ECOLOGICAL AND RESILIENCE INDICATORS FOR MANAGEMENT

Ralf Yorque, Editor

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I. INTRODUCTION

In February 1974, the Scientific Committee on Problems of the Environment (SCOPE) held a workshop under the sponsorship of the United Nations Environmental Program to develop a state of art handbook on environmental impact assessment*. A small group of workshop participants was charged with developing the chapters on the use of modelling in impact assessment procedures. This group consisted of a mix of mathematicians and resource ecologists from Venezuela, Argentina, U.K., Canada, U.S.A., and Japan. When the chapter was finally completed, it became clear that there was a very real potential for extending the state of the art in a relatively short time. Developments over the past five years have suggested new ways of dealing with uncertain information: new techniques of modelling and tested variants of older techniques which, together, might lead to a significant improvement of impact assessment procedures. Moreover, new concepts have evolved out of this work relating specifically to the issue of how to deal with unexpected events and unknown or uncertain relationships. This concept had both theoretical and applied relevance. From a theoretical point of view the stability behaviour of

* (R.E. Munn, ed. 1975. Environmental Impact Assessment: Principles and procedures. SCOPE report 5).

ecological systems led to a concept of resilience which emphasised the ability of such systems to absorb unexpected events. And on the management side, the concept focussed on "option foreclosure." That is, in many management situations, a series of decisions is often set in motion which gradually narrows the range of options that can be exploited if unexpected events emerge. Hence, both methodological and conceptual developments led the group to feel that the time was ripe to consolidate these developments with particular emphasis on ways to deal with uncertain information and unexpected events.

It was decided, therefore, to establish a two-year project with the following aims:

(1) To provide a series of handbooks for a specific client, i.e., the head of an environmental assessment team. Such a person has two problems -- first, to organise and focus his staff, and second, to provide information and recommendations for decision making. For the first problem the main question is one of reliability and for the second the main questions are simplicity, practicality and reliability of information.

(2) These handbooks will cover the following topics:

(a) the environmental impact assessment process,

(b) modelling and assessment techniques,

(c) case studies demonstrating these techniques,

(d) a resource science information library.

(3) A series of papers giving a scientific assessment of techniques and concepts.

In general the goal, therefore, is to explore and where necessary develop a hierarchy of methods of impact assessment which ranges from simple and qualitative to complex and highly quantitative. Along this spectrum there would be an increase in the amount of knowledge available and in the resources of expertise and computers. By testing each technique against different levels of information it should be possible to identify exactly how responsive each one is to the kinds of questions asked of impact assessment groups. Throughout there will be a strong emphasis on the use of resilience indicators and techniques to deal with uncertainties, unknowns, and unexpecteds.

Previous research at the International Institute of Applied Systems Analysis and the Institute of Resource Ecology, University of British Columbia has allowed us to develop a rich array of models of regional development problems in fisheries, forestry and wildlife. These will provide the testbed to develop key environmental indicators and environmental impact assessment procedures. A small group of scientists from the U.S.S.R., U.K., U.S.A., Canada, Venezuela, and Argentina will develop the series of handbooks and papers. That activity will cover approximately two years and will proceed in four stages. The first three stages will be the analysis and development of indicators and methodologies. At the end of each phase a workshop will be held involving the participating scientists to consolidate developments to the point, identify new tasks to be done, and assign responsibility for them. There will, therefore, be a revolving set of papers which will gradually move to consolidation. These papers will eventually form the briefing document for a major conference at the International Institute of Applied Systems Analysis in which practitioners of environmental impact assessment are brought together for a critique of this effort. With that critique as guidance, the documents will be rewritten as a series of handbooks for environmental impact assessment.

The timing of these events is as follows:

1974-75	Preparation of testbed of simulation models at IIASA and the Institute of Resource Ecology
Spring 1975	First draft of working papers on techniques and use

October 1975	Workshop I in Vancouver
April 1976	Workshop II in Vancouver
October 1976	Workshop III in Venezuela, Argentina or the U.S.A.
Spring 1977	Conference at IIASA

The first workshop has now been completed and the body of this document is a review thereof. The goals of the workshop were:

(a) to explore promising techniques and their needs -- both modelling, indicators, evaluation and communication,

(b) to identify the subset we will test,

(c) to select case studies to test techniques,

(d) to define the information packages and performance criteria,

(e) to define the common framework for the use of techniques and

(f) to organise subsequent steps and assign responsibilities.

Each of these items was explored and, in addition, some initial testing of two techniques was attempted using interactive computer facilities. The major effort until the next workshop will be to complete the task indicated in Section IV Recommendations. In addition, three of the case studies -- a forest pest problem, alpine development, and a hydroelectric development in northern Canada -- will be used by a group of faculty and students at the University of British Columbia in a pilot effort to test and evaluate techniques.

BRIEF AGENDA OF WORKSHOP I

Introduction and Review	C.S. Holling
Presentation of Techniques	
1. Loop analysis as a predictive tool for Environmental Impact Assessment. Considerations of cross impact designs.	G. Gallopin
2. Use of catastrophe theory in EIA.	D.D. Jones
3. Use of ecological community matrix methods for EIA.	J.H. Steele
4. Experiences with complex and simple simulation models for environment studies.	C.J. Walters
5. Defining functional relationships with minimal data.	C.S. Holling
6. What kinds of predictions are needed in the field by actual management personnel.	J. Gross
7. Design and use of indicators of resilience in EIA.	R.M. Peterman
8. Computer hardware and software environments for EIA.	S. Borden
9. Some proposed designs for testing impact assessment methodologies.	R. Hilborn
10. Qualitative modelling approaches.	D. Ludwig
Development of Briefing Papers by Subgroups	
1. The Process of Environmental Impact Assessment.	G. Gallopin J. Gross C.J. Walters D. Ludwig W. Greve W.C. Clark
2. Experimental Design for Comparison of Assessment Techniques.	J. Rabinovich R. Hilborn R.M. Peterman N. Sonntag

3. Technique Criteria

J.H. Steele
D.D. Jones
S. Borden
A. Bazykin
R. Fleming

Testing of KSIM and GSIM

Review and Planning

II. SUBGROUP REPORTS

II.1. THE PROCESS OF ENVIRONMENTAL IMPACT ASSESSMENT

This project has two central concerns: the basic process or organisation of Environmental Impact Assessment, and a set of techniques that might be used to improve the process. This paper examines the process problem: by looking at shortcomings of existing or traditional EIA approaches, we attempt to define directions to look for better approaches. We suggest that improvement will likely come in two dimensions:

1) more complete, consistent, and dynamically-oriented identification of recognisable impacts;

2) adaptive development planning and EIA that can better respond to the inevitable unrecognised impacts; i.e., to suprise.

