadings than rivers. Estuaries, in contrast, exhibit resistance to repeated stresses, and to displacement of structural and functional characteristics. Both thereby are relevant types of receiving ecosystems for research into improving functional knowledge of cumulative impacts. Much is known generally about their ecology and limnology, and comparative investigations of water bodies in different states of development will be particularly helpful to management (MAB 1972).

The problems associated with establishing time and space boundaries to take account of the serial repercussions associated with multiple hydro projects on a reach of a river, or with inter-basin diversions, represent a further emphasis for applied research. A candidate area for the first kind of review is the main stem of the Columbia River, from Grand Coulee to the Bonneville Dam, which contains perhaps the most intensive concentration of hydro-electric sites in the United States. The increasing use of these plants to supply peak power is resulting in incremental changes in stream flow, with subsequent repercussions on anadromous fisheries, riparian wildlife, recreation, navigation and other water uses (Muckleston 1977). Research on these additive, secondary impacts appears to be timely and relevant. The James Bay Development Scheme in Northern Quebec, which involves a massive rearrangement of the drainage pattern of three river basins to create a 11,500 km^2 reservoir impoundment, represents a focus for the second type of investigation. While not subject to EIA, an extensive monitoring program for mitigation and management is in place (Soucy 1983). It should provide some instructive lessons on the impacts associated with engineering transformations an order of magnitude higher than a single hydro dam. Much is known about the latter; very little about the former.

Water resources management cannot be separated from other environmental components. Due mention is given in the discussion paper to the linkages of aquatic with terrestrial, marine and atmospheric ecosystems. It is widely known, for example, that modifications to watershed conditions can exercise a decisive influence on river regime. The effects on aquatic ecosystems of forestry and agricultural practices and various domestic and industrial discharges are quite well understood in general terms. The cumulative interaction and synergistic impacts among these at the river basin level of organization is much less well known (MAB 1972). Priority work on lake or estuary components (which bear the effects of upstream events as well as direct pressures) presumably might be incorporated within simulation models for the total catchment system.

The scales at which an attempt should be made to integrate and develop perspectives on cumulative impacts can bear further scrutiny. Environmental quality ultimately is indivisible. regionally and globally. A graphic illustration of this fact is provided by the composite map, commissioned by Environment Canada, of the interaction of water, land, air and ocean in the Strait of Georgia-Puget Sound Basin (approximately 78,000 km^2).[7] It summarizes and correlates inter *alia*, a range of information relating to the cumulative effects of man's activities in the context of a natural unity formed by an inland sea and its landward margins, which contain the urban and industrial heartlands of the Pacific North West. While area-wide problems do not appear to have reached critical propor-

5. A relevant companion piece to Cairns's discussion on ecological indicators. is Brinkhurst (1983).

6. A particularly vivid application of the concept of mass balance, as a proxy to estimate assimilative capacity and to determine risk, is the assessment of the cumulative impacts of building artifical islands in the Beaufort Sea. The Mackenzie River is viewed as a large "smoke stack" pouring natural sediments into the Beaufort Sea, and tracemetal and particulate loadings from dredging are set against this natural scale of flux. (Thomas, MacDonald and Cornford 1983; Cornford, O'Riordan and Sadler 1985)

7. The map by Skoda and Robertson (ELD-2) is contained in Barker (1974)

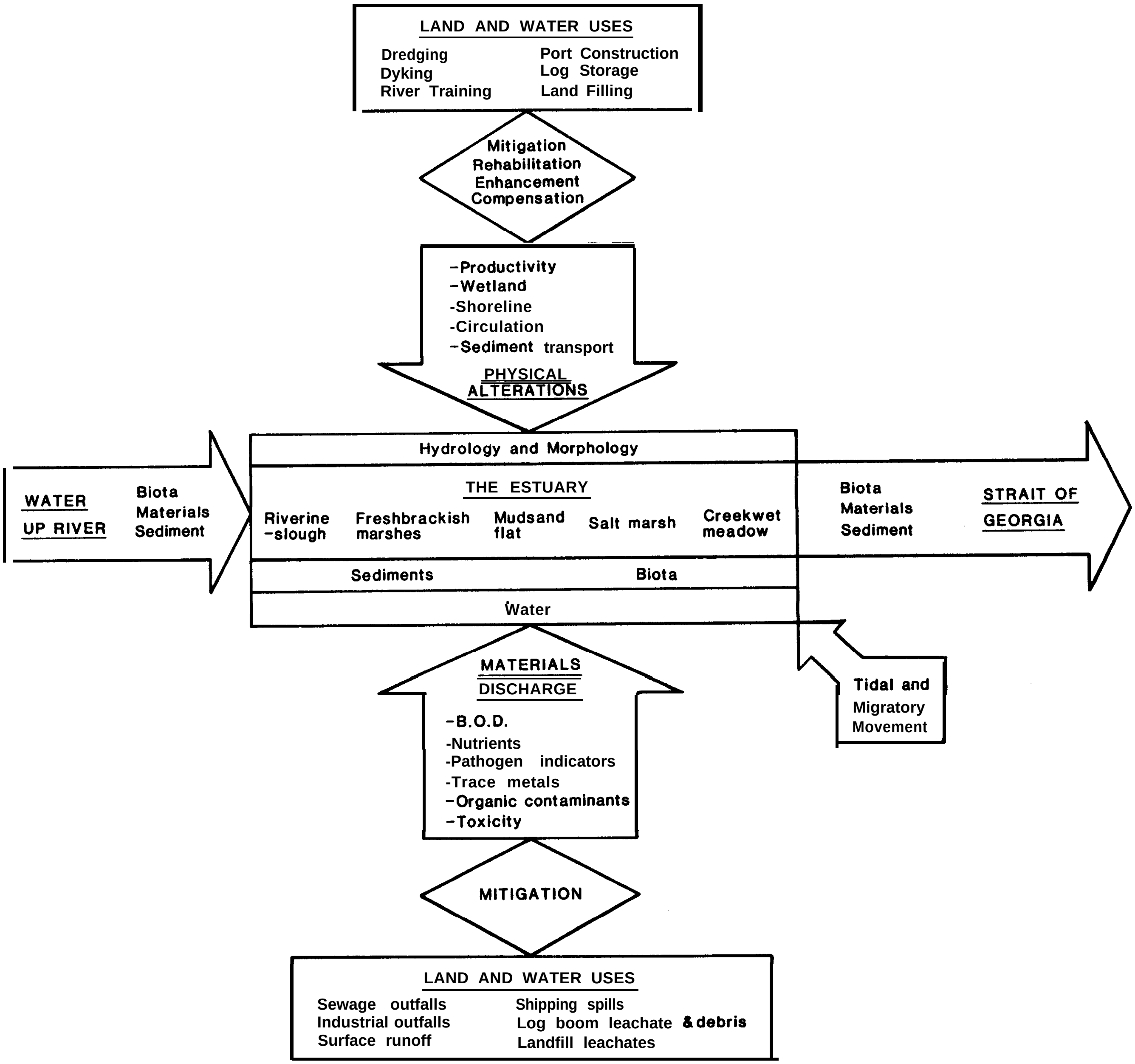

Figure 1. Cumulative impact of physical alterations and materials discharge on estuarine ecosystems (Dorcey and Hall 1981).

tions, they are the subject of growing concern on both sides of the international border. The emphasis is on the spatial dimensions of environmental problems, resource use and management interdependences, and their linkages across physical and political boundaries.

A number of key themes in water resources management become underlined by the reference to problems of cumulative environmental impact in the discussion paper. The increasing use of research as a planning tool is implied throughout. It certainly is a vital underpinning of the shift towards a more integrated approach to water resources management, i.e., one in which a range of means are deployed to advance multiple objectives (White 1969). The call for more emphasis on developing process knowledge to achieve a better understanding of multiple cause and effect relationships is reinforced here. So is the stress on experimental design, incorporating explicit testing of hypotheses. However, just how this line of research might be pursued remains unclear.

Figure 1 illustrates a framework for analysis of the estuary case study orientations suggested earlier. It is axiomatic that such work needs to be informed by further development of management perspectives and concepts of cumulative impact. These are not yet honed sufficiently. As a prelude to application it will also be necessary to ask two basic questions (Dorcey and Hall 1981): What new information would be most valuable in improving the basis for decision? What new information might be developed through research?

Research into management processes has become progressively more important in the water resources field. The reasons are covered in the discussion paper, and have to do with increasing concerns regarding the effectiveness and efficiency of decision making, and the policy contexts and institutional arrangements under which this process operates. A recent comparative analysis of the policy and institutional issues of two major river basins illustrates the general relevance of the avenues for coping with cumulative effects cited in the discussion paper (Sadler 1983; 1984). The tricky question, however, relates to setting priorities for research and focusing investigations. On the basis of experience gained above, there appears to be some merit in studies of selected basins (e.g., single and multi-jurisdictional) to gain insight into the nature of the difficulties encountered in analysing and managing cumulative effects within existing institutional arrangements and operational procedures.

Management dividends might be increased if these analyses could be undertaken in candidate areas for ecological study. A case in point might be the Fraser River estuary, cited in the discussion paper. Over 60 government agencies are currently involved in planning, monitoring and regulating the use of the resource base, each with distinctive policies and approaches. Following a lengthy study (Fraser River Estuary Study 1982), a formal agreement on cooperative management of the area is pending. This is based, in part, upon the acknowledgement of problems associated with cumulative impact. It could therefore prove worthwhile to monitor and follow this "experiment." Similar research, furthermore, might be envisaged into the policy and institutional interdependencies created by cumulative deterioration in water quality and related resource potential in the Strait of Georgia-Puget Sound Basin, and the particular problems generated by the international boundary. Study results should be examined in the light of other alternatives.

In this connection, finally, a cautionary note on bargaining seems in order. One argument for the application of this approach to cumulative impact management is that sophisticated models fail to provide useful long-term impact predictions. However, simpler models, which incorporate the pros and cons of mitigation alternatives, can be instrumental in arranging negotiated solutions to problems. (Barnthouse et *al.* 1984) This conclusion was drawn from the long-standing Hudson River controversy over the potential impacts of power development on fish populations. It appears to have even more relevance regarding the cumulative stresses of current concern. Where problems are encountered is in moving away from bargaining as a process for coping with scientific uncertainty towards mediation as a process for reconciling value conflicts. It is not clear from the discussion paper whether recommendations are being made regarding one or both of these applications. The former emphasis, geared to help compensate for insufficient understanding of ecological processes, lends itself to ready integration within the research thrusts already identified. The incorporation of the latter orientation, dealing with dispute settlement among a broader array of interest groups, might be relevant in the present context to the assignment of significance, the refinement of risk estimates, and the determination of mitigation and compensation.

Note, finally, that the discussion in the theme paper(s) is conducted almost entirely in terms of the ecological values at risk from cumulative impairment. Other yard sticks of interpretation are possible. Water is an integral element of landscape quality, yielding visual and recreational values which overlap with, but are not necessarily the same as, ecological values. (Sadler and Carlson 1982; Sadler 1979.) All values, of course, are ultimately social constructs; yet this dimension remains implicit in all the discussion papers. The cumulative impacts of water, land, marine and atmospheric resource uses are transmitted through market and community, as well as ecological, processes, and are reflected in adjustments in the lifestyle and livelihood of people. In short, there are a corresponding set of socio-economic impacts, and they are flagged as being as important as those under discussion.

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MARINE SYSTEMS

Scientific Perspective

CUMULATIVE IMPACTS IN THE MARINE REALM

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The background of the workshop includes a widely appreciated concern for the cumulative environmental effects of multiple perturbations on environmental systems. Present law does not clearly identify a means of evaluating cumulative impacts, either from methodological or regulatory viewpoints. It seems that the law focuses on project-specific impacts, irrespective of possible cumulative impacts already in effect or that could result from other projects known or expected. Furthermore, most environmental regulations ignore potential additive effects on linked ecosystems over any spatial or temporal scales. A practical result is that representatives supporting a proposed environmental perturbation can argue that the proposed project would have negligible effects compared to the background situation, even if the background situation is heavily disturbed. Clearly there is a real need for more holistic approaches.

The objective of this essay is to consider the evaluation of cumulative environmental impacts of various man-caused perturbations to marine ecosystems. Specifically, I discuss the scientific perspective of cumulative impact assessments (CIA) of marine environments with special regard to issues of scale, techniques, and recommendations for the future. I assume that an implicit objective is to consider CIAs as they relate to long-term stability (in the general sense) of marine ecological communities.

I lament the fact that specificity and generality are mutually exclusive such that well documented specific examples will appear to be special situations. I have spent some effort thinking about the bewitching problems of "ecological stability" from a natural history perspective (as opposed to engineering, physical-chemical or theoretical approaches often cunningly but irrelevantly applied to ecological problems). I think my most useful contribution to this workshop is in this context. I will present three background digressions on the complexity of ecological systems, a summary of some differences between marine systems and a few recent developments in the bioaccumulation literature. I will then consider community stability and some ideas about evaluating cumulative effects, and then attempt to consider general approaches to evaluating CIAs.

DIGRESSION # 1: ELEMENTARY ECOLOGY

I believe that one of the most difficult problems ecologists have communicating with legislators and regulators (and many ecologists with nonbiological backgrounds), is that many of the latter fail to appreciate the difficulties and complexities of natural ecosystems. It seems clear that this audience has no such limitations; nevertheless, I will summarize some of these problems for completeness. In essence, I will argue here that the simplistic baseline and monitoring approaches of environmental assessment are hopeless, no matter how sophisticated the analyses. This is because communities are composed of many populations, the individuals of which can be sampled, identified, counted, and listed. Such descriptive approaches however, are inadequate for an understanding, because the populations are in turn characterized by the following:

- Large numbers of components (individuals) interact with each other in a variety of ways. A few examples of classes of interactions include:

— reproductive behavior: this can be extraordinarily complex and is vital to the demography (and evolution) of the population, but is usually ignored in any impact study.

— intraspecific competition: this too can be omnipresent and extremely important in that it can dictate dispersion patterns (which are often sampled but not understood), behavior, age of maturation and age structure, etc.

— interspecific competition: while this is a popular subject, it remains little understood and is difficult to evaluate from descriptive data.

— information transfer: via pheromones, vibrations, posturing, etc.

— predation: this phenomenon is relatively well studied, but its role in the maintenance of natural communities can be almost absolute, in other situations equivocal, and in other situations nonexistent. I know of no way to generalize even the well understood predation effects.

— mutualism: little studied but, in one form or another, can have overriding importance to the patterns of distribution and abundance in many populations.

- Historical effects can be very important to all three levels of organization.
  - — individuals are strongly influenced by hunger, search images of various durations (sometimes instinctive and sometimes learned; even these distinctions have important consequences) frustration, fear, anger, sex, etc.
  - — populations have many historical properties such as sex ratios and age structures which are important to reproductive and mortality schedules, population oscillations responding to various predatory and competitive relationships, etc.
  - — communities experience disturbances or catastrophes of varying frequency and magnitude.
- Spatial and temporal relationships of physical and biological origin are also important.
  - — individuals: territoriality, gregarious settlement, foraging or predator avoidance tactics, etc.
  - — populations: migration, dispersa1 and adaptations of the propagules, various life history patterns, etc.
  - — communities: seral states, degree of environmental heterogeneity, internal patch structure, etc.

As a general rule, all of the above relationships are non-linear, and most are marked by thresholds, limits, and discontinuities. It is small wonder that ecologists have trouble agreeing to unifying themes! Nevertheless, many of these relationships have relatively unimportant community consequences, and many are little affected by modest levels of stress. I believe that it is futile to rely on purely descriptive work and the derivative summary statistics such as diversity indices, dendrograms, etc., because these approaches are blind to the complexities such as those listed above. Indeed, for habitats I am familiar with, I believe I can get more useful information from a species list and a photograph than from diversity indices or most of the dendrograms I have seen. On the other hand, even a moderate level of understanding of the dynamics of the populations, their interrelationships, and the functional organization of the community, can lead to considerable simplification and predictions based on understanding rather than facile correlations. The problem then is how to generalize this understanding; this leads us to Digression #2.

DIGRESSION #2: SOME GENERALIZATIONS ABOUT MARINE COMMUNITIES

Marine communities exist in seawater, which differs from freshwater systems in many ways, especially with respect to the vast volumes involved. Furthermore, the seawater is somewhat similar to the atmosphere in the complicated way it is mixed and moved. Coastal habitats are affected by large boundary currents, gyres and eddies, various types of upwelling resulting from current-land interactions and wind shear, thermoclines, internal waves, etc. Realistic boundaries in space and time are difficult to evaluate. Spatial boundaries are determined by the interactions between currents and various biological facets of the organisms involved (behavior, longevity, etc.). Temporal components are influenced by similar biological parameters of larvae and adults. Like all other communities, it is difficult to make valid generalizations about the organization of marine communities (Dayton 1984).

First, the famous *Pisaster* organization of rocky intertidal communities does have generai features which Paine (e.g. 1974), Connell (e.g. 1972), and others have discussed in great detail. These communities have been dissected experimentally and are very well understood. Yet if one could tabulate the rocky intertidal habitats around the world, I suspect that most of them would be very different from the familiar *Pisaster* system, because most are characterized by speciose algal turfs, sand, coralline algal crusts, fucoid algae, or simply bare rocks. The existence of a *Pisaster* system depends upon many factors including the presence of a population capable of monopolizing space, sufficient recruitment to insure such monopolization can be realized, sufficient primary production to allow the monopolization to persist, and a predator or disturbance that limits the monopolization in a predictable manner.

Subtidal hard-bottom habitats include kelp communities, fouling communities, encrusting communities, boring communities, and coral communities; all seem to have very different organizational patterns. Most kelp communities tend to have “important species” which exert their influence via competition, grazing and/or predation. They tend to have variably predictable recruitment, but within a particular locality, relatively predictable patterns of succession and disturbance. Fouling communities are characterized by frequent disturbance (including individuals dying of old age and sloughing off), very unpredictable recruitment, and low survivorship. Encrusting communities (bryozoans, sponges, and sometimes colonial tunicates) probably have unpredictable recruitment and succession, but are composed of very long-lived organisms resistent (via chemical defenses) to predation or invasion. Boring communities are little studied but appear long-lived, yet they probably eventually weaken the rock enough for the rock substratum to slough off, at which point I would guess that they are renewed with predictable recruitment and succession. Coral communities are extraordinarily diverse; their organization emphasizes biological habitats, lottery recruitment, competitive interactions, mutualistic relationships, and many forms of physical and biological disturbances.

Soft-bottom benthic communities may be the most relevant marine communities to this workshop. In summary, soft-bottom communities are utterly different from hard-bottom communities in almost every sense (Dayton 1984). Perhaps the most useful generalization for this workshop involves the existence of “functional groups” (Rhoads 1974) in many soft-bottom habitats. These groups are variously defined but usually fall into one of the following categories: suspension feeding (usually clams) guilds relying on relatively clean water and a semi-stable substrate for recruitment; deposit feeding associations (usually worms and organisms which rework the sediment) which maintain a usually soft mud habitat; burrowing organisms (usually thallasionasid shrimp, crabs and some echinoderms) which aerate the substrate and cause considerable heterogeneity on the surface, which itself forms microhabitats; and tubicolous organisms (various small crustacea, worms, or phoronids) which often occur in high densities and modify the substratum. These groups are not always mutually exclusive (burrowers, especially, can overlap suspension feeders, in fact, they are a subset of suspension feeders or deposit feeders), but they tend to be resistent. The important thing from our perspective is that by modifying the sediment, they restrict the recruitment of representatives of other groups, and thereby maintain a considerable internal stability. Indeed, these are some of the best cases of alternate steady states I can think of.

Finally, except for fisheries biologists, pelagic communities tend to be ignored. Historically the fisheries biologists have usually restricted their interest to vertebrates; this is unfortunate because fishing pressures may represent some of the most profound chronic and cumulative stresses in the marine realm. Yet the pelagic communities are, to me, so difficult to understand, in a population sense, that in essence I throw up my hands in defeat. Some insights can be obtained from the productivity approaches which many oceanographers use (Mann 1982), but I have a hard time translating productivity data to population or community stability.

In summary, it is very important in any impact assessment to tease apart natural and man-induced changes. Our challenge is to prevent the recognition of the considerable natural background variability from clouding the identification of cumulative impacts. The best overview I have seen of the organization of several marine communities is by Peter Yodzis (1978). This excellent, readable book has received little notice in our literature, and I highly recommend it; it seems much better than most of the popular Princeton Monograph series!

DIGRESSION #3: CHEMICAL CONTAMINATION OF MARINE LIFE AND BIOACCUMULATION

A misunderstanding of my assignment led me to look at some of the voluminous literature in this field. While it is a little outside the mainstream of this workshop, it certainly represents a prime example of cumulative impacts and deserves a short discussion. At one time the main issue was whether organisms concentrated pollutants via the water or the food chain. An overview of recent literature by Mearns and Young (1983) resulted in the following generalizations:

- Organic chemicals are concentrated in the sediments near their sources. Water concentrations are many orders of magnitude lower than the sediment concentrations.
- Based on whole body analyses, metals concentrate in animals near the source areas, but with the exception of mercury, there is little evidence of biomagnification. However, marine mammals and birds are subject to some bioaccumulation of metals through their food.
- Higher molecular weight chlorinated hydrocarbons (DDT, PCBs, etc.) remain very high in the sediment for years after the cessation of their input. Furthermore, they do tend to bioaccumulate in food webs and have been observed to impact reproductive success. However, lower molecular weight chlorinated hydrocarbons (such as cleaning solvents) appear not to reach excessive levels.
- Aromatic hydrocarbons concentrate near spill sites, but tend to decrease after the sources are reduced (but cf. Sanders et *al.* 1980, a discussion of benthic effects of a spill near Woods Hole).

A few other conclusions of interest include the fact that there are considerable data showing that marine organisms can accumulate organic chemicals and trace elements from solutions and suspensions, and some organisms can depurate and metabolize the chemicals. However, there is a hooker here, because the negative findings of scientists looking for the chemicals may result from the abilities of many species to metabolize the materials into metabolites, which do not show up on the tests, but are toxic, mutagenic, and carcinogenic. Thus many species may be carrying heavier loads then we realized. Finally, it is becoming clear that the marine particulates have critical roles in the transport and transformation of chemical contaminants. These particulates may find the pollutants, but at the same time, provide effective transport and recycling.

I emphasize that the above summary is from Mearns and Young. The literature I have looked at has very diverse opinions ranging from great concern about sublethal stresses greatly altering reproductive growth and larval survivorship, to the dismissal of the entire problem as a non-issue. Certainly we need to maintain an awareness of this issue, because such stresses represent an almost classic example of cumulative effects which can be subtly, but importantly, expressed through difficult to evaluate pathways such as feeding behavior, fecundity, larval survivorship and larval habitat selectivity.

INTERLUDE

At this point you will have noticed that my digressions are overly long. Furthermore, you are concluding that because I have no solution to cumulative impact assessment, I am resorting to the sophomoric trick of pontificating about irrelevant issues! True, but the real intention was to build some background for an additional discussion of stability, and how cumulative insults might destabilize natural marine systems.

BACK TO COMMUNITY STABILITY

Many facets of community stability have been defined, but at least three types need to be defined for our discussion:

- persistence stability, or constancy of a community;
- inertia or resistance stability, which refers to resistance to invasion or perturbation; and
- resilience, which refers to recovery following a strong perturbation.

In many cases a large perturbation can result in a new assemblage of species which is itself resistant to change; this can be considered an alternate steady state or stable assemblage. Clearly there are important scale issues (on small scales there is no stability and on large scales everything seems stable), but our burning question is: How does a particular assemblage respond to various cumulative perturbations and stresses, and what types of thresholds exist in natural communities?

Examples of marine perturbations which corne to my mind include the addition of material to the sea such as sewage, toxicants (hydrocarbons to various chemicals), sediment (dredge spoil, sewage sludge, or unnatural land runoff), thermal energy (usually from power plants), and introduced species. Larger scale perturbations include major storms and hurricanes, and massive oil spills. Other important perturbations include the selective removal of populations, especially by fishing-but when does such a perturbation significantly alter a community? If a community has critical species or functionally important groups of species, the effects of the perturbations on these isolated species can be evaluated. (An implicit risk of such a simplification is that there may be other species with equal, or more important, but still unrecognized roles which are sensitive to the perturbation.) My first digression outlined some of the biological processes likely to be affected by stress — for example, aspects of reproductive biology or foraging behaviour. My second digression summarized some characteristics of various marine habitats, and emphasized the futility of a priori identifying important species, or even of finding them in several communities. However, it is no longer a priori for many marine communities, and we can utilize a great deal of excellent research and natural history to make reasonable, if crude, predictions about a future impact. We do not have to know "everything about everybody" to identify important species and processes likely to be impacted.

SUCCESSION

Assuming a perturbation is likely to significantly alter a community (e.g., dredging or disposing of dredge or sewage spoils), it is important to consider the factors relevant to succession. The most obvious factors include propagule availability, propagule habitat selectivity and availability of appropriate habitat, survival through reproduction age, and habitat modification. Since we are interested in evaluating cumulative impacts on these factors, it may help to discuss them a little more carefully, as follows.

Propagule Availability

What determines availability of propagules? It is important to point out that the following types of information are often available:

- availability of adults — this is often ignored, but in situations with patchy low dispersing populations, rare species or selectively harvested species, it is not a trivial issue;
- life history patterns — for example, seasonal or restricted reproductive periods;
- dispersa1 biology of propagules — the mode of dispersa1 and the regional local current patterns, and the longevity of propagules in the dispersa1 stage, are all important factors.

Habitat Selectivity of Propagules

This is a missing component of our understanding of succession in marine systems, yet it is becoming more apparent that larvae have a great deal to say about where they settle, and that in many (almost all?) cases, they demand certain types of habitat conditioning or, more important to our consideration of CIA, the presence of adults. This is an arena crying for more laboratory and field experimentation carefully integrated to the appropriate natural scales.

Juvenile Survivorship

As marine animals grow, they are subject to increasingly large predators and competitors. Most marine species metamorphose into very small organisms with a host of little-studied predators and/or competitors. As they grow however, they become easier to study and there is more information available. Interesting and important larval/adult interactions are receiving attention (Woodin 1978; Peterson 1982), and there are examples of positive and negative relationships which emphasize the risk of generalizing. Finally, "nursery areas" are little understood but apparently very important. This last issue is especially important to us, because nursery areas may be relatively small, yet often seem targeted for man-caused perturbations; they should be a prime consideration of proper CIA.

Adult Survivorship

This is the focus of most research and needs little elaboration here.

Finally — overlapping all of the above but worth reiterating:

Patterns in Time

- Diurnal patterns are very common and while not really relevant to stability/succession issues, can confuse sampling programs.
- Seasonal patterns in biology, climate, and physical oceanography are critical, and should be considered in CIA.
- Episodic events are unpredictable over decades and sometimes centuries. Because of the longevity of many marine organisms, and especially because of the resistance of their patches, most observed natural patterns are probably footprints of episodic disturbance or, more often, recruitment events.

Patterns in Space

This obviously depends upon the dispersability of propagules. It seems to me that adult populations are often large and disperse relatively effectively. This is especially true in most open-ocean, pelagic or nearshore benthic systems, where man often disposes of waste, but not in bays or estuaries. This is important to us because it suggests that such disposal (especially of sewage kept free of toxic material) may have very little cumulative impact.

SUMMARY

The above long-winded discussion is important because these are the mechanisms of resistance stability and resilience or recoverability. If we are to corne up with generalizations of CIA rather than case-by-case evaluations, I believe they must be couched in these parameters. One can then refer to the discussions and literature in books such as Yodzis (1978), Steele (1978), Parsons and Takahashi (1973), Cushing (1982), or Mann (1982), and develop a feel for the relative importance of these general parameters to specific marine systems. It seems to me that this is the most meaningful approach to evaluating the cumulative effects of perturbations to linked ecosystems. Perhaps more importantly, evaluating the effects of various perturbations should allow the development of scientifically credible Occam's Razors to weed out non-issues or relatively trivial parameters.

The natural "noise" renders most monitoring procedures worthless, and they have been observed to miss some of the largest perturbations. Indeed, there is so much natural variation that it is very difficult to negate the null hypothesis of no cumulative effect. This leads to a very real risk of type II errors (not recognizing a real perturbation).

SUGGESTIONS FOR TYPES OF SIMPLIFICATION

Credible early warning signals have been the succubus of most pollution workshops which have corne up with numerous suggestions and indicator species. The scientific community usually snarls from its ivory tower about the inadequacy and danger of simplifying nature. While generalizations always have exceptions, I believe that much of this negative response is counterproductive and shallow. I urge this workshop to try to develop some form of early warning signal, and offer the following thoughts in hopes that they at least stimulate productive discussion. I emphasize soft-bottom communities because they are difficult, but receive most of the cumulative impacts.

Important species or groups of species. While "everything may be connected to everything else," there is abundant experimental evidence from many communities, that only a few species have important community roles (Elton 1966; Dayton 1984). In those systems where there is evidence (even natural history evidence) that important species exist, they should be studied or at least monitored (Lewis 1976). There is considerable evidence that soft-bottom benthic communities receive most of the impacts, and there is considerable evidence supporting the functional group concept. We should be able to take advantage of this, and evaluate whether or not habitats are shifting from, say, suspension feeding to deposit feeding groups. There are soft-bottom situations in which single species have important functional roles aerating the sediment, making mounds, etc. Often these are crustaceans which are difficult to study, because they tend to have episodic recruitment. Nevertheless these species deserve special study.

Indices — post hoc models with high "ground truth." The Southern California Coastal Water Research Project (SCCWRP) struggled with a "Trophic Index" which had promise in this respect. It offered great monitoring simplification and yet was sensitive to important shifts in species composition. There were problems, and SCCWRP seems to have dropped this, but I believe it has great promise and deserves more work. Like all post hoc models, it is idiosyncratic, but I believe that it has general value in temperate shallow (15-100 m) soft-bottom systems, because the genera seem ubiquitous and very similar worldwide.

Early warning signals include indicator species and accumulation of metals, toxicants, etc., in susceptible species. *Capitallia capitata*, a small polychaete, is attracted to sulfide compounds, and its presence is highly correlated with stressed soft-bottom habitats. It also occurs (rarely) in naturally disturbed habitats, so its use as an indicator must be done in conjunction with other programs. Barometers of accumulation of pollutants such as trace metals, radionuclides, and other toxicants include mussels in seawater (Goldberg et *al.* 1983), herring gulls in the Great Lakes, and honey bees in large terrestrial areas (Bromenshenk et *al.* 1985).

Bioaccumulation of pollutants is well documented (Bruce Thompson of SCCWRP gave me an envelope full of abstracts — I will not cite them here). In addition, there are metallothionein proteins which bind pollutants. When local examples of bioaccumulating or metallothionein laden species are known, it obviously is important to monitor them.

Life history studies of selected species seems an obvious idea in light of the importance of reproductive biology to the stability/succession processes. I believe that shifts in life history patterns might be the most important indicators of cumulative stress. Furthermore, I believe that this is a very feasible approach, because most soft-bottom communities include pericarid crustaceans which brood their young. Hence it should be easy to monitor parameters such as brood size, size (age?) of maturation, survivorship of young after they are released, and maybe even growth rates. These parameters are important, and should be responsive to sublethal stress, thus shifts could be early warning signals of cumulative impacts.

I know that nobody wants to hear that we need **more research,** and I have argued herein that great progress has been made in understanding many marine systems. Nevertheless, I must argue that a little focused research on the community effects of various stress, and the modes of resistance or resiliance is still urgently needed. While certain, but reduced, levels of monitoring are important, a fraction of monitoring cost should be invested in research, using the project as an experiment. When considered ahead of time, obvious questions can be posed in such a way that they produce answers, and can thus be built upon in the future. I believe that the failure to do this represents the greatest travesty of the environmental monitoring business (at all levels).

Afterthought: The Southern California Coastal Water Research Project (SCCWRP) is an excellent independent research organization studying all forms of cumulative impact assessment. They publish a biannual report which can be obtained by writing:

Mr. Willard Bascom, Director
SCCWRP
646 W. Pacific Coast Highway
Long Beach, California 90806

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COMMENTARY I

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This contribution[1] presents observations primarily focused on the speaker paper "Cumulative Impacts in the Marine Realm" by Paul Dayton, but also incorporates comments relevant to several other papers and personal work.

Dayton's paper has either highlighted or alluded to several important factors required for understanding and developing procedures that properly incorporate cumulative impact assessment (CIA) as an integral part of environmental impact assessment (EIA). Several are itemized below, repackaged and presented, perhaps in a slightly different fashion, but hopefully retaining the general intent.

COMMUNITY STABILITY / SUSTAINABILITY AND DEALING WITH COMPLEXITY

The major focus of Dayton's paper is the important role of community and ecological stability, emphasizing the myriad of parameters and interrelationships that usually frustrate assessments as a result of their extreme complexity. The examples include: large numbers of individual components and their interactions: reproduction, inter-intraspecific competition, communications, predation and mutualism; historical effects; and biophysical spatial/temporal relationships each involving aspects of individuals, populations and communities. Later in the paper, community stability is stressed again in terms of scales and thresholds for persistence, resistance and resilience or recoverability.

The underlying concept is the importance of "sustainable yields" or "sustainable reproductive capacity" of "important" biological species. In effect, the significance criteria for any individual or cumulative impact relates to the degree of loss or change affecting biological species sustainability. In terms of science, the preservation of biological species, "in their own right" and integral to the ecosystem, is the consideration; in terms of management, the social value placed upon species within the ecosystem becomes important, especially if biological trade-offs are involved.

These concepts, including the numerous components noted by Dayton and others (Beanlands and Duinker 1983), can be illustrated in several helpful combinations in Figure 1 (from Cornford, in preparation). In general, activity/species interactions must be characterized in time, space, and by significance, illustrating gradients in each to accommodate different types and scopes of impact. Dayton draws particular attention to one such example, i.e., levels of biological organization (or aggregate) — individual, population, community and ecosystem.

Figure 1, while indicating representative examples of components and representative gradients that contribute to assessing environmental impacts (including cumulative impacts), also suggests that there may be some semblance of order within the biological complexity. Dayton's paper also alludes to this, for example:

> *(kelp and benthic) communities tend to have important species... but within a particular locality relatively predictable patterns of succession and disturbance.*
>
> *If a community has critical species or functionally important groups of species, the effects of the perturbations on these isolated species can be evaluated.*

The challenge remains one of focusing upon those aspects of the biological and biophysical systems that lend some element of order or predictability. Important species and functional groups is just one hint.

DESCRIPTIVE APPROACHES VS UNDERSTANDING BIOLOGICAL PROCESSES AND DYNAMICS

The paper suggests the inadequacy of descriptive and simplistic baseline approaches and facile correlations, as opposed to "even moderate levels of understanding (of) the dynamics of populations, their interrelationships and the functional organization of the community, (which) can lead to considerable simplification and prediction."

While descriptive information may be the only information available in many instances, emphasis on understanding the processes and dynamics of both biological and biophysical systems is the best way to move towards understanding cause-and-effect relationships and possible prediction. Since most major biological criteria of importance — relating ultimately to sustaining populations — are all derived from combinations of basic physical (biophysical) measurements, it is virtually impossible to model or predict without a capability to parameterize relationships and processes. It is this understanding of processes that provides the best prospect for prediction. Figure 2 (Cornford, in preparation) highlights several important relationships among data, process knowledge, hypothesis, predictability, and research and monitoring that support this contention. Baskerville, Waldichuk and others

[1] The content and views expressed in this paper are solely those of the author and do not directly or indirectly represent the views or policies of the Government of British Columbia.

A: ACTMTIES: 1-N
Construction of closely rpoced offshore artifi– cial Islands in the londfast Ice zone ond trans- ition zone.

1A: DNELOPMENT STAGE
(1) Startup
(2) Ongoing
(3) Abandonment

1 A/B SEASON
(1) Spring
(2) Summer
(3) Fall
(4) Winter

1B LIFE CYCLE STAGE
(1) Breeding
(2) Feeding
(3) Migrating
(4) "Habitating"

Start-up

Spring

Breeding

QUESTION:
Potentlal for bridging and retention of landfast Ice In the tranrltion zone reeulting from closely spaced Islands delaying or significantly reducing zooplankton brseding and subsequent lack of food source for whales. Potential for lost whale resource and subsistance fishery.

2. SPATIAL ZONES

2B(1) TROPICAL LEVEL(S)
(1) Fish/Mammols
(2) Zooplankton
(3) Phytoplonkton
(4) Habitat

2B(2) BIOLOGICAL AÇGREGATE
Gradients
(1) Individuol
(2) Populotion
(3) Community
(4) Ecosystem

2A/B EXPOSURE STANDARDS
(1) Leathal/acute
(2) Sublethal
(3) Regulation limit
(4) Detection limit

Zooplankton

Community

Sublethal

PERSPECTIVES
Determination of magni- tude and natural range of variability of zooplonkton reproductive communities, patchiness; extent of feeding by wholes and degree of dependence on tooplonkton as a food source; significonce of role in zooplonkton in the entire food web.

(General time series biomass measurements with energetic calculations and temporal voriability and influences.)

3. SIGNIFANCE CRITERIA AND MEASURES

DERIVATION OR MEASUREMENT | CORRELATION | PROCESS OR HYPOTHESIS

3A/B SIGNIFICANCE
(1) Loss
(2) Change
(3) Perturbation
(4) Bockground

3B(1) BIOLOGICAL INDICATORS
(1) Tissue/Organ/Individual
(2) Population Success
(3) Bahavioural Intagrity
(4) Ecologicol Survival

3B(2) BIOLOGICAL RESPONSE
(1) Toxicological/Acute
(2) Physiological/behavioural
(3) Dehabituation/perturbation
(4) Background variability

3B(3) BIOLOGICAL MEASURES
(1) Mortality/!oss
(2) Domage/change
(3) Perturbation
(4) Naturol Variability

DERIVATION OR MEASUREMENT	CORRELATION	PROCESS OR HYPOTHESIS
Permanent Change		
Behavioural		
Physiological Behoviourol		
Community Fecundity with reproduction reduced 50%	Reproduction Rate	Extension of londfost ice between islar delays breakup ond influences productivity

INFORMATION:

SIGNIFICANCE OF BIOLOGICAL RESPONSE AND MEASURES

OBJECTIVE	SU BJECTIVE	INTUITIVE	UNKNOWN
	Apparent community size reductions in Spring		

DEVELOPMENT/NON–DEVELOPMENT CONDITION

RESEARCH	MONITORING	REGULATION	REDESIGN
Reproduction rate necessary to sustain vioble community structure	Recruits/ Time	Restrict minimum Island epacing	Production Island redesign

Figure 1.

reinforce this concept of a more rigorous scientific approach to both EIA and CIA, that includes better understanding of processes and utilization of process knowledge, for example via the mass balance concept. (Waldichuk, this volume; Baskerville, this volume; Thomas et *al.* 1983.)

BIOACCUMULATION AND MASS BALANCE

At various points in the paper Dayton provides comments which all relate well to the mass balance concept. For example:

.. unders tanding dynamics

... alternate steady states

tease apart natural and man-induced changes;. ..considerable na tural background variability.. .

Some organisms can depurate and metabolize the chemicals;. .. ...many species may be carrying heavier loads than we realized.

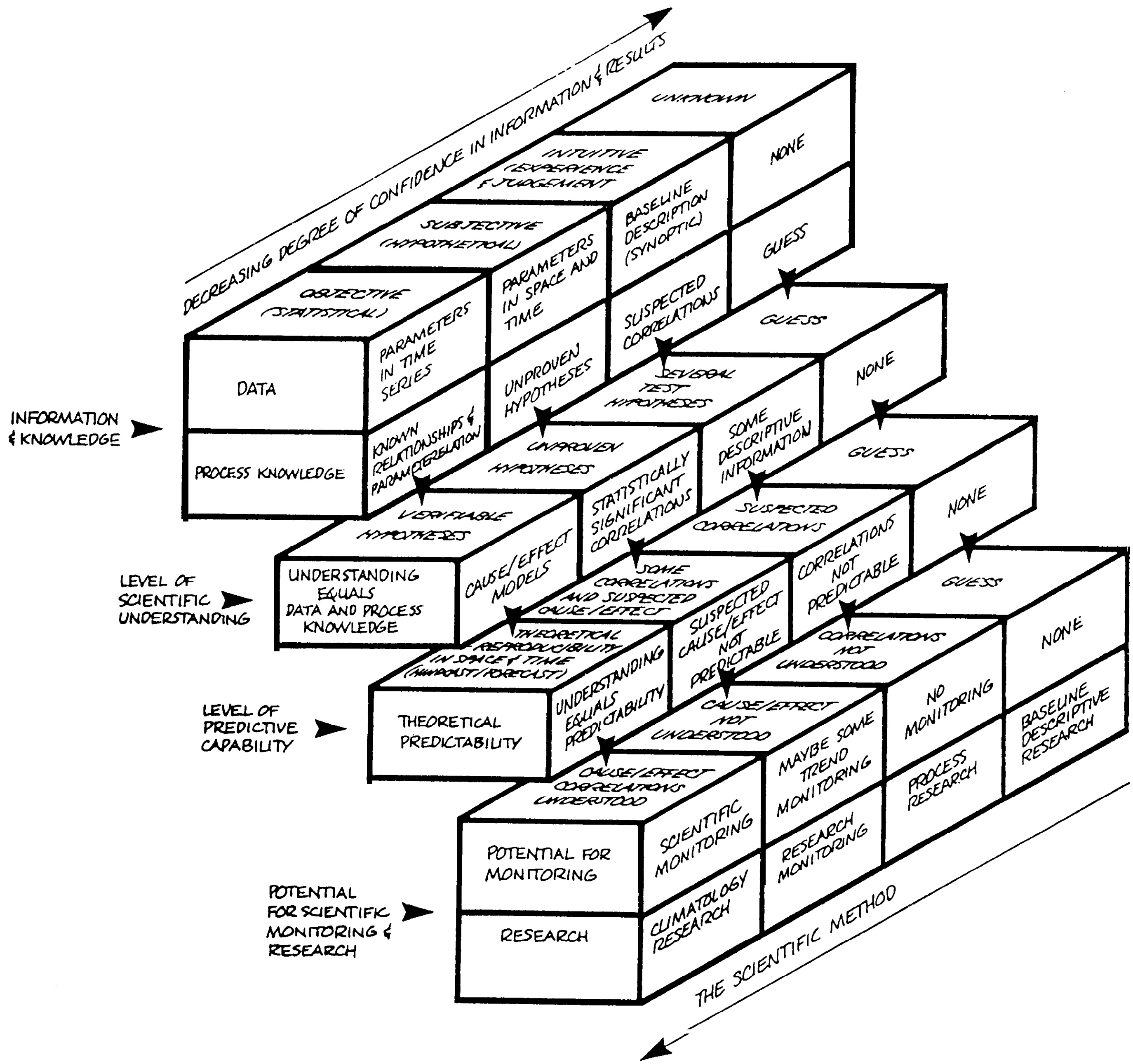

Figure 2.

> *particulates.. .provide effective transport (and transformation) and rec ycling.*
>
> *... there are important scale issues.. .*

Most of the authors have made similar types of references.

One of the most important underpinnings of cumulative impact assessment is an understanding of relevant scales of natural variability — the scales of historical, prevailing and potential future dominating processes. The dynamics of the environment itself provide natural "integration" or "accumulation" properties, as well as natural dispersa1 and cleansing — some keys to cumulative assessment.

Taking waste emissions as an example, the mass balance approach provides a means of comparing anthropogenic fluxes of a particular physical stress or chemical component for a given development scenario, via calculation of the natural flux for the same component within specified boundaries (or zone of influence). The major considerations are the rates of inputs (sources) to the rates of outputs (sinks), and hence estimations of residence times; i.e., the time the component remains available for exposure to biology before it is removed by natural processes. Residence times may be translated into exposure, bioavailability and bioaccumulation, leading to estimates of biological effects.

Anthropogenic pollutants may have natural counterparts (e.g., metals, nutrients, etc.) or no natural counterparts (e.g., pesticides, radionuclides, etc.). For the former, their occurrence and distribution are determined by fundamental natural cycles balancing their inputs and outputs, which serve as a valid comparison for human inputs. Often the natural cleansing rates of marine systems render most anthropogenic inputs indistinguishable from background variability or comparable to natural levels of stress.

Rates of inputs of harmful components, which far exceed rates of removal via precipitation, sedimentation, burial or chemical complexation to biochemically inert forms, cause buildups (or loading) that can be calculated by mass balance techniques long before a dangerous situation occurs. Hence the mass balance concept provides a very important cumulative perspective, and can serve as a proxy to estimate the cumulative and assimilative capacity of dynamic systems (both biophysical and biological) for certain components.

EARLY WARNING SIGNALS AND IMPORTANT SPECIES

Dayton and many others support the search for some form of early warning signal, looking towards the functional group concept and shifts in life history patterns for clues to cumulative stress. While both of these may provide hints, it is unlikely that forecasts having any measure of confidence will be possible until processes and system relationships are first understood. Baskerville (this volume) and I agree completely here. A systematic approach in a rigorous scientific framework is essential, at least to establish cumulative perspectives necessary to zero in on areas of most likely concern for intensive research, monitoring or safeguard. For such latent impacts as asbestosis, having a 25+ year gestation period, all the monitoring in the world is fruitless unless an understanding of the basic processes is first gained.

When key processes or interrelationships are understood, it is then imperative to identify and watch important species that will suggest on-set of loading or imbalance. Hence important species, sentinels, or valued ecosystem components are essential, but only in the proper sequence. Otherwise, so-called monitoring (cf. Figure 2 for an indication of scientific monitoring) is often little better than betting on the lottery.

SCIENCE AND MANAGEMENT

While Dayton's paper deals specifically with science, the links with management cannot be ignored in devising a suitable "recipe" for cumulative assessment. EIA and CIA are both information processes and decision processes (Baskerville, this volume; Waldichuk, this volume; Cornford *et al.* 1985.). It is therefore imperative that procedures recognize the types and quality of information required for decision making, and that decisions can and will be made with limited information. All cumulative impacts will never be predictable, but most can be given confidence limits within today's knowledge. What is required is a recipe that provides a fairly quick and ready way to establish perspectives relevant to cumulative impacts for most major concerns. It should also provide the pathway or framework for conducting detailed scientific investigation of those most likely to impact significantly on decisions and the public consultation process. This is reviewed in other work. (Cornford, in preparation; Cornford *et al.* 1985.)

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COMMENTARY II

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The paper by Dayton deals with cumulative effects by considering how ecology is done, how communities are structured, what types of impacts are likely to affect marine organisms, and how the complexities of nature can be usefully simplified. The paper provokes many thoughts, some directly and some indirectly. Some of the thoughts are not directly relevant to cumulative affects, but most of them are. Assuming that all readers of this discussion have read Dayton's paper, I will not summarize it here.

GENETICS AND EVOLUTION

I put this at the head of the list because it is so important and so often neglected. Evolution as a response to environmental change is very much a cumulative effect, and is usually ignored by managers. The word "evolution" evokes thoughts of "evolutionary time," but that is dangerous. Evolution can happen startlingly fast — look at how quickly insect populations evolve resistance to pesticides.

Dayton suggests that fishing pressures "may represent some of the most profound chronic and cumulative stresses in the marine realm." I would assert that they do represent profound stresses; and there is almost certainly evolution in response to them (see Beverton et *al.* 1984; Lawton and May 1984; and references therein). Further, many other environmental impacts are very likely to result in evolutionary (i.e., genetically based) changes. These impacts might include forestry, pest control, and contamination problems, and the potential changes need to be considered as responding to, and being, cumulative impacts.

THE IMPORTANCE OF NATURAL HISTORY

Dayton emphasizes how important it is to understand the biology of the organisms that are at risk, and this to me means knowing natural history. Although Dayton argues that "descriptive approaches are inadequate for an understanding..." and that "it is futile to rely on purely descriptive work...," I think he is arguing against "mindless species lists and population censuses" only, rather than against descriptive natural history. Most of his discussion underscores the value of descriptive natural history if it is intelligently collected: learning about life histories, larval stages, food habits, etc. I completely agree with this and Dayton's emphasis. I further agree that "derivative statistics such as diversity indices, dendrograms, etc..." are a bad idea, because in their use so much information is thrown away — information essential to their construction, thus information that is at hand anyway. This point, of course, applies to all assessment, whether problems are cumulative or not.

ECOSYSTEM AND COMMUNITY STRUCTURE

This is closely related to the previous point. Obviously we would like to know everything about ecosystems in order to predict the effects of impacts, but as Dayton makes clear from his list of topics in community ecology, we don't know how most of them work. I fear that a preoccupation with how the ecosystem or the community functions as a unit is a bad one, because it leads to semantic difficulties (What is an ecosystem?) and worse, it obscures the great amount of ecology that is known and is available to be applied to environmental problems. I want to make clear that interrelationships between species, trophic levels, nutrients, and other ecosystem components must be taken into account. Species do not live in vacuums. The distinction I am trying to make is that one must consider species and their interactions — as many of them as possible — but there is a great danger of being sidetracked by treating the community or ecosystem as some well-defined entity (superorganism) that responds and evolves. Partial knowledge is better than none.

CAN WE SIMPLIFY THINGS?

Maybe. Dayton's suggestions about early warning signals are good and useful, but only when what you're doing is collecting selected information. In other words, abstraction is not useful if it means discarding information, but it may be useful if it allows you to collect a manageable amount of information instead of everything. The attempt certainly seems worthwhile.

CUMULATIVE, SUBLETHAL PHYSIOLOGICAL EFFECTS ARE IMPORTANT

This is an important point, made by others as well. The organisms may look fine, because each microgram/liter of substance up to a point is either not harmful or does not affect survival; the next microgram pushes the organism over the edge or reduces reproduction even further. This is a real, important, cumulative effects problem.

ECOLOGY IS NOT YET A MATURE SCIENCE

This is not specific to cumulative effects, of course, but it is a real and serious problem. Dayton gives the image of the scientific community "snarling from its ivory tower" that it is dangerous to simplify nature. The argument is usually expanded to say that ecology is too complex to understand, so precise and accurate predictions are not possible. It is almost always accompanied by a plea for support for more research. If we go on making this argument people may actually start to believe it, and then we will really be in trouble. Dayton is right that we already know quite a lot. Natural history and experience are often adequate for making good decisions — I agree, for example, that Dayton would do well with a photograph and a species list if the community were one he had studied. All ecosystems are different, but all share certain processes, and experience is of great value. Experience is especially valuable where the change in an ecosystem is cumulative by-small increments, because such changes are hard to detect. -Experience alerts the investigator to things that might otherwise be missed. Ecologists cannot afford to excuse themselves from giving ecological advice, because the alternative is worse, and-because they often have good advice to give if they would just be willing to share in the responsibility for some risk.

VARIANCES, MEANS, AND EL NINO

The point has been made by several participants (including Dayton) that we must be able to distinguish human-induced change from natural variability. The variability of natural populations and environments is emphasized by Dayton; I would emphasize again here the importance of studying variances as well as means, and of considering large, natural perturbations that may be rare, but which are known to be recurrent (e.g., El Niño, climatic change, blizzards, floods, droughts, earthquakes, etc.). This is particularly important when trying to assess cumulative effects, because the effects of natural variability are less likely to be cumulative than are human-induced ones.

MULTIDISCIPLINARY STUDIES

This whole workshop reeks of multidisciplinarianism. Most of the participants have multidisciplinary experiences, most of the suggested solutions are multidisciplinary, and the workshop itself comprises as diverse a group as I have seen discussing a single topic. It is clear that multidisciplinary approaches will be needed in this area. Yet the structure of our science in North America makes it very difficult to be multidisciplinary. There are few programs with multidisciplinary focus (with some notable exceptions that have representatives here), and if you do succeed in getting a multidisciplinary education it is hard to get a job or a grant. I think this is a real problem and one that needs serious attention. The familiar refrain "More multidisciplinary studies are needed!" is not enough. The only specific recommendation I have at present is that government funding agencies or those that influence what programs are funded (National Science Foundation, Department of Energy, Environmental Protection Agency, etc., in the United States; National Research Council, Environment Canada, CEARC, and others in Canada) should establish funds that are to be used exclusively for multidisciplinary approaches to the types of problems being considered here. The existence of such funds would, I expect, drive the appropriate educational responses from universities, and would lead to the hiring of appropriate people. I add as an afterthought, suggested by discussion, that of course multidisciplinary approaches are not a substitute for good research.

GENERAL MUSINGS

There is a dichotomy between those who feel that ecologists need to provide the goals for managers and policy makers, and those who feel that ecologists should only provide engineering-type advice. In practice, ecologists do provide goals, for the things specified in some of our laws ("balanced, indigenous population," "health of the ecosystem," etc.) come from ecologists. My own view is that ecologists should try to stick to the engineering-type advice, but that they won't be able to remain pure in that way. The distinction is important, I think, and people need to be conscious of it, whatever their viewpoint. Once again a cumulative approach highlights the issue, because the management of cumulative effects so often requires agreement on some standard of environmental quality.

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Management Perspective

MANAGEMENT OF THE ESTUARINE ECOSYSTEM AGAINST CUMULATIVE EFFECTS OF POLLUTION AND DEVELOPMENT

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An estuary has been defined in many ways, e.g., "a semi-enclosed body of water which has a free access to the open ocean and within which sea water is measurably diluted with fresh water derived from land drainage" (Pritchard 1967). Basically, an estuary is where the river meets the sea. It is a complex system physically, chemically and biologically. There is interaction among many natural effects within an estuary. A sort of dynamic equilibrium exists here, where the combined action of runoff, tides, waves, currents, winds and atmospheric heating and cooling maintain a steadily changing condition diurnally and seasonally, but not necessarily altering the situation greatly from year to year.

Organisms living in an estuary are subjected to many natural stresses associated with the constantly changing conditions. Only certain organisms can adapt to this harsh environment. Food webs tend to be simplified, for this reason, with certain food chains being favoured for the transfer of energy through the different trophic levels from the primary producers to the top predators. Although estuaries are regarded normally as highly productive ecosystems, the productivity stems from comparatively few organisms. Diversity tends to be low, but the well adapted species can be present in large numbers. Anadromous species, such as salmon and sea-run trout, find estuaries highly desirable rearing areas because of the ready availability of food, particularly for the juveniles. Bird concentrations may also occur in estuaries for the same reason.

Many biogeochemical processes occur in an estuary. Freshwater mixes with sea water, and any silt present in the former will largely be flocculated and deposited in the estuary to build up the delta. Other substances, natural and man-made, which may be present in the water, will be scavenged from the water column as the flocs of silt settle into the sediments. Hence, estuaries tend to be sinks for river-borne substances entering the sea. They have been regarded as the greatest filters that exist in nature, to prevent particulate and dissolved materials present in river water from reaching the deep sea.

Industries and urban communities often favour estuarine regions as areas in which to become established, for a variety of reasons. The availability of flat land on a river delta, a good supply of freshwater and other raw materials for industry, and cheap marine transport are just some of the estuarine attributes favourable for industrial and urban development. Such developments, of course, may mean certain physical alterations in the estuary, as well as discharges of industrial wastes and domestic sewage, with possibly various degrees of treatment. In relatively undeveloped areas, concern has often been about single-source pollution stemming from a particular industry. In heavily developed areas, especially adjacent to urban centres, multiple-source pollution, both from local and upstream sources, is an issue. This may be compounded by physical alterations, with such structures as jetties, wharves and breakwaters changing circulation and sedimentation patterns in an estuary. Not all these changes have a negative impact on the estuarine ecosystem, but many of them do. It is important, from a management point of view, to be able to differentiate those changes that may have the most acute negative impact on the estuarine ecosystem.

The purpose of this paper is to examine the cumulative effects of pollution and development in estuaries, using two examples from the Canadian Pacific Coast as case studies. Stress will be placed on the impact on the fisheries resource.

SOME GENERAL CONSIDERATIONS

The interaction of the many factors operating in an estuary, must be considered in making any type of environmental impact assessment.

Critical Effects on an Estuarine Ecosystem

In an holistic approach to protection of an estuarine ecosystem, all ecological aspects must be considered. From a practical point of view, however, the approach usually taken is to protect significant food chains that lead to commercially important species. The food web in an estuary is greatly simplified by natural elimination of many species due to stress, and there may be only one significant food chain leading to juvenile salmonids or herring. When a vital link in a food chain is broken, a major impact on an important fisheries resource may occur, e.g., elimination of amphipods, which are fed on by juvenile salmonids, in the Squamish River estuary.

How do we manage an estuarine ecosystem for cumulative effects? We must select a critical environmental variable, e.g., dissolved oxygen, or a critical biological effect, e.g., toxicity. If certain pollutant inputs or developments already exist, and it is proposed to introduce a new pollutant and/or development, then it is essential to evaluate the impacts of the existing inputs and physical changes due to developments. Essentially a mass balance has to be made, whether one deals with uptake of dissolved oxygen by biodegradable organic materials, or introduction of metals from wastes. If conditions are already such that water quality is near a limiting level of toxicity, dissolved oxygen or temperature, then clearly the input of another pollutant that might further tax those water quality properties has to be severely limited. If one has to deal with a multiple-source input, where the different sources introduce different environmental or ecosystem effects, then the problem of management becomes much more complex. Certain mixtures of pollutants have synergistic effects, where the combined toxicity is greater than the sum of toxicities of individual constituents. Other mixtures may have antagonistic effects, wherein individual constituents may neutralize each other for toxicity. Both synergistic and antagonistic effects can be established in laboratory bioassays using suitable test organisms. It is difficult, however, to simulate in a laboratory all the conditions present in an estuary. Ideally, therefore, the final evaluation of the impact of a mixture of substances must be conducted in the field.

Environmental Considerations

The impact of pollutants or developments in an estuary depends a great deal on such factors as river discharge, tidal range, exposure to the open sea, prevailing winds, and swell and wave action (Waldichuk 1968). These physical characteristics of an estuary will determine how rapidly pollutants will be diluted, dispersed and transported away. Geochemical processes in an estuary are important in abstracting pollutants from the water and depositing them in the sediments. Such suspended solids in river water as glacial silt, will undergo flocculation as the freshwater mixes with sea water, and the flocculent aggregates of silt will settle by gravity at the estuarine delta, if the turbulence is not too great. The settling flocs have great sorption capacity and can remove suspended and dissolved substances of anthropogenic origin and deposit them in the sediments. These substances are not likely to become mobilized again as pollutants, unless they are disturbed by an activity such as dredging.

Certain developments, combined with the environmental characteristics in an estuary, can have beneficial effects on the estuarine ecosystem. A good example of this is the development of eelgrass habitat between the two causeways, for the Tsawwassen Ferry Terminal and the Roberts Bank Coal Port, on Roberts Bank of the Fraser River estuary (Waldichuk in press). As described in a later section, this eelgrass habitat is favourable for feeding of juvenile salmonids and aquatic birds. Thus, such an effect of development must be regarded as positive in the cumulative impact balance sheet.

The resilience of an estuary to certain perturbations is extremely important, and it is usually determined by the environmental characteristics which contribute to the magnitude of such parameters as flushing rate. The residence time of pollutants will be controlled by the flushing rate of the estuary. The recolonization of an estuary after dredging or filling will be a function of water exchange between the estuary and other nearby bodies of water from which larvae will be imported. A long recovery period of an estuary from a single major perturbation, such as massive dredging or an oil spill, can have a lasting impact on the system as a nursery area for juvenile salmonids. From a management point of view, the impact of development or pollutant input on vital food organisms of juvenile salmonids, e.g., amphipods, must be small.

Seasonal Effects

Seasonal changes must be taken into account from a physical and chemical point of view, as well as biologically. River flows change with the seasons as precipitation patterns vary from summer to winter, and from a simple dilution perspective, the impact of pollution can be expected to be less during heavy runoff. Temperatures also change seasonally in temperate zones, and this can account for a greater ecological impact of certain pollutants in summer, when temperatures are high, than during the cold period of winter when the metabolic processes are greatly slowed down. Biologically, there is a spawning season, a rearing season, a growing season and a dying-down season (for plant growth) in an estuary. Pollutants affect estuarine organisms differently in their various life stages.

An estuarine ecosystem generally has a higher capacity to withstand perturbation in winter than in summer. This is illustrated in Figure 1, which shows schematically how the capacities of an unperturbed system and a heavily perturbed system vary seasonally. The latter exhibits the cumulative impact of pollution. Often the season that sets the upper limit on the amount of pollutant that can be introduced into an estuarine system, without serious ecological damage, is the summer. This is the period when the Somass River has the

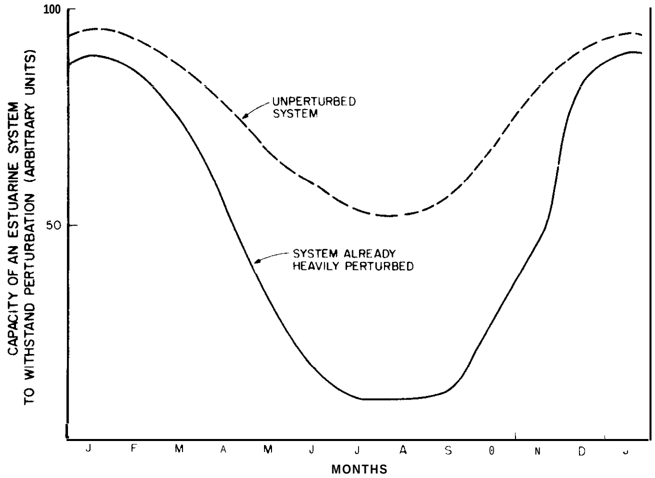

Figure 1. A hypothetical graph of seasonal variation in thecapacity of an estuarine system to withstand perturbation, showing the expected difference between a system already heavily perturbed and an unperturbed system.

lowest flow, and water temperatures can be expected to be highest. This has been the approach used in setting the upper limit for effluent disposal from the pulpmill in Port Alberni (Waldichuk 1983b). The permissible concentration of such effluent in this system must be based on the toxicity of the effluent to juvenile salmonids which migrate downstream mainly in spring and early summer.

The seasonal variation benthic macroinfaunal standing stock, benthic production and nutrient regeneration, phytoplankton primary production, and riverine nutrient input for the Corpus Christi Bay estuary, Texas, are shown from Flint (1984) in Figure 2. The periods of peak brown shrimp abundance and benthic larval colonization are also shown to illustrate the process of developing an integrated picture of how an estuarine ecosystem functions.

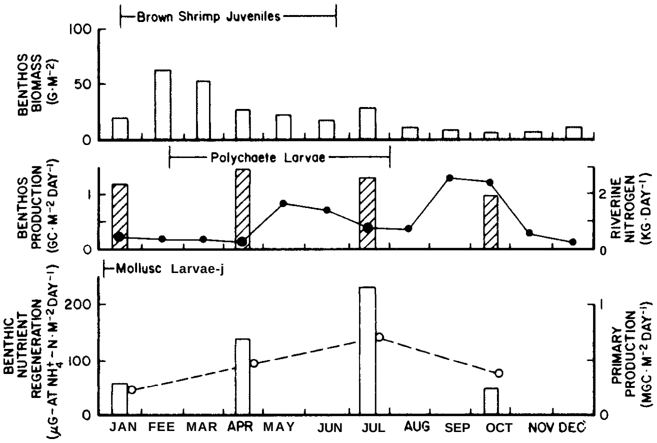

Figure 2. The seasonal variation in the Corpus Christi Bay estuary of benthic macroinfaunal standing stock, benthic production and nutrient regeneration, phytoplankton primary production, and riverine nutrient input. Periods of peak brown shrimp abundance and colonization by polychaete and mollusc larvae are also shown (From Flint 1984).

The Biota

Assuming that the estuary is managed for its living resources, we must consider the uses made by the various organisms that may be permanent residents there or merely transients. Again, from a pragmatic point of view, it is essential to examine the commercially important species that utilize the estuary. Do they use it for spawning, rearing and feeding as juveniles, full-time residence, or merely for passing through in downstream or upstream migration? The indigenous species may spawn, rear and live their full life cycle in the estuary. It may be essential to protect them in all their life stages because of their intrinsic value as part of the estuarine ecosystem. They may in themselves have commercial value, or they may serve as food for commercially important species.

Then there are the transients, such as Pacific herring that come into the estuary to spawn, or the Pacific salmon that migrate through the estuary as juveniles moving out to sea, and as adults returning to the stream to spawn. For herring spawning, the water quality must be satisfactory and a suitable uncontaminated substrate for deposition of eggs must be available. Juvenile herring and salmon also use the estuary for rearing in different degrees, according to species. They are highly vulnerable to water pollution at this time, which could not only destroy or debilitate the juvenile fish themselves, but could also adversely affect their food organisms. Adult salmon returning to the river to spawn do not normally feed in the estuary, but their passage through the estuary must not be impeded by any physical or chemical obstructions.

The cumulative effects of pollutants and any foreshore developments that can have an impact on migration and schooling behaviour of the various species in an estuary must be fully taken into account when managing an estuarine ecosystem for its living resources.

Legislative Controls

In British Columbia, pollution and other adverse environmental impacts from industrial wastes and domestic sewage on living resources can be controlled to some degree under provincial and federal legislation. The Waste Management Branch of the British Columbia Ministry of Environment issues permits for industries and municipalities, with guidelines for limits on constituent concentrations and other characteristics. The type of permit issued and guidelines on effluent quality may be determined by public hearings conducted by the B.C. Pollution Control Board.

The federal government has legislation for protecting the commercial fisheries within its jurisdiction. Under the Fisheries Act, both the water quality and habitats for fish and invertebrate species are protected. However, it is up to the Department of Fisheries and Oceans to prove in court that a certain waste disposal or nearshore development is deleterious to commercially important species or their habitats. Regulations have been developed under the Fisheries Act for different types of industrial wastes, such as the Metal Mining Liquid Effluent Regulations. Regulations such as these may be waived for a specific operation, through promulgation by order-in-council of new regulations for that particular operation, such as the Alice Arm Tailings Deposit Regulations.

The federal Ocean Dumping Control Act controls dumping of materials at sea in areas under federal jurisdiction. At the present time, the Supreme Court of Canada has ruled that the waters and the sea-bed between Vancouver Island and the mainland of British Columbia (Strait of Georgia, Discovery Passage and Johnstone Strait) are under provincial jurisdiction. Until an appeal is heard on a court judgment with respect to dumping wastes by the forest industry in Beaver Cove, on the northeast coast of Vancouver Island, ocean dumping applications for these internal waters are being processed under the Fisheries Act, and the permit fee is being waived.

Under the Ocean Dumping Control Act, there are regulations which prohibit the dumping of certain substances (e.g., mercury and cadmium and their compounds, organohalogen compounds, petroleum hydrocarbons) except in "trace

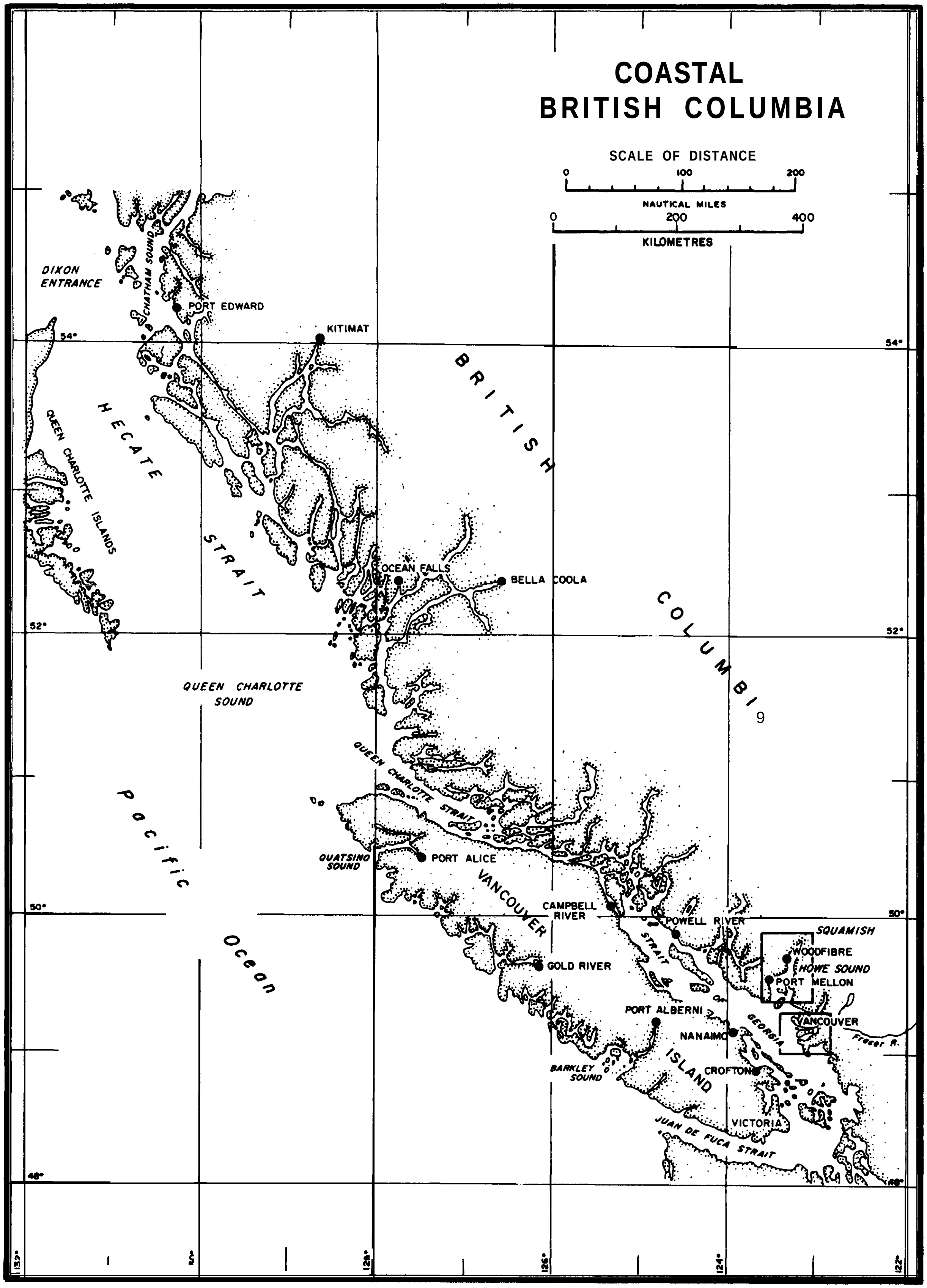

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Figure 3. Chart of the coast of British Columbia, showing the locations of some of the important estuaries, and the Fraser River estuary and Squamish River estuary study areas.

concentrations," which are defined. These trace concentration limits have presented problems in administering the Ocean Dumping Control Act, because they were set somewhat unrealistically when the Act was promulgated in 1975.

The Federal Environmental Assessment and Review Process approach to evaluating environmental impacts of federally supported projects allows for public input, and takes into account all available environmental and ecological information made available by the proponent, consultants and others who may have done studies in the area. A substantial number of projects have now undergone the Process, and there have been various degrees of success in controlling undesirable ecological impacts of federally supported projects by this approach. The lack of ecological consideration in the Process prompted the study by Beanlands and Duinker (1983).

In all legislative control of pollution and effects of development in British Columbia, federal and provincial, there has not been a conscious approach to the cumulative aspects. Rather, a piecemeal approach has been taken to control effluent, disposal and development. It must be admitted, however, that existing environmental conditions are examined, and these generally reflect the cumulative effects of previous waste disposal and development.

CASE STUDIES

There are many estuaries in British Columbia that could be used as case studies for this exercise. It was decided to focus on two of the most important estuaries in the province, however, both from the point of view of urbanization and industrial development, and the availability of living resources. These are the Fraser River estuary, with a major salmon fishery resource and near the major population concentration of the province, and the Squamish River estuary, which supports a substantial salmon fishery and considerable industrial development. Both estuaries, being near major academic institutions and government research establishments, have been extensively studied. The locations of these two estuaries are shown in Figure 3.

Fraser River Estuary

The Fraser River is extremely important from the point of view of the salmon runs it supports, which are worth hundreds of millions of dollars to Canadian and US. fishermen, All five species of Pacific salmon, genus *Oncorhynchus*, are found in this system, but the sockeye, 0. *nerka*, and pinks, 0. *gorbuscha*, are particularly important for commercial fishermen.

The Fraser River has a glacial origin in the Rockies, and therefore, is heavily loaded with glacial flour that gives it a natural turbid appearance. Much of the river silt flocculates in the estuary and settles out on the extensive delta.

The Fraser River has a comparatively fast and turbulent flow so that the river water constantly undergoes aeration. The water in the mainstem is always well oxygenated, but oxygen depression may occur in the "salt wedge" of the somewhat stagnant sloughs of the estuary.

The Fraser River receives assorted wastes and contaminated runoff along its whole course. These include domestic sewage from various urban communities and pulpmills located on the river, as well as agricultural and urban runoff. Logging and road-building activities introduce suspended solids that can have a serious impact on salmon habitats, especially spawning grounds. By the time water in the Fraser reaches its estuary, it has a load of sewage, industrial wastes, agricultural chemicals and suspended solids that is added to its natural load of glacial silt.

At the Fraser River estuary, there is further addition of sewage, industrial wastes and other materials from the urban communities and industries of the Greater Vancouver area. The major sources of sewage effluent are the lona Island Sewage Treatment Plant, the Annacis Island Sewage Treatment Plant, and the Lulu Island Sewage Treatment Plant. The latter two plants discharge their effluents into the Main Arm of the Fraser River, whereas the lona Island plant discharges into the Strait of Georgia via a channel across Sturgeon Bank. It is the effluent from this plant that has caused certain ecological problems with an impact on fish on Sturgeon Bank. Installed in 1963, this plant and effluent disposal system were designed to protect the water quality on Spanish Bank for bathing and other recreational purposes. A jetty was installed to the north of the ditch conveying sewage across Sturgeon Bank to prevent if from being carried by the currents directly onto Spanish Bank. This was generally considered successful.

Little consideration, however, was given to the effects of the lona Island Sewage Treatment Plant effluent on fisheries. There were no oyster leases in the area, so that high coliform counts were not a concern with respect to shellfish contamination. On the best advice of consultants prior to installation of the plant, there would be no problem for fish. The effluent was not considered to be particularly toxic, and it was not expected that low dissolved oxygen would be a problem, considering the amount of dilution that would be available. After 20 years of operation of the plant, this turned out not to be the case. The sewage effluent spills out of the ditch at high tide and contaminates Sturgeon Bank. Early studies showed that there was contamination of animals on the tideflats by metals, generally attributed to the lona Island Sewage Treatment Plant effluent (Parsons et al. 1973). There were also higher-than-background concentrations of metals in the sediments of Sturgeon Bank (Grieve and Fletcher 1976). Macroinvertebrate communities on Sturgeon Bank were being modified by the sewage effluent contamination (Otte and Levings 1975). During the summer investigations of 1979-83, it was found that low dissolved oxygen concentrations in water overlying Sturgeon Bank, during periods of warm weather and small tidal range, were associated with severely debilitated fish, mainly starry flounder, *Platichthys stellatus* (Birtwell et *al.* 1983). This led in part to hearings of the B.C. Pollution Control Board in early 1981 (Birtwell et *al.* 1981), which ultimately recommended ameliorative action with a submarine outfall at about 50 m depth off Sturgeon Bank.

More recent studies on the Fraser River estuary were associated with the enlargement of the Roberts Bank Coal Port. This project was assigned for study by an Environmental Assessment Panel under the Federal Environmental Assessment and Review Process, which subsequently issued a report (FEAR0 1979).

The project, as proposed by the National Harbours Board, was rejected by the Panel, but a scaled-down version of the project was considered acceptable. There was rapid follow-through by the National Harbours Board on the recommendations of the Panel, until the expanded Port went into operation in July 1984 (Waldichuk *in press).*

It is of interest to note that the Panel examined all aspects of the Roberts Bank Port expansion, including the construction phase and the utilization phase. The possible impact of spillage of product being shipped (mainly coal), as well as accidental spills of oil from freighters, were taken into account. The Panel did have the advantage of being able to examine the impact of the existing coal port, in determining what the impact of an expansion would be. This was when rather conclusive evidence was presented by consultants that there was a positive ecological impact from the existing causeways and terminals on Roberts Bank. The intercauseway area between the Tsawwassen Ferry Terminal causeway and the Roberts Bank Port causeway became a favourable habitat for eelgrass. This supplies food and shelter for juvenile salmon and crabs as well as food for aquatic birds. The decision of the Panel was to a large extent based on preservation of eelgrass habitat. Mitigation by the proponent for lost eelgrass habitat in the expansion program was based, to some extent, on creating new eelgrass habitat and enhancement of some of the existing habitat. Figure 5 illustrates the type of habitat present on Roberts Bank in the coal port and the ferry terminal area, as well as the extent of the originally proposed expansion of the coal port and the final installation.

The general characteristics of the Fraser River estuary have been described by Hoos and Packman (1974). The biomass distribution of Sturgeon Bank is shown in Figures 6 and 7. It is noteworthy that the most impoverished area for macrobenthos is in the apex between the North Arm Jetty and the lona Jetty. This is in contrast with the situation between the two jetties on Roberts Bank. The reason for this depauperate state is unknown. The area may always have been comparatively barren, but some investigators suspect that the two jetties here may have had a negative impact on productivity.

A simplified food web for the Fraser River estuary is shown in Figure 4. The practical interest, of course, is in those food chains terminating with juvenile salmon. One of the important food chains in this regard is shown in Figure 8. It is obvious that any type of disruption in the estuary that breaks a link in the food chain leading to salmon can be regarded as a serious impingement on the Fraser estuarine ecosystem, and particularly, on the commercially valuable living resources.

Squamish River Estuary

The Squamish River estuary entered the limelight ecologically in 197 l-72, when it was proposed by the British Columbia Railway to install a coal port in Squamish. The plan was to fill in a substantial part of the estuary for wharves and backup facilities for deep-sea shipping of coal. Figure 10 shows some

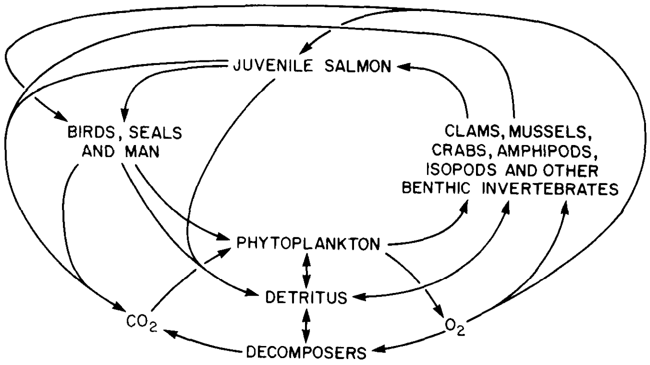

Figure 4. An idealized and simplified food web in the Fraser River estuary (From Hoos and Packman 1974).

of the area of the Squamish River estuary proposed for modification. A Federal-Provincial Task Force on the Squamish Estuary Harbour Development was set up, and it was backed up by scientific and technical support for field investigations. After essentially one field season a report was prepared (Environment Canada 1972). Although it would have been desirable to conduct a longer study in the Squamish River estuary, the brief six-month investigation conducted during the spring and summer of 1972 made it clear that construction of a coal port in the Squamish River estuary could be disastrous for salmonids utilizing the Squamish River system. It was recommended by the Task Force to the Federal Minister of Environment that the coal port project not proceed.

The status of environmental knowledge concerning the Squamish River estuary was summarized by Hoos and Vold (1975). The Squamish River system supports substantial numbers (1 O,OOO+ annual escapement) of chinook *Oncorhynchus tshawytscha,* coho 0. *kisutch*, pink 0. *gorbuscha* and chum 0. *keta* salmon, as well as steelhead *Salmo gairdneri* (ca. 10,000 escapement). These fish are partly taken by the commercial fishery, but their greatest contribution is to the extensive sport fishery in Howe Sound.