THE CONTEMPORARY EIA PARADIGM

Traditional frameworks for developing environmental impact assessments typically spell out check lists of components to be analysed, techniques to be utilised, end products to be obtained, plus step-by-step directions for orchestrating the entire assessment operation and assembling its varied products into a comprehensive package.

Major features of such check lists invariably include description of the environment as it would exist under disturbed and undisturbed conditions; identification of the decision makers who will make use of the assessment findings; clearly and comprehensively defining goals the assessment is addressing; and generating sufficient alternatives to respond to recognised (and unrecognised) events. A plethora of additional rhetorical lectures is usually included to complete the author's perspective of structural and functional completeness. The intent of such near-definitive, cookbook-structured guidelines for impact assessment is to supply a comprehensively preceived, rigorously organised process which will systematically guide the technical aspects of assessment to a successful conclusion. The result is invariably a process whose successful application requires a highly rational, organised, disciplined and knowledgeable framework for the assessment program. And it is a sad fact of life, well known to practitioners, that actual impact assessment must always be performed under severely constrained conditions remote from this ideal framework. Our concern in this paper is with the design of assessment process guidelines which more realistically and more usefully address these inevitable constraints.

For the audience towards which this paper is aimed, it will not be necessary to evaluate the efficiency and effectiveness of the typical assessment approaches beyond the general observation that much remains to be achieved. The shortcomings of present assessment approaches are to a considerable degree caused by guidelines which are conceptually inadequate in their approach to real-world ecological problems and woefully naive in the response they expect from real-world assessment programs.

Though well intentioned, traditional assessment guidelines erect three major hurdles which must be negotiated in any real world case. First, existing assessment processes require considerable managerial flexibility in order to fit a rigid conceptual system (e.g., to provide the real-world system with technologically -- or ecologically -- best solutions), but seldom include conceptual flexibility of a sort that will accommodate a rigid real-world system (e.g., to adapt the conceptual system to conditions of political reality and feasibility). Better assessment process guidelines must provide a negotiable, flexible boundary between technologically best and politically feasible assessment results.

Second, assessment process guidelines are usually presented in the format of a conceptual textbook. Seldom does one see guidelines augmented with real-world examples which would promote understanding within the user group. Since there is considerable doubt that impact assessment has attained a level of development which could be called a science, the attempt should be made to portray the assessment process and its guidelines as the imprecise, art-like process it truly appears to be.

Third, traditional assessment guidelines focus on principles and procedures which depend on uniform levels of detail across components for successful application. Guidelines for handling weak links in the information or assessment chain are seldom presented. Since real-world assessment activities are seldom able to meet such standards of uniformity, the entire process may be inapplicable.

In short, traditional guidelines to the assessment process -- although well intended and comparatively progressive -- seldom measure up to their conceptual expectations. Reasons for these shortcomings, which also point the way to development and evaluation of alternative assessment approaches, are discussed in the following section.

COMMON MYTHS ABOUT ENVIRONMENTAL IMPACT ASSESSMENT

The literature on EIA is replete with motherhood statements and implicit assumptions about the conduct and content of impact studies. Some of these ideas are meaningless in practice, others are deceptive, and some are downright false. The intent of this section is to help point the way toward better approaches by indicating some of the more obvious pitfalls and misconceptions that have found their way into present practice.

Myth #1: EIAs should consider all possible impacts of the proposed development.

This myth hardly deserves comment. The really interesting question is: does the fact that it is physically impossible to foresee all (or even most) of the impacts have any serious implications in terms of how the basic development plan should be structured?

Myth #2: Every new impact assessment is unique and must be designed as though there were no relevant background of principles, information, or comparable past cases.

It is certainly true that every environmental situation has some unique features (rare animal species, geological features, settlement patterns, etc). But most ecological systems must face a variety of natural disturbances and all organisms must face some common problems. The field of ecology has accumulated a rich descriptive and functional literature which makes at least some kinds of studies redundant and some predictions possible. The same is true for economic, social, and physical aspects of the assessment.

Myth #3: Comprehensive "state of the system" surveys (check lists, etc.) are a necessary first step in EIA.

Survey studies are often hideously expensive, yet produce nothing but masses of unreliable and undigested data. Also they seldom give any clues as to natural changes that may be about to occur independent of development impacts. Environmental systems are not static entities which can be understood by simply finding out what is where over a short survey period.

Myth #4: Detailed descriptive studies within subsystems can be integrated by systems analysis to provide overall understanding and predictions of system responses (impacts).

The predictions from systems analysis are built up from understanding of relationships between changing variables. Descriptive studies seldom give more than one point along each of the many curves which would normally be used to express such critical relationships. In short, what a complex systems is doing seldom gives any indication of what it would do under altered conditions. Again the interesting question is: what are the policy implications of the fact that even comprehensive systems models can only make predictions in sharply delimited areas.

Myth #5: *Any good scientific study is useful for decision making.*

The interests of scientists are usually quite narrow and are usually geared to a particular history of disciplinary activity. If you are concerned about the impact of a pesticide on some animal population, how would you use the scientific information from a study on the animal's reproductive physiology if no one had bothered to study juvenile survival rates (which might improve to balance any reproductive damage)?

Myth #6: *Physical boundaries based on watershed units or political jurisdictions can provide sensible limits for impact investigations.*

Modern transportation systems alone can produce environmental impacts in unexpected places. Transfers of impacts across political boundaries can lead to a wide range of political and economic reactions from the other side. A narrow study that fails at least to recognise these impacts and reactions may be worse than useless to the decision maker.

<u>*Myth #7*</u>*: Systems analysis will allow effective selection of the best alternative from several proposed plans and programs.*

This assertion would be incorrect even if systems models could produce reliable predictions on a broad front. "Comparison of alternatives" involves assessment of values placed on impacted system components. Rarely is this assessment a part of the environmental impact work.

<u>*Myth #8*</u>*: Development programs can be viewed as a fixed set of actions (e.g., a one-shot investment plan) which will not involve extensive modification, revision, or additional investment as program goals change over time and unexpected impacts arise.*

Unexpected impacts may trigger a sequence of corrective investment decisions which result in progressively greater economic and political commitments to make further corrections if the initial ones are not successful. Thus decisions can have <u>decision consequences</u> as well as direct environmental ones, and these induced decisions can generate greater environmental impacts than would ever seem possible based on the original development plan.