The food web in the Squamish River estuary can be quite complex (Figure 9). The important findings in the 1972 study were that a major food chain leading to juvenile salmonids stems from the sedge grass growing in the above-high-tide level of the delta and passes through the benthic amphipods *Anisogammarus confervicolus* (Figure 8). About an equal amount of primary plant material as food for the amphipods also originates from the benthic algae (Pomeroy and Stockner 1973). The presence of amphipods (Levings 1973) coincides to some extent with the number of juvenile salmonids present in the estuary (Goodman and Vroom 1972)(see Figure 11). Amphipods are an important component of the food of juvenile salmonids. The sedge not only provides food through detritus to the amphipods, but the roots and rhizomes of this plant hang into the intertidal channels on the delta, and provide good habitat with shelter for the amphipods. Clearly, dredging and filling on the delta would seriously disrupt the sedge-amphipod relationship, and ultimately have a potentially serious impact on salmonids.

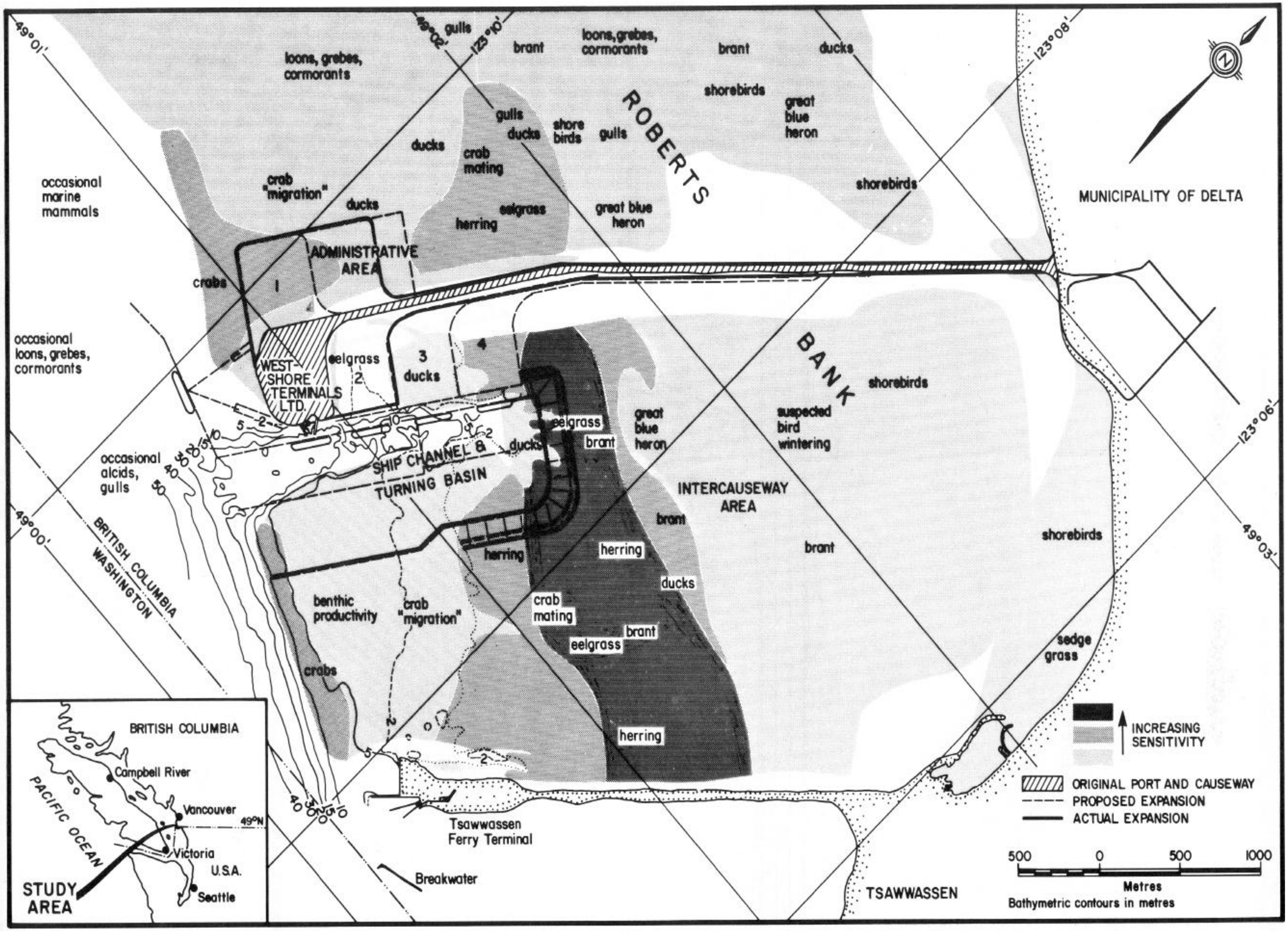

Figure 5. Chart of the waters adjacent to the Roberts Bank Port, showing the configuration of the original terminal and causeway, the proposed enlargement, and the actual expansion completed in 1984. The distribution of estuarine flora and fauna, and the different degrees of ecological sensitivity, identified by the consultants in the Environmental Impact Statement, are also shown.

ECOLOGY IS NOT YET A MATURE SCIENCE

This is not specific to cumulative effects, of course, but it is a real and serious problem. Dayton gives the image of the scientific community "snarling from its ivory tower" that it is dangerous to simplify nature. The argument is usually expanded to say that ecology is too complex to understand, so precise and accurate predictions are not possible. It is almost always accompanied by a plea for support for more research. If we go on making this argument people may actually start to believe it, and then we will really be in trouble. Dayton is right that we already know quite a lot. Natural history and experience are often adequate for making good decisions — I agree, for example, that Dayton would do well with a photograph and a species list if the community were one he had studied. All ecosystems are different, but all share certain processes, and experience is of great value. Experience is especially valuable where the change in an ecosystem is cumulative by-small increments, because such changes are hard to detect. -Experience alerts the investigator to things that might otherwise be missed. Ecologists cannot afford to excuse themselves from giving ecological advice, because the alternative is worse, and-because they often have good advice to give if they would just be willing to share in the responsibility for some risk.

VARIANCES, MEANS, AND EL NINO

The point has been made by several participants (including Dayton) that we must be able to distinguish human-induced change from natural variability. The variability of natural populations and environments is emphasized by Dayton; I would emphasize again here the importance of studying variances as well as means, and of considering large, natural perturbations that may be rare, but which are known to be recurrent (e.g., El Niño, climatic change, blizzards, floods, droughts, earthquakes, etc.). This is particularly important when trying to assess cumulative effects, because the effects of natural variability are less likely to be cumulative than are human-induced ones.

MULTIDISCIPLINARY STUDIES

This whole workshop reeks of multidisciplinarianism. Most of the participants have multidisciplinary experiences, most of the suggested solutions are multidisciplinary, and the workshop itself comprises as diverse a group as I have seen discussing a single topic. It is clear that multidisciplinary approaches will be needed in this area. Yet the structure of our science in North America makes it very difficult to be multidisciplinary. There are few programs with multidisciplinary focus (with some notable exceptions that have representatives here), and if you do succeed in getting a multidisciplinary education it is hard to get a job or a grant. I think this is a real problem and one that needs serious attention. The familiar refrain "More multidisciplinary studies are needed!" is not enough. The only specific recommendation I have at present is that government funding agencies or those that influence what programs are funded (National Science Foundation, Department of Energy, Environmental Protection Agency, etc., in the United States; National Research Council, Environment Canada, CEARC, and others in Canada) should establish funds that are to be used exclusively for multidisciplinary approaches to the types of problems being considered here. The existence of such funds would, I expect, drive the appropriate educational responses from universities, and would lead to the hiring of appropriate people. I add as an afterthought, suggested by discussion, that of course multidisciplinary approaches are not a substitute for good research.

GENERAL MUSINGS

There is a dichotomy between those who feel that ecologists need to provide the goals for managers and policy makers, and those who feel that ecologists should only provide engineering-type advice. In practice, ecologists do provide goals, for the things specified in some of our laws ("balanced, indigenous population," "health of the ecosystem," etc.) come from ecologists. My own view is that ecologists should try to stick to the engineering-type advice, but that they won't be able to remain pure in that way. The distinction is important, I think, and people need to be conscious of it, whatever their viewpoint. Once again a cumulative approach highlights the issue, because the management of cumulative effects so often requires agreement on some standard of environmental quality.

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Management Perspective

MANAGEMENT OF THE ESTUARINE ECOSYSTEM AGAINST CUMULATIVE EFFECTS OF POLLUTION AND DEVELOPMENT

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An estuary has been defined in many ways, e.g., "a semi-enclosed body of water which has a free access to the open ocean and within which sea water is measurably diluted with fresh water derived from land drainage" (Pritchard 1967). Basically, an estuary is where the river meets the sea. It is a complex system physically, chemically and biologically. There is interaction among many natural effects within an estuary. A sort of dynamic equilibrium exists here, where the combined action of runoff, tides, waves, currents, winds and atmospheric heating and cooling maintain a steadily changing condition diurnally and seasonally, but not necessarily altering the situation greatly from year to year.

Organisms living in an estuary are subjected to many natural stresses associated with the constantly changing conditions. Only certain organisms can adapt to this harsh environment. Food webs tend to be simplified, for this reason, with certain food chains being favoured for the transfer of energy through the different trophic levels from the primary producers to the top predators. Although estuaries are regarded normally as highly productive ecosystems, the productivity stems from comparatively few organisms. Diversity tends to be low, but the well adapted species can be present in large numbers. Anadromous species, such as salmon and sea-run trout, find estuaries highly desirable rearing areas because of the ready availability of food, particularly for the juveniles. Bird concentrations may also occur in estuaries for the same reason.

Many biogeochemical processes occur in an estuary. Freshwater mixes with sea water, and any silt present in the former will largely be flocculated and deposited in the estuary to build up the delta. Other substances, natural and man-made, which may be present in the water, will be scavenged from the water column as the flocs of silt settle into the sediments. Hence, estuaries tend to be sinks for river-borne substances entering the sea. They have been regarded as the greatest filters that exist in nature, to prevent particulate and dissolved materials present in river water from reaching the deep sea.

Industries and urban communities often favour estuarine regions as areas in which to become established, for a variety of reasons. The availability of flat land on a river delta, a good supply of freshwater and other raw materials for industry, and cheap marine transport are just some of the estuarine attributes favourable for industrial and urban development. Such developments, of course, may mean certain physical alterations in the estuary, as well as discharges of industrial wastes and domestic sewage, with possibly various degrees of treatment. In relatively undeveloped areas, concern has often been about single-source pollution stemming from a particular industry. In heavily developed areas, especially adjacent to urban centres, multiple-source pollution, both from local and upstream sources, is an issue. This may be compounded by physical alterations, with such structures as jetties, wharves and breakwaters changing circulation and sedimentation patterns in an estuary. Not all these changes have a negative impact on the estuarine ecosystem, but many of them do. It is important, from a management point of view, to be able to differentiate those changes that may have the most acute negative impact on the estuarine ecosystem.

The purpose of this paper is to examine the cumulative effects of pollution and development in estuaries, using two examples from the Canadian Pacific Coast as case studies. Stress will be placed on the impact on the fisheries resource.

SOME GENERAL CONSIDERATIONS

The interaction of the many factors operating in an estuary, must be considered in making any type of environmental impact assessment.

Critical Effects on an Estuarine Ecosystem

In an holistic approach to protection of an estuarine ecosystem, all ecological aspects must be considered. From a practical point of view, however, the approach usually taken is to protect significant food chains that lead to commercially important species. The food web in an estuary is greatly simplified by natural elimination of many species due to stress, and there may be only one significant food chain leading to juvenile salmonids or herring. When a vital link in a food chain is broken, a major impact on an important fisheries resource may occur, e.g., elimination of amphipods, which are fed on by juvenile salmonids, in the Squamish River estuary.

How do we manage an estuarine ecosystem for cumulative effects? We must select a critical environmental variable, e.g., dissolved oxygen, or a critical biological effect, e.g., toxicity. If certain pollutant inputs or developments already exist, and it is proposed to introduce a new pollutant and/or development, then it is essential to evaluate the impacts of the existing inputs and physical changes due to developments. Essentially a mass balance has to be made, whether one deals with uptake of dissolved oxygen by biodegradable organic materials, or introduction of metals from wastes. If conditions are already such that water quality is near a limiting level of toxicity, dissolved oxygen or temperature, then clearly the input of another pollutant that might further tax those water quality properties has to be severely limited. If one has to deal with a multiple-source input, where the different sources introduce different environmental or ecosystem effects, then the problem of management becomes much more complex. Certain mixtures of pollutants have synergistic effects, where the combined toxicity is greater than the sum of toxicities of individual constituents. Other mixtures may have antagonistic effects, wherein individual constituents may neutralize each other for toxicity. Both synergistic and antagonistic effects can be established in laboratory bioassays using suitable test organisms. It is difficult, however, to simulate in a laboratory all the conditions present in an estuary. Ideally, therefore, the final evaluation of the impact of a mixture of substances must be conducted in the field.

Environmental Considerations

The impact of pollutants or developments in an estuary depends a great deal on such factors as river discharge, tidal range, exposure to the open sea, prevailing winds, and swell and wave action (Waldichuk 1968). These physical characteristics of an estuary will determine how rapidly pollutants will be diluted, dispersed and transported away. Geochemical processes in an estuary are important in abstracting pollutants from the water and depositing them in the sediments. Such suspended solids in river water as glacial silt, will undergo flocculation as the freshwater mixes with sea water, and the flocculent aggregates of silt will settle by gravity at the estuarine delta, if the turbulence is not too great. The settling flocs have great sorption capacity and can remove suspended and dissolved substances of anthropogenic origin and deposit them in the sediments. These substances are not likely to become mobilized again as pollutants, unless they are disturbed by an activity such as dredging.

Certain developments, combined with the environmental characteristics in an estuary, can have beneficial effects on the estuarine ecosystem. A good example of this is the development of eelgrass habitat between the two causeways, for the Tsawwassen Ferry Terminal and the Roberts Bank Coal Port, on Roberts Bank of the Fraser River estuary (Waldichuk in press). As described in a later section, this eelgrass habitat is favourable for feeding of juvenile salmonids and aquatic birds. Thus, such an effect of development must be regarded as positive in the cumulative impact balance sheet.

The resilience of an estuary to certain perturbations is extremely important, and it is usually determined by the environmental characteristics which contribute to the magnitude of such parameters as flushing rate. The residence time of pollutants will be controlled by the flushing rate of the estuary. The recolonization of an estuary after dredging or filling will be a function of water exchange between the estuary and other nearby bodies of water from which larvae will be imported. A long recovery period of an estuary from a single major perturbation, such as massive dredging or an oil spill, can have a lasting impact on the system as a nursery area for juvenile salmonids. From a management point of view, the impact of development or pollutant input on vital food organisms of juvenile salmonids, e.g., amphipods, must be small.

Seasonal Effects

Seasonal changes must be taken into account from a physical and chemical point of view, as well as biologically. River flows change with the seasons as precipitation patterns vary from summer to winter, and from a simple dilution perspective, the impact of pollution can be expected to be less during heavy runoff. Temperatures also change seasonally in temperate zones, and this can account for a greater ecological impact of certain pollutants in summer, when temperatures are high, than during the cold period of winter when the metabolic processes are greatly slowed down. Biologically, there is a spawning season, a rearing season, a growing season and a dying-down season (for plant growth) in an estuary. Pollutants affect estuarine organisms differently in their various life stages.

An estuarine ecosystem generally has a higher capacity to withstand perturbation in winter than in summer. This is illustrated in Figure 1, which shows schematically how the capacities of an unperturbed system and a heavily perturbed system vary seasonally. The latter exhibits the cumulative impact of pollution. Often the season that sets the upper limit on the amount of pollutant that can be introduced into an estuarine system, without serious ecological damage, is the summer. This is the period when the Somass River has the

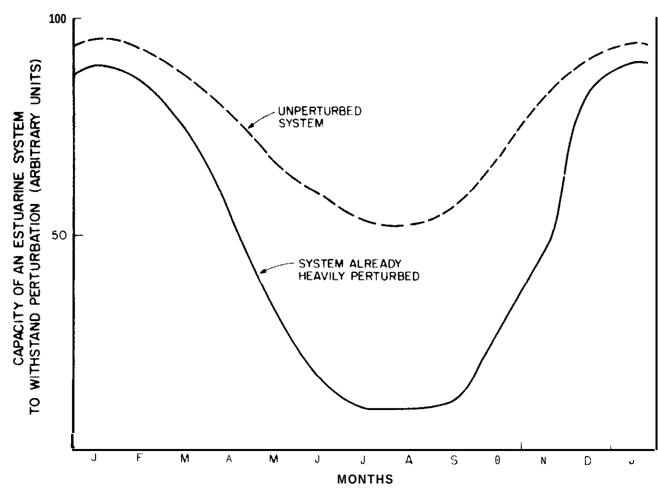

Figure 1. A hypothetical graph of seasonal variation in thecapacity of an estuarine system to withstand perturbation, showing the expected difference between a system already heavily perturbed and an unperturbed system.

lowest flow, and water temperatures can be expected to be highest. This has been the approach used in setting the upper limit for effluent disposal from the pulpmill in Port Alberni (Waldichuk 1983b). The permissible concentration of such effluent in this system must be based on the toxicity of the effluent to juvenile salmonids which migrate downstream mainly in spring and early summer.

The seasonal variation benthic macroinfaunal standing stock, benthic production and nutrient regeneration, phytoplankton primary production, and riverine nutrient input for the Corpus Christi Bay estuary, Texas, are shown from Flint (1984) in Figure 2. The periods of peak brown shrimp abundance and benthic larval colonization are also shown to illustrate the process of developing an integrated picture of how an estuarine ecosystem functions.

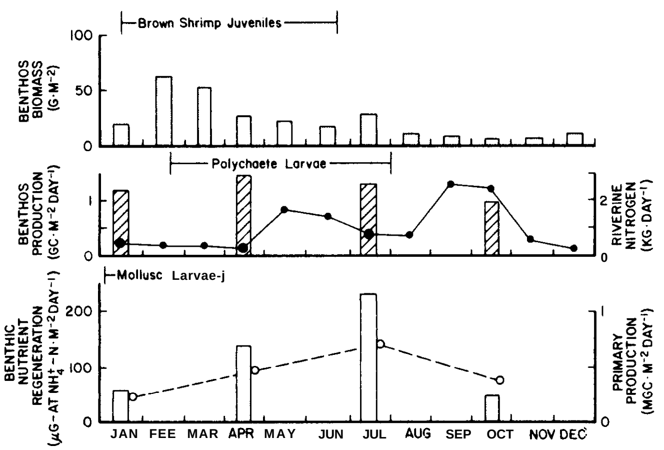

Figure 2. The seasonal variation in the Corpus Christi Bay estuary of benthic macroinfaunal standing stock, benthic production and nutrient regeneration, phytoplankton primary production, and riverine nutrient input. Periods of peak brown shrimp abundance and colonization by polychaete and mollusc larvae are also shown (From Flint 1984).

The Biota

Assuming that the estuary is managed for its living resources, we must consider the uses made by the various organisms that may be permanent residents there or merely transients. Again, from a pragmatic point of view, it is essential to examine the commercially important species that utilize the estuary. Do they use it for spawning, rearing and feeding as juveniles, full-time residence, or merely for passing through in downstream or upstream migration? The indigenous species may spawn, rear and live their full life cycle in the estuary. It may be essential to protect them in all their life stages because of their intrinsic value as part of the estuarine ecosystem. They may in themselves have commercial value, or they may serve as food for commercially important species.

Then there are the transients, such as Pacific herring that come into the estuary to spawn, or the Pacific salmon that migrate through the estuary as juveniles moving out to sea, and as adults returning to the stream to spawn. For herring spawning, the water quality must be satisfactory and a suitable uncontaminated substrate for deposition of eggs must be available. Juvenile herring and salmon also use the estuary for rearing in different degrees, according to species. They are highly vulnerable to water pollution at this time, which could not only destroy or debilitate the juvenile fish themselves, but could also adversely affect their food organisms. Adult salmon returning to the river to spawn do not normally feed in the estuary, but their passage through the estuary must not be impeded by any physical or chemical obstructions.

The cumulative effects of pollutants and any foreshore developments that can have an impact on migration and schooling behaviour of the various species in an estuary must be fully taken into account when managing an estuarine ecosystem for its living resources.

Legislative Controls

In British Columbia, pollution and other adverse environmental impacts from industrial wastes and domestic sewage on living resources can be controlled to some degree under provincial and federal legislation. The Waste Management Branch of the British Columbia Ministry of Environment issues permits for industries and municipalities, with guidelines for limits on constituent concentrations and other characteristics. The type of permit issued and guidelines on effluent quality may be determined by public hearings conducted by the B.C. Pollution Control Board.

The federal government has legislation for protecting the commercial fisheries within its jurisdiction. Under the Fisheries Act, both the water quality and habitats for fish and invertebrate species are protected. However, it is up to the Department of Fisheries and Oceans to prove in court that a certain waste disposal or nearshore development is deleterious to commercially important species or their habitats. Regulations have been developed under the Fisheries Act for different types of industrial wastes, such as the Metal Mining Liquid Effluent Regulations. Regulations such as these may be waived for a specific operation, through promulgation by order-in-council of new regulations for that particular operation, such as the Alice Arm Tailings Deposit Regulations.

The federal Ocean Dumping Control Act controls dumping of materials at sea in areas under federal jurisdiction. At the present time, the Supreme Court of Canada has ruled that the waters and the sea-bed between Vancouver Island and the mainland of British Columbia (Strait of Georgia, Discovery Passage and Johnstone Strait) are under provincial jurisdiction. Until an appeal is heard on a court judgment with respect to dumping wastes by the forest industry in Beaver Cove, on the northeast coast of Vancouver Island, ocean dumping applications for these internal waters are being processed under the Fisheries Act, and the permit fee is being waived.

Under the Ocean Dumping Control Act, there are regulations which prohibit the dumping of certain substances (e.g., mercury and cadmium and their compounds, organohalogen compounds, petroleum hydrocarbons) except in "trace

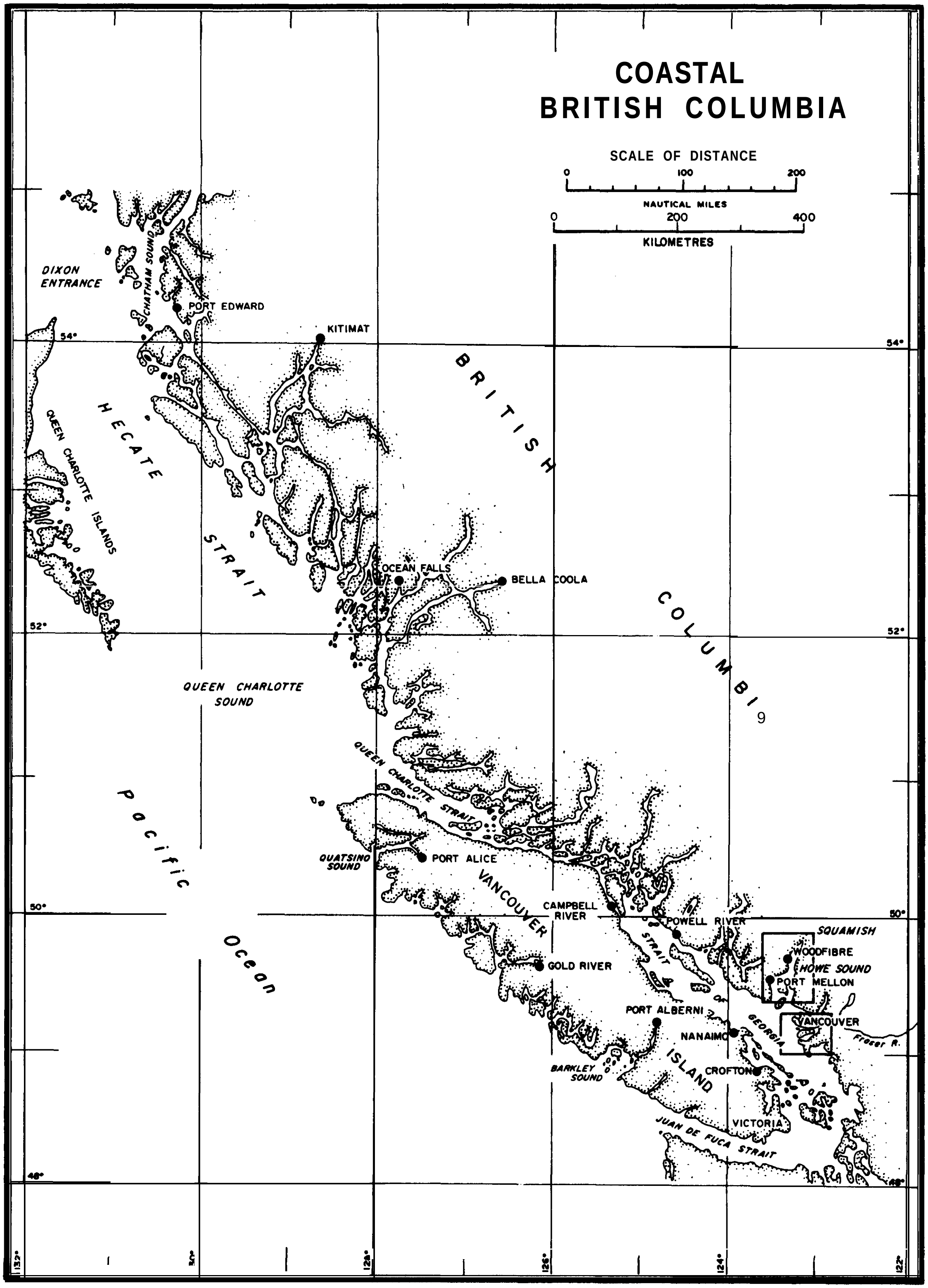

Figure 3. Chart of the coast of British Columbia, showing the locations of some of the important estuaries, and the Fraser River estuary and Squamish River estuary study areas.

concentrations," which are defined. These trace concentration limits have presented problems in administering the Ocean Dumping Control Act, because they were set somewhat unrealistically when the Act was promulgated in 1975.

The Federal Environmental Assessment and Review Process approach to evaluating environmental impacts of federally supported projects allows for public input, and takes into account all available environmental and ecological information made available by the proponent, consultants and others who may have done studies in the area. A substantial number of projects have now undergone the Process, and there have been various degrees of success in controlling undesirable ecological impacts of federally supported projects by this approach. The lack of ecological consideration in the Process prompted the study by Beanlands and Duinker (1983).

In all legislative control of pollution and effects of development in British Columbia, federal and provincial, there has not been a conscious approach to the cumulative aspects. Rather, a piecemeal approach has been taken to control effluent, disposal and development. It must be admitted, however, that existing environmental conditions are examined, and these generally reflect the cumulative effects of previous waste disposal and development.

CASE STUDIES

There are many estuaries in British Columbia that could be used as case studies for this exercise. It was decided to focus on two of the most important estuaries in the province, however, both from the point of view of urbanization and industrial development, and the availability of living resources. These are the Fraser River estuary, with a major salmon fishery resource and near the major population concentration of the province, and the Squamish River estuary, which supports a substantial salmon fishery and considerable industrial development. Both estuaries, being near major academic institutions and government research establishments, have been extensively studied. The locations of these two estuaries are shown in Figure 3.

Fraser River Estuary

The Fraser River is extremely important from the point of view of the salmon runs it supports, which are worth hundreds of millions of dollars to Canadian and US. fishermen, All five species of Pacific salmon, genus *Oncorhynchus*, are found in this system, but the sockeye, 0. *nerka*, and pinks, 0. *gorbuscha*, are particularly important for commercial fishermen.

The Fraser River has a glacial origin in the Rockies, and therefore, is heavily loaded with glacial flour that gives it a natural turbid appearance. Much of the river silt flocculates in the estuary and settles out on the extensive delta.

The Fraser River has a comparatively fast and turbulent flow so that the river water constantly undergoes aeration. The water in the mainstem is always well oxygenated, but oxygen depression may occur in the "salt wedge" of the somewhat stagnant sloughs of the estuary.

The Fraser River receives assorted wastes and contaminated runoff along its whole course. These include domestic sewage from various urban communities and pulpmills located on the river, as well as agricultural and urban runoff. Logging and road-building activities introduce suspended solids that can have a serious impact on salmon habitats, especially spawning grounds. By the time water in the Fraser reaches its estuary, it has a load of sewage, industrial wastes, agricultural chemicals and suspended solids that is added to its natural load of glacial silt.

At the Fraser River estuary, there is further addition of sewage, industrial wastes and other materials from the urban communities and industries of the Greater Vancouver area. The major sources of sewage effluent are the lona Island Sewage Treatment Plant, the Annacis Island Sewage Treatment Plant, and the Lulu Island Sewage Treatment Plant. The latter two plants discharge their effluents into the Main Arm of the Fraser River, whereas the lona Island plant discharges into the Strait of Georgia via a channel across Sturgeon Bank. It is the effluent from this plant that has caused certain ecological problems with an impact on fish on Sturgeon Bank. Installed in 1963, this plant and effluent disposal system were designed to protect the water quality on Spanish Bank for bathing and other recreational purposes. A jetty was installed to the north of the ditch conveying sewage across Sturgeon Bank to prevent if from being carried by the currents directly onto Spanish Bank. This was generally considered successful.

Little consideration, however, was given to the effects of the lona Island Sewage Treatment Plant effluent on fisheries. There were no oyster leases in the area, so that high coliform counts were not a concern with respect to shellfish contamination. On the best advice of consultants prior to installation of the plant, there would be no problem for fish. The effluent was not considered to be particularly toxic, and it was not expected that low dissolved oxygen would be a problem, considering the amount of dilution that would be available. After 20 years of operation of the plant, this turned out not to be the case. The sewage effluent spills out of the ditch at high tide and contaminates Sturgeon Bank. Early studies showed that there was contamination of animals on the tideflats by metals, generally attributed to the lona Island Sewage Treatment Plant effluent (Parsons et al. 1973). There were also higher-than-background concentrations of metals in the sediments of Sturgeon Bank (Grieve and Fletcher 1976). Macroinvertebrate communities on Sturgeon Bank were being modified by the sewage effluent contamination (Otte and Levings 1975). During the summer investigations of 1979-83, it was found that low dissolved oxygen concentrations in water overlying Sturgeon Bank, during periods of warm weather and small tidal range, were associated with severely debilitated fish, mainly starry flounder, *Platichthys stellatus* (Birtwell et *al.* 1983). This led in part to hearings of the B.C. Pollution Control Board in early 1981 (Birtwell et *al.* 1981), which ultimately recommended ameliorative action with a submarine outfall at about 50 m depth off Sturgeon Bank.

More recent studies on the Fraser River estuary were associated with the enlargement of the Roberts Bank Coal Port. This project was assigned for study by an Environmental Assessment Panel under the Federal Environmental Assess-

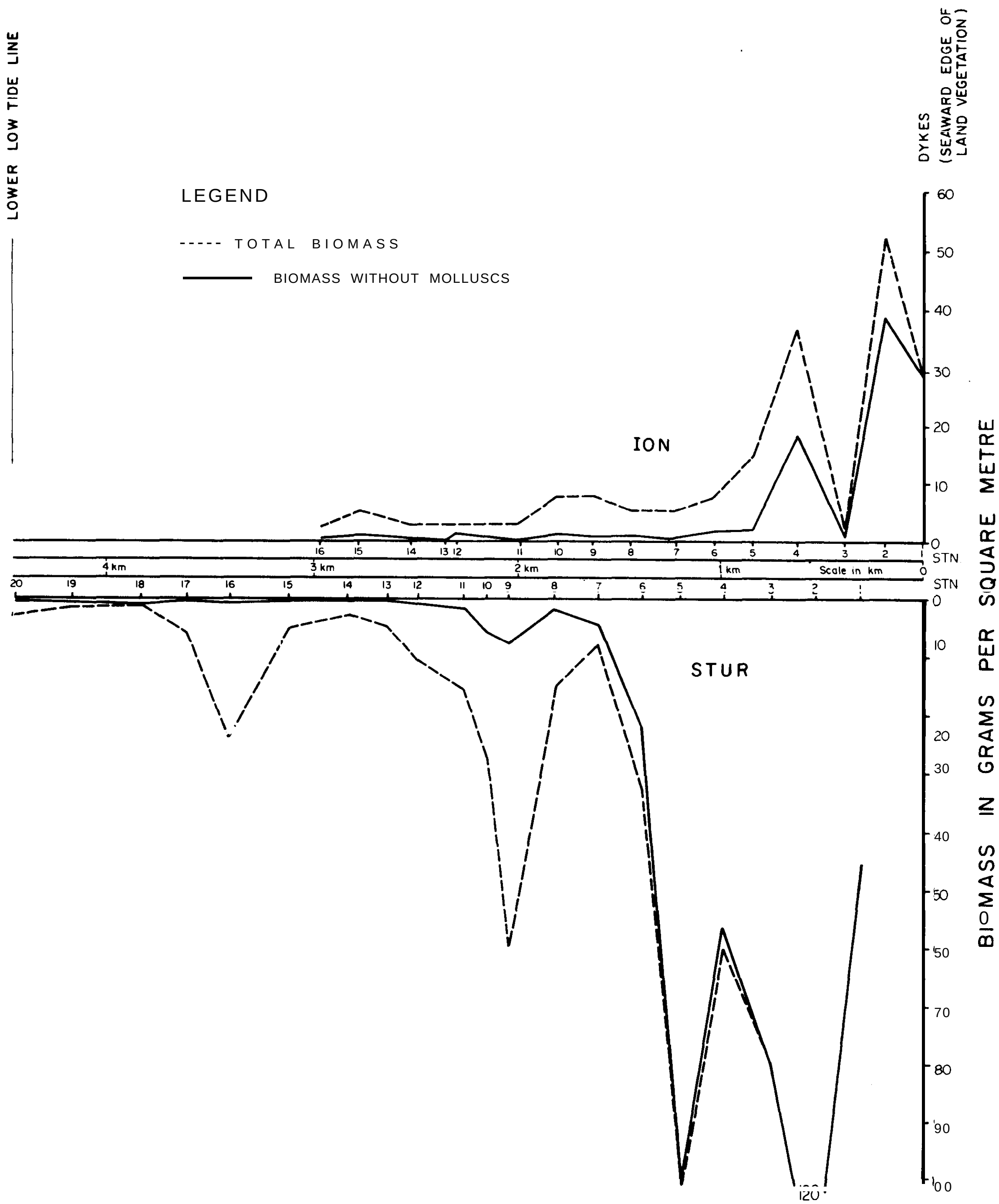

Figure 6. Variation of macroinvertebrate biomass on Sturgeon Bank with distance from the dyke (From Levings 1975).

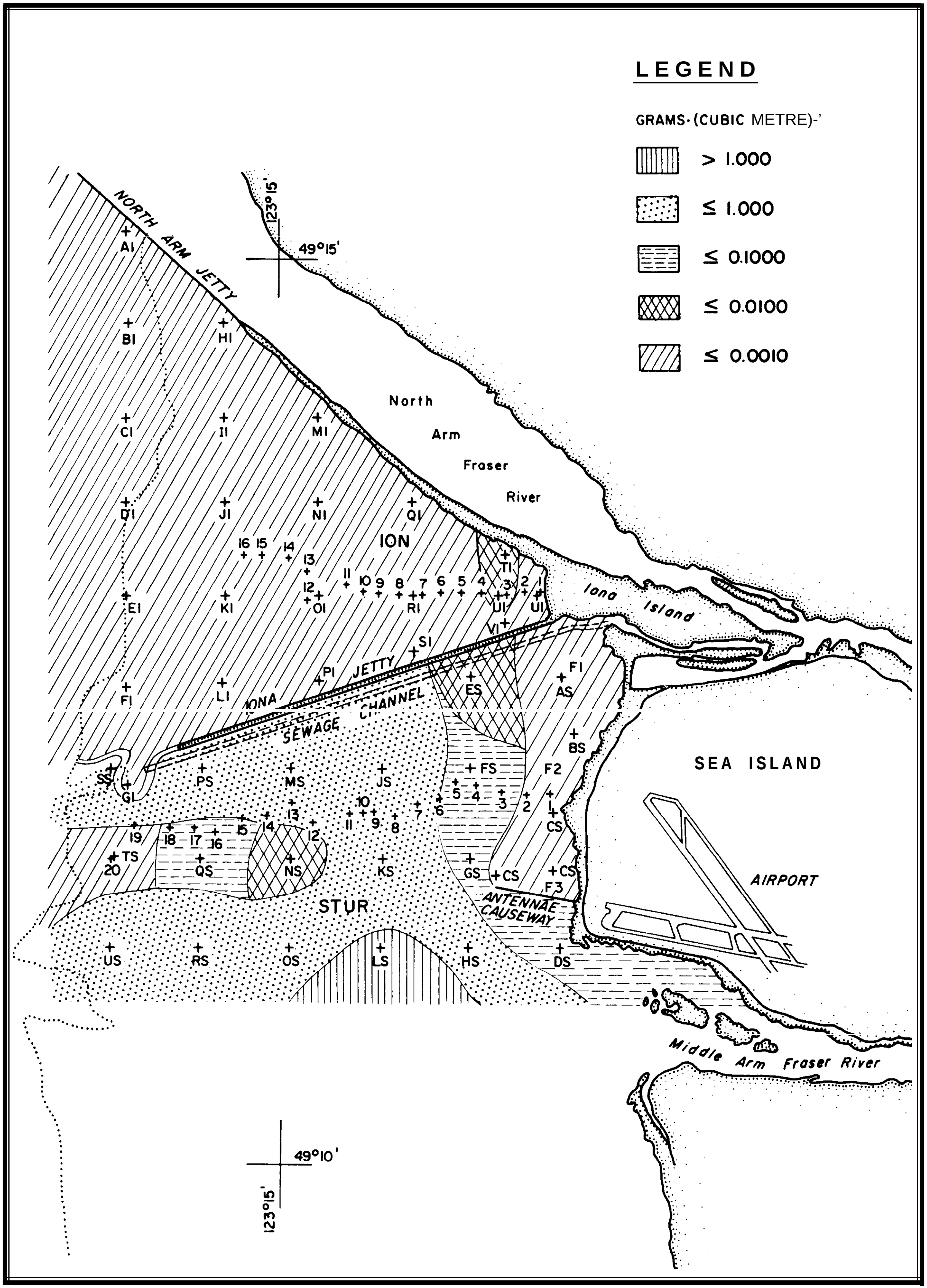

Figure 7. Macroinvertebrate biomass on Sturgeon Bank (From Levings 1975).

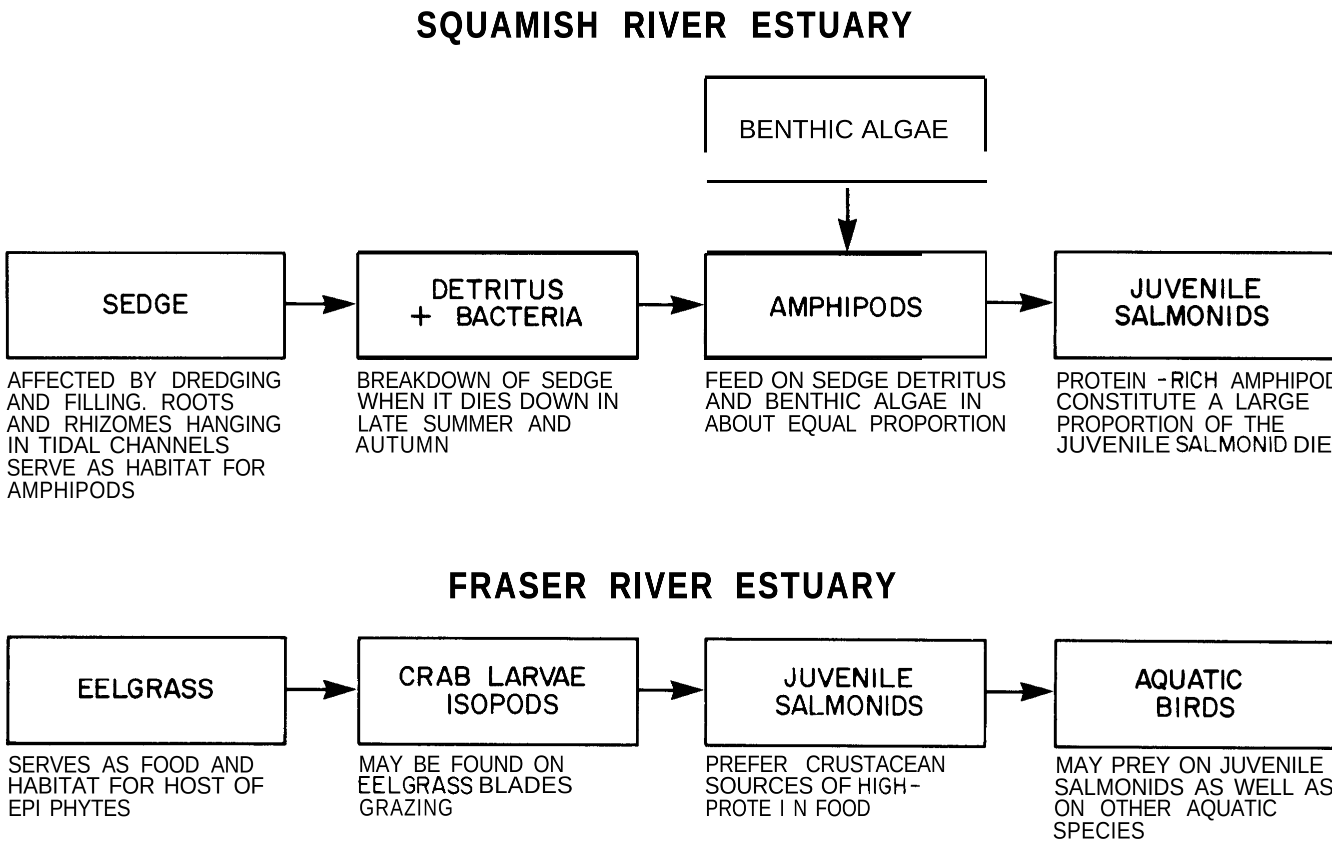

Figure 8. Food chains leading to juvenile salmonids in the Squamish and Fraser river estuaries.

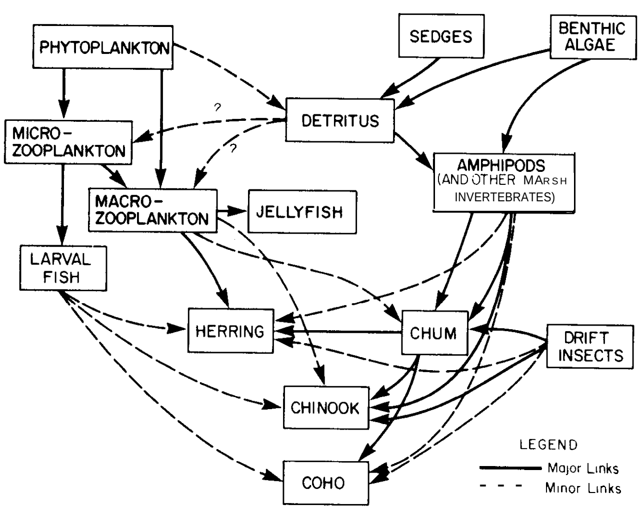

Figure 9. One version of the food web in the Squamish River estuary (From Environment Canada 1972).

The study on the Squamish River estuary was confined mainly to the impact of coal port development. No doubt there is already a certain impact of existing industries, such as sawmills, FMC Canada Ltd. (a chlor-alkali plant with a mercury cell) and a kraft pulpmill at Woodfibre, southwest of Squamish. An environmental impact assessment should take into account the cumulative effect of these industries.

DISCUSSION

Studies of environmental impact conducted so far in British Columbia have generally ignored the cumulative effect of other pollutant inputs or shoreline developments in estuaries. In some instances, where existing environmental conditions had to be examined in making an environmental impact assessment of a proposed waste discharge or coastal development, there was in fact a tacit accounting of environmental impact of existing discharges or developments. This was done, of course, in the study of the environmental impact of the expansion of the Roberts Bank Port.

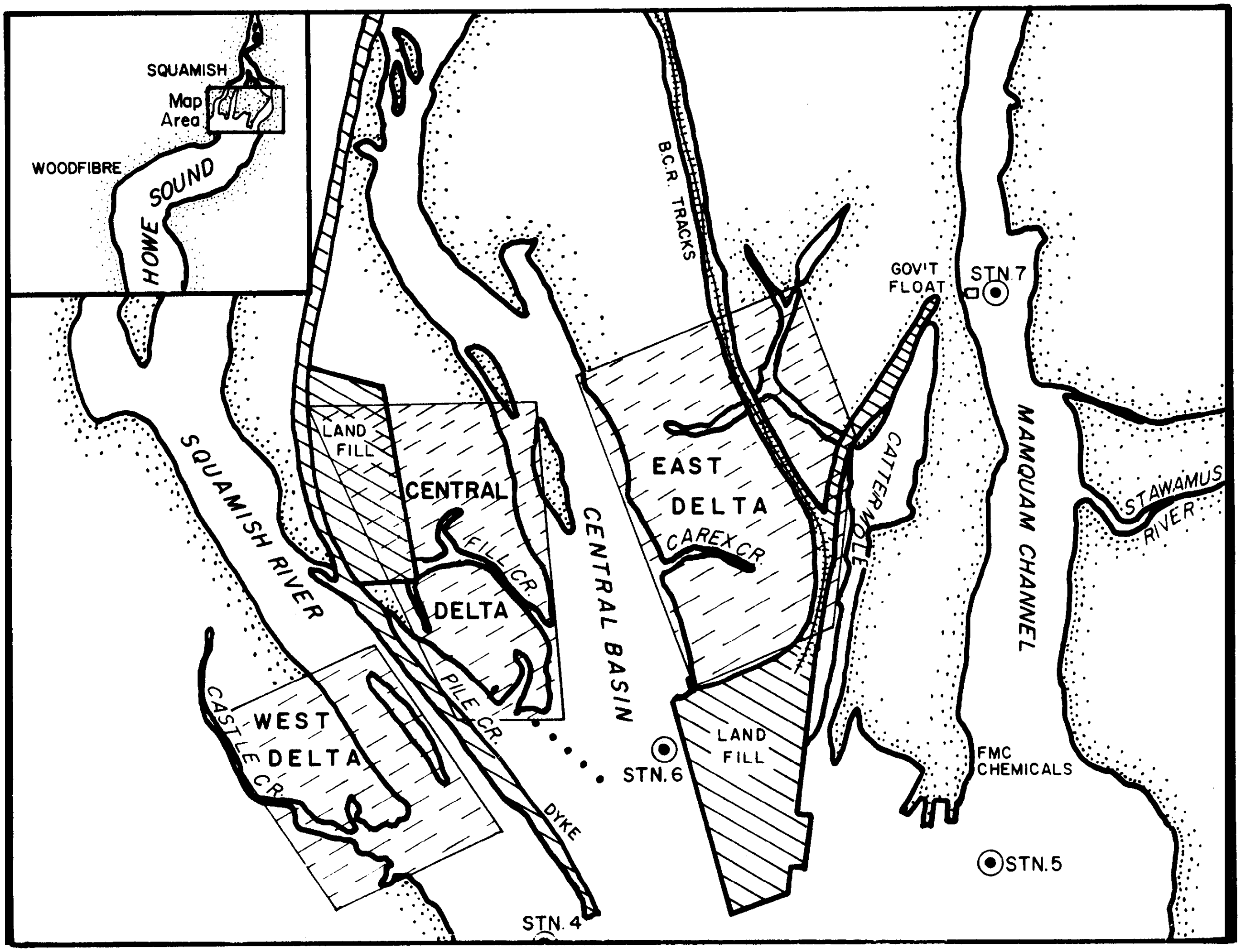

Figure 10. Chart of the Squamish River estuary, showing portions of the delta that were proposed in 1972 for modification as a coal port. as a coal port.

By and large, in a comparatively undeveloped province like British Columbia, the sole-source impact approach to environmental problems has not erred too far. In many areas where a pulpmill or a mine is installed on the coast, that particular industry is virtually the only source of disruption. It is when one approaches problems in heavily populated areas with industry, such as the Fraser River estuary, that one must look at cumulative effects. Even there however, not all developments necessarily create negative impacts, as witnessed by the enhancement of eelgrass habitat in the intercauseway area on Roberts Bank. The other point that should be noted is that not everything that comes down the Fraser River will necessarily be available to do damage in the Fraser River estuary. Some of the material may be degraded enroute in the river. Much of it may be sedimented out in the Fraser River estuary through flocculation and settling of the river silt.

In more densely populated and industralized parts of the world, the cumulative impact of multiple sources of pollution and of multiple developments definitely have to be taken into account. This is appropriate in some parts of Canada, e.g., Southern Ontario and Quebec. Bella and colleagues (Bella 1978; Bella and Overton 1972; Bella and Klingeman 1973) in Oregon have examined in a somewhat philosophical way some of the options available in impact assessment, and have postulated the consequences.

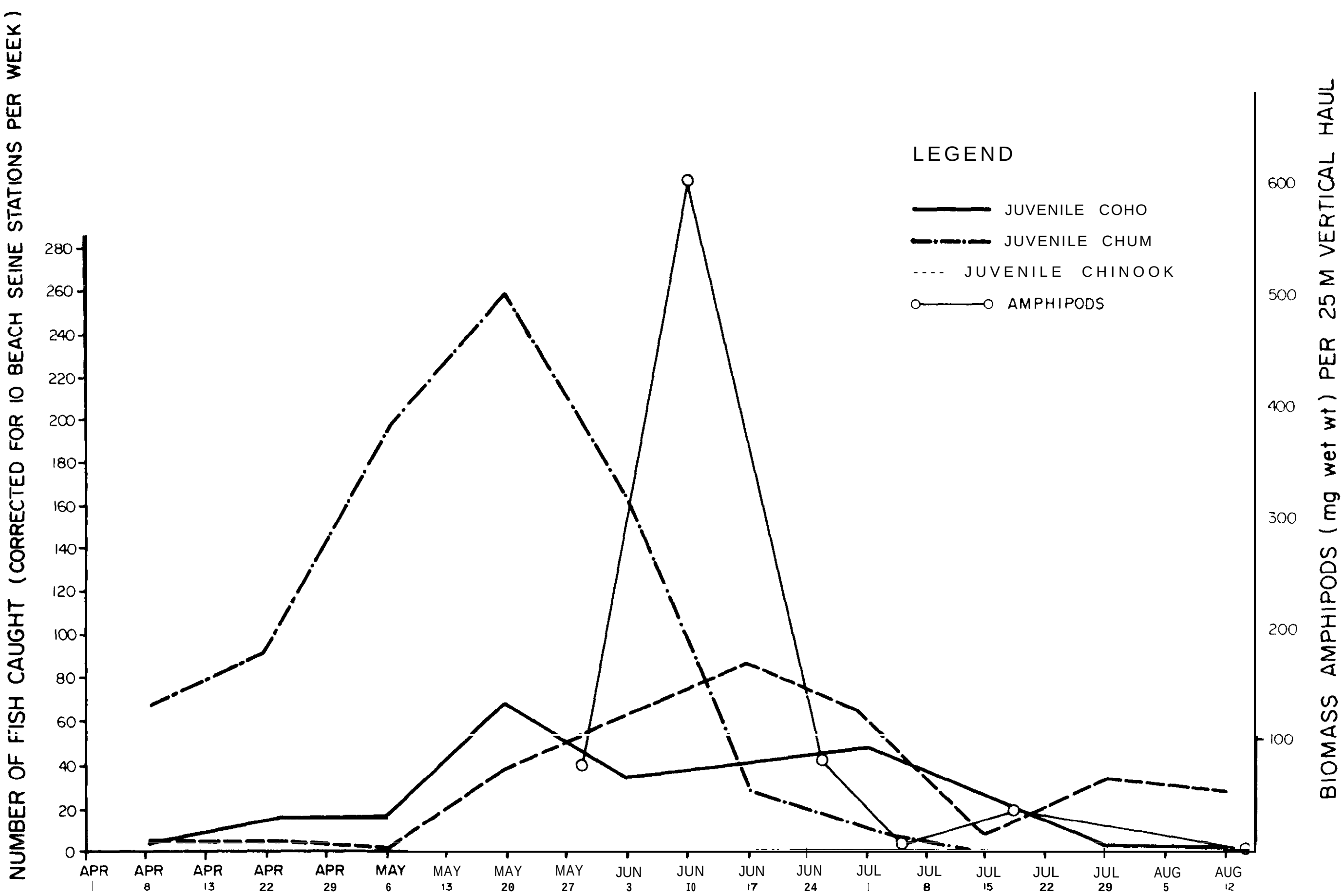

Figure 11. Variation in juvenile salmon catch and the biomass of amphipods in the Squamish River estuary, during the period 1 April-15 August 1972.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- Little deliberate work on the environmental impact of multiple sources of pollution or multiple developments has been conducted in British Columbia thus far.
- The approach sometimes taken in examining the effect of a given waste on dissolved oxygen concentration, for example, may inadvertently examine cumulative effects.
- The environmental impact of expansion of an existing structure can be approximated by examining the impact of the existing facility. This, in a sense, looks at cumulative effects.
- Not all impacts of development and waste input are necessarily negative or cumulative. Some developments, such as the two causeways on Roberts Bank, have actually enhanced eelgrass beds. Certain pollutants may have antagonistic effects when combined and partially neutralize each other.
- Environmental characteristics are extremely important in any situation and should be carefully examined. A large tidal range, strong wave action and good exposure to open water can lead to rapid dilution and dispersion of effluent.
- An estuary is a place where many substances carried down the river are either flocculated and settled into the sediments or taken up by the estuarine biota. Very little of the dissolved or particulate riverine material ever reaches the open sea.
- As urbanization and industrialization increase, there will be a real need to develop approaches toward cumulative environmental impact assessment.

Recommendations

- A conceptual framework should be developed within which the cumulative environmental impacts from contaminants and development in estuaries can be evaluated.

- Balance sheets of negative and positive environmental impacts should be prepared on some estuaries for which there are reliable, quantitative data on ecological effects of individual contaminants and developments.

- Research should be conducted in the laboratory on the cumulative biological effects of some common contaminants, and the results of this research compared with the cumulative impact of identical contaminants introduced into an estuary.

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COMMENTARY I

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Waldichuk's paper is an interesting description of a resource manager's viewpoint of the ecological importance of west coast estuaries to salmonids and the environmental impact assessments for three projects in British Columbia. However, the topic of "current or recommended management techniques for cumulative impact assessment in marine environments" is treated lightly at best. Waldichuk observes that "a [CIA] should take into account the cumulative effect of [multiple] industries [in an estuary] '' and that ''... there will be a real need to develop approaches toward cumulative environmental impact assessments." Support of this workshop by agencies of Canada and the United States, and attendance by this highly qualified group of scientists and managers indicates agreement by a large segment of the environmental community (i.e., government regulators, consultants, industry, academia, and public or private interest groups).

Waldichuk's first recommendation is described by the workshop organizers as the principal objective of this workshop, i.e., '' [Develop] a conceptual framework ... within which the cumulative impacts from contaminants and developments ... can be evaluated."

THE MANAGER'S PERSPECTIVE

From the manager's perspective, requiring or conducting a cumulative impact assessment presents a number of difficult issues. The need for cumulative impact assessment arises out of a general absence of comprehensive environmental planning within jurisdictions (e.g., land use, resource management, public versus private rights), as well as between jurisdictions (e.g., marine resource exploration, marine water pollution, acid rain). While the main environmental legislation we deal with establishes government policy on environmental considerations, all of the procedures are oriented to specific projects. If agencies, large land owners and managers, and governments did planning (in its broadest sense) on the basis of environmental criteria, the preparation of an environmental assessment impact report would be superfluous. This would even include the balance of environmental values against dollars when considered in the long term of several decades or more. The subject of cumulative impacts would be moot, because either planning decision would be based on assessments of aggregate impacts, or planning decisions would be phrased in terms of performance objectives that would place planned limits on cumulative impacts.

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

In the real world, comprehensive environment planning is hindered or stopped by being subject to the political process or even worse, free market influences. Choice in politics and markets is not a matter of right or wrong, but means agreement between opposing interests. This is to say that the public planning process is at great risk of coming up with the wrong (i.e., environmentally unacceptable) answer. (It might be imagined that in an environmentally minded totalitarian government, this would not happen.) So even though comprehensive environmental planning seems like a correct way to deal with CIA, it is hard to think of a case where this was successful, due to political or market influence.

PROJECT IMPACTS

One could argue that if project-specific impact assessments were conducted properly, the activity of looking at cumulative impact should be integrated indistinguishably in the project-specific impact assessment process, or vice versa. What sense does it make to look at the impacts of a project in the context of an unrealistic future environment? Project impacts should be measured against what the baseline is likely to be in the future, when the project starts up and runs. The future baseline should include all "reasonably foreseeable projects," scheduled through time. Then one could estimate the significance of the proposed projects' impacts against likely future environmental conditions. In the existing pertinent environmental legislation, and regulations and guidelines, the bottom-line interest is in what kind of an environment is likely to result in the long term, and is that acceptable? Given that kind of an outcome-oriented perspective, the only appropriate kind of impact assessment to do for a single project or many projects is what we ordinarily would call a cumulative impact assessment. This would be the "bottom-up" approach.

THE CONTROLLING PROBLEM

I believe the insurmountable problem is institutional. The institutional problem is unavoidably a topic for the workshop. However, most of the attendees, including me, are much less qualified to deal with this issue than would be economists, lawyers, policy analysts, social scientists, etc. There are a large number of political, social, economic, and other institutional issues such as: Who pays? Who decides when to stop any more "small decisions''? How do decision makers allocate the remaining resources? Who has the jurisdiction (local, state, federal, international authorities etc.)? Why should the first applicant(s) have to pay for the major effort required initially when subsequent applicants would also use the information, but for free; after all, this gives the Johnny-come-later competitor the economic edge in reduced permitting costs. As one who has to conduct CIAs, I can confirm that simply deciding who is the "they" that will have jurisdictional control, over what time and space scale, and with what degree of regulatory clout is a monumental obstacle to overcome. Yet, if it is not overcome, controlling cumulative impacts will be impossible.

NON-INSTITUTIONAL CONSTRAINTS

The major non-institutional or technical constraints that affect cumulative impact assessments are of three types: procedural, from a legal viewpoint; methodological, from a "how do we conduct the analysis" perspective; and technical, from the standpoint of what data/problems/analysis/etc. are available and do we understand how the system(s) work. I only deal with the latter two in the following.

Spatial Boundaries

Spatial boundaries must be defined to allow for a quantitative approach, and the boundaries must be practical with regard to the proposed project. Requiring a housing developer to analyze the decrease in riparian habitat due to his project in light of cumulative loss in the entire Fraser River Valley is not practical, given his limited resources. Asking a major wood products firm to analyze the loss of forest habitat and increased erosion effects, due to their projects, on the cumulative losses of Pacific Coast salmon populations is also not practical, even given their larger resources. Yet it is exactly these kinds of spatial boundaries that need to be considered if cumulative impacts are to be evaluated properly from an ecosystem perspective. Spatial boundaries are easy to define for some types of problems (e.g., removal of mangroves or wetlands), but very difficult for others (e.g., the extent of point and non-point source contamination in the Fraser River Delta and Straits of Georgia).

Temporal Boundaries

Temporal boundaries also need to be set. What time frame is appropriate for considering the impacts? Again, unless these are set realistically, the analysis, results and conclusions will be unreliable and unmanageable. As ecologists, we do not even make very accurate or precise predictions of impacts of a single action/project on a single species/habitat/ecosystem in a small area, when we extend the time scale to years or decades (read "numerous generation times"). If the comparison is to be to natural (pristine, unaffected) environments, the temporal scale should be retroactive, because a substantial amount of the cumulative impact has already occurred (e.g., loss of mangroves in Florida, sewage sludge and other organic pollution in Long Island Sound, New York).

Kinds of Projects/Actions

Kinds of projects/actions also need to be carefully considered and selected. Most of the environmental resources (however you choose to define that term) such as air, water, species, habitats, etc. are influenced by numerous projects and actions, some to most of which are completely unrelated to one another. For example, agriculture, domestic water supplies, steel mills, and tourism may all make extensive use of a surface water resource and have quite different impacts. Ultimately, however, they all contribute to a cumulative adverse impact even though each one individually may make a "negligible," "insignificant", "legally allowable" impact. The challenge to the CIA preparer is to decide which projects/actions to include and why. This will require clear selection criteria. It also supposes that we, as ecologists, engineers, environmental scientists, etc., understand how the system works so we can identify what kinds of projects/actions are likely to have an influence and understand how to evaluate the effects on that system.

Threshold Effects

Threshold effects may be very important for cumulative impacts, Basically, as an impact increases, it reaches and passes a threshold at which the impact can change from positive to neutral to adverse (and probably one could envision examples of the opposite sequence). However, for most marine or estuarine situations, we simply do not know what these thresholds are until they are passed.

Significance of Individual Impacts

Significance of the individual impacts compared to the already accumulated plus anticipated cumulative impacts is perhaps the most complex, contentious and difficult-to-analyze issue. Even developing a methodology for identifying the impacts (single and cumulative) probably cannot be done in more than a general way. After all, it is a problem similar to trying to formulate a single model that would describe the response of an entire ecosystem to several perturbations that vary in magnitude, mechanism, temporal duration and spatial distribution. Even assuming we knew all the elements and their interactions, the mathematics of the model will be very difficult if not intractable.

The significance evaluation is important procedurally. If the applicant can demonstrate that the proposed action will not have a "significant effect" (read measurable or probably detectable) on the resource, and therefore it will not contribute significantly to the cumulative impacts, then the specific, small project will probably receive a permit. Indeed, there may be no legal way that the decision makers could not grant the permit. Yet it is this very difficulty with the significance evaluation that leads to the cumulative "nibbling at" and "dribbling on" natural resources. It is intuitively obvious (and readily apparent with some resources such as wetlands, native grasslands, prime agricultural land, salmon, etc.) that each tiny, undetectable nibble at the resource eventually accumulates to become a major loss. Also, each new, small point or non-point dribble to a lake, river, or estuary eventually accumulates to major contamination.

However, despite all my reservations about our technical understanding and ability to deal with cumulative impacts, I think the scientific and engineering communities have some reasonable chance of addressing these technical problems, and finding appropriate methods for evaluating the significance of cumulative impacts in marine and estuarine systems.

COMMENTARY II

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I would like to touch on the issue of cumulative effects of management practices in managing the use of living marine resources as another type of cumulative effects assessment and management problem.

MANAGING CUMULATIVE WATER QUALITY ISSUES

To my knowledge, we have not used approaches commonly used elsewhere in environmental management to cope with cumulative effects on water quality in coastal areas. These are:

- comprehensive planning of coastal ocean areas like the Fraser estuary, in the same way that comprehensive land use planning is employed in important terrestrial areas; that is, identifying environmental and resource supply, future demands and critical risks and developing an environmental management plan in concert with a master development plan for the same area; and

- establishing optimum and minimum ambient water quality requirements to protect the most sensitive water uses for the area in question, as a basis for regulatory agencies to decide on acceptable development, the degree of treatment of discharges, and the allocation of available dilution capacity; this is how air quality is managed in urban areas, and it would seem that the same principles could apply to the aquatic estuarine environment.

MAINTAINING SUITABLE HABITAT FOR AQUATIC LIFE

The water quality management actions discussed above would need to have an additional provision to meet the needs of maintaining an adequate quantity and quality of fish habitat in estuaries, beyond the water quality aspects. Assuming that it is possible to quantify the area and location of required fish habitat for juvenile salmonids in the Fraser or Squamish estuaries, then the comprehensive plan for the estuary would make provision for maintenance and protection of these requirements in special zones. Provision should be made, though, for replacement of former natural habitat with new, man-made ones, using enhancement techniques developed and demonstrated in marine estuarine environments.

ST. LAWRENCE RIVER ESTUARY AND GULF EXAMPLE

Some investigators now believe that massive fresh water flow regulation in the 932,000 km^2 St. Lawrence River Basin is influencing nutrient upwelling, water temperature and primary productivity in the Gulf of St. Lawrence, an inland sea of 214,000 km^2, which in turn could be affecting the productivity of the Scotian Shelf in the North Western Atlantic (Bugden et *al.* 1982). Storage dams on the many tributaries of the St. Lawrence now impound 70 km^3 of the mean annual 424 km^3 flow of the river for purposes of power generation and navigational controls. Thus the natural flow regime of the discharge of the river at its mouth has been modified over the past 20 years or more by a reduction of the peak spring and summer flows of up to 35%, and an augmentation of flows in the winter season. A series of observations over a number of years suggest that these changes bring about changes in the physical and chemical oceanography of the Gulf, which appear to reduce its biological productivity. In turn, these waters, when discharged through Cabot Strait into the Northwest Atlantic, contribute 130,000 km^3 of rich, brackish flow over the Scotian Shelf region annually.

The reason I introduced this example of long-term, multi-sourced cumulative environmental impact resulting from decisions in two countries and many provincial, state and local jurisdictions, was to raise three questions:

- Could these multi-sourced developments have ever been accurately predicted in time for a macro cumulative effects assessment to be made before development?

- If yes, could the effects on the marine environment have been predictable?

- Is this a manageable environmental impact, in any practical sense, or do we just have to hunker down and accept the consequences, good or bad, as they slowly unfold?

SOME OBSERVATIONS ON THE CUMULATIVE IMPACTS OF SOME FISHERIES MANAGEMENT REGIMES

Knowing that there are some participants at this workshop with a fisheries background, I hope that they could contribute some insight into improved management approaches (and some better examples) to overcome what I perceive to be cumulative impact problems in the way in which we manage the use of some fish resources.

One example is the possible cumulative genetic effect of fishing selectively one age/size class of Atlantic salmon (i.e., larger, two sea-year fish) in New Brunswick, and allowing the major spawning escapement from the same fishery to be composed of grilse (i.e., smaller, one sea-year fish), through selective net size regulations.

Another example is the intensive fishing of a long-maturing species like bluefin tuna which migrate over long distances during their life history (in the waters of four continents, in the case of the Atlantic bluefin), so that there is insufficient breeding stock as the result of controlled, but cumulative, fishing effort by fishermen from a number of countries.

The interaction of cumulative environmental impacts on anadromous species, like the salmons, also interplay with the cumulative impacts of aggressive fisheries management policies, so that the species faces the double jeopardy of its numbers being critically reduced by fishing as well as environmental hazards. It seems to me that there needs to be a meshing of management approaches to establish a coordinated conservation strategy for the species.

REFERENCE

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ATMOSPHERIC SYSTEMS

Scientific Perspective

THE CUMULATIVE IMPACTS OF HUMAN ACTIVITIES ON THE ATMOSPHERE

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This paper sketches a framework for the use of scientific knowledge in analysing the cumulative impacts of human activities on the atmosphere. It is not written for atmospheric scientists, who will find its contents familiar if somewhat strangely presented. Rather, I have tried to summarize recent work in atmospheric impact studies for scientists and managers in other fields of environmental assessment who might benefit from the experience of a distant cousin. This paper concentrates on the scientific dimensions of cumulative impact assessment, leaving the important questions of management, politics, and social context to a companion paper by Glantz and McKay (this volume).

I begin the first section with a conceptual framework, designed to introduce some terminology and structure to the discussion of cumulative impacts. My main objective is to identify criteria which can distinguish between two types of activities: those that can be addressed as simple, noncumulative sources of environmental impacts, and those activities requiring more difficult and complex cumulative assessment. The second section then presents a synoptic perspective on atmospheric impact assessment. Its aim is to show how valued atmospheric components — i.e., the properties of the atmosphere that constitute the focus of impact assessment — are related to sources of atmospheric disturbance — i.e., the human activities that necessitate such assessment. Three sources of cumulative impacts are identified, based on considerations of time, space, and multiple kinds of impacts.

The third section develops the cumulative aspect of this synoptic perspective. It explores the significance of cumulative impacts that arise from multiple sources of environmental disturbance. I argue that the cumulative dimension of impact assessment provides only one half of the synoptic perspective needed for useful analysis of environmental problems. Also needed to complete the impact picture is a systematic analysis of how single sources or activities simultaneously affect a large number of valued environmental components. The fourth section explores the origin of cumulative impacts in relations of temporal and spatial scale. Characteristic scales for the chemical constituents of the atmosphere and the sources of human activity that perturb them are described and applied to the cumulative impact problem. Finally, the fifth section presents some summary remarks and recommends steps for further research.

This paper as a whole draws strongly on contributions to the program for "Sustainable Development of the Biosphere" being conducted at the International Institute for Applied Systems Analysis in Austria. Studies prepared for that program by Thomas Graedel of ATT-Bell Laboratories, Paul Crutzen of the Max-Planck Institute for Chemistry, and Robert Dickinson of the National Center for Atmospheric Research provide the conceptual center and much of the data for my analysis.

CONCEPTUAL FRAMEWORK

In the vulgar version of environmentalism, where "everything is connected to everything else," all impact assessments would be cumulative impact assessments. The vulgar version, however, is both wrong and impractical.

From a scientific perspective, biological organisms look like they have gone to a great deal of evolutionary trouble not to be connected to things that they can't control. Complex physical systems likewise tend to be loosely or un-connected collections of more tightly coupled but simpler subsystems (Simon 1962). Most important, environmental systems in general show substantial capacities to return to their previous or average condition after disturbance. Most impacts do not accumulate, because most environmental systems are sufficiently "resilient" to absorb a good number of shocks and perturbations (Holling 1978; 1985). The scientifically interesting question is not whether things are connected at all, but rather which things are so tightly connected that they must be analyzed jointly in environmental assessments.

From a practical perspective, a world which insisted on seeing all things as connected would be a world of catatonia. Virtually all effective social undertakings rely for their forward momentum on what Hirschman (1967) has called "The Principle of the Hiding Hand" — i.e., the ability not to imagine all the possible connections, ramifications, and contingencies that would militate for caution and inaction. Designing solutions for cumulative impact problems is almost always more complicated and contentious than designing solutions for individual impacts. One of the most useful roles for science in environmental impact assessment is therefore to reduce as many apparently cumulative problems as possible to simple cases of single cause and single effect. Residual cases of cumulative impacts will exist, and must be addressed. However, our goal should be to minimize, not maximize, such cases.

Terminology

For the purposes of this paper, I will adopt a somewhat stylized distinction between traditional impact assessment and cumulative impact assessment. Where possible, my terminology and usage is based on Beanlands and Duinker **(1983).**

Traditional impact assessment examines the consequences of a single source of environmental disturbance. The source is most often a discrete event, project or policy. Consequences are assessed in terms of their impacts on valued environmental components. Valued environmental components are those properties of the environment that are thought to be most worthy of attention or protection in a given assessment context. As such, they are statements of what people value. They (should) therefore reflect the judgments of the broader political and social communities, as well as those of scientific experts.

Cumulative impact assessment examines the consequences of multiple sources of environmental disturbance that impinge on the same valued environmental components. The characteristic "multiple" nature of the sources of cumulative impacts may arise in three ways: the same kind of source recurs sufficiently frequently through time; the same kind of source recurs sufficiently densely through space; different kinds of sources impose similar consequences on a valued environmental component.

How can the possibility of cumulative impacts be examined in a skeptical but fair light? A useful conceptual framework for impact analysis might well begin with the null hypothesis that no significant cumulative effects exist. In developing what Beanlands and Duinker have called the study strategy for any given impact problem, an early goal of scientific investigation would then be to define and assess conditions necessary for rejecting the null hypothesis, and thus for determining that significant cumulative effects exist. In terms of the distinctive characteristics of cumulative impacts defined earlier, three conditions for rejecting the simple impact hypothesis seem most important, and are discussed below.

Impacts Cumulative in Time

An environmental system will generally recover from disturbance at some characteristic rate. Individual impacts will therefore accumulate only when they recur with sufficient frequency, because "large" disturbances will generally take longer to smooth out than "small" ones. The magnitude of individual impacts must also be taken into account when assessing their cumulative potential. At first, the null hypothesis of no cumulative impact potential should therefore be called into question whenever the time required for the natural system to remove or dissipate a unit of disturbance is of the same order or greater than the time between such disturbances in a (proposed) program of human activities.[1]

Impacts Cumulative in Space

An analogous argument applies in the spatial dimension. Generally speaking, both ecological and physical processes of environmental systems will attenuate local disturbances through space. That is, at some distance from the site of a perturbation, its impacts will have diminished to insignificant levels. Individual impacts will therefore accumulate only when they are spaced sufficiently closely, because "large" disturbances will generally be felt over longer distances than "small" disturbances. The magnitude of individual impacts must also be taken into account when assessing their cumulative potential. At first the null hypothesis of no cumulative impact potential should therefore be called into question whenever the distance required for the natural system to remove or dissipate a unit of disturbance is of the same order or greater than the distance between such disturbances in a (proposed) program of human activities.[1]

Impacts Cumulative in Kind

In some cases, a variety of human activities will cause the same sort of environmental disturbance, thus raising the possibility of cumulative impacts due to different kinds of activity. At first, the null hypothesis of no cumulative impact potential should therefore be seriously questioned whenever the impact can be induced by more than one kind of (planned) activity, and when those activities, considered together, are grouped sufficiently "closely" to meet the time- or space criteria described above.

In the remainder of this paper, I will use this general conceptual framework to show how scientific knowledge has been applied to illuminate problems of cumulative impacts on the atmospheric environment. My intention is not to test in any rigorous way the hypotheses erected above. Rather, I hope that structuring the argument in terms of hypothesis testing will help to identify which scientific knowledge is now available, and which is still needed, to enable a critical assessment of the problem of cumulative impacts in the atmosphere.

A SYNOPTIC PERSPECTIVE ON ATMOSPHERIC IMPACT ASSESSMENT

As noted earlier, a central goal of scientific analysis in environmental impact assessment is to describe the relationships (if any) between valued environmental components and potential sources of changes to those components. In the case of cumulative impact assessment, a special requirement is that the scientific description be synoptic — that it consider not just one kind of source, but rather all potentially significant sources of impacts.

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1. These qualitative conditions are also appropriate for the case of continuous disturbances, like automobile exhausts, where the contemplated program or activity is one of changing the intensity of the source. This can be seen by examining the dimensionality of the stated condition. For the case of time, the form of the condition given in the text is of dimension T/M, or time per unit mass. The reciprocal of this condition is in units of M/T, or mass per unit time. This latter expression, however, is a classical rate of flow, appropriate for expressing the continuous emission case. In such a reciprocal formulation, the condition for questioning the null hypothesis of no cumulative impact would be that the rate (M/T) at which the natural system removes an added substance is less than the rate at which all sources, taken together, add such a substance. A completely analogous argument can be made for the spatial dimension.

One such synoptic framework for assessing cumulative atmospheric impacts is being developed by Thomas Graedel of ATT-Bell Laboratories and Paul Crutzen of the Max-Planck Institute for Chemistry as part of their contribution to IIASA's study on "Sustainable Development of the Biosphere." Much of the material reported in this paper is freely adapted from Crutzen and Graedel(1985).

We begin, as instructed by Beanlands and Duinker, by specifying valued environmental components of the atmosphere. These will vary in detail according to specific social, political, and environmental circumstances. For our general purposes here, however, the valued environmental components identified by Crutzen and Graedel and described in Table 1 will suffice.

Environmental impact assessment aims to establish the causal relationships between such valued environmental components and potential sources of environmental disturbance. Science contributes to this goal by addressing relevant relationships at the deeper level of atmospheric constituents and processes. The last decade has brought about major advances in our understanding of atmospheric chemistry and its interactions with the biosphere (National Research Council 1981; National Research Council 1984; Bolin and Cook 1983). This understanding now lets us begin, systematically, to connect sources of atmospheric perturbation to higher-level atmospheric properties in terms of fundamental chemistry and physics.

Present knowledge regarding the relevance of changes in specific atmospheric chemicals to changes in those valued atmospheric components of major social and scientific concern, is given qualitative expression in Figure 1. Note that the convention used in Figure 1, is to indicate only direct effects. Thus changes in ozone concentrations are shown to affect the valued atmospheric component of "Ultraviolet absorption," because it is ozone molecules themselves that have the ultimate impact. Halocarbons (e.g., "Freons") and nitrous oxide, though assuredly relevant to ultraviolet energy absorption, are not shown to affect this valued atmospheric component, because their action occurs indirectly, by changing the concentration of ozone. The rationale for this "direct effects" convention will become clear shortly. Note from Figure 1 that a significant number of chemicals are involved in multiple impacts. Sources of disturbance or intentional policies that affect these chemicals must therefore be assessed in terms of multiple kinds of impacts on the atmosphere.

The chemical compounds of Figure 1 provide a common denominator for linking sources and impacts of atmospheric perturbations. Present knowledge regarding the specific atmospheric chemicals affected by changes in potential sources of disturbance is given qualitative expression in Figure 2. Again, the convention of indicating only direct effects is employed. Note that a significant number of atmospheric chemicals are affected by multiple kinds of sources. The pervasive influence of changes in the biosphere — ocean life, plants, soils, and animals — on atmospheric chemistry is worth emphasizing. It has come as a surprise to many scientists, and is only now beginning to be appreciated (Lovelock 1979; National Research Council 1984).

CHEMICAL CONSTITUENTS	Ultraviolet Energy Absorbtion	Thermal Radiation Budget Alteration	Photo chemical Oxidant Formation	Precipitation Acid – ification	Visibility Degration	Material Corrosion
C (Soot)						
CO_2						
CO						
CH_4						
C_xH_y					+	
NO_x						
N_2O						
NH_3/NH_4^+						
SO_x		+				
H_2S						
COS						
organic S						
Halocarbons						
Other Halogens						
Trace Elements						
O_3						

Figure 1. Major impacts of atmospheric chemistry on valued atmospheric components. The '+' entries indicate that the listed chemical is expected to have a significant direct effect on the listed property of the atmosphere. Definitions of the atmospheric properties are given in Table 1. Data is from Crutzen (1983; Table 3.1) and National Research Council (1984; Table 5.2), modified as a result of personal communications with P. J. Crutzen and R.C. Harris.

To complete the chemical connection between sources and valued atmospheric components, it is finally necessary to attend to the matter of indirect effects — the fact that source-induced changes in chemical species 'a' may affect a given valued atmospheric component only through an intermediate influence on chemical species 'b'. (We have already alluded to an example of such indirect effects in the case of the ozone problem. Industrial processes add halocarbons to the atmosphere. These affect the ultraviolet energy absorption only via intermediate impacts of halocarbons on ozone.)

Tracking the indirect effects of chemical interactions is one of the central tasks of contemporary atmospheric science. The immense complexity of even the relatively well understood interactions precludes their discussion here. (An excellent overview of the field is provided in the recent U.S. National Research Council report on Global Tropospheric Chemistry (National Research Council 1984).) Conceptually, however, the substance of such a discussion could be captured in a matrix constructed along the lines of Figure 3.

The three figures discussed above can be combined to provide a synoptic framework for atmospheric assessment that allows us to deal systematically with the question of cumulative impacts. As suggested in Figure 4, we can begin with a valued atmospheric component like "precipitation acidity" and its immediate chemical causes (Figure 1), trace these back through their interactions with other atmospheric chemicals (Figure 3), and finally identify the sources responsible for initiating those interactions (Figure 2). The ultimate product is a matrix showing the impact of each potential source on each valued atmospheric component. The results of Crutzen and Graedel's initial effort to fill in such a matrix are discussed in the next section.

CHEMICAL CONSTITUENTS	Oceans and Estuaries	Vegetation and soils	Wild Animals	Wetlands	Biomass Burning	Crop Production	Domestic Animals	Petroleum Combustion	Coal Combustion	Industrial Processes
C (Soot)					+			+	+	
CO_2	+	+			+	+		+	+	
CO	+	+			+			+	+	+
CH_4		+	+	+	+	+	+			
C_xH_y	+	+			+	+				
NO_x	+				+	+		+	+	+
N_2O	+	+			+	+		+	+	
NH_3/NH_4^+		+	+	+	+	+	+		+	
SO_x								+	+	+
H_2S	+	+		+		+				
COS	+	+		+						
Organic S	+	+		+						
Halocarbons										+
Other Halogens	+							+	+	+
Trace Elements	+				+			+	+	+
O_3										

Figure 2. Sources of major perturbations to atmospheric chemistry. The '+' entries indicate that the listed source is expected to exert a significant direct effect on the listed chemical. Definitions of the sources are given in Table 1. Data sources as for Figure 1.