BETTER APPROACHES TO RECOGNISABLE IMPACTS: BOUNDING THE ASSESSMENT IN SPACE, TIME, AND ACROSS SUBSYSTEMS

Our analysis of EIA myths strongly suggests that major problems arise not from the specific way impacts are described and measured, but rather from the more basic problem of impacts that are not recognised at all. This section tries to suggest some process considerations which would allow the number of unrecognised impacts to be reduced. The final section will argue that we must go still further and seek fundamentally different approaches which do not depend on how clever we are at *a priori* recognition.

Systems analysts have been especially and properly fond of telling decision makers about the need to carefully define and bound problems. It is in setting the boundaries that the impact recognition paradigm becomes critically important; the boundaries must be defined in three basic dimensions:

(1) space -- how far away will the impacts reach

(2) time -- how long will the impacts last

(3) across subsystems -- how will the impacts spread from component to component.

The usual spatial bounding assumption is shown in Figure 1a: we expect the greatest impacts "nearby," with decreasing effects as we move away from the location or abstract decision point. We call this assumption the "dilution of impacts" paradigm. Harmful physical effects (pollutants) are assumed to diffuse in space, damages are assumed to repair themselves over time, economic perturbations are assumed to be damped in a complex network of economic transactions, and so forth.

An alternative world view is shown in Figure 1b. In this view impacts and problems are not related in any simple way to the location of the development. We would obviously not take this view seriously in dealing with many physical problems (though some pollutants can be concentrated to dangerous levels by biological and physical mechanisms far from their source), but it is not clear that the physical analogy holds in dealing with other subsystems. We might argue (and examples will be presented later) that economic impacts in particular need bear no obvious relation to the initial investment, within broad geographical and temporal limits.

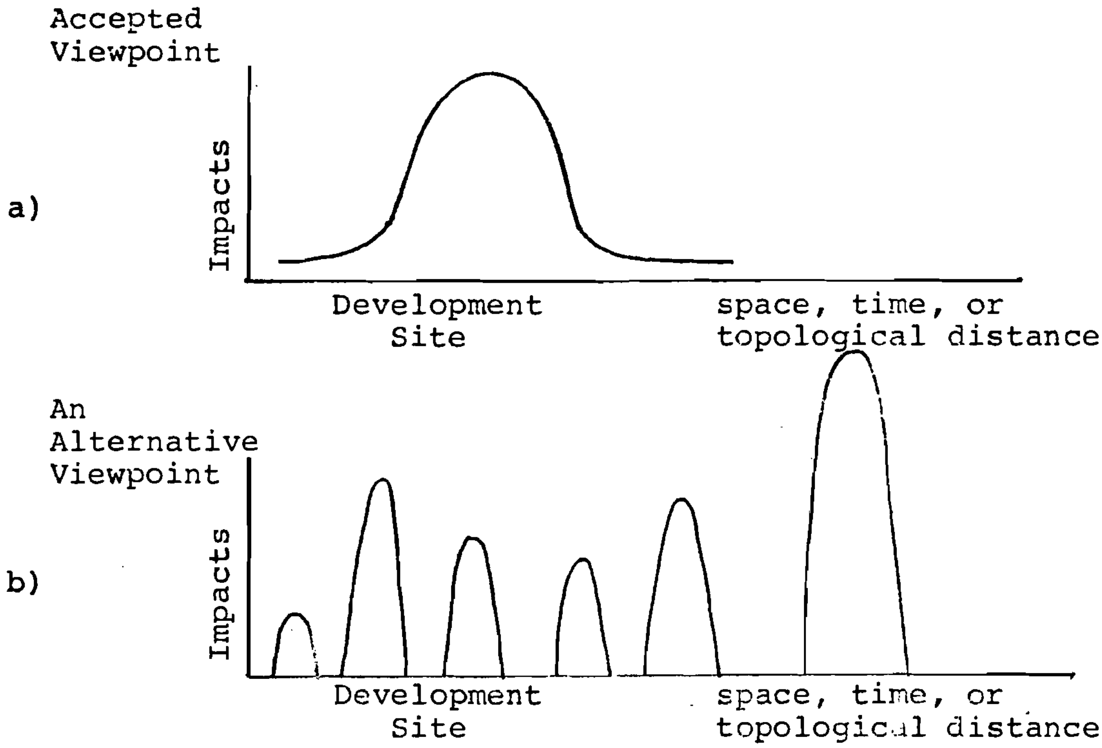

Figure 1. Alternative paradigms for the distribution of development impacts.

It is obvious why the viewpoint of Figure 1a has developed and been found acceptable. Until very recently, physical and economic isolation has been great enough to prevent strong cross-impacts. Ecological and economic systems have had strong mechanisms to buffer change. Also, many scientists would argue that a world structured as in Figure 1b should be essentially chaotic, with large and unpredictable changes occurring in all subsystems at apparently random times.

The dilution of impacts world view is apparent in many tools and associated terminology currently popular in resource planning. The most obvious example is benefit-cost analysis, which calls for a careful accounting of "primary" and "secondary" (or "direct" and "indirect") benefits and costs, and the use of smooth discounting functions. In practical applications, "secondary" is usually equated with "less important" or "less certain to occur." Benefit-cost analyses often make use of the results of another common tool, input-output analysis. The multipliers from this analysis are supposed to capture overall increases in economic activity induced by investment decisions. It is usually assumed that the spatial distribution of the induced activity is diffused or unimportant, and that the time transition of increase will be smooth and controlled.

It has been said that the way to recognise a planner is to look for crayon (or felt pen) marks on his hands. Development plans are always accompanied by a profusion of maps. Recognizing that rectangular maps introduce arbitrary boundaries, many planners prefer to delimit problems by natural units such as watersheds and elaborate technology is available for producing overlay transparency maps to show how different land use attributes impinge on one another.

Spatial divisions of political jurisdiction and responsibility (in the Western countries at least) have helped to encourage the development of the "dilution of impacts" paradigm. Existing patterns of jurisdiction have arisen for perfectly good reasons related to provision of public services (transportation, law enforcement, etc.). However, political boundaries are often used to excuse very narrow planning viewpoints. Too often the attitude is: yes, I see that impacts may occur over there, but that is outside the boundary of my government's responsibility; let's concentrate on our own problems first."

It is somewhat difficult to find examples of how well the usual paradigm works in practice, since most evaluation studies begin with the assumption that the spatial and temporal framework was properly defined in the first place -- impact patterns as in Figure 1b may have gone unrecognised in the past simply because no one has looked for them. However, glaring examples are beginning to appear with increasing regularity.