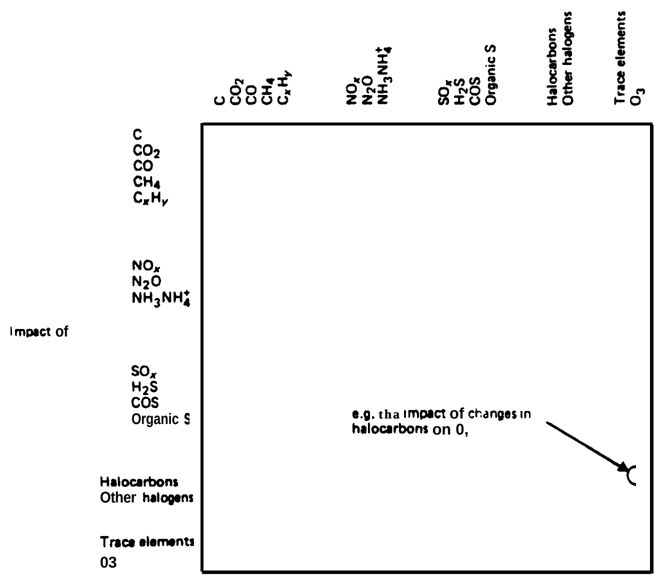

Figure 3. Chemical interactions in the atmosphere. A framework for assessing interactions among the chemical compounds listed in Figures 1 and 2.

CUMULATIVE IMPACTS DUE TO MULTIPLE KINDS OF SOURCES

The preliminary effort of Crutzen and Graedel (1985) to fill in the synoptic matrix of Figure 4 with qualitative information reflecting our present understanding of atmospheric impacts is presented in Figure 5. In this section, we will use the Crutzen and Graedel matrix to examine the varieties of atmospheric impact assessment now being employed. This perspective will in turn provide the foundation for an orderly analysis of the special problems of cumulative impacts.

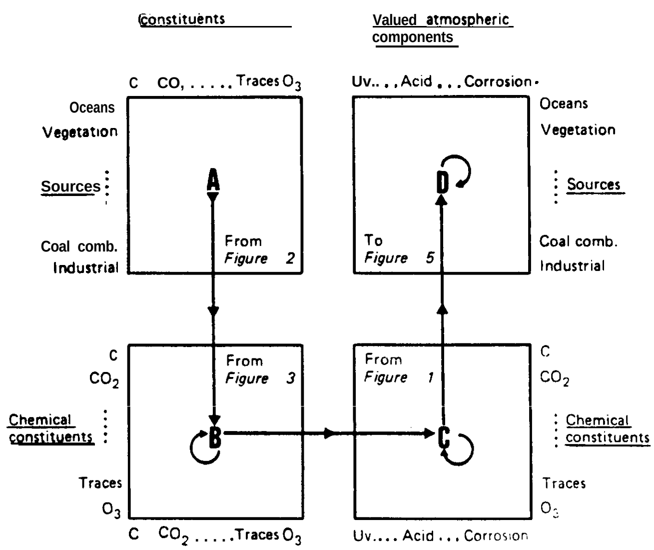

Figure 4. The science of impact assessment. An integrating framework for determining the relation ('D' in this figure) between valued atmospheric components and the sources that perturb them as a function of the relationships shown in Figure 1 ('C' in this figure), 2 ('A' in this figure), and 3 ('B' in this figure).

Single Cell Assessments

The simplest atmospheric impact assessments involve only a single cell of the matrix. A typical example is the study of effects of a single source, such as a new coal-fired power station, on a single valued environmental component, such as precipitation acidification (Location 'a' in Figure 5). The qualitative assessment of Figure 5 suggests that we should be highly confident that additional coal combustion could have major consequences for precipitation acidity unless specific remedial measures are taken. The synoptic nature of Figure 5 also emphasizes two additional features of relevance for impact assessment.

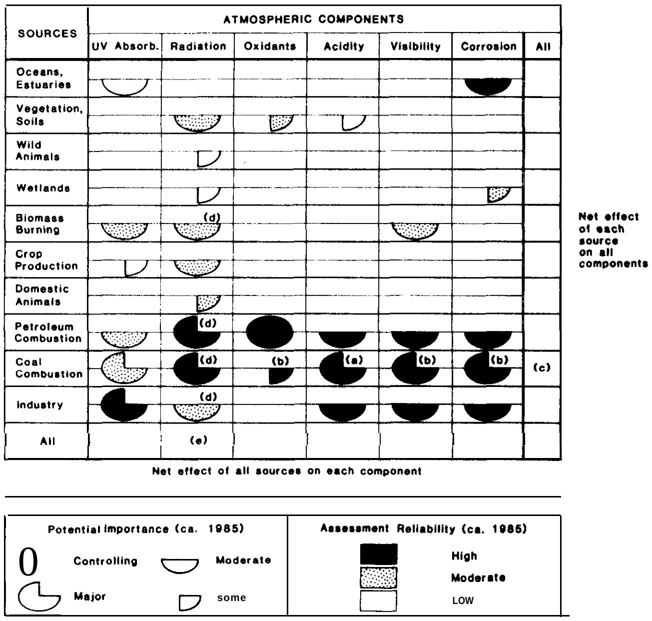

Figure 5. Perturbations to the atmosphere. A synoptic assessment of impacts on the atmosphere. This figure, adapted from Crutzen and Graedel (1985) gives a completed version of panel 'D' from Figure 4. The valued atmospheric components defined in Table 1 are listed as the column headings of the matrix, the sources of perturbations to those components are listed as row headings. Cell entries assess the relative impact of each source on each component, and the relative scientific certainty of the assessment. "Column totals" would, in principle, represent the net effect of all sources on each valued atmospheric component. "Row totals" would indicate the net effect of each source on all valued atmospheric components. These totals are envisioned as judgmental qualitative assessments rather than as literal quantitative summations. The significance of the letters in certain cells is defined in the text.

First, coal combustion is not likely to be the only source of precipitation acidification. The conclusions of a narrowly focused environmental impact assessment could well be rendered useless or misleading by changes in other significant sources of acidification like industrial activity and petroleum combustion. Second, precipitation acidification is not the only major impact of coal combustion. Taken together, the additional impacts of coal combustion on other valued atmospheric components like materials corrosion, visibility degredation, and perturbations to the thermal radiation budget could conceivably exceed the narrower significance of impacts on acidification.

Clearly, no firm conclusions can be reached at the highly aggregate and qualitative level of analysis suggested in Figure 5. At a minimum, quantification of impact magnitude and scale (see section "Cumulative Impacts Due to Scale Effects") would be necessary in any specific case of assessment. Nonetheless, the synoptic perspective can help to avoid the pitfalls of an unconsciously narrow focus that plague too many contemporary environmental impact assessments.

Row Summation Assessments

More complex atmospheric assessments have addressed the impact of a single source on several valued environmental components. The simple study noted above would fall into this category, if not only the acidification impacts of coal combustion, but also impacts on photochemical oxidant production, materials corrosion, and visibility degredation, were explicity included (e.g., Locations 'b'). The impact assessment then becomes a row total in the synoptic matrix (Location 'c'). From the qualitative perspective of the Crutzen and Graedel matrix, it is clear that coal combustion as a source of atmospheric perturbations may well have both a greater impact on the atmosphere as a whole, and a more widespread impact across multiple valued environmental components, than any other human activity or natural fluctuation.

Detailed, quantitative "row summation" assessments are typical in many areas of environmental analysis, but relatively uncommon in large scale atmospheric impact studies. Among the few exceptions is the important — and controversial — study by the U.S. National Research Council on *Atmosphere–*Biosphere Interactions: Towards a better understanding of the ecological consequences of *fossil fuel combustion (198* 1). Even this pathbreaking work did not examine all valued atmospheric components identified in the Crutzen and Graedel figure, but instead focused on the impacts of fossil fuel burning via pathways of sulfur oxides, nitrogen oxides, and trace metals other than lead. Despite its less-than-synoptic approach, however, the report shed new light on the alarmingly diverse and intensive character of environmental impacts resulting from fossil fuel based energy strategies.

Would it be useful to view such "row summation" assessments as indicative of cumulative degradation across valued atmospheric components and of the overall atmospheric resource? The "cumulative" appelation does not fit by the definitions I proposed in the first section "Conceptual Framework". Indeed, if row summation assessments were to be classed as cumulative, then many traditional assessments involving several valued environmental components would logically receive the label as well. Personally, I suspect that this would not be a useful step, and that the "cumulative" appelation can be more profitably applied to the sorts of cases discussed in the remainder of this paper. Nonetheless, it is not clear that traditional environmental impact assessment practice gives adequate attention to the way that degradation of individual valued environmental components accumulates to cause an overall degradation of whole environmental systems. This might be a topic that would require further study.

Column Summation Assessments

The simplest case of atmospheric impacts that may be cumulative across different kinds of sources, appears in the matrix where studies focus on perturbations of a single valued ecosystem component by a number of different natural events or human activities. A contemporary example is the study of net impacts on the earth's thermal radiation budget caused by the cumulative actions of fossil fuel combustion, biomass burning, and industrialization (e.g., Locations 'd' in Figure 5). The assessment then becomes a column total (Location 'e') in the synoptic framework. Again, the Crutzen and Graedel matrix shows how important a synoptic, "cumulative-in-kind" perspective is for useful atmospheric impact assessment. For example, early studies of CO, impacts on climate overlooked important chemicals and sources of perturbations to the radiation budget. The rapid maturing of atmospheric impact assessment in recent years is indicated by the adoption of an explicitly multi-source, cumulative approach in the best contemporary studies of climate impacts (e.g., National Research Council 1983a; Dickinson 1985; see also the fourth section "Cumulative Impacts Due to Scale Effects").

The "column summation," cumulative-in-kind assessments noted above seem more common in atmospheric impact studies than in other areas of environmental analysis. Why is this true? What does it mean in terms of atmospheric impact assessment as a model for cumulative studies in other environmental fields? The reason for the difference, I suspect, is that atmospheric impact assessments to date have been largely shaped by physical scientists preoccupied with individual properties of the atmosphere. Other fields of impact assessment have often adopted a synthetic perspective across valued environmental components due to the location-specific, often fundamentally descriptive interests of their practitioners. Landscape geographers, limnologists, ecologists, and above all the lawyers who write the assessment protocols, seem most comfortable when they are thinking about a specific multi-splendored place, and hope to tally the multiple impacts of some specific perturbation on it.

In contrast, climatologists, stratospheric ozone chemists, transport and deposition specialists, and materials corrosion analysts remain (almost) isolated in their separate specialties, each focusing on one or two valued atmospheric components. Within their specialities, however, the process orientation of the atmospheric sciences typically leads to studies that explore the impacts of all manner of perturbations on specific atmospheric properties. The result is a wealth of studies that, in the terminology used here, produce "column summation" assessments of cumulative impacts across different kinds of sources. This is as true for present assessments of the ozone question (National Research Council 1982) and acid deposition (e.g., National Research Council 1983b) as it is for the studies of climate change noted above.

Summary

Extremely complex assessments combining column and row perspectives, examining the impacts of multiple kinds of sources across several valued environmental components, and including cumulative considerations, are possible in principle. At least for studies of the atmospheric environment, however, few such comprehensive assessments have been seriously attempted. Even without considering these more complex cases, however, the synoptic matrix of Figure 5 lets us advance some tentative conclusions regarding the prospects for rejecting the null hypothesis of no cumulative impacts that was posed in the first section "Conceptual Framework."

Those conclusions must remain tentative, contingent on both our degree of confidence in the principal features of Figure 5, and the analysis of scale considerations that will be presented in the fourth section 'Cumulative Impacts Due to Scale Effects." (Recall that the hypothesis of no cumulative impacts in kind can be rejected only if both conditions of multiple sources and appropriate clustering of sources in space and time are met.) Nonetheless, a look at Figure 5 shows that for most valued atmospheric components it will be necessary to consider the possible cumulative impacts of multiple kinds of sources if a useful environmental impact assessment is to be produced.

Only in the case of photochemical smog can we be highly confident that a single source (in this case, petroleum combustion) dominates the overall impact.* At the other extreme (perhaps because it is among the most heavily studied valued atmospheric components?) is the thermal radiation budget. Here, we can be reasonably confident that the cumulative impacts of at least four and probably more sources may have to be considered to account for the majority of total effects. Even in the less extreme cases, it seems that the cumulative impacts of a minimum of two or three sources require consideration to provide useful assessment of a single valued atmospheric component. If several valued atmospheric components are considered, the need for multi-source studies of possible cumulative effects becomes even more compelling.

Given the difficulty of performing cumulative impact assessments, the tentative conclusion reached here is gloomy indeed. In the next section, I will explore whether careful attention to the scales of sources, impacts, and their relationships can be used to eliminate some of the need for cumulative analysis suggested in Figure 5.

CUMULATIVE IMPACTS DUE TO SCALE EFFECTS

I argued in the section "Conceptual Framework," that the null hypothesis of no cumulative impact should be called into question whenever (proposed) sequences of sources are

2. Petroleum combustion dominates at the local, urban scale. Global scale oxidation impacts are not considered in the matrix. At the regional scale, sources of impact on oxidation properties remain uncertain. Generally speaking, separate matrices of the sort shown here could be constructed for global, regional, and local impacts.

grouped sufficiently closely in space or time that they exceed the natural system's ability to remove or dissipate the resulting disturbance. Conceptually, the analysis at this point should therefore specify characteristic time and space scales for the potential impact sources and valued atmospheric components listed in Table 1. To be directly useful, these characteristic scales should be normalized to a standard unit of disturbance.

Such an analysis should not be impossible, and indeed is a central concern of the IIASA program on "Sustainable Development of the Biosphere" referred to earlier. Nonetheless, the necessary research has not been completed, and the task lies beyond the scope of this paper. I will therefore confine my comments in this section to a suggestion of the kinds of considerations and data that such an analysis might eventually employ. Again, my objective is to suggest perspectives, long familiar to atmospheric scientists, that might prove useful in a wider range of environmental impact assessments.

Scientific understanding of the atmosphere can best be applied to the question of impact scales at the level of the chemical constituents already introduced in Figures 1 and 2.

TABLE 1:

Definitions of valued atmospheric components and sources of disturbance: This table provides definitions of terms used in the text, adapted mainly from Crutzen and Graedel (1985).

Valued Atmospheric Components

Ultraviolet energy absorption: This property reflects the ability of the stratosphere to absorb ultraviolet solar radiation, thus shielding the earth's surface from its effects. This property is commonly addressed in discussions of "the stratospheric ozone problem."

Thermal radiation budget alteration: This property reflects the complicated relationships through which the atmosphere transmits much of the energy arriving from the sun at visible wavelengths while absorbing much of the energy radiated from earth at infrared wavelengths. The balance of these forces, interacting with the hydrological cycle, exerts considerable influence on the earth's temperature. This property is commonly addressed in discussions of "the greenhouse problem."

Photochemical oxidant formation: This property reflects the oxidizing properties of the atmosphere, caused by a concentration of a variety of highly reactive gases. The treatment here focuses on local scale oxidants that are often implicated in problems of "smog," crop damage, and degradation of works of art.

Precipitation acidification: This property reflects the acid-base balance of the atmosphere as reflected in rain, snow, and fog. It is commonly addressed in discussion of "acid rain."

Visibility degradation: Visibility is reduced when light of visible wavelengths is scattered by gasses or particles in the atmosphere.

Material corrosion: This property reflects the ability of the atmosphere to corrode materials exposed to it, often through the chloridation or sulfidation of marble, masonry, iron, aluminum, copper and materials containing them.

Sources of Perturbation

The sources are largely self explanatory. Notes, provided here, are confined to special considerations important in the text. For more details, see Crutzen and Graedel (1985).

Oceans and estuaries: includes coastal waters and biological activity of the oceans.

Vegetation and soils: does not include wetlands or agricultural systems, for these see below; does include activities of soil micro-organisms.

Wild animals: does not include domestic or marine animals, for these see elsewhere; does include microbes except for those of soils, for these see above.

Wetlands: an important subcomponent of vegetation and soils; does not include rice, for this see below.

Biomass burning: includes both natural and anthropogenic burning.

Crop production: includes rice but not forestry; includes fertilization and irrigation.

Domestic animals: includes grazing systems and the microbial flora of the guts of domestic animals,

Petroleum combustion: includes impacts of refining and waste disposal.

Coal combustion: includes impacts of mining, processing, and waste disposal.

Industrial processes: includes cement production and the processing of non-fuel minerals.

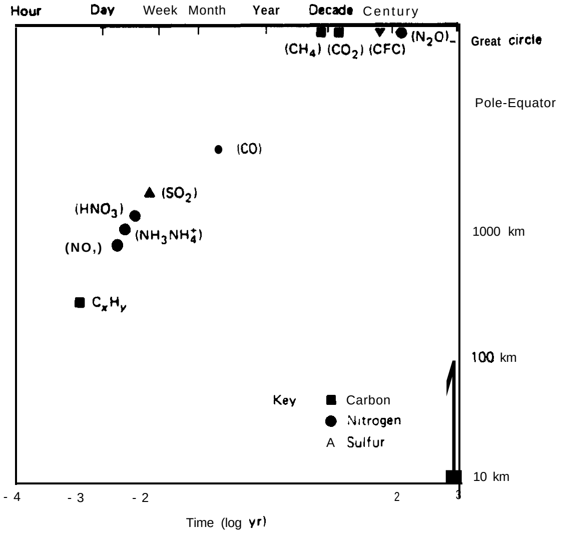

Figure 6. Characteristic scales of atmospheric constituents. The figure applies to the clean troposphere above the boundary layer. The abscissa indicates the amount of time required for the concentration of the listed chemicals to be reduced to 30% of their initial valued through chemical reactions. The ordinate indicates the mean horizontal displacement (square root of EW times NS displacement) likely to occur over that lifetime. Data is from Crutzen (1983), modified as a result of personal communications with P.J. Crutzen and R.C. Harris.

Research on the interactions among those chemicals (cf. Figure 3) has allowed most of them to be characterized in terms of the time and space scales at which chemical processes remove them from the atmosphere. Recent results reported in Figure 6 should be accurate to within a factor of two or three. Physical processes of transport and deposition also dissipate local concentrations of atmospheric chemicals. These physical processes have been well studied by meteorologists, and can also be assigned characteristic scales of operation (Dickinson 1985; Clark 1985). Some common examples are presented in Figure 7.

Figure 8 combines the information on characteristic scales of relevant atmospheric phenomena discussed above. For perspective, it also shows the spatial dimension of several geographic features relevant to human activities. Several features of this figure, bearing on strategies of environmental impact assessment, are discussed below.

Mesoscale Constituents

In the lower left corner of Figure 8 are the mesoscale atmospheric constituents, including many highly reactive chemicals (not shown), hydrocarbons heavier than methane, aerosols, and particulates. These have atmospheric lifetimes of a few hours or less, and transport distances of tens to hundreds of kilometers. Their concentrations and distributions are strongly influenced by the local weather of cloud formation, squall lines, and frontal systems in the neighborhood of sources.

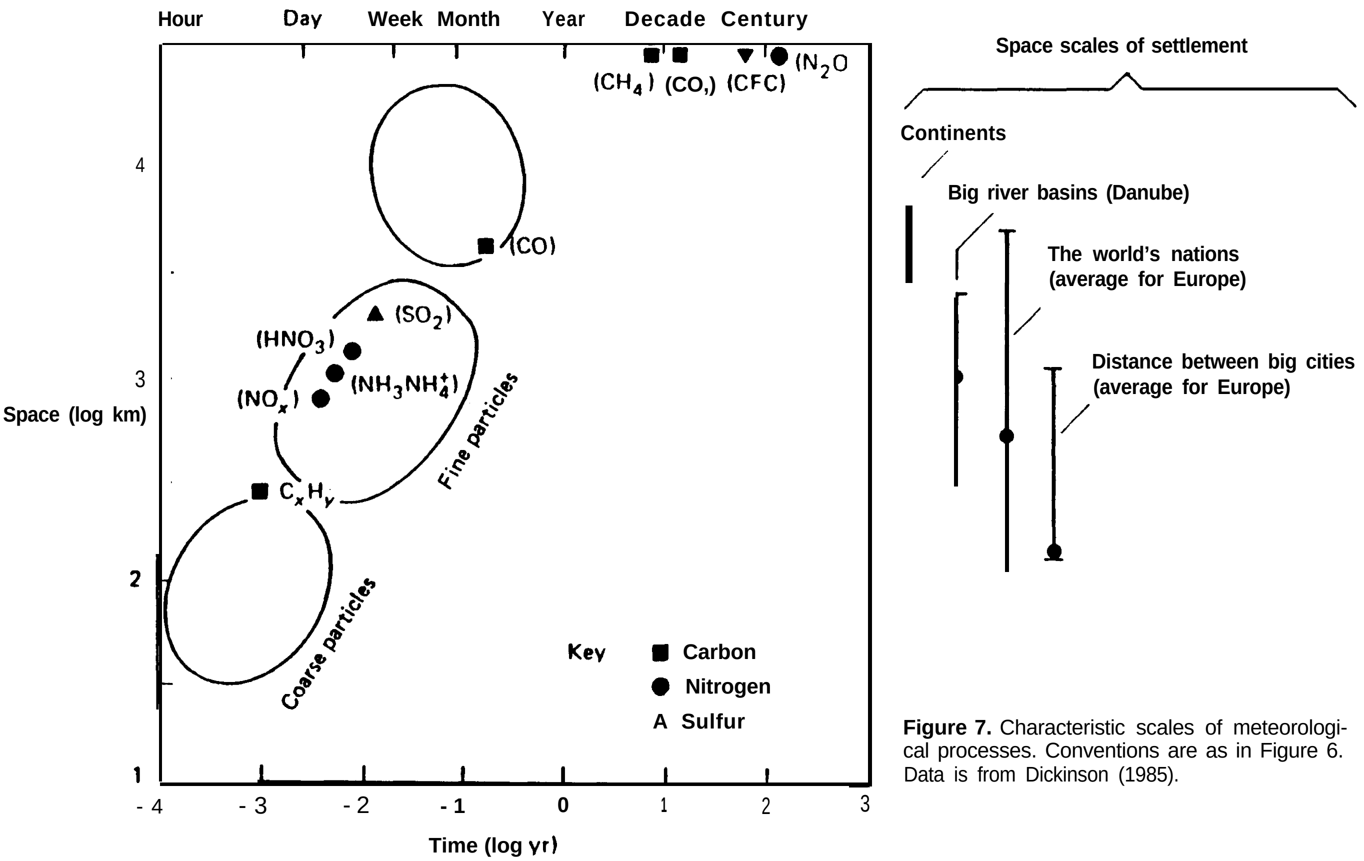

Figure 7. Characteristic scales of meteorological processes. Conventions are as in Figure 6. Data is from Dickinson (1985).

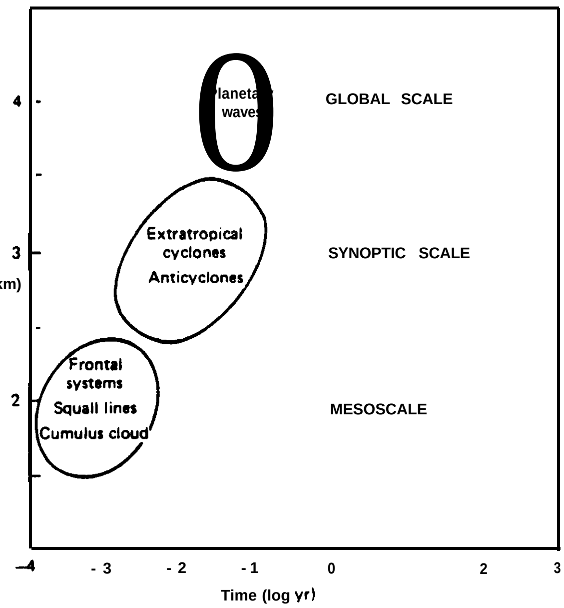

Figure 8. Relevant scales for atmospheric impact assessment. This figure combines the characteristic scales of atmospheric chemistry from Figure 6 with those of meteorological processes from Figure 7. It also includes for reference characteristic spatial scales of human settlement, derived from Clark (1985).

Note that the spatial dimension of the mesoscale constituents is of the same order as the distance between big (ie. 500,000 people) cities in the more densely populated portions of the world, including not only Europe and Japan, but also India and China. Contingent on the relative magnitude of the source and sink terms for such constituents, the impacts of emissions from individual cities have a good chance of accumulating across space, from one city to the next. For valued atmospheric components affected by mesoscale constitutents released from fossil fuel combustion or industrial activity, it would therefore seem reasonable to design an assessment strategy to question the null hypothesis of no cumulative impacts. By way of contrast, the figure suggests that tentative retention of the no cumulative impact hypothesis could be justified, other things being equal, in the case of emissions from individual countries. In other words, mesoscale constituents released in one country of average size for the world (e.g., France) are, on average, not likely to significantly affect valued atmospheric components in neighboring countries.

Synoptic Scale Constituents

Moving upwards and to the right in Figure 8, a large and important group of synoptic scale atmospheric constituents is encountered. These include the oxides of nitrogen and sulfur important in acidification of precipitation, as well as the ammonia/ammonium released from many natural and managed biological systems. Distribution and dissipation at the synoptic scale is strongly influenced by the large-scale weather of cyclone formation and movement.

To pursue the example suggested above, it is clear that these constituents travel sufficiently far that the emissions from one large city can be expected to reach the next large city, not only in densely populated areas, but virtually everywhere on earth. In the case of synoptic scale constituents, however, there is also a good prospect of cumulative impacts across countries. In other words, for all but the largest nations, efforts to assess the impacts of activities releasing synoptic constituents, and policies to control those impacts, will probably have to take the policies and activities of other countries into account. It is only at the continental scale of analysis that the null hypothesis of no cumulative impacts can reasonably be retained for sources of the synoptic scale constituents. Finally, note that the characteristic spatial dimension of these atmospheric constituents is of the same order as the spatial scale of the world's major river basins. Thus, many important hydrologic properties will be integrated over the same scales as the valued atmospheric components affected by the synoptic scale atmospheric constituents.

Again, any quantitative assessment would have to consider the relative magnitude of source and sink terms before reaching firm conclusions. Nonetheless, in terms of the design of assessment strategies, the qualitative implications of the foregoing scale analysis should be relatively robust.

Global Scale Constituents

Continuing up scale, a gap of almost two orders of magnitude is encountered in the atmospheric lifetimes of the listed atmospheric constituents. Then, in the upper right corner of the figure appear the global scale atmospheric constituents. With residence times of a decade to a few centuries, all of these constituents have more than adequate time to be distributed around the world. These global scale gases include carbon dioxide, methane, nitrous oxide, and some of the major man-made chlorcfluorocarbons — all of which were shown in Figure 1 to have their principal direct impacts on the earth's thermal radiation budget. The long time scale and large space scales of these gases mean that human activities producing them anywhere on earth, at any time over the last 10–100 years, may have contributed significantly and cumulatively to present concentrations in the atmosphere.

Not surprisingly, measurements indeed show a long-term, world-wide increase in each of the global gases (McElroy 1985). Recent studies suggest that by the year 2100, the cumulative impact of continued increases in these and other gases on the earth's radiation budget could be substantial (Dickinson 1985). An increase of about 5°C is not improbable, and an increase of as much as 15° is consistent with present models. Significantly, no single chemical constituent seems likely to be responsible for more than half of this increase. Thus, the cumulative dimension of the impact assessment is essential to an understanding of the problem.

Towards Quantitative Use of Scale Characterizations

Before these data on characteristic scales of the atmosphere's chemical constituents can be used in rigorous explorations of the cumulative impact question, two additional kinds of information are necessary. First, we require data on characteristic scales of the possible sources of perturbations to these chemicals listed in Table 1. Elsewhere, I have made an initial attempt to assemble and evaluate such scale data for use in climate impact assessments (Clark 1985). Second, we need data on the absolute quantities of the various constituents that are removed by natural processes, or added by changes to sources over intervals defined by their characteristic scales. (Without this latter data to normalize the scale characterizations, the quantitative comparisons necessary to "test" the hypotheses of the first section are impossible.) Initial efforts in this direction are summarized in Crutzen (1983) and National Research Council (1984). Most of this data, however, summarize source and sink strengths at a global scale. Only for the principal constituents involved in precipitation acidity is reasonable systematic coverage of source and sink strengths at smaller scales presently available. New programs of measurement are seeking to remedy this shortcoming, offering prospects for a more rigorous quantification of the scale perspective in years to come.

SUMMARY AND CONCLUSIONS

Due to the mobility of the atmosphere, human activities impose a variety of cumulative impacts on valued atmospheric components. Relative to other areas of environmental concern, cumulative atmospheric impacts may be especially common but they are also probably relatively well understood.

At meso- and smaller scales, cumulative impact assessment is the rule rather than the exception in contemporary air quality management. This is evident in the structure of urban air quality standards, and especially, in the relatively sophisticated strategies that have evolved for the management of photochemical oxidants in urban areas. The same is true, if to a lesser degree, for impacts involving synoptic scale constituents of the atmosphere. Largely under the impetus of contemporary concern for acidification of precipitation, more and more atmospheric impact studies are adopting study strategies that consider the possibility of multiple sources, linked across significant spatial and temporal scales. At the global scale, as well, impact assessments are becoming increasingly cumulative in orientation. Some of the more moribund government programs may lag behind — still, for example, focusing on the effects of carbon dioxide alone on the radiation budget — but academically respectable work, almost without exception, is now taking a wider, cumulative view.

My impression is that the tendency to adopt a cumulative perspective is further and more generally advanced in atmospheric studies than elsewhere in environmental impact assessment. I have suggested in this paper that the reason may have much to do with atmospheric impact studies' relatively strong foundations in basic, as opposed to applied, research. It is worth pointing out that at least in the case of the global-scale constituents referred to above, the serious impact assessments are now being performed by the same people who are at the forefront of basic research. The basic science is hard enough, and central enough to the assessments, that the second-rate studies so common in other environmental assessment areas (and hardly unheard of in atmospheric assessments even 10 years ago) are becoming increasingly rare. If this perception is even partially true, it raises important questions concerning the creation of environmental knowledge that will be useful for dealing with the cumulative impact problem. My own feeling is that where basic scientific understanding of process and causation is strong, cumulative impact perspectives will naturally emerge as a component of the applied assessment strategies. I therefore suspect that we would gain more useful knowledge on cumulative impacts by putting more of our funding into basic research by our best scientists, and less into the endless case-specific "single cell" impact assessments that contribute little to management or understanding. The old question of basic research versus applied problem solving is perhaps worth reexamining in the context of the cumulative impact question.

Having noted the relative strengths of cumulative impact studies in atmospheric science, it is true that much remains to be done. I have already commented on the need for studies focusing on the scalar relationships of potentially cumulative sources to valued atmospheric components. Beyond this, even the best cumulative atmospheric assessments still tend to focus on only single valued atmospheric components. The results are intellectually satisfying, but not particularly useful as a guide to social action. What matters to the environment is indeed the cumulative impacts reflected in the "column summation" assessments of Figure 5. However, what is most relevant to policy is the "row summation" impacts of corrective actions applied to single sources of atmospheric disturbance. A policy to restrict the use of coal in electricity generation, for example, will affect not only the valued atmospheric component of acidification of precipitation, but every other valued atmospheric component listed in Figure 5 as well. The political debate over such a decision should reflect an awareness of these "row summation" impacts — an awareness that only a synoptic scientific understanding of the relationship of sources to valued atmospheric components can provide. The most useful assessments of the future will be those that incorporate both column perspectives (cumulative impact on valued atmospheric components) and row perspectives (policy impact of source changes) to yield a truly synoptic view of the relation between human activities and the environment. It may be that less will be gained by focusing on the cumulative impact problem in isolation, than by tackling directly this ultimate need for synoptic environmental impact assessment.

Acknowledgements

Helpful criticism and suggestions were provided by participants in the workshop, as well as by J.H. Clark, P.J. Crutzen, R.E. Dickinson, T. Graedel, and R.C. Harris. Anna Clark helped greatly with the analysis. My thanks to all.

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COMMENTARY I

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Clark's paper is innovative, providing a new perspective for examining large-scale cumulative impacts in which atmospheric processes are involved (transport, photochemistry, wet deposition, radiation). The subsequent paper by Glantz and McKay also deals with the large scale (1000 km up to global). I have only one comment to make that is directly related to Clark's paper, namely, that M. Neiburger suggested 15 years ago that distances between large metropolitan areas are often insufficient for pollution concentrations to return to background levels. A schematic representation of this idea is contained in Figure 1 (Neiburger 1969).

Turning to the local and the regional scales, it is interesting to recall that the phrase "airshed" was first used by President Kennedy in a speech to the United Nations in the 1960s. That phrase is not really appropriate for the atmosphere but it is widely used. An "airshed" is a very leaky box indeed. Nevertheless, there may be episodes of high local concentrations when air quality must take account of the cumulative (in the sense of "additive") effects of multiple emissions. To use the Ontario experience as an example, some airsheds (e.g., Sarnia) are considered to be already saturated with point-source emitters. If a new industry wishes to locate in such a region, it is necessary to negotiate a cutback in the emissions of other users.

In other areas (e.g., Toronto) in cases where an EIA is mandated, there is a requirement for the proponent to assess background pollution concentrations, and to agree to install control equipment that will ensure that air quality criteria are not exceeded. In a recent proposal to modify the R.L. Hearne power station to burn solid wastes, for example, a metropolitan Toronto multiple-source dispersion model was used to assess the effect of adding the Hearne emissions to the already existing pollution levels in the local airshed.

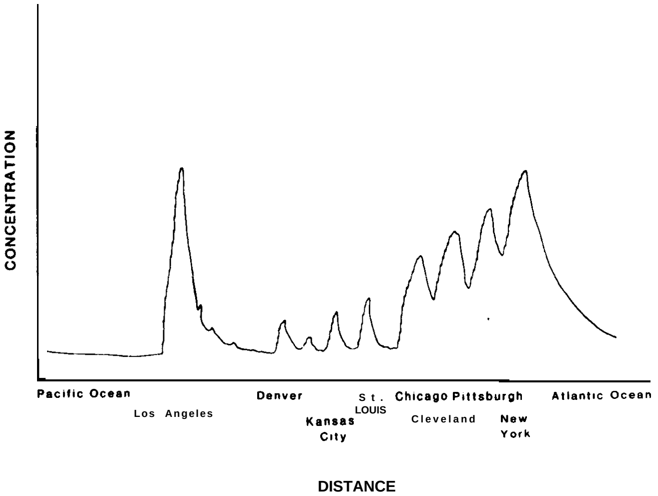

Figure 1. Schematic representation of pollution concentration in air crossing the United States.

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COMMENTARY II

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Clark's paper details the matrix of human contributions to the atmosphere and the probable atmospheric response. It is reviewed in terms of an analogous canonical correlation framework that should lead to future research directions.

The paper is an excellent submission — complete, systematic and apparently unbiased by preconceptions. My commentary has two objectives: to present a quantitative analogue that should serve to stimulate discussion, and to encourage training programs in cumulative impact analysis.

Clark defines a summary matrix (attributed to Crutzen and Graedel 1985) of n x p dimension, where n refers to the various types of human activity that impact the atmosphere, and p represents the various impacted atmospheric phenomena. For each non-zero element, two scalar quantities are defined: the potential importance of the human/atmosphere problem at that intersection, and a measure of the reliability of our understanding at that element.

The purposes of Clark's paper are to define and scale the important human/atmosphere interactions, and also to provide a simultaneous ("cumulative") representation of the different variables involved. Rather than having "everything connected to everything else," this matrix serves to underscore the important connections where investment is liable to yield the most substantial returns.

Cumulative impact assessment (CIA) means two things in this context: that there exists a partially correlated set of human disturbances, and that there are a series of responses that also interact with each other.

Thus CIA can be viewed analogously to canonical correlation - where a combination of input variables maximally explain the variance in a combination of response variables. However, canonical correlation clearly differs from Clark's conceptual model in that it forms linear combinations of each set of variables. In reality, the interactions between the predictors and especially the atmospheric response variables are nonlinear, and sometimes even stepwise.

CANONICAL CORRELATION MODEL

The canonical correlation analogue applicable to Clark's presentation is:

$$\sum_{i=1}^{n} \widehat{\alpha_i P_i} = \sum_{i=1}^{n} \beta_i N_i + e_i,$$

$$\sum_{i=1}^{n} \widehat{\alpha' P_i} = \sum_{i=1}^{n} \beta_i' N_i + e_i, \text{ etc. . .}$$

where the P, refer to the p-dimension (atmospheric response) variables in Clark's matrix, and the N, refer to the n-dimension (human input) variables. The weighting factors, α_i and β_i refer to the strengths, or "importances" of each term, and Clark's "assessment reliability" can be considered a measure of the error associated with the measurement of each of these weightings. The caret signifies that each relation is only incompletely predictive. The e, are the unexplained residuals.

In the canonical correlation model, a hierarchial series of such relations are generated that successively explain less of the total system variation. I suspect that there exists an analogous hierarchy within Clark's scheme that could possibly be used to allocate remedial resources once the canonical relations are defined.

I recognize that the CIA problem is not completely analogous to such a statistical procedure; however, these and other aspects suggest that it may be useful as a heuristic device for the purpose of stimulating discussion at this workshop.

It seems likely in the first (most important) canonical relation that a number of the anthropogenic (n-dimension) variables will act in highly correlated fashion to disturb the p-dimension. This is true because the concentrations of most of the anthropogenic compounds are simultaneously increasing. However, the signs of the weightings associated with some are unclear — particularly for soot and haze at different levels during polar night. Until these signs are clarified, CIA is not yet appropriate.

The limitations of the current (before CIA) state of knowledge become evident even when attempting to stimulate the temporal and spatial climatic distribution over the period of reliable instrumentation. An interesting example of the prediction limitations was given inadvertently by Manabe et al. (1981). In that work, the global distributions of the output variables of a CO,-driven climatic change model were tested for statistically significant differences from present climate. Simple calculations show that less than 10% of the model globe display significantly changed climate at the 90% confidence level, assuming a doubling of CO,. Commenting upon these types of problems, J. Smagorinsky noted in a University of Virginia seminar in 1984 that he would not be surprised if there were some currently overlooked parameters that will greatly damp the warming scenarios. The uncertainty concerning the degree of warming is implicit in the probable error ranges suggested in the NRC (1983) report.

However, assuming that most of the signs and some of the magnitudes of the n-variables will eventually be clarified, the appropriate way to apply a CIA may indeed be via the hierarchial qualities of the canonical correlation analogue.

Clearly, some combinations of n-variables likely effect some discrete combinations of p-variables, and further, it is possible that a major portion of the variation explained in the p-dataset may be concentrated in the first new sets of canonical relations.

It is the variance explained by each level of the canonical analogy that provides guidance on the utility of response for the management side. For example, the variates with the highest weightings on the p-variables and the highest statistical reliability will be those towards which remedial economic efforts should be tendered.

This canonical interpretation of Clark's paper is not a completely appropriate analogy. I offer, for example, no explicit suggestion that the next step in CIA of the atmosphere is to actually perform such an analysis on the n and p variables. However, the form of the output — where explained variances, statistical reliabilities, and multivariate relationships are defined — is worth considering as a framework for future work.

ACADEMIC INFRASTRUCTURE

There are also some serious problems within the academic infrastructure that may hinder proposed CIA work. The primary cause is that CIA will be almost definitionally inter- (or, perhaps, multi-) disciplinary in future.

A cursory look at the training, institutional history, and published research of most of the participants at this workshop reveals that, while most were trained in traditional disciplines, they often later developed an interdisciplinary orientation.

In most cases this expertise was developed after passing through the academic tenure process in the traditional disciplinary mode. Thus, few individuals are trained specifically to deal with inter- and multi-disciplinary problems. This should be remedied.

One problem with this involves the ingrained perception that interdisciplinary training is by definition bad training. True, there are some interdisciplinary programs that do not produce high-quality graduates; but there are clearly others that consistently do.

It is therefore necessary to determine which programs have the best track records, and to encourage the training of students in CIA at those institutions. A necessary initial step would be an inventory of the breadth and quality of interdisciplinary science training available. This can then be used to determine which institutions are likely to yield the best return on educational investment.