The United States recently invested millions of dollars on environmental impact studies for the Alaska Oil Pipeline. A small army of researchers and consulting firms made very detailed studies along the pipeline route and these studies prompted several engineering changes and safeguard measures. The pipeline will be buried along much of its route and will be high above the ground in some places; indeed, the local environmental impacts are almost certain to be small. However, little attention was paid to impacts the large influx of construction workers (10,000 at present) will cause. These impacts are not likely to occur along the construction route, but rather around Alaska's population centers and transportation routes to the south. The city of Juneau will be hit especially hard. To accommodate workers on leave from the construction areas, housing will have to be built and some use will have to be found for it after the pipeline is completed. Outside the cities, recreation areas (especially for hunting and fishing) which are already crowded are likely to see considerable additional pressure. With a bit of foresight, many of these problems might be handled quite well -- but the Alaskan government now considers itself in a crisis situation and will almost certainly make a series of blunders.

Canada has a similar example with the James Bay Hydroelectric Development. This development involves an enormous area in the northern quarter of Quebec. Environmental impact studies (complicated by institutional problems between the federal and Quebec governments) have proceeded in the usual way with emphasis on resources in, around, and downstream from the hydroelectric dam sites. There is a pretense of broad, systems thinking about the problem -- studies are being conducted on issues like climatic change (the dams will add huge areas of water surface) and the welfare of local Indian populations. However, a key factor has been largely neglected: road access will be provided to the area, and the influx of recreational use may be very large. Our calculations (walters, 1974) indicate that fish and wildlife losses (recreational harvesting, etc) well away from the dam sites may be ten to twenty times greater than the direct losses due to flooding and downstream damages. Again, with a little foresight this problem could be avoided, controlled, or even turned into a socioeconomic advantage.

These examples suggest that two obvious factors which we have been able to ignore in the past are becoming critical determinants of development impact patterns: transportation and economic interdependence. Both have their major influences on the "secondary" rather than "primary" benefits and costs of development.

We usually think of modern transportation systems as a mechanism for dispersing people and the assorted problems they cause. Clearly we need to consider the reverse process as well; resource developments which permit or induce population redistribution can cause highly undesirable concentrations of human activity.

Increasing economic interdependence over large areas is a less obvious and more disturbing factor. In part this interdependence is related to transportation systems, but in general it appears to be a by-product of increasing technological efficiency. As we strive for efficiency in the production of critical goods (such as fertilizer and food), we seem to depend more and more on specialised inputs which cannot be readily substituted. There is a basic principle in ecology that appears to apply in economics as well: increased net production or output can be obtained only at the price of specialisation and simplification.

While it is apparent that modern technology can cause shifts in the spatial and inter-subsystem distribution of impacts, it is not clear that we should also expect changes in the time distribution of impacts. In other words, should we be watching for mechanisms by which potential impacts might be "stored" such that they surface suddenly and unexpectedly in the future? In part this question has been addressed by Holling (1973) in his resilience work. He argues that some actions and management patterns may trigger unforeseen (and unmeasured) ecological changes, leading to contraction of stability regions in a forest insect pest system. The stability properties of this system may depend on spatial heterogeneity of the forest. Pesticide spraying triggers a progressive loss of spatial heterogeneity until an explosive and destructive insect outbreak becomes inevitable.

Consider another (purely hypothetical) example of the time-distribution problem. Suppose we are trying to predict the impacts of a hydroelectric dam in Western North America on salmon populations downstream. The salmon require clean gravel beds for spawning. Silt and other pollutants accumulate in such gravel beds, and it may be that periodic high water flows are necessary to clear the gravel. By stabilising water flows, the dam may trigger a slow process of material accumulation and deterioration that may take many years to make itself felt. It is not likely that the deterioration would be monitored or noticed until too late.

Economic systems also appear to have mechanisms which can lead to sudden impacts after a considerable time lag. One way to view the recent western ethic of economic growth is as a mechanism to defer impacts to the future. We recently developed a demographic-economic growth-environment impacts model for the small alpine valley of Obergurgl in Austria (Himamowa, 1974). The village and the alpine valley surrounding it form a nicely closed physical and demographic system (no immigration is permitted). Tourism is the main industry and the village has grown rapidly for the last two decades. Almost every young man builds or inherits a small hotel and saves money for building investment by a combination of tourist service and construction employment. However, safe land for building is quite limited and environmental degradation is becoming serious -- within two or three decades the hotel construction will have to stop. This will trigger a wave of emigration of young people from the village with attendant social problems which will continue for at least a decade due to the population age structure. Economic growth temporarily hides the demographic problems, just as insecticide spraying hides the changing pattern of spatial heterogeneity in Holling's forest insect example.

Environmental planning seems well on the way to becoming a structured discipline like macroeconomics, whose spectacular failures to predict the events of recent years (witness the energy crisis) may stem from a similar myopia about modern systems. The macroeconomists seem determined to cling to descriptions of the world based on traditional indicators (GNP, etc); environmental planning might make a comparable mistake by clinging to the dilution of impacts paradigm.

As a first step, there is a critical need for objective documentation of more examples of development impacts. One might well argue that our examples are rare exceptions and that we simply do not hear about the vast majority of successful development programs that do not result in any major surprises. This may well be true, but some comparative studies might help us sort out a methodology for recognising the pathological cases _before_ they begin to cause trouble.

It is not really a major conceptual step to move beyond the map-making, spatially restricted thinking that characterises most current environmental planning. The same methodologies and ways of thinking we now devote to the development of tedious lists of impacts and indicators can be fruitfully redirected, simply by paying more attention to mechanisms which may result in redistribution of impacts in space and time. Also we can pay more attention to the obvious fact that development programs involve and induce many inputs and outputs other than physical facilities and pollutants.

Certainly there are difficulties, particularly in relation to the diffusion of economic impacts. But simplistic, first order environmental planning should not be excused simply because economic interrelationships are poorly understood. As an initial step, we suggest that it is particularly important to discard the primitive notion that costs and benefits can be meaningfully divided into "primary" and "secondary" categories. There is no reason why we cannot deal with complex economic patterns just as we deal with complex ecological ones.

The many procedures that now exist in environmental planning, ranging from the formulation of checklists to elaborate cross impact matrices and simulation models, all have the same goal: to help structure and improve the way we ask questions. Yet most of these procedures ask the analyst to look directly at the <u>things</u> (subsystems, indicators) which might be affected; the analyst is supposed to implicitly take account of the <u>processes</u> involved. Mathematical modelling and simulation techniques demand more deliberate consideration of processes and mechanisms, and it has been our experience that modelling exercises always turn up a variety of impacts and problems that have been overlooked in applying the simpler procedures.

Unfortunately, formal modelling exercises require a variety of resources that are not always available; also they seldom produce products of quantitative predictive value, and by concentrating on quantifiable relationships they often lead to elegant but trivial analyses of very narrow subproblems (water pollution models are an especially good example of this difficulty). However, there are at least two model building tricks which might be generally applicable when trying to deal with situations where the spatial and temporal impact pattern is not clear:

(1) the "looking outward" approach to variable identification,

(2) "input-process" impact tables.

Both these tricks are nothing more than formalisms to help structure the way questions are asked.

The "looking outward" approach was developed by our modelling group at the University of British Columbia through various attempts to encourage traditional discipline-oriented scientists away from reductionist ways of thinking. Typically in model building (and impact assessment) exercises and workshops, each disciplinarian is asked to devise lists of variables and relationships needed to describe the dynamics of the subsystem which is his speciality. His natural tendency then is to come up with a list that reflects current scientific interest within his discipline; this list is usually unnecessarily complex and often has little relevance to the development problem at hand.

In the "looking outward" approach, we simply turn the question around. Instead of asking "What is important to describe subsystem x?", we ask "What do you need to know about subsystem y in order to predict how your subsystem x will respond?" That is, we ask the disciplinarian to look outward at the kinds of inputs which affect his subsystem.

After iteratively going through this questioning process for each subsystem, we can present each disciplinarian with a critical set of variables whose dynamics he must describe before we can generate any picture of overall system responses. Also by asking him to identify the inputs to his subsystem, we in effect ask him to think more precisely and broadly about how the subsystem works. Of course, the subsystem modelling process is also much simplified when the desired outputs are precisely known.

Input-process impact tables are a variant of the cross-impacts or action-impacts matrices commonly used in environmental assessment. The idea is to list a series of inputs (proposed development actions, materials involved in development, pollutants released into the environment, etc.) as the rows of the table, and a series of important <u>processes</u> as the columns of the table. The columns might be for example:

transportation substitution of inputs plant siting effluent release	economic processes
migration choice of recreational sites demographic (birth-death)	social processes
material transport mass balance relations	physical processes

dispersal competition predation	ecological processes

Then for each input-process combination in the table we ask two questions:

(1) Will the input directly affect the process in relation to at least one sub-unit (economic sector, social group, physical area, or material, type of organism, etc.)?

(2) If so, what spatial and temporal consequences can be expected for each sub-unit being affected?

Thus the input-process questioning tends to focus expert attention on mechanisms which might produce unexpected impacts. Once the table has been developed (and it is usually not even necessary to write down any answers to the two questions above), it is easy to move on to a more specific table where particular impacts or indicator changes are identified in relation to inputs.

BETTER APPROACHES FOR DEALING WITH SUPRISE: TOWARDS AN ADAPTIVE STRATEGY OF DEVELOPMENT DESIGN AND ASSESSMENT

It follows from the *Myths* discussed earlier that Group X should not seek to develop simply a new improved "cookbook" approach to impact assessment. There is no possible fixed set of pigeon holes or protocol into which a given EIA problem can usefully be forced, although this is what most existing reviews of EIA technique imply. We cannot provide general rules for performing EIAs, but we may be able to provide guidelines for making those rules in any given instance.

The central message of the Myths is that EIA must be an essentially adaptive enterprise. Since constraints differ radically among problems, any EIA 'guidelines' must allow the given assessment to adapt to these constraints. Since we cannot predict reliably, we must design our development programs in such a way that we can adapt our actions in response to our experience. Since we cannot include everything important in our analysis we must know how to adapt our use of a given, necessarily limited EIA with respect to what our bounding operation consciously and unconsciously left out of the analysis. In short, the fundamental failing of present EIA approaches is their insensitivity to the importance of flexibility and adaptiveness in good environmental design, management and assessment.

Most EIA work is inherently passive in orientation, as its focus on 'assessment' suggests. The central message of the adaptiveness concept is that good EIA must provide meaningful feedback to the process of impact (i.e. development) design. That is, our EIA must explicitly help us to design good development programs, rather than merely 'ranking' or 'assessing' fixed possibilities. This attitude leads inexorably to a concept of EIA as an ongoing iterative process of design/assessment/design/assessment...

The traditional focus of design and assessment activities is on the known part of the world. We do our best to predict (assess) and mitigate (design) known impacts of known acts on the environment. Unknowns are treated as imperfections in this process, leading to uncertainties in our predictions and recommendations. A radically different attitude focusses instead on the unknown itself. Its central concern is the adaptive and creative management of the unknown itself. Its goal is not to eliminate the unknown -- this being the ultimate myth -- but rather to design both the 'kinds' of unknowns impinging upon development programs and the framework for adaptive assessment/response which will allow us to cope with and capitalise on inevitable unforeseen contingencies as they arise in the course of any development program.

These somewhat vague notions of strategy, adaptiveness, design, and the managed unknown are dealt with in more detail elsewhere, and constitute the present focus of much theoretical and applied research. Our immediate goal is to encompass these issues in an <u>operational</u> manner, delineating their immediate relevance to the process of environmental impact assessment and design. We are not charged with developing a treatise on "Strategies of Environmental Development," however important and urgent such a document might be. Rather, our charge is to touch on the essential elements of such a strategy just enough to provide practical guidelines and aids to our decision-maker/manager clients as they go about fulfilling and defining their real world EIA responsibilities. It would seem that in meeting this goal, we will have to develop a delicate mix of the normative and the positive; leading beyond the abysmal state-of-the-art, without becoming irrelevantly academic, and simultaneously providing specific and useful guidelines without writing tactical cookbooks.

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II.2. EXPERIMENTAL DESIGN FOR COMPARISON OF ASSESSMENT TECHNIQUES

I. GENERAL FRAMEWORK AND LOGISTICS

The following description of experimental design for comparing impact assessment techniques consists of four parts; 1) the general framework and logistics, 2) definition of levels of information packages, 3) performance criteria for evaluating each technique, and 4) ways of handling uncertainty.

Overall Goals

The primary goal of this comparison is to determine the utility of different assessment techniques in making an environmental impact assessment. These different techniques will be evaluated by comparing their predictions of policy impacts in each of a series of case study problem areas (e.g., hydroelectric development) with similar predictions made by detailed simulation models of these problem areas.
Since we do not have enough information from real-world situations to describe the impacts of various policies on a system, we need a standard basis for comparison. Hence, we have chosen full-scale simulation models to represent, for the moment, the real world. We fully recognize the dangers inherent in this procedure, but we found it necessary in order to standardize the comparison of techniques.
A broad range of case studies has been chosen to span as great a possible range of impact assessment conditions as possible. There are several complexities of the problem; they are:

--- The assessment may be made under different degrees of information about the system. Therefore we have chosen to repeat the analysis for different data levels (see section on data and information packages.

--- Different assessment techniques may work better for different types of problems, thus the selection of different case studies (see Appendix I on case studies).