CONCLUSION

In conclusion, it seems to me that there are three primary problems currently associated with CIA research on the atmosphere:

- We currently do not have a sufficient understanding of the magnitude, and, in some cases, the sign of relationships between some of the anthropogenic pollutants and the atmospheric response.
- We need to factor the CIA matrix in a hierarchial, or canonical, fashion to determine the important combinations of cause and effect.
- We need to identify and support institutions that will produce the best analysts. It is quite likely that this means more support for interdisciplinary programs.

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Management Perspective

CUMULATIVE ATMOSPHERIC IMPACT ASSESSMENT

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A crucial exchange, perhaps the fundamental problem confronted by the Conference, occurred when a participant suggested that we should convey to the public the conclusion that 'we don't know enough, we are trying to learn more, let's hang on tight while we can.' Immediately came the response, 'No, let's hedge against the worst.'
(Kellogg and Mead 1977)

MAJOR CONCERNS

There are numerous ways that human activities can adversely affect the atmosphere. Dr. Mostafa Tolba, Executive Director of the United Nations Environment Program (UNEP), identified three major environmental concerns at the 1982 Stockholm Conference on Acidification of the Environment that are directly related to the atmospheric sciences:

- acid rain,
- the increased concentration of atmospheric carbon dioxide,
- the projected depletion of stratospheric ozone (resulting from chlorofluorocarbon emissions).

Acid Rain

Briefly, acid rain results from the chemical transformation of atmospheric concentrations of sulfur dioxide and oxides of nitrogen. The main sources of these pollutants are fossil fuels used by factories, power plants, and vehicles. Acid deposition in the form of rain, fog, and snow and as dry matter has been blamed for the destruction of aquatic ecosystems and forests. It is considered a local and regional problem, one that occurs primarily downwind of the major industrial regions of the world.

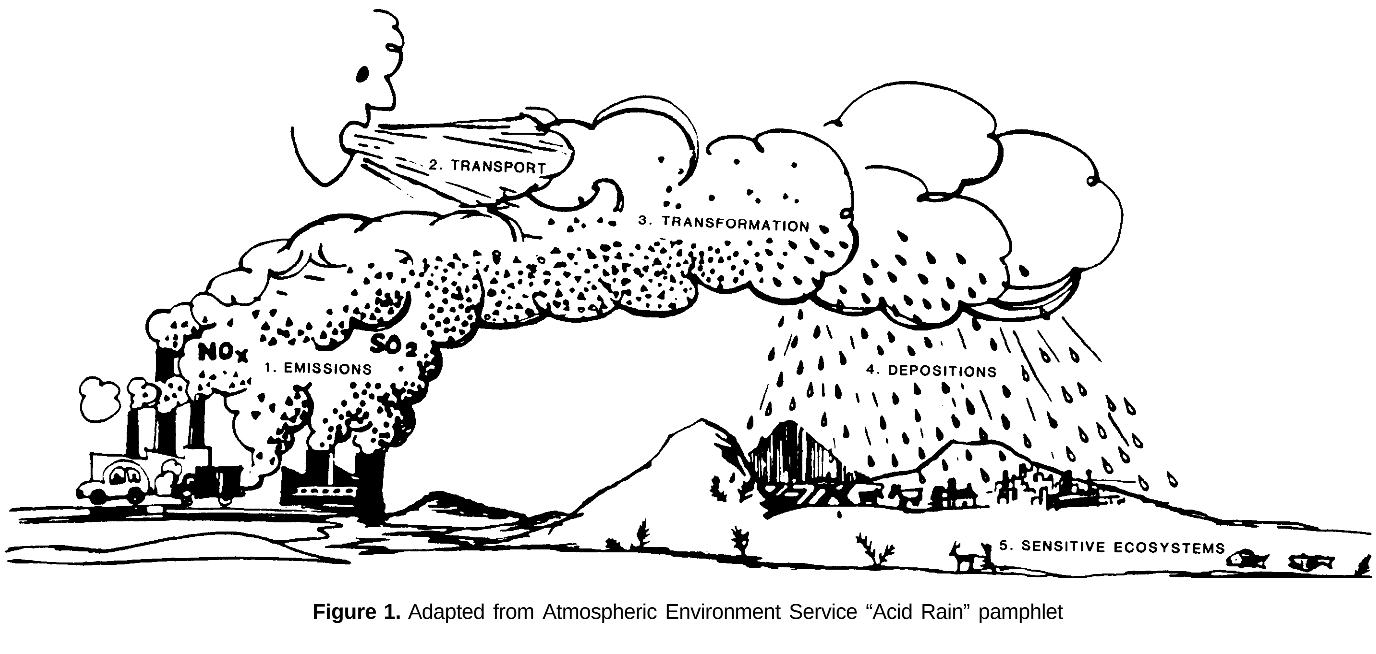


Figure 1. Adapted from Atmospheric Environment Service "Acid Rain" pamphlet

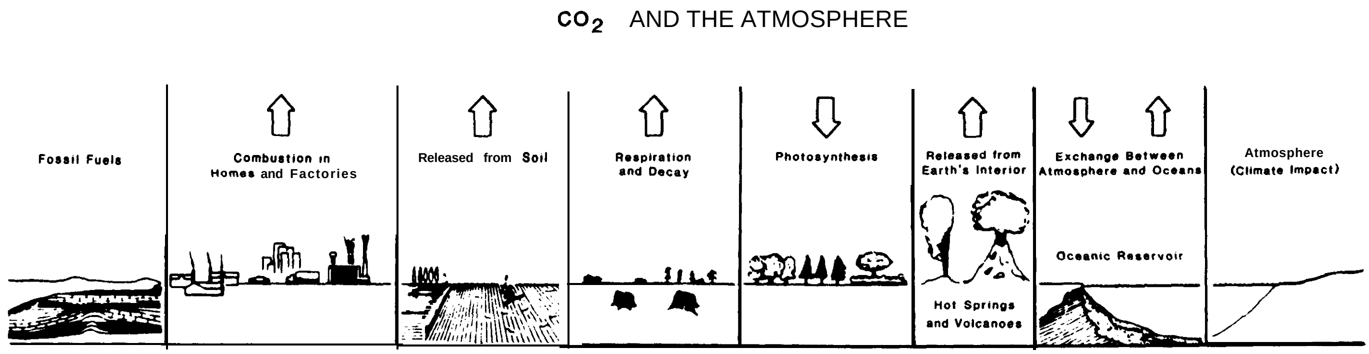


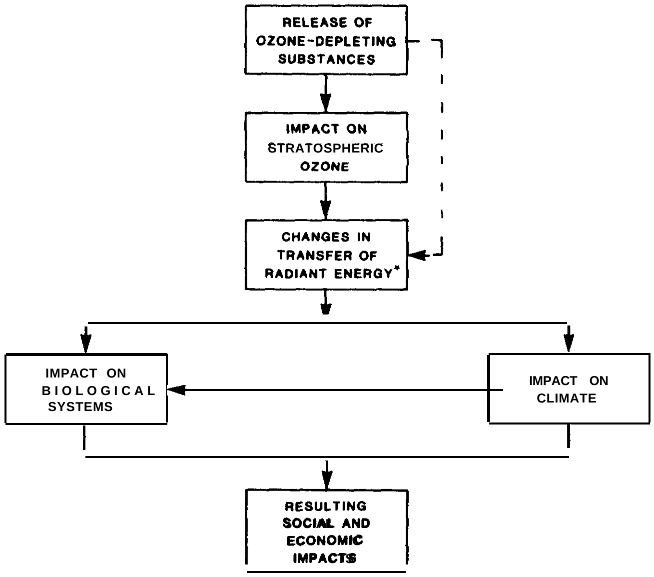
Figure 2. Adapted from N. Plass

Carbon Dioxide (CO,)

Increased loading of the atmosphere with carbon dioxide results in large measure from the burning of fossil fuels, from deforestation, and as a result of land use practices. Concern with CO, has centered around the probable increase in the temperature of the lower atmosphere, and the alterations in rainfall regimes that it might produce around the world. This is considered a global problem in cause as well as in effect.

Chlorofluorocarbons (CFCs)

Chlorofluorocarbons (CFCs) are man-made chemicals that have been used extensively in the manufacture of consumer and industrial products, ranging from hair sprays and deodorants to refrigerants and chemical solvents. They are inert gases that diffuse into the stratosphere where, by their dissociation, they enter into a complex reaction that destoys ozone. Ozone shields the earth's surface from harmful ultraviolet radiation (UV), and it has been suggested that with a 1% decrease in stratospheric ozone there would be a 2% increase in skin cancer. An increase in UV would also have an adverse effect on marine and terrestrial ecosystems. In addition, CFCs are known to contribute both directly and indirectly to the warming of the atmosphere, and therefore reinforce the atmospheric warming associated with CO, increases. Both effects may have global consequences.



*Includes both ultraviolet radiation (notably uv-S. 290 to 320 nanometers wavelength), visible. and infrared (IR) radiation.

Figure 3. From SRI International (1980).

AUTHORS' ASSUMPTIONS

There are many other chemicals emitted to the atmosphere as gases or particulates that we shall not discuss in this paper such as methane, ammonia, tropospheric ozone, VOCs, and so forth. Each of these has impacts on the environment and especially on the atmosphere. We have chosen to focus our attention in this discussion paper on three of the most popularly discussed "pollutants": CO_2, CFCs, and SO, and NO,.

The worldwide distribution of the sources of these pollutants (CO,, CFCs, SO, and NO,), and the difficulty in understanding the environmental changes they might bring about, underscores the need for cumulative impact assessment. By cumulative impact assessment we mean the quantitative evaluation of the collective effects, actual or projected, of pollutants acting singly and in combination over a specified period of time.

The authors assume that among the important goals of North American societies are the maintenance of ecosystems, human health, and, more generally, the quality of life, and that the maintenance of atmospheric quality is an important step toward achieving those goals. For example, changes in the kind and proportion of chemical constituents of the atmosphere (such as CO, and CFCs) can alter precipitation, temperature, wind stability, and other atmospheric factors that are environmentally important. Thus, these atmospheric pollutants, either alone or in combination, could bring about a redistribution on local, regional, and global scales of some of the earth's ecological resources and natural hazards. Of major importance also is the atmosphere's role in diffusing, transforming and transporting pollutants. The impact of many but not all pollutants on the atmosphere is minimal from the standpoint of the functioning of the atmosphere as a system.

IMPORTANT QUESTIONS

Recognizing that we are deviating somewhat from the suggestions set out in the worksheet for the authors, we will approach the topic of cumulative impact assessment by asking a set of questions that we consider important. The questions that we shall focus on are as follows:

- Has cumulative impact assessment been neglected?
- Whose responsibility is cumulative impact assessment?
- Do technologies exist to reduce future pollution of the atmosphere to acceptable levels?
- Where is the best place to control the problems under consideration?
- Should we focus on integrated management of these disparate "pollutants" rather than on cumulative impact assessment?

Has Large-Scale Cumulative Impact Assessment Been Neglected?

The statement to participants about what is expected of them for this meeting implies that many of the efforts at cumulative impact assessments have been site-specific, industrial project-specific, or pollutant-specific studies. In addition, it suggests that most of those studies failed to address the broader, cumulative (and interactive) nature and impacts of "pollutants."

One could effectively argue that scientific information gathered from networks, models, and other sources is already being used in cumulative assessments. For example, the damaging regional effects of sulfur dioxide and oxides of nitrogen, have been considered jointly (EPA 1983; Middleton 1984). The effects of CO, on global temperature averages are being considered in conjunction with the effects of chlorofluorocarbons (CFCs) and other radiatively active gases (e.g., Dickinson 1985; Ramanathan et *al.* 1985).

The atmosphere and its propensity to diffuse, disperse, retain, and deposit airborne chemical gases and particulates have been studied worldwide on local, regional, and global scales. There are monitoring networks and large-scale models of the atmosphere. Global atmospheric circulation models are highly advanced. Well developed programs exist nationally and internationally to monitor and acquire the data needed for predictive models of the atmosphere. The World Meteorological Organization's background air pollution monitoring network (BAPMoN) now consists of about 140 stations operational and 50 more planned in more than 100 countries. The purpose of the WMO's network, which provides information on pH, NH,+, SO,- –, SO_2, NO_3^- and CO_2, is to measure background concentrations of these chemical constituents and their variability, so that the influence of human activities on the composition of the atmosphere can be better understood (Georgii 1982).

Regional monitoring networks, developed for the study of the long-range transport of air pollutants such as those involved in the formation of acid rain, provide a considerable amount of detailed information required for regional atmospheric monitoring, modeling, and in some general way, prediction.

Urban air pollution models account for physical and chemical properties of the urban atmospheric environment, and of the chemical reaction behavior of these pollutants.

It is important, however, to remember that models of the atmosphere are simplifications of reality. Thus, model "results" should not be allowed to take on a reality of their own, as they are used as inputs into the policy-making process. As heuristic devices they can be quite useful, but they do not provide definitive guidelines to those who make policy related to atmospheric pollution. One of the major problems relates to the prediction of the movement of atmospheric systems. Yet, further understanding of those movements depends more on the development of scientific understanding than on obtaining additional research funds for impact assessment. Therefore, from the perspective of the atmospheric sciences, it seems that cumulative impact assessments are undertaken to some degree, within the limitations imposed by the state of the art of scientific understanding, and the relatively scarce resources thus far allocated by governments for such purposes. Clearly, more could be done in this area, but to argue that nothing is being done would be misleading.

Whose Responsibility is Cumulative Impact Assessment?

There are many social, political, economic, and environmental groups interested in the state of the atmosphere. The two main operative groups are atmospheric scientists (in the broadest sense), and atmospheric managers. Scientists can be further divided, according to their scope of interest, into those who focus on a specific element of a larger complex system, and those who focus on broader aspects of the atmosphere. The former group, for example, might concentrate on the effects of a particular item (chemical constituent) or a particular factory (one pollutant), or on a specific local area (adjacent ecosystem), and on a short time-frame (e.g., the impacts that occur in a short time after emission). This might be viewed as a "bottom-up" approach to understanding the environment. The latter group, taking a "top-down" approach believes new understanding of the atmosphere might be uncovered by taking a global approach.

An example of such an approach might be experiments with global circulation models (GCMs) to assess the possible impact on atmospheric temperatures of large CO_2 increases in the atmosphere. These GCM experiments are sensitivity studies designed to ascertain the limits to the robustness or resilience of the atmosphere. While they are in reality gross simplifications of the real world, they can identify relationships between parameters that could further our knowledge of how the atmosphere works. The results of the GCM experiments, however, must be treated as suggestive and not definitive. For example, they are not presently capable of reliably predicting regional impacts of a CO_2 warming, information that would be required as input into the policy-making process with respect to the continued dependence of societies on the use of fossil fuels.

Similar subdivisions can be used for atmospheric managers as well. For example, a manager's responsibility might be site-specific, assuring the well-being of people and the atmosphere in his relatively narrow area of jurisdiction (e.g., air quality in Denver). His concerns and actions would normally reflect the spatial limitations of his jurisdiction. Other managers have responsibility for broader geographic (atmospheric) jurisdictions up to and sometimes beyond the nation-state (e.g., transboundary air pollution). As generalists, they may be more concerned with broad problems related to the atmosphere rather than specific ones taken in isolation from others,

Atmospheric scientists and managers are in many ways dependent on each other in dealing with atmospheric problems, yet neither can give the other what they most need: managers can't provide scientists with political support at the highest (or maybe at any) level so that immediate action could be taken based on scientific research findings; scientists are unable to provide managers with the high degree of certainty that they need to build political (as well as popular) consensus to support their atmospheric management strategies.

Different groups have different responsibilities at the various stages in the pollution process. Who then should be the appropriate responsible party for undertaking cumulative impact assessment is difficult to determine or agree upon. Take, as an example, the acid rain formation process in which the important stages have been identified as follows: emissions of the precursors, transport, transformation, deposition (wet and dry), impacts on sensitive ecosystems, and impacts on society and economy. The responsible authority must have relevant information not only about all stages in the pollution process, but from other related sciences concerned with atmospheric pollution as well.

A serious difficulty in impact assessment is the mismatch between management mandates and jurisdictions and the time and spatial scales that the scientist should consider in dealing with natural processes and ecosystems. This mismatch results in inadequate understanding being acquired, and inappropriate responses by management. To adequately address this problem, major changes are required in the way assessments are performed and results implemented.

An additional aspect must be considered in assigning responsibility for management of atmospheric pollution. For many pollutants the atmosphere serves primarily as a conduit, providing a mechanism for transporting them from one place to another in a relatively short period of time. When it serves primarily as a conduit, such as in the transport and transformation of SO_2, the major deleterious impact of pollutants is directly on ecosystems, man-made materials and human health; and the major requirement for the impact assessment should rest with researchers in those fields.

Atmospheric scientists and managers can play a supporting role, however. They can model, measure, and identify the kind of atmospheric pollutants they are concerned with, and advise health departments, ecologists, foresters, oceanographers, and so forth, about what is or will be happening with respect to atmospheric quality. They can also use this information to inform responsible agencies about what is being dumped into the atmosphere and, given the state of the art, tell them what and where the likely effects will be. They can also advise them about what happens to seemingly benign pollutants once they are airborne and react with similar and other pollutants supplied to the atmosphere by other sources, and about extra-juristictional transport issues about which they may have little information or concern.

The atmosphere can also be a receptor of pollutants. This is the case for CO_2 and CFCs, radiative gases that have long residence times in the atmosphere. Their diffusion and impacts are considered global in nature. In such cases the leading responsibility (as opposed to a supportive role) should by analogy rest with the atmospheric managers. They will have to be involved with the atmospheric scientists in determining what the effect of those pollutants will be on climatic factors, such as precipitation, temperature, wind speed and direction and so forth. They will also be involved in determining what locations on a worldwide basis might be affected by changes in these important climatic factors. In turn, they would become involved with ecologists, foresters, oceanographers, fish biologist, weather-crop specialists, among others, in identifying how changes in climatic factors might affect human activities as well as ecosystems. They should become more concerned with understanding what the secondary effects of pollutants with relatively long residence times in the atmosphere might be. To do so, they would have to know what these scientists in other disciplines consider to be the critical climatic factors that will need to be monitored and possibly managed.

In sum, the responsibility for cumulative impact assessment of global pollutants should, ideally, rest with an international agency that can act as an "atmospheric manager," with enough influence on polluting nations to restrict their emission levels. This agency, of course, would have to have the inputs of an international, multidisciplinary scientific community, that would include ecologists, chemists, oceanographers, and atmospheric scientists, among others. Since there is presently no international agency with sufficient political influence to carry out this job, the responsibility for cumulative impact assessment rests with the scientists themselves; ecologists, in the case of pollutants where the atmosphere acts as a conduit, and atmospheric scientists when the atmosphere acts as the receptor.

Do Technologies Exist to Reduce Future Pollution of the Atmosphere to "Acceptable" Levels?

The answer to this question depends on the specific pollution problem, and the specific stage in the pollution process. In general, however, the answer for acid rain and for CFCs must be yes. MacNeill (1982) of the Organization for Economic Cooperation and Development (OECD) Environment Directorate, stated that:

> *Excepting CO_2, adequate and reliable technologies now exist on a commercial basis to control to a high level of efficiency most of the potential air pollutants associated with coal combustion, at least in the large boilers used for electricity generation. Some new technologies which could prove of great significance are a/so on the horizon.*

The problem of controls for any of the three atmospheric pollutants we are discussing — CO_2, CFCs, and acid rain (SO, and NO,), is exacerbated by the worldwide nature of the many sources of emissions.

To control acid rain, three principal methods for reducing the emission of SO, from coal burning have been extensively used: coal washing, flue gas desulfurization (scrubbing), and switching to low-sulfur coal. Promising new technologies now being introduced for coal burning include fluidized bed combustion and limestone injection. Technology is also available for the reduction of NO, emissions from vehicles, and some regulations are already in effect through the U.S. Clean Air Act. All of these technological measures, however, are costly. Steinberg and Albanese (1980), for example, estimate that 90% of SO, recovery at the stack would reduce power plant efficiency by 6-15 % . A study by the National Research Council (NAS 1980), however, estimates that power plant efficiency would be reduced by only 2 %; from 40% to 38%. Whatever the cost, as MacNeill (1982) notes "the control issue is no longer primarily a technological one. The issue has become an economic one. How much does pollution control cost, or more specifically, how much pollution control is cost effective?" Former Canadian Minister of the Environment, John Roberts, painted a slightly different picture of the existing constraints on acid rain reduction, when he commented that "the evidence all leads to the inevitable conclusion that the most effective countermeasure is a system of emission controls at source. Politicians must make decisions based on this evidence. They must solve the problems of acid rain" (Roberts 1984).

With respect to the release of CFCs to the atmosphere, effective steps have already been taken in many countries to reduce CFC emissions. The production of CFCs dropped 18 % between 1974 and 1980, as a result of decisions taken by governments and industries. The controls range from the outright banning of production for non-essential (e.g., spray can) use, to warnings on labels of aerosol cans, to a request to industry for voluntary restrictions. Action on the CFCs was taken despite scientific uncertainties in the evidence as to the depletion of stratospheric ozone, most probably because suitable alternatives were available, and because the economic consequences of emission reduction (in this case, product substitution) were not considered to be major. However, CFC production for industrial and consumer use as refrigerants, solvents, and foams has not been affected by these controls, and the initial reduction in CFC production is now being partly offset by increased production in developing countries (Weather and Climate Report 1984). There is no presently available technology for the capture and disposal of CFCs once they are emitted to the atmosphere.

Likewise, with respect to the capture and disposal of carbon dioxide emissions, there are no viable control strategies at present (Baes *et al.* 1980). Therefore, the amount of CO, produced can only be controlled at the pre-emissions end of the pollution process, a problem that is much more political and economic than technological. A reduction in CO, emissions could be achieved by using fossil fuels that are less polluting, i.e., natural gas instead of coal; or by using non-fossil fuel energy sources, such as nuclear power, hydropower, or solar, wind, and other renewable energy sources, as well as conservation (Bach 1984). The use of alternative energy sources would also contribute to the reduction in acid rain precursors. However, each of these energy alternatives pose problems of either cost, scarcity of the energy sources for some countries, perceived safety in the case of nuclear power, and perceived effects on economics and lifestyles in general (Clark and Marland 1984).

Where is the Best Place to Control the Problems Under Consideration?

The general consensus among environmentalists is that the most effective place to restrict atmospheric pollution is at the source. From. an atmospheric management perspective, intervention in the pollution process at the pre-emission or emission stage could minimize the atmospheric component of the problem. For acid rain this view was strongly stated by the Swedish Minister of Agriculture (Dahlgren 1982) who noted that "Any reduction of the acidifying emissions of sulphur and nitrogen compounds will be beneficial to the environment; there is no threshold value that must be achieved before one can discern a positive environmental effect". MacNeill (1982) states, "By and large, it seems clear that control-at-source is preferable from the viewpoint of macro-economy efficiency."

The sources of these "pollutants," however, are many and frequently are in areas outside the one being adversely affected. For acid rain, for example, the use of tall stacks, specifically employed to disperse the pollutants over larger, more distant areas by increasing the long-range transport, made specific sources of pollution that caused damage in a particular area difficult to identify. NO, emissions add to the complexity of source determination. We ultimately come back to the questions of which source(s) to control, and to what degree?

Control at the source has not been acceptable to various interest groups, who argue that emissions control at the source would require draconian economic measures that would hurt industry and society. Yet, costs of inaction as well as of different actions will have to be borne by someone in society. Depending on the place in the pollution process that one seeks to apply controls, different groups will have to bear the costs. In a way, that is why it is so difficult to reach agreement on how, where, and when to control these pollutants or their precursors. If policy makers cannot implement control measures at the source (such as the use of scrubbers or the switching either to low-sulfur coal or to alternative sources of energy), then the problem has been converted from one of energy to one of the atmosphere, and thereby passed on to the atmospheric managers for resolution. Yet, all the atmospheric managers might be able to do is to monitor the constituents of the atmosphere, and to provide that information to policy makers, industry, and the public. In other words, the atmospheric scientists and managers (and, later, the ecologists, foresters, etc.) have inherited a pollution problem, because decision makers failed to accept the optimal control strategy (i.e., at the source).

Once the pollutants are airborne, it becomes necessary to find a tolerable fallback position, such as the acceptance of a predetermined level of atmospheric degradation. This approach, too, has generated much debate about what those predetermined acceptable levels of atmospheric pollution should be. Such a fallback position requires consensus among competing and often diametrically opposed interest groups on standards, on the management tools to ensure compliance, and on compensation for damages or punishment for violations. Once the pollutants are emitted to the atmosphere, demands are made on the atmospheric scientists to provide for the monitoring (and prediction) of levels, as well as trajectories of these pollutants so that appropriate controls can be instituted or a foundation for possible legal action established.

Political instruments are available for the control or regulation of emissions. Among these are:

- direct control, taxation, licenses, etc.,
- consensus building,
- multilateral principles of conduct, treaties and conventions,
- compensation, litigation,
- unilateral extraterritorial application of laws,
- import /export controls, EISs, disclosure requirements, withholding incentives, etc.

These instruments allow governments to affect environmental policies both within and outside their borders. Collectively, they can be quite effective.

For example, the Economic Commission for Europe (ECE) has negotiated a convention (the 1979 Geneva Convention on Long Range Transboundary Air Pollution) on acid rain, which, as of October 1984 has been ratified by 30 out of 36 countries. It commits the signatories to develop the best policies and strategies to combat air pollution. Many members of the ECE, including Canada, have agreed to reduce emissions or transboundary fluxes of sulfur by 30% over the next decade.

Instruments for pollution control exist, but political compromise is needed. The Geneva Convention does not stop pollution, but instead enables a level of reduction that is acceptable to the signatories. The 1979 Convention of Long-Range Transboundary Air Pollution and the United States-Canada Memorandum of Intent on Transboundary Air Pollution, which could eventually lead to a binding air quality agreement, are steps in the right direction, but they, too, represent compromise. A Canadian strategy now under discussion is to use a threshold value for sulfate deposition of 20 kg/ha/yr for sensitive receptor areas. Similar strategies have now been proposed by the States of New York and Minnesota. Again there is no intent to stop the pollution, but to limit it. Recently, some ecologists have suggested that wet sulfate deposits should be reduced even further to 14-16 kg/ha/yr (e.g., Weather and Climate Report 1984). Singer (1984) states that "we know that it is not possible at this time to establish a precise loading (i.e., deposition) below which the average sensitive aquatic system will be protected."

The preceding discussions raise the paradox of second best with respect to the environmental issues; if acceptance of the set of best strategies cannot be achieved, then a second best must be resorted to, even though it is known that a second-best strategy would yield a much less desirable outcome. If we assume there are known technologies that reduce the amount of effluent into the atmosphere, but agreement cannot be reached among contending parties about whether, when, where, or how to apply them, then alternatives must be sought. These alternatives, although less effective, may prove to be the only choices that can be made through political compromise. One must ask, however, if such second-best strategies can achieve desired goals. Furthermore, this brings up the question of whose goals are being achieved. Short-term socioeconomic rewards may be rated higher by the decision maker than long-term sustainability of the environment. Consider this question for the three pollutants we've been discussing — acid rain, CO_2, and CFCs.

As previously noted, acid rain can be controlled at its sources: power plants, smelters, factories, and motor vehicles. Switching from high- to low-sulfer coal and the use of scrubbers, etc. can reduce SO, emissions, but the price is costly for control equipment or for lost jobs, if certain coal fields must be abandoned. The U.S. Electric Power Research Institute has estimated the cost of a 50% reduction in SO_2 emissions at $10 billion (U.S.) a year for many years (Abelson 1984). Therefore such strategies have been opposed. The environmentally optimal actions for the reduction of acid rain appear to be denied to those seeking its control because of economic and political factors. Options that are being implemented do not aspire to rigorous control, but are acceptable to governments, industry, and labor, because they do not threaten their established activities. Stanovnik (1982), commenting on the decade after the U.N. Stockholm Conference on the Environment, claims "that while attitudes are changing, the process is too slow in view of the magnitude of the challenge."

While the 1979 Convention of Long-Range Transboundary Air Pollution and the United States-Canada Memorandum of Intent on Transboundary Air Pollution are steps in the right direction they, too, represent compromise. Yet, there are costs, not only of action but of inaction as well. Presently much of the cost is borne by lake and forest ecosystems, health, and property. The cost is partly borne by industry, and is passed on to the consumer as increased prices. Taxing the public directly to further diffuse the cost of control at the source, and hence make it more acceptable to industry is yet another option. These solutions are second-best fallback solutions that offer only partial relief. Nevertheless, they serve as evidence that positions held by varying groups on atmospheric pollution are beginning to converge. Although, at least on some issues, environmentally desirable solutions may not be attainable, steps are being taken to agree on second-best strategies.

Strategies for the control of CO, center on reduced use of fossil fuels, These strategies have not been well received because of the favorable characteristics of fossil fuels as an energy source, and the related economic advantages they provide. In view of the importance of coal to many economies, it is not likely to be abandoned for environmental threats for which the evidence is relatively more tenuous than for acid rain.

With respect to the control of CFCs, compromises also had to be made. "Nonessential" uses of CFCs were curtailed or in some cases eliminated, but the reduction of CFC production for industrial and consumer use as refrigerants, solvents, etc. has not been implemented. On the contrary, production for these uses has been increasing, negating some of the benefits achieved by the elimination of CFCs in aerosol cans.

Even if some of the sources, even the major ones, are controlled, the cumulative problem will only be delayed, not avoided. If, for example, the United States stops all nonessential production of CFCs (as it did in the mid-1970s) without compliance with similar controls elsewhere, the decrease will eventually be replaced by new or increased production elsewhere. Similarly, the industrialized countries are presently the major producers of CO_2, but the share of total CO, production by developing countries has been increasing. Thus, one could argue that, unless unilateral action to reduce CO_2 production is followed by general support (and action) on an international scale to reduce CO, emissions elsewhere (an unlikely prospect), the unilateral action would only have delayed briefly the CO, loading of the atmosphere. In the acid rain situation, transnational boundary pollution has become an international political crisis, subject to all the problems associated with polluters on one side of the border benefiting from activities that produce the pollution, and affected parties on both sides of the border bearing all the costs.

Should We Focus on Integrated Management of These Disparate Atmospheric "Pollutants" Rather than on Cumulative Impact Assessment?

The notion of integrated management refers to the management of the major airborne pollutants, the sources of those pollutants and their receptors (the atmosphere or ecosystems).

As pointed out, it is now technologically possible to control the polluting effects of fossil fuel combustion at the source, except for CO,. It is also possible, with integrated management strategies, to protect the stratosphere through regulation and/or substitution. Given that we have the technology, why does the problem persist?

The lack of action does not stem from an inability to carry out meaningful cumulative impact assessments. Rather, it appears to be centered on politics, economics and scientific uncertainty.

As noted throughout this discussion paper, each of the atmospheric concerns can be considered in stages from emissions to transport to impact. Different authorities have responsibility for each of the different stages in the process of pollution. Those who are responsible for ensuring that the country has ample supplies of cheap energy will foster their use in place of the costlier, though cleaner, energy sources. Thus, in the United States, the Department of Energy has certain responsibilities to keep the supplies of energy high and to keep energy flowing. The Labor Department is concerned with unemployment and would not favor the switching from high-sulfur to low-sulfur coal because of the economic dislocations that might ensue. The Commerce Department would be reluctant to support policies to protect the environment at the cost of idling factories or cutting back on their levels of productivity. Ecologists in other parts of the country (or in other countries, for the CO, and CFC problems) might oppose the use of dirty fuels in some distant place for the sake of protecting ecosystems in their jurisdiction.

Perhaps a single supra-state or supra-national decision-making unit with authority over each and all stages in the acid rain process from pre-emissions to ecological impacts, is what is needed; an organization that could operate like the European Steel and Coal Community did in the 1960s. This community was among the first supra-national organizations designed to make policy not directly subjected to the veto of any one European country over which it had jurisdiction with respect to steel production. Of course, the establishment of such an organization would be a political nightmare.

Controls in one county or country alone will not solve regional and global atmospheric problems. The concurrence of at least the major polluting countries is required. Unilateral action to reduce emissions gives an economic advantage to others who do not. That consideration alone tends to delay positive action (much like the concept of "Tragedy of the Commons"), as a stand-off develops with none of the contending parties willing to take the first step without assurances that others will do likewise.

Obtaining universal accord on transboundary (intranational as **well** as international) pollution issues is unlikely when some of those involved will be winners while others **will** be losers. For example, it might be in the self-interest of countries in the high latitudes and in the arid tropics, according to some Climate change scenarios, to promote the increased emissions of radiatively active gases. In fact, one Third World scientist has suggested such a strategy (Bandyopandhyaya 1983). A warmer climate might shift agricultural potential poleward, improve transportation at sea, and produce a rainy climate in the circum-Saharan regions as it was thousands of years ago.

Strong economic arguments have been put forward in favor of acid rain control: the losses from acid rain include the decline and disappearance of fish species, a $4 to $7 loss per capita per annum through materials degradation, and the damage to agricultural crops and forests wrought by oxidants and acid rain (Stanovnik 1982). However, strong economic arguments have also been put up against acid rain control by those sectors most likely to bear the cost of such controls. As MacNeill (1982) noted, "The principal issue and the main source of controversy is who should bear the costs, how the costs should be borne, and when." The costs may be borne by society at large (acid rain destruction of buildings and ecosystems), by industry (the emitter), or by the taxpayer in the region responsible for the emissions, or by the country at large (as having benefitted from the products developed by the use of fossil fuels that caused the pollution). The decisions as to who pays, ultimately resides with governments and the publics that they represent.

While some degree of scientific certainty has been established for the damaging effects of acid rain on certain ecosystems, it needs to be more firmly demonstrated for others (e.g., forests, health, and agriculture.) Firor (1984) identified three areas of uncertainty concerning acid rain — What areas need to be cleaned up? How much must emissions be reduced? What loading is tolerable? These are primarily modeling, ecological, and cost/benefit problems.

Concerning the impacts of radiatively active gases, such as CFCs, on stratospheric ozone, even greater uncertainties exist. CFCs are a problem for human health (e.g., the UV and skin cancer link), as well as a problem for global atmospheric temperature. Yet, the results regarding ozone depletion related to the man-made CFCs has constantly been changing, as, for example, new scientific information becomes available about the possible effects on stratospheric ozone of volcanic eruptions, and variations in UV output of the sun (e.g., Weather and Climate Report 1984), not to mention new insights into chemical reaction rates of CFCs.

Continued research has led to improved understanding of CFCs' impacts on both the atmosphere and ecosystems, and has called attention tc the possible effects of other chemicals on ozone (e.g., carbon tetrachloride, chloroform, methane, and nitrous oxide), as well as to the implications for the climate system of the radiative characteristics of CFCs and other chemicals. CFCs, for example, are 100,000 times as effective as CO, on a molecular basis in contributing to the greenhouse effect, and may prove equally as important as CO, by the year 2000 (Cumberland et *al.* 1982).

There are other questions that influence decisions about controlling emissions: Who is affected, the polluter or someone else? To what degree should the future be discounted? What are the political commitments to different interest groups such as labor and industry? With respect to the last question, can industry (and ultimately the consumer) cope with the projected costs of emissions control? Will labor groups tolerate the unemployment associated with the projected closings of mines that produce high sulfur content coal? Many factors must be weighed and political "wisdom" might be to select inaction at a particular time, attributing the selection of that option to scientific uncertainty.

Scientific uncertainty paves the way for policy makers to avoid dealing directly with the environmental problems at hand. If there are scientists supporting the environmental groups saying that the lack of control of atmospheric pollutants will lead to the degradation of the atmospheric environment and scientists supporting the industrial polluters, saying that the relationship of emissions to damage is not clear, then these scientific opinions can be said to balance each other out. As a result, the decision makers are freed from basing their policies on scientific information, and can resort to those policies that might be most politically expedient to them. A narrowing of the band of uncertainty is needed to enable better legal and economic decisions. Ensuring that this need is reflected in the impact assessment process would be a step in the right direction.

In brief, the technology exists for control and assessments: the obstacles are economic, political and scientific (e.g., uncertainty). Overcoming these obstacles is unlikely in the near future given the present division of political authority and existence of a multiplicity of self-interest. The solution may be in integrated management — integrated to those levels that match the spatial scale and complexity, both scientific and political, of the impact problem. UNEP has a monitoring function for monitoring CFC production on a worldwide basis, but it lacks the authority to control production. The delegation of such supra-national authority is needed. However, as Ashby (1984) points out, "international law and policing cannot alone cope with the issues; there will need to be a massive consensus which puts long-range interests before short-term convenience, and as yet there is no sign of that."

CONCLUDING COMMENTS

No matter where society decides to control these environmental problems, one issue remains: Who pays? In North American societies it appears that we have a conflict between norms that we live by when it comes to atmospheric pollution. For example, there is a general principle that "polluters must pay" for the pollution that they cause. On the other hand, there is the view that "one is innocent until proven guilty." Clearly these two norms are in conflict when it comes to atmospheric pollution problems. Acid rain is an example. We know that tall stacks were used at least as early as the 1950s to disperse pollution that had been a local problem; the solution to pollution was dilution. While it is very difficult, if not impossible, to relate a specific source of pollution to a particular impact on an ecosystem, (i.e., a lake) it is known that the tall stack in a certain part of the United States or Canada is spewing out precursors to acid rain formation, and that it is responsible for an epsilon of pollution somewhere in an area that can be determined by regional atmospheric models. In general, one could argue that the polluter is known without tying that polluter to this particular impact on that particular ecosystem. The questions this discussion raises are as follows: should the dictum that the polluting factory be considered innocent until proven guilty apply? Can it be proven beyond a reasonable doubt? How can the "polluter pays" principle be reconciled to the "innocent until proven guilty" principle before it is too late and society at large has paid an unacceptable price? Is the "polluter must pay" principle applicable to regional and global issues?

With respect to CFCs, Mishan and Page (1982) have suggested two regulatory guidelines. One guideline they suggest, is currently in effect and would permit continuing any economic activity until evidence of damage beyond reasonable doubt is provided. The other guideline which they support for CFCs "would ban potentially catastrophic products until plausible evidence of safety is provided (the use of materials like CFCs cannot justify even the small risk of future catastrophe)."

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COMMENTARY I

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The materials sent by the workshop organizers requested that the papers illustrate basic problems and principles in cumulative impact assessment (CIA); and then develop recommendations for scientific research to improve practices in CIA and how management activities relate to CIA.

My discussion of the issue of cumulative impacts on the atmosphere, from a management perspective, and of the paper by Glantz and McKay (this volume) is presented in two parts. First, I set forth comments on the paper, and then I address the general issue of what can be managed in the atmosphere, and how that relates to cumulative impacts.

GLANTZ-MCKAY PAPER

One could assess the Glantz-McKay paper from the standpoint of fulfilling the assigned questions and workshop goals and objectives. The authors chose to deviate, at least partly, from their assigned activities, but the paper is very informative.

Glantz and McKay chose three large-scale, hemispheric or global atmospheric problems to focus on: acid rain, CO_2, and CFC, those inert gases that affect ultraviolet radiation and can cause global climate effects. The authors' chose these because of their global distribution and wide-scale effects, which may need cumulative impacts assessment. By their choices, they force their consideration of CIA within a global perspective. The authors' choice of large, global scale phenomena to illustrate cumulative impacts on the atmosphere should not be construed as a necessary scale. Studies of how major urban areas affect clouds and precipitation have conclusively illustrated that four different influences (heating, moisture, particulates, and mechanical mixing) interact to increase clouds and rainfall (Changnon et al. 1981). The authors' do define CIA as "an assessment of the summation of all atmospheric impacts that these pollutants cause." Basically, it appears that their concern over CIA is on the physical effects and not the socio-economic impacts, although they do deal with the institutional approaches for resolving the impacts of CO_2, acid rain, and CFC.

The basic focus of their paper on CIA and the three atmospheric pollutants is centered around five major questions, which in turn form the five major sections of their paper.

Has large scale CIA been neglected? After analyzing what is being done in CIA and in other impact research, the authors conclude that some CIA is being done, and that much more could be done.