--- Some assessment techniques may be better for different criteria of performance, thus the selection of several criteria of performance (see section on pèrformance criteria).

The actual process of the comparison, the experimental design, relies heavily upon two groups of people:

(A) The Case Study Coordinator

The case study coordinator is a person or group intimately familiar with the case study and the simulation model being used as the "real world." The assigned jobs of a case study coordinator are:

(1) Prepare three data packages ranging from very skimpy (level I) to very detailed (level III), with the level II data package falling somewhere between the two.

(2) Define the possible policy or management options. These should be somewhere between 3 and 4 in number and completely specified in the data package.

(3) Make up the impact assessment form which will be filled in by the assessment group. This form is described in detail in Appendix II.

(4) Analyse the results of the assessments made by the different assessment groups receiving the data packages. The case study coordination groups will meet as a whole at the end of the project to write up the summary of modelling technique performance.

(5) Carry out an impact assessment with each technique, using all the knowledge available for his particular case study including his detailed understanding of the full simulation model. This will test the true ability of the given technique to predict the impact of various policies.

(B) The Assessment Group

The assessment group will consist of persons completely unfamiliar with a specific case study. They will receive a data package provided by a case study coordination group and carry out an environmental impact assessment using one or several modelling techniques (e.g., KSIM, GSIM). Specifically:

(1) They will receive a data package for a case study and familiarize themselves with all the information contained in it.

(2) They will then fill in the preliminary "intuitive" policy impact matrix provided by the case study coordinators. This is before they have used any modelling technique.

(3) They will then use one of the modelling techniques, sufficiently described in the package provided by the techniques group, to try to forecast the results of the different management policies they have been asked to consider.

(4) They will then fill in the environmental impact assessment form provided with the data package and return it to the case study coordinators.

(5) Each assessment group will indicate, for each technique-data level, how much time,effort, and operational difficulties were involved in order to give some evaluation of the relative

ease of use of each technique.

Order of Events

The two groups will interact in the following order:

(1) Case study coordinators prepare data packages and send them to a group. This group becomes the assessment group.

(2) The assessment group reads the data package and makes a first intuitive cut at the policy impact table assessment.

(3) The assessment group uses a modelling technique to make a new assessment and completes the assessment forms.

(4) The case study coordinators analyze the predictions made by the assessment team and construct measures of performance for the technique used.

Several experimental cautions should be noted:

--- A member of an assessment team should never be a member of the case study coordinators for the same case study. Coordinators for one case study may be part of an assessment team for another case study.

--- An individual should not be part of an assessment team for a case study for which he has previously performed an assessment with a data package containing a higher level of information.

--- If an assessment team is carrying out an assessment for a case study previously used with a different modelling technique, they should not make a new intuitive assessment, but use the original one, as they might be prejudiced the second time around.

--- Assessment teams should not be informed of their performance until they are no longer candidates for further assessment of any particular case study.

Information used in evaluating the relative merits of the different techniques can be summarized as shown in Appendix III.

II. DEFINITION OF LEVELS OF INFORMATION PACKAGES

In order to have a common framework to compare the performances of different techniques when using several levels of information, it is essential that these levels be standardized so that the case studies used to test these techniques can be compared to each other. We will establish guidelines to define three levels of information about a system's structure: crude, intermediate and detailed. Three factors determine our degree of "knowledge" of a system:

(1) The number of processes we know to exist in the system; that is, the number of variables and their interactions taking place in the functioning of the system.

(2) The degree of detail with which we can describe the above processes; that is, the amount of (quantitative) information we can attach to identified processes.

(3) The amount of information available about the initial conditions of the system; that is, the magnitude of the present day conditions of the state variables.

It was thought that the organization of information knowledge of a system into well-defined packages could be achieved by using factors (1) and (2), and leaving factor (3) to be dealt with at the time of evaluating the performance of each technique (see below).

To simplify possible different classification procedures, the continuous factors (1) and (2) were arbitrarily divided into 3 groups each,

Number of Processess:	1 = descriptions of a small proportion (0.1 - 0.3) of the processes are known
	2 = intermediate proportions (0.3 - 0.7) of the processes are known
	3 = a high proportion (0.7 - 1.) of the processes are known
Detail of understanding Processes:	1 = relationships between variables are known only in sign or at the most with a sign and relative intensity
	2 = a functional relationship is known to exist between most of the variables
	3 = a functional relationship plus parameter estimates are available for most of the variables.

When there is a mixed situation regarding process description, that is, some processes fall under 1, others under 2, and others under 3, only common sense using subjective weights will permit establishment of the "group number."

We are now left with a 9-entry matrix, as follows:

Proportion of Processes	Detail of description: 1	2	3
1	1	2	3
2	4	5	6
3	7	8	9

Comments about this matrix:

(1) Definition of LIP (Information Level Packages). Cross-hatched blocks (1, 2, and 4) will be considered lowest ILP, blank blocks (3, 5, and 7) intermediate ILP, and straight hatched blocks (6, 8, and 9) high ILP. Note that in creating any data package, the case study coordinator should randomly choose the variables or relations to be described (say, 30% of all those available).

(2) Dubious cases. Some blocks, e.g., 3 and 7, may appear unrealistic. However, some data sets may occasionally fall in these blocks.

(3) Possible continuous classification of blocks. For the sake of a common framework to compare techniques across case studies that are from very different systems, have different environmental impact goals and time-space scales, we could try to classify the blocks in a more continuous fashion.

One possible criterion would be to attribute more importance to detail of decription, in which case we would read along rows (1, 2, ..., 9). The opposite decision of assigning more importance to proportion of processes rather than to detail of description will make us read along columns. The information level would increase for the following block order:

1, 4, 7, 2, 5, 8, 3, 6, and 9.

In addition to these easily quantifiable measures of knowledge of the system, there may be information on the response of the system studied to historically encountered perturbations (e.g, spruce budworm, other hydroelectric projects). This historical perturbation information may be a useful addition to a given technique's predictive capabilities, so that such data should be considered a valid part of the information packages.

Finally, a fourth data level can be defined to be the full knowledge of the case study coordinator, who will then test each technique as described in the experimental design section.

The matter of the amount of information available on the initial conditions of the system could be used to move a given case study from one ILP to another ILP. However, it was thought that this information could be used better in conjunction with policy evaluation criteria.

The possible different levels of knowledge concerning initial conditions of a given variable were considered to be one of the following:

(i) no information,

(ii) information about possible range of values,

(iii) fragmentary sampling information, providing a relatively reliable mean value,

(iv) full scale sampling information providing frequency distribution of estimates.

These different degrees of information could be used either:

(a) to weight the reliability of each impact in relation to the degree of information available on the variables more related to it. This could be done through sensitivity analysis with the technique at hand;

(b) to obtain a numerical value condensing our degree of knowledge of the initial conditions of the system and use this value in the decision-making prior to the application of any performance criterion, e.g.,

Variable(s)	Initial conditions knowledge
1	1
2	3
3	2
4	1
5	4
.	.
.	.
.	.

III. PERFORMANCE CRITERIA

This section describes the criteria we will use to evaluate the performance of each modelling methodology (e.g., KSIM, GSIM) with each data level.

We want to compare how each method performs in each of four categories: (1) prediction of general impacts of policy acts, (2) prediction of the "optimal" policy using some simple objective function, (3) prediction of quantitative results, and (4) amount of insight provided by using the given technique. We are evaluating each assessment technique by comparing its predictions with those of the detailed case study simulation model.

General Policy Impacts

A policy impact table, such as that shown in Appendix IV, should be filled in by the assessor both before and after applying any technique and level of data. The upper corner of each element in the table will be filled in with +, -, or 0, depending on whether the impact of policy i on indicator (or variable) j is positive, negative, or negligible. The case study coordinators will fill in a similar table using the full simulation model. This will then be used to evaluate the predictions of each technique-data level combination, using the following algorithm:

boxes in policy table = # policies x # indicators.

At 1 point per box, this will give a maximum score (# of points) possible for any technique. Points will be subtracted for each wrong answer; -1 point for opposite answers (+ when there should have been -, or vice versa) and -.5 point for "adjacent" answers (0 instead of + or -, or vice versa).

Thus we will end up with a policy table "score" for each technique-data level combination.

"Optimal" Policies

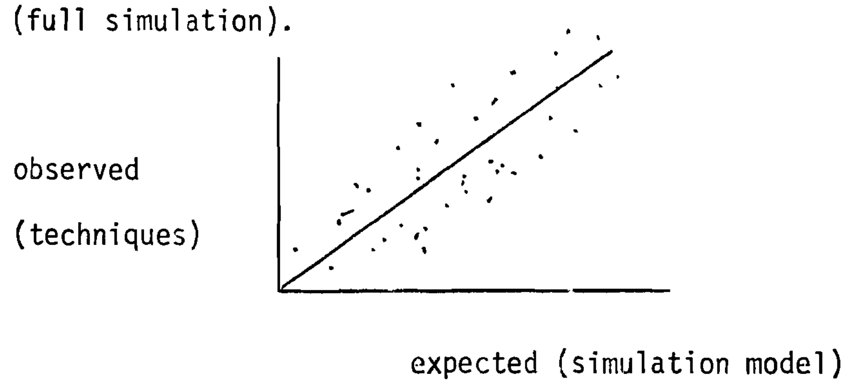
As part of the information packages provided, a series of different policies is given which applies to that particular case study. An objective function can be used to evaluate (in all technique-data level combinations and in the real-world simulation model) which policy is the "optimum." This objective function should be simple so that it can be calculated by even the crudest of the assessment techniques. Case study coordinators should choose this objective function as carefully as possible to avoid biasing the ability of any one technique to predict the "correct" optimal policy. Each technique-data level prediction of the optimal policy will be either right or wrong, and a score of 0 or 1 will be given for this performance criterion.

Quantitative Results

Next, we can make more specific comparisons of predictions of assessment techniques and the full simulation model. The following is a list of criteria for such comparisons in order of increasing precision;

1. We can ask if the occurrences of certain events are predicted (e.g., extinction of a population, the elimination of arable land, or an outbreak).

2. What are the frequencies and durations of these events?
3. What are the general trends predicted over the specified time period? Increase, decrease, or staying at same level?
4. What are the shorter term predicted trends?
5. How close are the frequency distributions of values of indicators generated over time to the frequency distributions in the real world-simulation model?
6. How congruent are the time traces as measured by the slope (and correlation) of the regression of time-by-time results of observed on expected (full simulation).



Each of these techniques can be given a value which measures how good the technique-data level is compared to the full simulation model. All values can be combined into some value function. These criteria should be general enough to apply to any model. Details have not yet been worked out. However, as an example, we can assume that for criterion 1 there will be a Yes or No (1 or 0) answer for each event (e.g. extinction) which occurs. By summing over events and multiplying by appropriate weightings ($\frac{1}{n}$ events), we get a value for the prediction of occurrence of n events $[\, V_1 = \sum_{i=1}^{n} (E_i * \frac{1}{n}) \,]$

Or, for example, criterion 5 can be assigned a value by comparing the frequency distributions of each of m indicators with the distributions from the real world using the Kilmogorov-Smirnov test. The deviations from the desired level (KS = 0.0) can be summed in a similar way to the previous example,

$$V_5 = \sum_{i=1}^{m} (KS_i - 0.0) * \frac{1}{m}.$$

We then can define a value function which measures the performance of a technique in relation to the above six criteria,

$$V_T = V_1 + V_2 + \ldots V_6.$$

Thus, each technique-data level will get a score for this type of performance criterion.

<u>Insight</u>

The final class of performance criteria attempts to measure the ability of any technique-data level to provide insight into the workings of the system and possible policy alternatives. This can be measured in any of three ways.

(1) After having gone through the exercise of using a given technique-data level, the assessor should list the 5 most important variables and the 5 most important relationships about which the assessor wants to know more , i.e., research recommendations. This can then be compared to what are known by the case study coordinators to be the most important relations.

(2) Through sensitivity analysis of the system to changes in initial conditions and/or functional relations, a similar list of research recommendations for 5 important state variables and relations

can be created. Again, this should be compared to the full model. This step involves considerable extra work and may remain optional.

(3) A policy impact table such as the one in Appendix IV should be filled in by an assessor before any techniques are applied and after having looked at the appropriate data package. This table will then be filled in after each technique-data level is used. The amount of insight gained by using the various techniques can be measured by the improvement in the policy impact table score.

Thus, there will be four numbers measuring the performance of each technique-data level.

(1) General policy impacts

(2) Prediction of "optimal" policy

(3) Prediction of quantitative results

(4) Amount of insight

These numbers will be written into the table summarizing the results of across-technique comparisons described in the experimental design section. It is important to distinguish between a technique being unable to predict something (owing to technical reasons) and a technique predicting poorly when considering performance criteria.

IV. WAYS OF HANDLING UNCERTAINTY

(1) We assume that different data levels give some measure of response to unknown functional relationships and/or detail of data. By comparing the performance of a given methodology across the data levels the constraints imposed by the unknowns can be evaluated.

For example, if a data level jump increases by a certain fraction the number of functions known, is the method's performance improved in the same proportion? This can also be compared to the next data level jump to see if the performance change is the same.