Whose responsibility is CIA? They recognize that many groups are interested in the atmosphere, but that they fall into two basic categories: the scientists and the managers. Both of these two categories have two subdivisions. The scientific group is either those interested in working on the local level, or those working on the global scale. The atmospheric managers are also categorized at two levels: those functioning at the local level, and those at the larger or national scales.

They express a very key point for CIA considerations in that "The results of the GCM experiments however, must be treated as suggestive and not definitive. For example, they are not presently capable of reliably predicting regional impacts of a CO, warming, information that would be required as input into the policy-making process with respect to the continued dependence of societies on the use of fossil fuels." This is a theme that is found throughout their paper, and leads to some of their most important later conclusions relating to the value of CIA.

They further indicate that the ideal world would have an interaction between atmospheric scientists and managers, but this interactive model fails because neither group can deliver necessary ingredients. I agree with their somewhat negative concept.

An interesting conclusion is that when the atmosphere serves as a pollutant conduit (SO,), the responsibility for action lies with the scientists, and when the atmosphere acts as a "receptor" (CO,), then the responsibility lies with the managers. Regardless, atmospheric scientists and managers can only play a supporting role, according to the authors, and others are left to make final decisions in the political process. Glantz and McKay may miss an important point: one of the problems existing between scientists and managers is that managers have to act and make decisions frequently at different time and space scales than the scientists or the phenomena lend itself to. There are excellent recommendations for the roles of the scientists and the managers. The major conclusion is that the responsibility for CIA and management in the area of global pollutants should ideally rest with an international agency ("atmospheric manager"), but then the authors conclude that this is an impossible condition to occur. Is it too negative?

Do technologies exist to reduce future atmospheric pollution to an acceptable level? The authors conclude that the technology exists to address acid rain and CFC problems, but the options include technologies that are costly, and they are also faced with uncertain controls or reductions. CO, does not have an existing technology, and requires "pre-emission controls" such as using less coal, more natural gas, nuclear power, and other alternative energy sources. Thus, it is more an economic and a political issue than a technological one.

Where is the best place to control the problems? Obviously the best place to control each of them is at the source, but the authors believe that our current society and institutional arrangements will not allow that to be done. Controlling pollutants in the atmosphere is difficult, because there is too little scientific agreement on their dispersion, transformation, and concentrations.

I was impressed with the ideas and statement of the problems relating to these three atmospheric pollutants, their control, their impacts, and the difficulty faced by policy makers. The authors conclude that without control at the source, whatever atmosphere control is done will be via the process of compromise between countries and economic sectors. As stated, “although, at least on some issues, environmentally desirable solutions may not be attainable, steps are being taken to agree on second-best strategies.” That is probably the most optimistic view presented in this “best place assessment.”

Should we focus on integrated management of disparate pollutants rather than on CIA? This gutsy question is a key one in relation to this workshop. Many interesting conclusions are presented in this section. The previously stated technological, social and institutional problems presented in the prior section lead the authors to the point of saying that “The lack of action (on these major pollutants) does not stem from an inability to carry out meaningful cumulative impact assessment. Rather it appears to be centered on politics, economics, and scientific uncertainties.” If I had to choose one statement that typifies the authors’ views, this would be it.

The lack of ability to control these pollutants at the source, and the difficulties of controlling them in the atmosphere, relate largely to the fact that so many different authorities have responsibility for each of the different stages in the process of pollution, a very critical and important concept. One might ask the authors whether the economic and legal uncertainties related to inaction might be due to the lack of CIA? Regardless, the authors come to the general conclusion that integrated management of these disparate pollutants has more likely value than CIA in solving the problem. As they argue, “the solution may be in integrated management... integrated to those levels that match the spatial scale and complexity of the impact problem.” Thus, they doubt that CIA offers a major solution to the atmospheric problems created by these three major pollutants.

They offer some other important views with which I strongly agree and which impact on CIA. First, “scientific uncertainty paves the way for policy makers to avoid dealing directly with the environmental problems at hand.” And then, “In brief the technologies exist for control and assessments: the obstacles are economic, political and scientific (e.g., uncertainty). Overcoming these obstacles is unlikely in the near future given the present division of political authority, and existence of a multiplicity of self-interests.”

In general, I have little to quarrel with in their paper. It brings extremely insightful views to the issue. CIA is not seen as a special solution to answering these problems. The general philosophy is one that believes the world will go on unchanged, even with better impact information.

ATMOSPHERIC MANAGEMENT

Beyond the analysis of Glantz and McKay, which considered cumulative impacts from three global scale pollutants in the atmosphere, other effects on the atmosphere reflecting diverse influences, multiple impacts, and related management should be considered. I have chosen to address the question: What is being and could be managed in the atmosphere? This is a different approach from that of Glantz and McKay as to what is managed in the atmosphere. This approach tries to use that information to detect ways to address management of conditions causing cumulative impacts on the atmosphere.

In this assessment, I have attempted to list most man-made influences on the atmosphere, such as changes in the chemistry of the atmosphere, and then what conditions are altered, the scale of the change, why management is needed, and what control approaches have been employed. Table 1 summarizes these issues for four general classes of “foreign” objects found in the atmosphere. These include vehicles and communication systems that utilize air space; gases and particulates that affect atmospheric chemistry; changes in land use and emissions of moisture and heat that affect atmospheric processes: weather conditions and climate; and structures that affect the atmosphere. Air space listings (Table 1) identify that aircraft, missiles, satellites, and communications (transmitted in the atmosphere) all utilize the atmosphere. Control of these is needed for maintaining communications, assuring transportation safety and timeliness, national defense, and noise management. The basic existing control institutions for these conditions are established at the national and international levels. As shown in Table 1, the scale of these atmospheric intrusions ranges from regional up to global, and their control approaches are also national up to global in scale.

Table 1 also addresses the issue of atmospheric effects resulting from releases of gases and particulates, leading to effects on the chemistry of the atmosphere. The effects and management strategies have differed between near-surface conditions and those defined as aloft, or those well above the biosphere. We find effects and management needs in the near surface for aesthetic values such as visibility, for safety, health and for controlling structural and environmental damage. The control is achieved through regulations, economic incentives, and social incentives involving technological innovations.

A third area of atmospheric effects and management relates to human-induced changes in the land surface plus emissions of moisture and heat, all of which can alter atmospheric properties. These effects are also sorted into those near the surface and those aloft. For example, the effects aloft bring alterations in cloud cover, precipitation, and storminess. Management is needed for safety (air travel), to minimize effects on communications due to heavy precipitation and storms, and to address general undesirable effects on climate. An example here would be the influence of jet contrails that produce cirrus cloudiness across the central United States. The effects aloft have been noted from the local (large city) scale up to the regional scales. Control approaches have addressed the purposeful modification of weather, and in the United States the states regulate this activity; hence we have a regional scale of control on purposeful weather modification. We also have controls of certain inadvertent weather modification effects including state laws that protect access to solar and/or wind energy.

A final human-produced effect on the atmosphere relates to structures such as tall buildings that directly affect atmospheric conditions. Management is needed to insure safety, comfort and efficiency in these structures, and that control is totally at the local scale, and done through regulation of structure size and placement.

Comparison of scales of influences and controls in Table 1 reveals that in general, the scale of effects of air space utilization by vehicles or communication systems occurs at the same scale as the controls; that is, management of those atmospheric effects matches the scale of the effects. The same appears to be true with the atmospheric chemistry effects near the surface where controls and effects are in spatial agreement. However, this is obviously not true when one examines atmospheric chemical effects aloft. Here, the effects are shown to range from local to global (such as CO,), whereas the controls range from the point to partial regional scales. Clearly, management has not matched the scale of effect, which reflects the general views in the Glantz and McKay paper. Weather and climate changes aloft have effects ranging from local to global scales, but the controls often strictly point to local events, and thus do not match the effects.

Table 1. Natural and Artificial Atmospheric Influences and Scales.

INFLUENCE	SCALE
Vehicles, Communications Systems and Weapons	Point to global
Control needed for communications, transport, safety, defense, noise abatement	Regional to global
Control approaches — national and international institutions which regulate	National to global
Gases and Particulates	
A. Near surface	Point to regional
B. Aloft	Regional to global
Control approaches to A and B a) regulations, b) economic incentives, and c) social adoption to technological innovations	Point to regional
Emissions of Water and Heat	Point to global
A. Near surface — changed radiation, temperatures, precipitation, humidity, winds, sunshine, severe storms. Control needed for alternative energy, dissipation of heat and moisture, transportation problems, land use management, insurance	Point to local
B. Aloft — changes in clouds, precipitation, storms. Needed for safety, communications, and understanding effects on climate	Local to regional
Control approaches to A and B	
a) Purposeful — regulations	Regional (states)
b) Inadvertent regulations — solar and wind power access — regulate sites — technological fixes — reaction adjustments, insurance	Local to regional
Structures Affecting the Atmosphere	Point to local
Control needed for safety, comfort, and efficiency	Local
Control — by regulations (codes)	Local

The above observations offer some important conclusions related to cumulative impacts and what is, and could be, managed in the atmosphere. First, many atmospheric effects are indeed a result of the interjection and interactions of many foreign objects, pollutants, land surface changes, aircraft, etc.

Examination of Table 1 reveals that some atmospheric conditions that are managed are distinctly local, whereas a few others are regional or global. Generally, one would conclude that the scale of management is a practical one based on what has been established, both scientifically and technically, as an effect. Thus, it would appear that management institutions have been established to handle any scale of effect when the influence was well recognized and considered important.

The regional and larger scale shifts in air quality, both at the surface and aloft, and of climate change aloft are not yet being adequately managed on the scale of their effects. One would conclude that the basic chemical and physical processes are not well understood or have not been sufficiently defined to call for reasonable management choices. Conditions like polluted rainfall, more severe storms caused by St. Louis, and altered cloudiness from jet contrails are the “average” of many point (or line) effects of a physical and chemical nature. The effects are occurring both at and well beyond the source of effect. Such events can not be well managed with a local-state scale management philosophy.

These views of atmospheric management and cumulative impacts point to three recommendations. First, the cost of data collection and surveillance of atmospheric effects, whether they change the climate or alter the atmosphere chemistry, is high. Thus, cumulative impact assessment may be a proper framework to address the design and operation of surveillance-data collection networks. The weather-climate and atmospheric chemistry networks in the United States reflect a disorganized approach to measurements.

A second recommendation for cumulative impact research is that scientific understanding of regional scale pollutant interactions and their direct and secondary environmental effects are not well established. This is an area where CIA studies could be of specific help to management decisions.

A final recommendation, that relates specifically to cumulative impact assessment, is that the management of air quality and climate changes *aloft* is clearly a federal/international role. However, what is being done in North America is done largely by the states and provinces.

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COMMENTARY II

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> **Men** *and* governments *must act to the best of their ability. There is no such thing as absolute certainty, but there is assurance sufficient for the purposes of human life.*

It was with these words of John Stuart Mill that Ronald Irwin, M.P. presented "Still Waters," the first report of the Sub-Committee on Acid Rain. The report defines acid rain as the greatest environmental threat in the 114 years of Canada's existence as a nation.

Acid rain is an example of spatial and temporal effects of multiple development occurring within regional ecosystems and social systems.

Acid rain can then be said to have a cumulative environmental impact.

How could we in the 1950s and 1960s have been so short-sighted as to think that "the solution to pollution was dilution," and build tall stacks thus creating acid rain?

The problem then, as it remains to a large extent today, was the human failing of not seeing, and therefore thinking, beyond "my family" and "next week." Meadows *et al.* (1972) presented an elegant figure of the distribution in time and space of human perspectives (Figure 1).

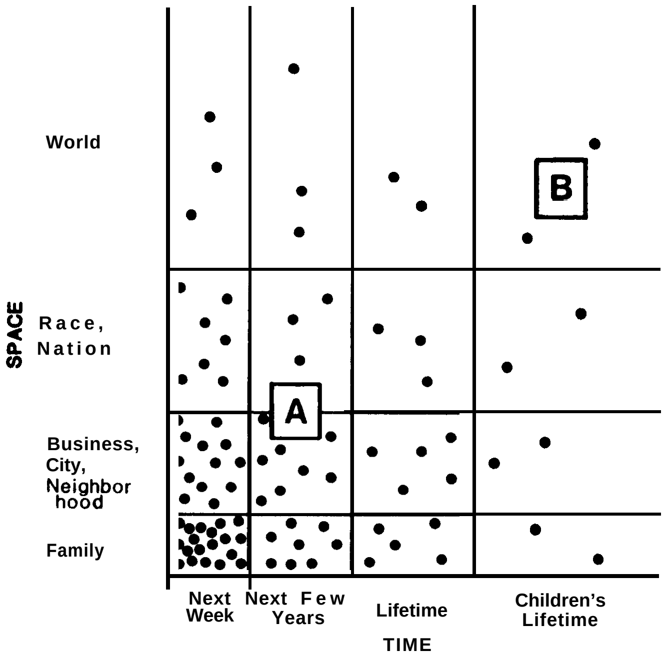

Figure 1.

Carrying out environmental impact assessments forced industry and government to work farther out on the axes — nearer area A.

> *Although the perspectives of the world's people vary in space and in rime, every human concern falls somewhere on the space-rime graph. The majority of the world's people are concerned with matters that affect on/y family of friends over a short period of rime. Others look farther ahead in rime of over a larger area — a city of a nation. Only a few people have a global perspective that extends far into the future.*

The statements made in the definitions for this workshop suggest that we should be working even further out — near area B. (Figure 1) The hypothesis is that environmental assessment and management of individual projects fails to address the full environmental and social consequences of multiple projects whose effects can be additive.

I support this hypothesis in practical terms, but reject it in philosophical terms.

WHERE ARE WE TODAY?

My contention is that the majority of us (scientists and managers) have not progressed away from area A. (Figure 1) Let me give three examples.

- The program for this meeting is divided into four separate areas (terrestrial, freshwater, marine and atmospheric) examining themselves individually to make recommendations for a whole.
- Glantz and McKay (this volume) suggest we focus on "integrated management," where this is defined as related to airborne pollutants, their sources and their receptors — individual components *nor* joined with the whole.
- Government departments look separately at atmosphere, forestry, water, fish and land. Who integrates the pieces?

These examples are indicative of a major gap in environmental activities — the integration of data from different components of environmental and social systems. Such an activity would enable governments to identify significant problems earlier, to pinpoint critical pathways and to more quickly arrive at viable solutions. The acid rain problem is a prime example of the need for such a proactive approach. The correlation of the sulfate loadings of lakes and streams with the acidity of precipitation was not recognized until long after the two kinds of data had been available in their separate disciplines. Within the last two years, these spatial patterns have been confirmed once again by the sulfur in lichens data. This integration of data, reflecting differing temporal scales of acidic deposition, produces much stronger evidence and support for policy (management) positions.

UNCERTAINTY — THE SCIENTIFIC SCAPEGOAT

Glantz and McKay (this volume) introduce uncertainty as a major cause of inaction by politicians. They argue that scientists are "unable to provide managers with the high degree of certainty that they need to build potential (as well as popular) consensus to support their atmospheric management strategies." I suggest that neither the scientist nor the manager is doing his job.

As John Stuart Mill stated "There is no such thing as absolute certainty." The question we should ask is: Are we handling uncertainty properly?

Let us examine this question by comparing the present state of acid rain models (proposed for use in control decisions) and simple climate models used in other kinds of environmental/economic decision making.

Regional climate data such as mean annual precipitation, mean monthly wind speeds and the mean length of the frost-free period, together with their standard deviations, other time series statistics and spatial distributions, do not encompass all possible knowledge, nor even everything scientists now know about these processes. These data, which can be regarded as simple regional climate models, cannot be used to answer all possible questions that might arise anywhere or on any time or space scale about precipitation, winds or frost. Clearly a basic description of the mean annual precipitation over southern Ontario, together with its related statistics, would not allow one to determine the specific annual value for 1985 at one point such as Ottawa, nor to explain a monthly precipitation observation in Washington.

For these problems, it would be equally inappropriate to apply a sophisticated ten-level national weather prediction model.

The mean annual precipitation over southern Ontario and its related statistics are useful for initial construction planning purposes, for example for building dams on waterways (water control structures represent a large investment activity on the continental, national or the state/province scale). These statistics have also been used in the design of bridges where the public requires a large safety factor to be built-in, because the risks involved in not doing so are unacceptable. As in building bridges, where human life is at risk, the protection of intangible environmental components is a major element to consider in the case of acid rain.

In the use of regional average frost-free period statistics and similar data, economically significant decisions are made regarding the choice of major agricultural crop options. Such data (constituting the general planning model) proscribe the envelope of feasibility or the broad decision framework. At a specific farm within the region, where more detailed information is available or can be obtained, more detailed plans can be developed. For example, it is well recognized that the annual frost-free period varies spatially as well as from one year to the next, and that a farm situated in a valley can expect to have a frost-free period shorter than the regional norm. The planning strategy to be used for that particular farm will represent a refinement or a subsequent level of planning within the general regional "planning control parameters." Decisions leading to an optimum management of the farm are not necessarily going to be made all at once. The farmer may gather information and experience over several years before achieving the optimum. This does not mean that he does not do anything for that period of time. In order to meet his particular objectives he can implement a least-risk strategy based upon the information available.

Models are obviously simplifications of reality and as such, the results they give should be used for policy guidance. They can guide the policy maker to reject obviously bad decisions and if policy making is approached in a stepwise manner, one can use the lessons learned (and the passage of time) to improve the next policy step. This might be known as "cumulative policy making" but really would reflect the management of uncertainty.

Let us examine in some more detail how a scientist can provide guidance to a manager by looking at some recent work from the acid rain forum.

CONTROLLING ACID RAIN — SCIENCE AND MANAGEMENT

There are thought to be two modes of ecosystem failure — gradual and catastrophic. From the fanatical perspective, this leads to the black and white dilemma in which we have two extreme options for bilateral control action. These can be simply stated as "no control" and "comprehensive control."

The "no control" option requires that no action be taken until we understand all the processes in detail. Some proponents of this approach indicate that the existing air quality regulations are sufficient to protect the environment while more research is undertaken on acid rain. This option is not realistic for two reasons: the load of sulfur to the ecosystem continues, and there are regions in the United States which currently do not meet the primary sulfur dioxide standards (health-based), let alone the secondary (welfare-based) standards, so that the current strategy is not working.

The "comprehensive control" option is politically impossible because of its cost. Also there is not sufficient information on which to base either a nitrogen, oxidants or even a speciated sulfur control plan. There is growing evidence that "episodicity" is very important, and that consideration of a type of "supplementary control system" targeted at sensitive areas might be a viable option once we can forecast the episodes.

At the same time, economic issues must be considered, so how can the scientist advise the manager?

Acid rain models (relating emissions to depositions) can be exercised to answer the question: What is the minimum amount of sulfur that should be removed (and where) to meet a deposition value that will protect the ecosystem? Young and Shaw (1985) have shown that, if there were no constraints, most of the sulfur reductions should take place in the Ohio River Valley, northern Appalachia, the lower Great Lakes region and the provinces of Ontario and Quebec. When technical constraints were placed upon the allowable emission reductions, the solution remained essentially the same except that a larger area required reductions. They also examined the effect of year-to-year meteorological variability and model-to-model differences. They showed that this type of uncertainty has little affect on the selection of the regions having the greatest contribution to deposition. Rather, this uncertainty affects the selection of source regions which have a small influence on deposition.

Shaw (1985) and Streets et *al.* (1984) have taken this analysis one step further by including the cost of control, so that they attempt to answer the question: What is the most economical way to reduce emissions to meet a deposition value that will protect the ecosystem? Shaw found, for eastern North America, that significant cost reductions, over the minimized sulfur removal strategy, could be achieved in the early and middle steps of a control program. Streets et *al.* showed that the use of targeted strategies to protect the Adirondacks would result in a cost saving of 75-90%, compared to two of the bills before the U.S. Senate, to achieve the same amount of deposit ion reduction.

Alcamo et *al*. (1984) are developing a link between the forest soil pH and emissions of sulfur, to assist decision makers in evaluating the most effective strategies for controlling acid rain impacts in Europe. This will be the first time that the energy system of a country is linked to the acidifying impact on the ecosystem.

Inherently, these types of solutions pose new challenges to the manager because they can only be handled through an "environmental tax," and because it may be better for Canada to pay for some control in the United States, or for one province to pay for control in another province. Glantz and McKay see this type of solution as second best. I cannot agree, if one looks at the scope of the problem. The solution does not fall within the traditional solution parameters which have been rejected out of hand.

The manager, who is in a unique position to integrate different components, may not be doing his job because he:

- is not thinking on the right scale[1];
- is not getting/taking advice from a senior level scientist;
- is hamstrung by the structure within which he works: or
- believes there is a lot of uncertainty and does not know how to manage it.

1 the classical forest and tree problem

SOLUTION

The Oxford English Dictionary defines *cumulative* as "increasing in **force** by successive additions." If we work on the correct spatial scale, "the forest," then we can resolve conflicts at the level of the "individual tree."

Current environmental impact assessments are relatively simple (looking at a group of trees) and so provide simple guidance. This guidance should be interpreted to simplify a definitive policy.

Decision/policy makers can easily be put off by "red herrings". One such red herring in the acid rain debate is described in Glantz and McKay's paper, as linearity (or how much should emissions be reduced?) Oppenheimer (1982) has suggested that predictions of total sulfur may be in error by at most 10% at the state/sub-province level of aggregation. A 10% non-linearity would not change the selection of areas for a first control step.

In practical terms, we fail to address the full environmental and social consequences because the majority of us think too small.

In philosophical terms, as our knowledge grows, we think bigger and we increase our awareness of the consequences of each action (tree).

Our job is really education and encouraging the scientist to look beyond his own work to the larger scale of things. Part of the responsibility of cumulative impact assessment rests with the scientist, but the manager is in the best position to have the broad view and to advise the policy maker to take the "cumulative policy approach."

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CLOSING REMARKS
A CURRENT ASSESSMENT OF CUMULATIVE ASSESSMENT

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THE PROBLEM

A closing commentary has similarities to a statement of cumulative effects assessment. It should be a summary of what has happened or has been said, and the significance of what happened; but it should be more than a simple summary The design and presentation of a cumulative effects assessment statement should show an awareness of the importance of changing things for the better, and assess developments in that light, rather than attempting to be falsely objective or presenting a simple record. Similarly with the assessment of a workshop: if the summary deals, as it should, with what happened at the conference, the comments cannot have been prepared in advance. But the comments are not going to mean much unless what happened at the workshop is related to some framework of knowledge or decision. The closing speaker has the task of trying to place other people's comments into the context of the workshop as a whole. This applies also to a cumulative assessment of environmental effects: the assessment will not mean much if it assumes in advance what the effects will be; nor will it be of much value if it is mechanical reporting of a series of observed changes.

A further similarity between closing remarks and cumulative assessment is that the presence of the summary can be purely mechanical; its function may be simply to round out the specialist presentations with some general conclusions. This, one fears, may all too often be the role that authorities give to assessment of cumulative impacts in the environmental assessment process. Look at the way that cumulative effects are dealt with in most environmental impact statements by federal, state, or provincial agencies. They merit a paragraph or two at the end, after the main concerns of the subject have been dealt with. Just like the summary at a workshop. Dissatisfaction with this state of affairs is, of course, one of the main reasons for this workshop.

The workshop proceedings represent a cascade of ideas and issues that tumbled from subject to subject on our agenda. I will try to stand back from the organized agenda and reflect on what was said and thought about the complex and integrated problem of assessing the cumulative effects of human-induced environmental changes on the environment. I will attempt this by asking some simple questions about the workshop, and answering them with personal comments and reactions. Such an objective or mechanical approach leads quickly to subjective results, and I suspect this is also how nearly all assessments of cumulative effects are made.

SOME QUESTIONS

- What did the participants come for? Did the participants have the same goals and expectations as the sponsors?
- How well were the expectations realized? Did the sponsors get their money's worth?
- What main areas of interest or concern emerged?
- What are our strengths for dealing with questions of cumulative impact assessment?
- What areas of weakness or ignorance became apparent?
- In what areas did the workshop make real progress? Make little headway?
- What areas were omitted or left outstanding?
- What has the workshop shown about the concept and processes of assessment of cumulative effects?
- How does collective thinking about assessment of cumulative effects relate to our "toybox," and to the games we play in the real world?

Each participant and reader will have quite different answers to many of these questions. Nevertheless despite the variety of backgrounds and positions that were brought to bear on this subject, the workshop developed a coherence in its discussions, and we made collective progress in exploring a complex and very important subject.

WHAT DID THE PARTICIPANTS COME FOR?

From the outset, two schools of thought were apparent:

- There were those particularly concerned about how to deal with repeated, multiple, interacting impacts from many activities, in time and space, within institutional mechanisms that were designed or have evolved to consider one project at a time.
- Others were concerned mainly with how to identify, measure and understand the processes of environmental change and recovery from a series of events or a compound impact that may be imposed upon it.

Each camp recognizes the legitimacy of the other's interest, but they have different views about whether discussions should, in the main, be focused around knowledge, or around management and application. At this workshop, both hoped that the interaction between researchers and managers at the workshop would provide a better basis from which to address the scientific and institutional aspects, and they hoped to learn about the thinking and practice of others in this field. But neither camp expected to find magic answers to their problems.

WHAT DID THE SPONSORS EXPECT FROM THE WORKSHOP?

The Canadian Environmental Assessment Research Council stated that it anticipated that the workshop would result in a clearer definition of the concept of cumulative effects assessment; of its importance in the determination of the overall effect of human activities on the environment; and of its relation to other areas of environmental assessment, such as social impact assessment, risk assessment, etc. In particular, CEARC hoped that the workshop would identify areas where future research should be focused, to help in developing its own research agenda.

The Environmental Protection Agency, Department of Energy, and the National Research Council (U.S.) also had expectations that related to both "camps" of participants: they argued for a knowledgeable discussion of the state of the art of cumulative effects assessment to identify problems and areas for future research, and to explore possibilities of incorporating the assessment of cumulative impacts into present techniques and methodologies for environmental assessment and review.

HOW WELL WERE THE EXPECTATIONS REALIZED?

Participants who came to find new ways to include cumulative effects in the present procedures for environmental impact assessment did not find what they were looking for. There is, as yet, apparently no satisfactory simple mechanism for adapting one-project specific environmental assessment procedures to deal with multiple or cumulative impacts.

At the same time, however, it became apparent that the environmental effects of previous and interacting activities are very often already taken into account in the environmental assessment procedures. Thus some effective cumulative impact assessment is already being done. Some workshop participants consider that it is the exceptions — where the effects are subtle, delayed, or synergistic, or where political considerations prohibit or hinder taking into account the effects of other activities — that research programs should deal with.

Others argued that these "exceptions" showed serious mismatches between the knowledge that is needed to identify and appraise environmental perturbation, and the authority and ability to make the assessments. They expressed concern that such mis-matches pose a real threat, indicating a progressive weakness in the whole environmental assessment system that could be fatal. Those who expected the workshop to confirm their fears probably did get what they came for. In this respect, however, the message from the workshop is sobering.

Those who came with the objective of exploring the scientific challenges and opportunities of expanding our ability to identify and understand the interplay of human-caused effects on the environment, and who were fascinated by the processes of environmental response to cumulative impacts or perturbations, probably got what they came for.

The scientists had an opportunity to air their current ideas and enthusiasms. Everyone castigated management and institutional structures. Many lamented the enormous amount of data gathering which seemed to be of little or no use; the poor science done by others; and agreed how hard it is to get the scientific establishment and fund-granting agencies to support multidisciplinary research. There was a little, but not much collective thinking about the areas where research is most needed, and how it should be organized.

While no one abandoned his biases, some shared concerns and some resolutions for action were developed. These can be taken back to our respective responsibilities where each of us can, perhaps in a way more effective than before the workshop, attempt to implement them . Looked at from that point of view, most participants got from the workshop what they came for.

DID THE SPONSORS GET WHAT THEY WANTED?

For CEARC, the answer to this question is yes. There are plenty of ideas and information for the Council to work on in developing its research agenda. The workshop illuminated a number of research areas — e.g., the use of modeling of disturbances in energy flow to reduce the data requirements in post-construction monitoring — where it would be useful for the Council to focus its attention and research assistance. In other areas the workshop served to bring together a number of persons involved in research on environmental assessment, and this too is an important objective of the Council.

In the case of the U.S. sponsoring agencies, the answer is less clear. The workshop did serve to increase both the coherence with which cumulative impacts are described, and the clarity of future research proposals in this field.

Furthermore, a number of those who will be reviewers and referees of future research proposals in this field were participants in the workshop. They may have been helped to develop a sounder basis on which to judge the scientific merit of the projects with which they have to deal. The discussions should also have helped to develop a common language for this important topic, and to understand different approaches to its study.

WHAT MAIN AREAS OF INTEREST OR CONCERN EMERGED?

What is Meant by the Term Cumulative Effects Assessment?

Most participants were not really clear about what is involved in the idea of assessment of cumulative impacts; and those who were, and knew perfectly well what they meant, found that others did not fully agree with them. The depth of uncertainty was shown by the large amount of time we spent on definitions. Much of that discussion was inconclusive, yet we returned to it repeatedly. Definitions and concepts become elusive, and quite different when viewed from different angles:

- Cumulative effects assessment was said by some to be equivalent to the assessment of cumulative effects. Others thought it included cumulative assessments of effects which, although related, is quite a different problem. I did not hear anyone equate it to the cumulative effect of assessments, although that may well be what we will have to deal with if we cannot get the assessment house in order.

- To some people, cumulative effects assessment meant determining the net environmental effect of a number of activities. To others, it was a measure of the gross environmental effect; while to still others, it was a way of identifying and following progressive environmental perturbation from a variety or series of causes.

- Some felt that definitions of the concept were a waste of time, and that cumulative impact assessment was simply a practical tool for regional planning, which enabled planners to account for the effects of several activities.

- And still others argued that cumulative effects assessment was nothing more than a means of accounting, in a legally defensible way, for the effect on the environment, by any number of actions extraneous to the activity being evaluated or regulated.

All of these definitions and ideas are valid. There is a common interest in ensuring that the term does not become defined too narrowly before we understand fully what it is that we are defining.

Are the Main Problems of Cumulative Effects Assessment Scientific, or Managerial, or Both?

Discussion at the workshop showed that there are both scientific and managerial aspects to most cumulative effects assessment issues. It was agreed that as far as possible these different aspects should be considered separately. Yet each time participants discussed the scientific aspects, they also touched upon managerial and institutional questions. Conversely, discussions of process and implementation considered inadequacy of data, or gaps in knowledge about how the environment works. It appears that science and management are not really separable in the real world, and in the "toy" world referred to by Baskerville, even the scientists are fascinated by lining up our toy soldiers (research projects) to play management games.

There was some agreement that the scientific questions should be dealt with by scientists at arm's length from management responsibility, and the institutional or managerial aspects of impact assessment should be developed as independently as possible from the activities that support, conduct and appraise the science. The progressive harnessing of scientists directly into the decision structures of environmental assessment and project approval was seen to be bad for science and bad for the decisions.

THE NATURE OF THE SCIENTIFIC PROBLEMS

What are the most important scientific problems connected with cumulative effects assessment?

- Do we lack basic knowledge of physical, chemical and biological processes related to environmental disturbance and recovery?

- Do we lack data or adequate synthesis and accessibility of information?

- Are the problems amenable to solution if more research is done, or are they so intractible and complex that it is not reasonable to expect important advances?

- Do the scientific problems simply need more dollars, or is it necessary to develop new types of expertise and research approaches?

The answer of course, is "all of the above, and more." Some serious gaps in knowledge were identified, especially about the basic architecture and rates of response of ecosystems. In some of these areas, it is not realistic to expect major advances in scientific understanding. In others, such as those related to identifying the accumulation of chemical substances in organisms, even modest increases in research can be expected to provide important new information or understanding. There is already a great deal of data on environmental changes, but much of it is poorly organized or of little value because we are just beginning to learn which are the right questions to ask.

Interdisciplinary and transdisciplinary knowledge and understanding is often poor. This stems in part from difficulties in gaining support for significant multidisciplinary studies, and from problems of carrying out such studies within the traditional confines of university and government systems. Cumulative effects research, which by its nature must be multidisciplinary, may indirectly benefit science as a whole by encouraging a more holistic and flexible approach to research support.

ARE THE MANAGERIAL AND INSTITUTIONAL PROBLEMS SOLVABLE WITHIN THE PRESENT SYSTEMS?

The workshop discussion was generally pessimistic on this point. Present structures for environmental assessment and review are part of a system intended to preserve and perpetuate the very economic practices and values (such as short-term profit taking precedence over long-term social good and sustainable environmental productivity) that have given rise to the environmental problems we are trying to correct. The assessment of cumulative effects directly challenges these entrenched practices, jurisdictions, and value systems, and so will not easily be accommodated within established mechanisms.

It was not the purpose of this workshop to challenge or redesign existing environmental processes, but one of the commonly shared concerns was that structural and conceptual changes were needed in the processes in both Canada and the United States, if cumulative assessments were to be dealt with adequately.

Are the Problems Surrounding Cumulative Environmental Assessment Having a Serious Effect on the Environment or Resources?

The workshop was quite clear on this question. Failure to take cumulative effects properly into account is resulting in damage to the environment. The lack of systematic attention to cumulative effects is leading to a potentially serious situation on a range of scales, in many places, in both countries. The problems vary from "nibbling" at critical habitats, to unknown degrees of loading of environmental compartments with interacting chemicals, to ignorance of the severity and imminence of regional or global threats. These questions are ultimately what environmental assessment and review is all about. Workshop participants clearly felt that if cumulative impacts could not properly be taken into account, the usefulness and credibility of the whole process must be in doubt.

What Can be Done to Keep the Scientists and Managers Concerned with Cumulative Effects Assessment, Imaginative, and Forward-Looking in Their Fields?

Some participants at the workshop were concerned that consideration of cumulative effects could reinforce the present tendency for public groups to concentrate on perceived or potential damages and become alarmist in outlook, while the assessment agencies become obliged, not to defend the environment, but to ensure that environmental problems do not interfere with economic or industrial policies. This growing division or separation in viewpoint is unfortunate, and a major problem in cumulative effects assessment was seen to be the achievement of breadth of outlook with credibility to all concerned. Generally, it was felt that the assessment of cumulative effects need not delay project approvals significantly provided there was an adequate and systematic data base.

A more serious problem possibly exacerbated by cumulative effects assessment was seen to be that scientists involved in impact assessment were in danger of being seen not as sources of knowledge, but as actors in a government-managed play. Efficient assessment depends on a judicious selection of data and evidence. The credibility and usefulness of the assessment will depend importantly on the motives and criteria for selection of the evidence. The perception of whether assessment of cumulative effects is undertaken to obtain the most complete knowledge possible, or whether it is to find evidence that will facilitate decisions in conformity with established policy, is very important. There were a few comments expressing skepticism whether scientifically defensible assessment of cumulative effects was possible under the U.S. National Environmental Policy Act (NEPA) or the Environmental Assessment and Review Process (EARP), as presently constituted.

There was also concern that the increasing difficulties of obtaining and exchanging information, and the tendency of court actions to hold assessors legally responsible for their predictions or decisions, are going to make it more difficult to take a number of possible but unprovable influences into account when approving or modifying a project. The pressure to produce rapid assessments, based on verified information and defendable in court, worked against the inclusion of cumulative effects in the assessment of projects for approval by authorities. This is an area that will need careful study.

WHAT ARE OUR STRENGTHS FOR DEALING WITH QUESTIONS OF CUMULATIVE EFFECTS ASSESSMENT?

The following were some of the "strengths" identified: as pertaining to Canada and the United States in 1985:

- There is a well developed scientific methodology for identifying environmental change in most physical and some biological systems.
- For most areas, there are records and some data on earlier or similar activities which have affected the environment, although these data are of varying scales and accuracy.
- A few examples exist of very good local and regional data, and there are some environmental inventories that pre-date recent industrial development. These areas may serve as "test cases" to establish cumulative assessment methodologies.
- The knowledge of environmental processes that has been found useful for single-project impact assessment provides a good start for assessment of cumulative impacts.
- Significant advances are being made in basic scientific knowledge relating to processes of response of organisms and populations to physical and chemical perturbations.
- There is rapid development of improved technologies relevant to environmental assessment, such as techniques for determining changes in biomass, detection and rates of travel of trace substances and the presence of artificially introduced compounds in biological and chemical systems, remote sensing from micro to global scales, etc.
- There is a growing public and political acceptance that not only is environmental assessment necessary, but that many activities have overlapping or simultaneous effects on the

environment. There is broad understanding or expectation that effective environmental protection in the public interest requires knowledge of cumulative impacts.

- There are examples of poor practice where the environment has been harmed by the impact of several activities, each of which would by itself have had little effect; and evidence from a few good examples, such as the clean-up of Chesapeake Bay or the improvement of air quality at Sarnia, to show that cumulative effects can be successfully dealt with.

- Citizens' environmental groups have long objected to single-project assessment, and focus easily on cumulative impacts. They provide pressure for public action.

- Other countries — Hungary, the United Kingdom, Sweden — have developed methods of incorporating the overall or cumulative effects on the environment into industrial management. Although these countries have a degree of central planning authority that is probably unacceptable to Americans or Canadians, they provide examples of cumulative assessment methodologies from which we can learn. Their experience appears to demonstrate the value of a holistic or collective approach to industrial and environmental issues.

WHAT ARE SOME AREAS OF WEAKNESS OR IGNORANCE IN INSTITUTING ASSESSMENTS OF CUMULATIVE EFFECTS?

Scale Problems

Existing assessment and review systems are often unable to deal with the interrelated problems of both large and small time and space scales of impacts. The premises outlined by Fox (this volume) are very pertinent to this problem, and indicate the kind of adjustment that would have to be made by existing institutions.

Inadequate Understanding of Process

Understanding of processes of environmental change is often insufficient to enable useful relationships to be drawn between different stresses and the environmental or ecosystem response. Most needed in this area are reliable data on the mass balance — both in total, and with respect to particular elements or chemical constituents — and the energy balance in critical environmental compartments. Another vital area that has been little studied is the relationship between the rate of geochemical or geophysical adjustment from a specific physical or chemical perturbation, and the rate of biological or ecological response. Such knowledge of rates of adjustment is vital to understanding stress-response relationships in the environment, and is a key to being able to understand cumulative impacts in a holistic way, instead of attempting the often futile task of adding the effect of one impact after another.

Uneven State of Knowledge

The state of environmental knowledge is uneven, making it hard to avoid a bias toward giving most attention to managing the things we know most about. There are relative differences in the state of data and knowledge in major environmental areas, It was also acknowledged that a rigid compartmentalization into land, water and air was unsatisfactory for environmental assessment purposes, and was itself one of the common handicaps to cumulative assessment.

A crude and probably scientifically indefensible summary emerged.

There is generally good knowledge of the components of terrestrial ecosystems except for subsurface microbiota. Less well understood are ecosystem boundaries, and the relationships between species and between trophic levels. In most areas, knowledge of rates and stabilities of mass exchange and energy flow is weak.

For marine and aquatic ecosystems, there is generally good knowledge of inter-specific and inter-trophic relationships, but there are few complete or satisfactory descriptions of the components of ecosystems. In most areas, knowledge of aquatic-based populations is poor, as is understanding of resilicency and response to natural or human-caused chemical or physical perturbations. Techniques for determining changes in mass balance or energy flow in marine systems are difficult and unsatisfactory.

There is comparatively good understanding of atmospheric dynamics and patterns of mass and energy flow. On the whole, good knowledge exists about the processes of chemical interaction in the atmosphere, but poor knowledge of rates, and regional or continental distributions. Net and gross loadings and transport pathways for introduced substances are known for only a few well studied constituents. Knowledge of airborne microbiota is very spotty.

Difficulty of Assessing Cumulative Effects

The absence of generally accepted rules or principles for identifying the significance of ecosystem response to perturbations was seen to be a greater problem for assessment of cumulative effects, than for impacts from a single source of activity. Identification of "important species" can become critical. The varying time and space scales necessary for assessment of cumulative effects may require an approach to selection of "valued ecosystem components," that is different from that used for assessment of single projects.

Learning from Experience

An important handicap to satisfactory assessment of cumulative effects was seen to be the difficulty in sharing information and learning from experience. As noted by McLoughlin (1983) and others, while purely scientific data and routine environmental measurements taken prior to project construction are often readily available, information on post-completion performance, and the subsequent effects on the environment are not as well documented. It is particularly hard to get information about projects that have failed, or to obtain support for investigations and assessments of instances where approved protection practices did not protect the environment.

A particular weakness is the lack of responsibility and funds for follow-up studies, not only to monitor the effects on the environment, but to investigate the relative contribution of human influences superimposed on "natural" influences leading to environmental change.

Importance of Social Sciences

A potentially important weakness lies in the difficulty or inability of applying studies in behavioural science, political science and economics to cumulative effects assessment. The separation of biophysical aspects from the socioeconomic and behavioural aspects provides for scientific rigour and clean-cut managerial decision; but environmental assessments must be made in the light of social or economic values. In order to assess the cumulative effect of several influences that may differ in time and character, it is important that knowledge of the behavioural and socioeconomic effects be integrated with biophysical information.

Constituency of Ignorance

In some areas, successful implementation of assessment of cumulative effects can be very difficult, because there is what might be termed a "constituency of ignorance." For example, there may be a reluctance to consider openly the "nibbling" and "ripple" effects, because of a fear that this might reveal environmental concerns hitherto unrecognized, and thus arouse demands for actions that those responsible are unable or unwilling to undertake. This constituency is sometimes openly stated, as in industrial announcements which proclaim the environmental safety of a product or process not yet introduced and on which no environmental impact studies have been made; more often it is unexpressed but nevertheless real, as when for non-environmental reasons, governments exempt certain projects from environmental assessment. These problems are likely to be magnified in the assessment of cumulative effects.

IN WHAT AREAS DID THE WORKSHOP MAKE REAL PROGRESS?

Collective progress was made in the realization that assessments of cumulative effects should be an integral and normal part of most comprehensive environmental assessment, not a separate and distinct activity. It was also realized that successful assessment of cumulative impacts makes distinctive and special demands on data and scientific knowledge, and requires a different managerial approach than assessment of one activity at a time.

An excellent start was made in clarifying a typology for cumulative effects, so that influences from different sources can be identified and related.

Workshop participants also explored the possibility of determining the relationship between the sources or causes of environmental effects, and their environmental consequences in socially valued terms. A preliminary categorization of these effects showed that, in many cases, the areas of management and control of activities that lead, ultimately, to environmental changes are in a different dimension from the areas that must be managed to achieve the desired environmental result. Successful assessment of cumulative effects must tackle one of the central institutional questions of environmental management, namely that the environmental response to impact is integrated, but the institutional responsibility for controlling activities that impact the environment is often fragmented.

Recognition and exploration of the ability to analyse this relationship and mis-match was one of the principal accomplishments of the workshop, and the enthusiasm for extending the pioneer work of Crutzen and Graedel (1985) may be one of the important substantial fall-outs.

A good start was made at developing a hierarchy of scales of distance and time, both for environmental effects and for the effectiveness of institutional responsibilities and controls. This accomplishment opens up the possibility of identification of areas where the scale or scope of environmental effect is quite different from the scale or scope of management or control actions, both in a technological sense and in an institutional or jurisdictional framework. Discussion of this problem brought out, importantly, areas of mis-match between institutionally imposed thresholds of management action, and the thresholds or turn-over points in the behaviour of natural systems where ecological resiliency, geochemical buffering, or habitat characteristics change in non-linear fashion. Examples ranged from international management of acid rain, which had severe local effects on a particular lake or forest, to the alteration of continental habitat for migratory birds by municipal programs for draining of local wetlands.

IN WHAT AREAS DID THE WORKSHOP MAKE LITTLE PROGRESS?

In some areas, the workshop appeared to make little progress.

No headway was made in learning how to incorporate social science studies and their findings into assessment of cumulative effects in a systematic and responsible way. Almost everyone agreed on the desirability of including more reliable information or predictions on socioeconomic consequences and responses into environmental assessments, but workshop participants were unable to identify how this could be done other than in the present ad hoc manner. There was considerable skepticism as to whether reliable methods existed to determine the scientific rigour of social and economic research, yet without a basis for assessment of the quality of the research, the results were not helpful toward putting social values on environmental assessment. The workshop did not have the expertise to deal properly with this question.

Little attempt was made to identify social goals and relate them to environmental values. This problem was tied up with the question of defining and defending "valued ecosystem components" as a factor in environmental assessment. The difficulty was compounded when cumulative effects from several activities, each of which have different and sometimes conflicting social values, had to be considered. Particularly difficult was the problem of inherent conflict between short-term benefits and long-term costs, as perceived by a society already under social and economic stress.

Left incomplete was a discussion on how to deal with the many types of scientific uncertainty that were inherent in cumulative assessment. Several distinct types of uncertainty were identified that could present particular problems in assessing impacts from several sources. These include:

- Statistical uncertainty in data or measurements — this is largely a consequence of the methodologies employed, and is a major problem when uneven time-series of information from different sources, obtained for differing purposes, must be used;

- Uncertainty as to environmental processes — incomplete incomplete understanding of ecological or geophysical processes involved (noted above) may lead to erroneous conclusions as to causes of disturbance or pathways of environmental action, when judged from the point of view of several disturbing activities contributing to environmental change; examples cited included linking the dying of forests to the production of industrial sulfur dioxide, or how much to relate changes of fish stocks in the Gulf of St. Lawrence to the construction of the St. Lawrence Seaway;

- Uncertainty as to representativeness of the effects being considered — in time, space, or ecosystem behaviour. All environmental and ecological change is dynamic and continually responsive to cumulative impact, and the characteristics and combinations of processes vary widely from place to place and from one time to another. And yet, human actions to manage impacts or set standards of behaviour attempt to be non-discriminatory and uniform, in order to be legally defensible. This circumstance places a heavy responsibility on the environmental assessors to have the best possible knowledge of the representativeness and range of variability, natural and human-caused, of the issues being dealt with.

The workshop did not make progress in exploring the possibility of making assessment of cumulative impacts itself a tool for the management of environmental instabilities and continuous change, rather than a means of describing perturbations in the attempt to reduce them to a static minimum. This was one of the more exciting and forward-looking ideas to be brought forward. The same uncertainties and complexity of interplay of activities which make an attempted static regulation of environmental quality so difficult could, if flexible institutional arrangements could be agreed upon, be used positively for environmental management based on steering toward a desired end result, and not limited to the prevention of undesired change. Clearly this approach leads to considerations of regional planning and multi-jurisdictional cooperation, which were beyond the scope and expertise of the workshop. It is one of the more promising areas to be pursued in the future.

WHAT AREAS WERE OMITTED OR LEFT OUTSTANDING?

There were a number of subject areas that seem important to the whole issue of assessment of cumulative effects, but which were either not given attention or were merely mentioned and left hanging without discussion or resolution.

The Various Decision Makers

The workshop seemed to concentrate almost exclusively on cumulative effects assessment as a formal activity designed to assist the regulating authority as the maker of decisions which would affect the future quality and stability of the environment. There was an implicit assumption that the purpose of assessment of environmental impact is to influence formal approval or non-approval of proposed projects.

Although decisions by regulatory agencies are, of course, very important, other decision makers also have a vital role in determining the net or final environmental consequences arising out of environmental assessment. Many individual decision makers affect the environment in small ways, but if their actions are assessed and the likely cumulative results made known to them, they could do much to ensure that environmental standards are maintained while the economic and social goals of society are being met. Two groups whose decisions have an important effect on the environment and who could benefit from the information that comes from systematic cumulative effects assessment are:

- **The engineer or technician** who has to redesign or adapt a process to meet environmental specifications. It is his selection of design which will determine the nature of environmental disturbance and its side effects, including combinations with the impacts from other industrial activities in the region. Cumulative effects assessment practices and information distribution systems should, therefore, be set up with these professionals in mind.

- **The farmer** who decides what crop to plant, how to till and fertilize his fields. The decisions by individual farmers on crop type, drainage systems, irrigation systems can collectively have significant cumulative effects on quality of topsoil, groundwater availability and water quality. The farmer's individual decisions may not be made on environmental or agricultural grounds at all, but will be set in motion by other decisions such as pesticide approval or funds for a drainage scheme.

There are many examples of this kind, where the chain of consequent decisions means that the final action that affects the environment is made by a different person than the decision maker with government authority or industrial management responsibility. It is important that results of cumulative effects assessment be useful to the sequence of people whose actions can do most to benefit the environment.

Three other forces bearing on decision making were also identified as important to cumulative environmental assessment:

- **The public.** Public knowledge and perceptions of the relationship between industrial or societal action and environmental change, set the political context for environmental protection policies. What the public "decides" to be important in environmental protection and control is obviously strongly influenced by the availability of information about the cumulative effect on the environment of a variety of activities that contaminate or disturb it. Yet the characteristic inconsistency within the public, between broad concern over collective issues and intense personal protectionism — the NIMBY ("not-in-my-backyard") syndrome and related reactions — over specific solutions, places special demands on cumulative environmental assessment information.

  Experience to date in North America has shown that public interest is most easily aroused over specific dramatic incidents, and is much harder to sustain for important environmental concerns that call for persistent alertness or institutional change. Cumulative effects assessment can play an important role in creating public awareness of the interrelatedness of environmental concerns, while the public itself will be aroused most strongly over specific single issues.

- **The institutional system,** which leads to progressive or automatic actions that affect the environment. Much of the political and public attention has been focused on initial approval: a "go" or "no-go" decision for a major project. After a project has been approved, it is much harder to obtain resources or maintain policy interest in undertaking subsequent assessments during and following project construction. There is a growing recognition of the need to include project valuation and monitoring in the terms and conditions for project approval (e.g., Beaufort Sea hydrocarbon production and transportation). These reviews them become part of cumulative effects assessments.

- **Natural Initiative.** The selective response by the ecosystem itself is a factor in the assessment of cumulative effects. The workshop ignored the active role of biological and geophysical agents, and tended to view the environment as a sensitive but passive system. Many species in the ecosystem in addition to mankind have considerable scope for conscious choice in their behaviour, habitat and lifestyle, and exercise that choice just as humans do when environmental conditions change. These initiatives within nature may be called avoidance behaviour, a learning syndrome, or a hunger-driven search for alternative habitats; but they are simply evidence of response and choice within natural systems.

  There are many examples of the initiatives taken by non-human species to changed environmental conditions. The changes in feeding habits and nesting routines of herring gulls as a consequence of development of inland urban sources of food supply; the self-domestication of wild ring seals in arctic oilspill experiments who have learned to put up with a little smelly oil to obtain free food and so have frustrated studies of the sensitivity of seals to petroleum; the inconsistent behaviour shown by different bowhead whales when subjected to the noise of shipping are illustrations that humans are not the only decision makers who assess the environment. The important thing to note is that these "decisions" by birds and mammals are responses to cumulative impacts, some of which may contradict the effect of impacts from a single source.

Changes of Complexity with Changes of Scale

An important area not addressed at the workshop was the relationship of information needs to assessment processes at different scales and complexity. If one attempts to carry out cumulative assessment in the same way that assessments are made of local impacts, the need for information invariably increases faster than the number of sources of disturbance. This is because there must be data from each source and also information on the interaction and synergism between sources. Thus, established procedures of environmental assessment may easily become data-limited or too cumbersome to be useful, if they are applied to cumulative assessment of the effects on the regional environment or over an extended period.

It should be noted, however, that as the scale and complexity increases, the recognition of environmental processes, or of changes in processes and rates, becomes dominant over the need for detailed knowledge of the components. What becomes important for environmental quality of a region are changes in mass and energy flows, or in rates of change of flow, not concentrations of particular chemicals or adjustments in population of selected species. At still larger scales or longer time periods, stability of environmental system design and structure become important, rather than the health and activity of particular components.

Thus, the identification of the valued ecosystem components around which the assessment is built must change with the scale and complexity of the assessment. One can assess the soundness and utility of a building by examining the quality of the bricks used in construction, by testing the strength of a wall made of bricks and mortar, or by considering the architectural design. In each case the standards and methods of assessment, and the information needs, are different. It is the same with environmental assessment; we should not attempt or expect the procedures and information developed for single-project assessment to be adequate for assessment of cumulative impacts in a region or over time.

Increasing complexity and scale of cumulative impacts need not necessarily mean more cumbersome or difficult assessment. The larger scale may, with proper design and approach, lead to simplification on a new level of understanding and generalization. One is reminded of the popular story that the mathematical system of the Australian aborigines is "1-2-3-plenty" — and that is all. Such a system, while precise only up to a point, is much more comprehensible than the open-ended Arabic system "1-2-3-4.....". In the same way, cumulative impact assessment may, in fact, serve to simplify environmental assessment procedures, by replacing tedious detailed description with a measure of the dynamic flow of ecosystem adjustment to progressive, repeated or varied stresses, against which the costs or benefits of additional impacts or changes can be measured.

It would be useful for another workshop to examine these relationships in some depth.

Environmental Assessment other than through Formal Processes

There are several areas of activity where knowledge of the cumulative or net effect on the environment' of a variety of impacts is important to decisions or policies, but where the information is not marshalled primarily through formal environmental assessment procedures. Activities which can make important contributions to cumulative assessment include: regional or community planning; the development of public awareness of environmental sensitivity; planning, management and conservation of parks and nature reserves; and selection of sites or development of regulations for industrial activities that are subject to public or unidentified multiple uses, e.g., deep-water ports, shipping channels. The workshop did not explore these other mechanisms of assessing cumulative impact.

The Identification of Future Cumulative Effects

A further aspect of the subject, which was not discussed, is the forecasting of the net environmental impacts of activities likely to come into being if a desired development project goes ahead as planned. An example is the effect on water quality that might result from secondary activities that could develop in a region if a new road is built. These may not be considered during environmental assessment of the road itself, because future development is not the prime responsibility of the proponent for the road. However, the cumulative environmental effect of building the road should include the impact of the activities that result from the presence of the road.

Economic planning is more and more concerned with estimates or forecasts of future developments and their downstream ripple effects. Environmental planning, if it is to contribute to major socio-economic decisions and ensure the future quality of the environment, must do likewise.

Cumulative Impacts Affecting Evolution or the Structure of the Ecosystem

The workshop did not discuss the problem that institutions are structured, for the most part, around an assumption of a static or inherently stable environment, with tendency to return to "normality" — i.e., to pre-disturbance conditions — after perturbation. In many cases, it is clear that cumulative impacts have a time scale commensurate with that of natural environmental change or significant evolutionary development, and that the changes consequent to the impacts are not necessarily followed by a return to "normality." They may result in a new condition with different sensitivities and responses. Such changes enormously increase the complexity of assessing cumulative effects, and of predicting the environmental consequences or effects of control measures.

Several examples of this kind of situation can be given:

- Deforestation of the wooded hills of Scotland and parts of Ireland and introduction of sheep by large land-owners came at a time of local climatic change; the boreal moorland vegetation effectively became dominant, changing the nature of the soil and effectively preventing the return of natural forests in the past three centuries.

- Depletion of populations of adult large whales by hunting in the Southern Ocean in the early twentieth century, at a time of fluctuation of the Antarctic Convergence and concentrated food supply, has resulted in noticeable earlier sexual maturity among whale populations and lowered the age at which reproduction takes place. The effect on the social structure among whales and on the Southern Ocean ecosystem is not clear, but could have considerable importance on the productivity of the region.

- The response of insects to stresses of many kinds, from drought to newly formulated pesticides, provides numerous examples of how cumulative impact can serve as a stimulus to rapid evolutionary development of new strains, species or modes of behaviour.

It is useful to keep in mind that such responses are not always negative. One of the important purposes of cumulative effects assessment is to provide information that will allow the net impact from human activities to be designed to work in optimum manner with the stresses from natural causes, to maintain the most productive or desired environment.

Problems of Research Quality, and Cooperation

The need to maintain an adequate standard of research and of scientific interpretation when assessing the impacts from a variety of sources or over an extended period was not discussed at the workshop. In most cases, assessment of cumulative effects must be made by a number of people, often from different institutions, who get their information from a variety of sources not under their own control. The problem is related to the problems of obtaining reliable and compatible data (noted in the section "Areas of Weakness or Ignorance," above). A successful system for cumulative impact assessment requires adequate coordination of scientific and technical activities and standards between all those involved, and adequate documentation to facilitate coordination and compatibility between one assessment exercise and another. The public and political credibility of assessment of cumulative effects will likely depend on the perceived consistency and reliability of the procedures, and the quality of the technical and scientific standards maintained.

This subject area clearly merits further discussion and development.

The Tendency to Homogenize Society

Little attention was given at the workshop to the consequences or dangers inherent in lumping together impacts and assessing their significance in a generalized way. Most discussions of cumulative effects assessment implied dealing with a net effect, a single end result impacting on a single societal entity. The tendency to view human communities as a single collective entity with common concepts and an agreed set of values, and for which net or average benefits and costs can be calculated, is prevalent in environmental assessment and incorporated into much government policy and regulation. There is a real risk that in the socio-cultural-economic ecosystem, no less than in the biophysical ecosystem, reduction in diversity leads to instability and vulnerability to unforeseen change.

Environmental assessment, if it is to be useful to society, must be able to express conclusions in terms that are relevant to different parts of society that have different environmental values. For assessments of single projects, with localized impacts, conclusions that evaluate environmental changes in terms on the overall social effect may be satisfactory. A system for interpretating the importance of the cumulative change in environment from a number of impacts, however, will have to pay much greater attention to the differences within society. This is an area of cumulative effects that needs careful attention.

Selective Responses Within the Environment

A further important area that was not discussed is the role of cumulative impact assessment in linking together effects which in themselves appear to be separate. Different activities will affect different parts of the ecosystem fabric, so that the resultant net vulnerability to change or rate of response may be quite different from that due to each impact separately. For example, harbour dedging may affect a fish spawning ground, while a nearby chemical processing plant may produce a toxin to which a selected part of the aquatic food chain that does not spawn in the area is vulnerable; and the effect on the ecosystem of the two separate impacts combined may be very different than the effect of each separately.

A fascinating illustration of the interspecific, international and long-distance effects of local actions affecting environmental resources is provided by Graham Cooch of the Canadian Wildlife Service and his colleagues from the Soviet Union, the United States and Mexico. The management of the reindeer herd on Wrangell Island off the north coast of Siberia has inadvertently had a severe deleterious effect on the breeding population of snow geese on that island, which were already being stressed by changes in regional climate. The collapse of the Wrangell Island snow goose population, which normally winters in California and British Columbia together with snow geese that breed on Banks Island in northern Canada, has placed relatively greater hunting pressure on the Banks Island birds from hunters in California, because state game regulations have been based on the traditional combined populations from both Wrangell and Banks Islands. Increased hunting has caused a reduction in that portion of the Banks Island population that winters in California, and has given more opportunity for expansion of that part of the flock that winters in the highlands of Mexico. The Mexican wintering grounds however, are vulnerable to periodic disastrous drought. Thus, the snow geese that breed on Banks Island in the Canadian arctic are placed in a more vulnerable position because of climatic instabilities in Mexico, through reindeer management practices in Siberia and the hunting laws of California.

This important area of cumulative effects assessment requires the best possible understanding of environmental processes and ecosystem response. It needs careful exploration and research to determine data requirements and scientific approaches, combined with analysis of the institutional and jurisdictional factors.

Accumulation of Environmental Hazards

A neglected aspect of cumulative assessment, as pointed out by Gordon McKay, concerns the growth or accumulation of potential environmental hazards. Quite legitimate activities each posing limited environmental threats in themselves, may lead collectively to a growing hazard. This topic has received some attention with respect to the movement and disposal of toxic wastes, contamination of groundwater, etc. But the problem is considerably wider. For example, the increasing size and number of salt dumps on the prairies from petroleum processing raises the possibility of serious and widespread airborne pollution in the event of strong winds; highway construction with attendant disturbance of drainage in areas of unstable soils may lead to danger of landslides or accelerated erosion from forest management practices, (which would be quite safe had the highway not already undermined the stability); avalanche hazard has increased in the Alps because acid rain has killed the larger trees, and this hazard has caused winter tourism to be shifted to non-forested areas, with consequent disruption of land use patterns in traditionally productive pastoral regions.

The assessment of cumulative effects should include assessment of the growth or accumulation of environmental hazards from a variety or a chain of activities.

Use of Special Techniques

The workshop focused on concepts, scope, and management of cumulative effects assessment, and only to a minor degree on how this process was to be established. Most participants realize that new techniques and procedures will have to be developed and tested in careful experiments, before satisfactory and credible cumulative assessment systems can be put into place. The role of simulation modeling of environmental behaviour, of the use of decision theory in relating relative impacts, of simplified environmental experiments (playing with toys) and their extrapolation to the real world: these and many other techniques will require serious and patient exploration, New methods of monitoring ecosystem stress as indicators of cumulative impact, such as those being developed by Bewley and Parkinson (1984) for forest soils and by Regier and Rapport (1983) for the Great Lakes, point the way to fruitful new fields of research.

The Information Needed to Develop Policy Choices

An important and largely unstated aspect of environmental assessment that lay behind workshop discussions concerns the use of assessment results to determine what should or could be done to control, ameliorate, adapt to or even to take advantage of cumulative environmental change. This is clearly the necessary follow-up to any assessment of change due to cumulative impact. Some impacts may be beneficial in human terms, some may be controllable at some cost, or others may be uncontrollable once the change has begun. The effects assessment must provide information that can be used to enable society to take advantage of, control, or if necessary adapt to the cumulative changes it helped to bring about. It should enable the response or adaptation to be planned, and not left to crisis or ad hoc developments (Schelling 1983a, b).

WHAT HAS THE WORKSHOP SHOWN US?

The principal message from the workshop is not a new revelation, nor a description of a box of new environmental assessment toys. Rather, it is a general agreement on the need for a *change of perspective in assessing environmental stress.* It is a sober message, implying a great deal of hard work and major adjustment to environment assessment institutions and approaches in both countries. This change, however, is inevitable. It will bring with it changes in environmental assessment institutions, approaches, and costs, in both countries.

In summary, the message I received from the workshop is as follows. Both the United States and Canada have come to expect that good environmental and resource management practices will be achieved in large part through an institutional process that has been built around assessing the environmental effects of separate industrial activities or public works, and then controlling these activities individually to avoid undesired change. This process may never have been consciously intended to be a dominant agent of environmental management, but in many cases it has come to be regarded as such, by government institutions, some industries, and the public. As society's influence on natural environmental processes has become stronger and more pervasive, and the effects of activities overlap and exceed the adaptive capacity of the environment, it has become evident that a process of examination and control of each activity independently of the effect on, or of, the others is inadequate. Assessments of cumulative or net impacts of a full range of human activities, in the context of natural environmental stresses and changes, is henceforth a necessary and integral part of responsible management of the environment. Such assessments are essential to achievement of a stable economy and acceptable social conditions.

The first reaction to the realization of increased complexity and need to take cumulative effects into account, has been to try to force-fit the problem into a process designed to consider one activity at a time. This clearly deals with complexity by attacking it with increased complexity, but does little to resolve the problem.

A more reflective examination reveals that the major purposes of assessment of cumulative effects are not simply to be part of an institutional regulatory process. They involve increasing awareness of the varied nature and range of scales of environmental response to disturbances of all kinds; building up an appreciation of the economic and social benefit of environmental protection and sustained management of renewable resources; providing the basis for a widespread public and political demand for adaptive regional planning, with broad public and industry participation; making environmental assessment everybody's business; and making environmental assessment and approval not an imposed process but an integral part of project planning and design, within the context of other activities in the region and the health of the regional environment.

In brief, the workshop has shown us that cumulative environmental effects assessment is not a methodology for adding together assessments of separate projects, but rather a means for putting the effects of any project into the perspective of larger dynamics of human activities and environmental change.

HOW DO CUMULATIVE IMPACT ASSESSMENTS RELATE TO OUR TOYBOX AND THE GAMES WE PLAY IN THE REAL WORLD?

Our discussions of cumulative impact assessment have shown that we need new research ideas and experiences in order to develop new skills in relating multiple impacts to comprehensive environmental and socioeconomic dynamics. In the image of Gordon Baskerville we need new research toys to play games (experiments and test cases) with, so that we can learn about the real world. How will we acquire or select the new toys, and how will we learn to play with them?

The following are some recent activities that illustrate different aspects of the problems of assessment of cumulative effects:

- **Beaufort Sea Hydrocarbon Production.** A review of this topic completed in 1984, was the largest and most comprehensive environmental assessment and review activity yet undertaken in Canada (FEAR0 1984). It covered many areas where assessment of cumulative effects were essential to the final recommendations. Two aspects are of particular interest in this connection:

  — The interventions from local residents and communities were not focused on specific effects of particular technological or operational elements of the proposed development, but presented concerns about the hydrocarbon development in the Beaufort Sea in the context of all other developments in the region. In other words, northern intervenors in the Beaufort Sea hearings made their own cumulative effects assessment as a basis for their presentations to the Panel.

  — A post-hearing survey was undertaken to identify areas still outstanding where, in the opinion of the intervenors themselves, decisions about hydrocarbon development in the Beaufort Sea region were, after all the research results and data had been presented, still handicapped by lack of scientific knowledge. This survey uncovered numerous areas where background data were inadequate; areas where basic scientific understanding of environmental processes on mechanisms of environmental response was still insufficient to enable fair judgment to be made of the environmental significance of the proposed development to be assessed; and areas where failure to consider regional or global changes weakened the ability to make a sound assessment of the local effects of industrial disturbances. All of these deficiencies are aspects of the fact that assessment of the environmental impact of any major project necessarily becomes an assessment of the cumulative effect of that project in the context of everything else that is going on in the region.

- **Nuclear Winter.** Assessment of the potential impact that nuclear warfare may have on the environment and on society is perhaps the ultimate in cumulative effects assessment. This is one “toy game” that is being played not to learn how to do it in the real world, but to help find means to ensure that it never will be played for real (Hare 1985). The assessment must start with considerations of the basic changes in the environment caused by nuclear explosions. It then becomes complicated, because the environmental changes resulting from the initial disturbance then become causative agents for further environmental or socioeconomic changes. This sequence of interacting ripple effects is probably typical of the cumulative impact of many major environmental disturbances. Those concerned with the methodology and application of assessing cumulative effects in general may be able to benefit from the current attempts to assess the impact of extreme events like nuclear warfare.

- **ENMOD Treaty.** Another instructive example of the problems and the application of assessment of cumulative effects is to be found in connection with the United Nations *Treaty on Prohibition of Modification of the Environment for Hostile Purposes* (the so-called ENMOD Treaty). Assessment of both the individual and the combined or synergistic effect of actions that could be taken deliberately to cause environmental catastrophe required careful consideration of available data and the state of knowledge of environmental behaviour, as a basis for judgment of the possibility and consequences of deliberately changing the environment in order to inflict damage on an enemy. This combination of technical and judgmental cumulative assessment led to an important step in international cooperation.

- **Economic Summit.** The Report on Environment to the 1985 Economic Summit identified major areas where environmental factors have a significant effect on economic growth or employment. It does not deal with individual projects but notes the current and potential environmental effects of industrial policies and practices in major fields of economic and industrial activity in both the developed and developing world. Its recommendations are based on cumulative environmental impact assessed on an international basis (Economic Summit 1985(a)). This assessment resulted in the Heads of State of the Summit Countries making a major international statement on the importance of environmental protection in national and international policies (Economic Summit 1985(b)).

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DISCUSSIONS AND CONCLUSIONS

DISCUSSIONS

Discussions during the plenary sessions were wide-ranging. The participants, especially at the beginning of the workshop, had difficulty in defining cumulative effects clearly and in separating discussions of scientific and management issues. Those difficulties reflect the complexities of the concept of cumulative effects, the strength of the connections between scientific and management issues, and perhaps the artificiality of making the contributed papers discrete presentations. In addition, the workshop was organized around problems in each of the four major components of the global environment, as many issues and problems were common to all four.

What are Cumulative Effects?

This question, around which the workshop was organized, dominated discussions throughout. In general, discussions focused on defining examples or classes of cumulative effects, and in trying to decide whether such effects are qualitatively different from other environmental effects. Most of the participants felt that cumulative effects are not qualitatively different from other environmental effects, but that they often require different kinds of research and management approaches if they are to be dealt with effectively.

Several ways of classifying cumulative effects were discussed; some of these appear in the recommendations. "Nibbling," the decremental or incremental changes that are so hard to notice, was recognized as the most important example of cumulative effects. The term nibbling can be applied to incremental as well as to decremental changes, because they are conceptually similar and pose similar scientific and management problems. However, participants wanted to develop a more complete typology of cumulative effects which resulted in the following classification.

Time-crowded Perturbations. Cumulative effects can occur because perturbations are so close in time that the effects of one are not dissipated before the next one occurs. An example is repeated harvesting of agricultural crops or forests that remove some nutrients faster than they are regenerated between harvests (Geppert et *al. 1984;* Krebs 1985). Similarly, the evolution of resistance to pesticides occurs because the susceptible genotypes are repeatedly reduced in number each time the pesticide is applied (Georghiou et *al*. 1983; May and Dobson *in press).*

Space-crowded Perturbations. Cumulative effects can occur when perturbations are so close in space that their effects overlap. An example is power plants close enough that the heat plumes of their cooling water overlap (e.g., Slawson and Marcy 1976).

Synergisms. Different types of perturbations occurring in the same area may interact to produce qualitatively and quantitatively different responses by the receiving ecological communities. For example, several pollutants may interact to produce toxic mixtures (e.g., National Research Council 1982, 1983; for examples of mixtures toxic to humans, see Reif 1984); combinations of forestry practices can also produce cumulative effects (Geppert et *al.* 1984).

Indirect Effects. Cumulative effects can be produced at some time or distance from the initial perturbation, or by a complex pathway. For example, when the level of Southern Indian Lake in Manitoba was raised, the increased rates of erosion of the lake shorelines resulted in the release of mercury into the lake (Bodaly et *al*. 1984) and increased the turbidity of the water (Hecky 1984). Neither of these consequences was predicted by knowledgeable limnologists (Hecky et al. 1984).

Nibbling. Incremental and decremental effects are often (but not always) involved in each of the above categories. There was general agreement that nibbling should be given its own category. The numerous examples include time and space crowding (adding power plants to a river one at a time, several pollutant sources in a lake) as well as removal of habitat piece by piece (e.g., degradation of Chesapeake Bay; Flemer et *al*. 1983).

Other types of impacts have sometimes been considered cumulative such as threshold developments that stimulate additional activity (e.g., new energy developments in Northern Canada, which stimulated logging, road building, and other activities) or projects whose environmental effects are delayed (time lags) or are felt over large distances (space lags). Such effects can be cumulative if they overlap in time, space, or are synergistic with those of other developments.

The Relationship Between Science and Management

There was considerable discussion on the extent to which problems resulting from different types of cumulative effects were related to scientific or management issues. The issues included multiple jurisdictions controlling one environmental system (e.g., estuaries); poor communication between scientists, managers, policy makers, and the general public with respect to articulating social goals; the relationship of those goals to science and management; which components of environmental science are well enough understood to be useful to managers; the quality of scientific inquiry into cumulative effects, and especially, the role of science in planning. Above all, participants agreed that there is uncertainty in predicting cumulative effects in most environmental systems. There was a consensus that scientists and managers need to agree on time and space boundaries appropriate to the problem at hand. For example, it is not sensible to use a county scale for looking at air pollution; nor is it necessary to use a global scale for understanding the eutrophication of a lake. There was agreement that the use of graphs in which problems are plotted along axes of time and space, as has been done in the section "Atmospheric Systems", could usefully be applied to problems in all types of environments.

Scientific and management approaches to cumulative effects are more successful with bounded systems such as lakes and watersheds than with open estuarine and marine environments, where much research is still needed. International cooperation seems to be leading to increased ability to deal with cumulative effects in the atmosphere, but the great diversity of terrestrial environments and their complex patterns of property rights make them very difficult to manage.

Goals and Planning

The primary issues included development of goals, precise articulation of goals, and the use of ambient environmental objectives in pristine and heavily used systems. Some participants felt that environmental carrying capacities, to the extent that they could be quantified, should form a constraint; others felt that more emphasis should be placed on bargaining and mediation to resolve disputes, especially if there was uncertainty about the capacity of the environment to assimilate impacts. It is difficult to gain consensus on such issues, but most participants felt that the scientist's role should be that of advisor to policy makers; that goals should come from or be acceptable to the public, with guidance coming from both scientists and managers.

Monitoring

Monitoring was recognized as essential when testing the predictions of projects used as experiments, and for evaluating compliance with environmental objectives. Monitoring should also be part of all project plans. However, environmental and social indicators most useful in detecting cumulative effects need to be identified. The importance of making all types of monitoring information readily available was repeatedly stressed. Many participants pointed out how easy it is to overlook the importance of monitoring in various phases of research and management.

Interdisciplinary Approach

All participants agreed that cumulative effects, by their nature, require an interdisciplinary approach for their solution. The most important conclusion was that scientists and decision makers must jointly develop procedures for managing cumulative effects. Although such communication is often weak in project-specific environmental assessment, it is critical to the management of cumulative effects, especially when they cross jurisdictional boundaries, as they often do. Some participants thought it important for interdisciplinary work to be fostered and encouraged by government, but others warned that quality control over interdisciplinary programs funded by governmental agencies is difficult. Unless great care is taken, such programs can fail to meet normal standards of scientific rigour. Many participants agreed that the importance of an interdisciplinary approach, despite its difficulties, affects all levels of activity, from education of scientists and managers to publishing, hiring, and funding in both academe and government. There was concern that most funding sources for research do not favor multidisciplinary studies because they are difficult to evaluate. This makes applied research on cumulative effects more difficult.

Scientific Issues

Important scientific issues in the study of cumulative effects include the degree of connection among species in ecological communities, and between organisms and their environment; the time it takes ecosystems to recover from disturbances; the bounding of systems; the degree of compartmentalization and of spatial structure in the system (little in the atmosphere, a lot on land); frequencies and distributions of natural disturbances; understanding and identifying key interactions in ecosystems; and the importance of learning from previous experiences. There was consensus that science has more to offer managers than is now used, but that the domain of ignorance is still vast. More attention is needed on regional instead of site-specific environmental analysis; examples include mass-balance for physical effects, and ambient environmental objectives for air and water resources (see Roots's "Closing Remarks").

Management Issues — Time and Space Scales and Regional Planning

Management issues are seldom easy to separate from scientific issues. The most pervasive management issue seemed to be the proper matching of the scale of management to the scale of the cumulative effects. In this respect, management of cumulative effects falls between the two schools of project-specific environmental assessment and regional planning, or area assessment. The former is generally too limited to detect all effects; the latter too broad to guide specific management activities. Frequently, cumulative effects affect several jurisdictions, either because the impacts cross jurisdictional boundaries (e.g., atmospheric pollution), or because single ecosystems are affected by impacts that originate in several jurisdictions (an example is the collapsing snow goose population on Wrangell Island, mentioned by Roots). Not only do jurisdictional boundaries seldom match those relevant to the management of cumulative effects, but often government agencies have overlapping responsibilities in the geographic unit of impact (e.g., federal, provincial or state, and local government interest in estuary management).

CONCLUSIONS

- Management of cumulative environmental effects is a subset of management of environmental effects in general, but it requires special attention. Improvements in both science and management are needed. Some are dependent on the progress of basic research on environmental effects, but others would benefit from specific research on cumulative effects.

- The widespread mismatch between the time and space scales of management and research and those of cumulative effects causes much difficulty in understanding and managing such effects. Bounding of problems is difficult and sometimes arbitrary. The mismatch of boundaries is often very difficult to redress, because the most useful boundaries may be different for natural systems and for management institutions.

- Incremental losses and additions (nibbling) to natural systems are among the most difficult perturbations to study and manage. Piecemeal habitat loss (death from a thousand cuts) is a good example of this type of cumulative effect for which there are few established management standards or institutional arrangements, and for which overlapping political boundaries are a major part of the problem.

- Current institutions do not foster the cooperation between scientists, managers, and decision makers needed to improve the quality of decision. There are sometimes political and economic reasons for not seeking advice, and when it is sought, the advice may not be appropriately focused or expressed. Scientists tend to be cautious and may be unwilling to offer any advice in the face of uncertainty, but managers must make decisions even if they lack information. Scientists, however, should not overstate their predictive and management abilities. Generally, it is possible to manage in the face of uncertainty, even when we cannot predict the fate of natural systems precisely. Such management requires a flexible system that expects surprises and is prepared to deal with them. Designing such a system requires fundamental changes in many established procedures.

- Monitoring is often improperly designed and executed — it should be built into project design, it should be periodic and long-term, and it should enable us to learn from experience. Research is needed to indentify what kinds of monitoring are best suited to different types of systems and effects. Some organisms or ecosystems accumulate certain pollutants more than others do. Some pollutants are more likely than others to be stored and accumulated rather than metabolized. Some types of ecosystems may be more susceptible to cumulative effects than others.

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RECOMMENDATIONS

On the second day of the workshop, the participants were organized into four working groups. They were instructed by the organizers to:

- determine which difficult problems of environmental assessment are truly cumulative, and to outline the criteria they used for those judgments;

- specify for each type of cumulative effect identified whether it is currently being dealt with satisfactorily, both with respect to science and management; and

- develop research recommendations to strengthen scientific and management weaknesses in dealing with cumulative effects.

Each group produced a set of recommendations, which the editorial committee has combined, expanded, and edited. They are divided primarily into scientific and institutional ones, both of which involve social and natural sciences.

The recommendations reflect the views of the workshop and not necessarily those of NRC or CEARC. The purpose of the workshop was to assist NRC and CEARC in developing research proposals, but we believe that the recommendations will also be of use to others.

SCIENTIFIC

Scales

Environmental effects should be analyzed in accordance with clearly defined time and space scales as described in the section "Atmospheric Systems." This approach should help in identifying the various sensitivities of different environments and ecosystems to cumulative effects caused by various kinds of perturbations.

A better match between geographic and temporal scales of decision making and management and scales of environmental effects is needed. To this end, cases in which cumulative environmental problems have been dealt with — both successfully and unsuccessfully — should be reviewed to understand how the setting of management and ecological boundaries influenced their success or lack of it.

Environmental Processes

- Research should be conducted to determine the rates at which materials can be added to environments, and resources harvested from them, that are consistent with human use of various environmental systems and the integrity of the systems themselves. Included in this research should be studies of response rates and recovery times.

- Research should be conducted to determine the types of indicators and thresholds most likely to be useful for assessing and managing different kinds of cumulative effects in diverse environments.

Monitoring

- Monitoring should be built into the design of projects that could result in cumulative effects. This requires an understanding of the appropriate time and space boundaries. In addition, monitoring should be frequent enough and carried out for long enough to detect cumulative effects.

INSTITUTIONAL

Communication

- Communication between scientists, managers, and policy makers needs improvement. To this end, the institutional and informal channels for such communication should be reviewed, and methods for improving such channels and associated decision-making processes should be identified.

Scales

- The management of cumulative effects is particularly difficult because of frequent mismatches between the scale of management and the scale of some societal goals. Research should be conducted into the ways that societal goals and associated performance criteria are identified and incorporated into management policy and practice.

- Research should be done to identify improvements in decision-making structures and in the allocation of responsibility for effective management of cumulative effects, so that political institutions can act at time and space scales appropriate to environmental problems, and so that recommendations for institutional improvements can be directed to the responsible parties. This is particularly important if several jurisdictions are involved in management.

Regional Planning

- Research should be done to assess the role of regional planning and area assessments in managing cumulative effects. Review of cases is recommended to determine to what extent regional analyses provide a basis for policy concerning the development of single and multiple projects.

Institutions

- Institutional structures for interdisciplinary studies of cumulative effects need to be established and appropriately funded. The means of assuring scientific rigour should be included in their operating procedures.

GENERAL

- Agreements between decision makers, managers, and scientists with respects to the appropriate time and space boundaries for dealing with cumulative effects should be documented. This will force clear thinking about this important issue, will indicate potential weaknesses in decision making due to mismatched boundaries, and will provide a record so that procedures can be improved.

- Understanding and managing cumulative effects requires action in the face of uncertainty. The best approaches for dealing with uncertainty should also be researched; general principles are desirable.

- Reviews of the state of assessment of cumulative effects, with case studies, were recommended several times. The implementation of the recommendations above and the publication of results will provide such reviews.

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