(2) How does a method respond to an outside driving variable, such as some sort of unexpected "disaster" or "blessing" (i.e., a forest fire or extreme weather in budworm)?

This could possibly be evaluated as a predetermined input or interception in a method's "time trace," evaluating its resultant performance against the "real-world" simulation's response to the same "disaster." For example, does the interference greatly change the method's stability? Does the model used for assessment recover or collapse in the same manner as the simulation? Are the policy rankings and value functions affected?

(3) The possibility exists that such "catastrophic" system behaviour is inherent in the real world simulation. If so, this can be indicated in the data. (i.e., some data point which could trigger a collapse but does not explicitly indicate its location or existence). By so doing, one of the performance criteria could be the ability of the system to predict the existence of such behaviour or at least infer uncertainty in system behaviour within a certain region.

This could be incorporated in the performance package as a question such as "Do you suspect any drastic behaviour in any of the variables and/or indicators?"

In summary, the ability of each technique to handle some uncertainties can be evaluated by testing each technique-data level with

(a) normal policy, (b) policy failure introduced (e.g. a dam's inability to control water flow sufficiently), and (c) occurrence of unexpected perturbation (e.g., flood or drought).

II.2. Appendix I

Nine Case Studies were chosen as the potential test-bed for techniques. Detailed simulation models exist, or are being developed for each.

GURI: A region of Venezuela has recently been chosen for major resource development. At the moment population is very sparse, but proposed hydro-electric, mining and forestry developments will have a profound influence over a very large area.

Capybara: The capybara is a rodent valued for its fur. Alternate forms of harvesting these animals represent a classic problem of resource development with significant social, economic and ecological impacts on non-urban regions.

Gulf of Venezuela Fisheries: Good historical data are available on this multi-species, multi-trophic level fishery; essentially all components of the aquatic ecosystem are harvested by several conflicting fleet of fishermen. Such situations are very common around the world, especially in the tropics and are usually managed by attempting to apply classical methods and theories developed for single species, with predictably poor results.

Oil Shale: Recent increases in cost of energy have radically accelerated interest in the large oil shale deposits in the western United States and in Canada. Huge areas can be potentially affected by strip mining operating and waste disposals. The U.S. is now engaged in a major impact assessment, and one of our members (Gross) is charged with assessment of impacts on wildlife.

Kemano: The Kemano case study concerns a very large region in central B.C. which is being considered for hydroelectric development. The problem involves effects of hydro development on fisheries, recreational use and wildlife.

GIRLS: The Gulf Islands of British Columbia are in the process of gradual but accelerating recreational development. An existing study and model of recreational land use provide the opportunity to explore the consequences of a variety of policies - zoning, taxation, transportation environmental controls.

Obergurgl: The alpine village of Obergurgl lies in a narrow valley in the Tirolean Alps of Austria. It has received intensive study (ecology, economics, sociology) through the Man and Biosphere Program and through modelling work at IIASA. Since 1950 the area has undergone a thorough transition from a simple agricultural economy to an economy based largely on tourism. Ski slopes and hotels have replaced much of the old pasture land, and the high emigration rates characteristic of agricultural families have been translated into a population explosion in the area. The boom period is nearing its end: environmental conditions are deteriorating rapidly and almost no land safe from avalanches is left for hotel building. Thus we see in Obergurgl a microcosm of economic growth problems faced all over the world, but on a scale that can be easily studied.

Budworm/Forest: The spruce budworm periodically causes devastating mortality of spruce and balsam over a large region of Canada and the United States. In those provinces and states whose economy is based on the pulp industry, this has major social consequences. Moreover management of this problem through rise of insecticides, while protecting trees, has also generated semi-outbreak conditions over huge areas. If spraying is stopped, outbreaks of a severity and extent will be generated that have never occurred before. It is both a classic example of an insect pest system and of a policy that forecloses option. It therefore provides an admirable base for EIA with an emphasis on alternate policies that are more robust, less sensitive to the unexpected.

James Bay: The northern quarter of Canada's Province of Quebec has been placed under the control of the James Bay Corporation. The aim is to develop the region's recources, particularly for hydroelectric power. Environmental impact assessment work has concentrated on the obvious direct impacts of dams and water diversions, though our modelling suggests that indirect factors, such as road building which will open the area for recreational use, may be much more important. A variety of unexpected problems and impacts have occurred as the development has proceeded, and each of these setbacks has stimulated further costly investment; thus this case study is an ideal example for our concerns about option foreclosure and the decision consequences of faulty initial development decisions.

	Case Study Coordinator	Range of Societal Impacts	Range of Management Acts	Number of State Variables	Degree of Spatial Dis-aggregation	Degree of Resolution of the Functional Relations	Time Resolution	Expected Date of Data Package Completion
GURI	Rabinovich	high	simple	simple	40 spatial units	complex	complex	
CAPYBARA	Rabinovich	simple	simple	simple	1	complex	moderate	
Gulf of Venezuela Fisheries	Walters	small	simple	6	3	simple	simple	
Oil Shale	Gross	complex	large	large	3	simple	simple	
KEMANO	Peterman	high	moderate	large	11	low	1 year	
GIRLS	Holling	moderate	large	large	many	moderate	simple	
Obergurgl	Hilborn	high	moderate	moderate	simple	moderate	simple	
Budworm	Holling	moderate	few	few	265	complex	simple	
James Bay	Peterman	high	large	large	20	simple	simple	

II.2. APPENDIX II

SAMPLE ENVIRONMENTAL IMPACT ASSESSMENT FORM -- OBERGURGL

Date of impact assessment ______________

Names of assessment group and previous experience with techniques and case studies

Level of data used for this assessment ______________

Technique used for this assessment ___________________

Section I. General Impacts

1. Given no changes in policy, will tourist demand be reduced due to decreasing environmental quality in the Obergurgl area?

2. If tourist demand will be reduced, how severe will the reduction be?

3. When would this reduction be expected to occur (when will it be less than 90% of present day demand)?

4. Are occupancy rates likely to drop so low that hotel owners are unable to meet their mortgage payments?

5. If so, approximately what percentage of hotel owners would be in this group?

6. Are any of the proposed policies (taxation, subsidization, ...) likely to have a significant effect on the failure to meet mortgages?

7. Is it likely that large groups of people are going to have to emigrate from the village due to poor economic conditions?

8. If so, how many people are likely to be out of work?

9. When would these conditions be expected to occur?

Section II. Specific impacts

In the information package you have been given three alternative policies for control of Obergurgl. Control A is leaving everything as it is now, completely free market with some government subsidization. Control B is elimination of the subsidization. Control C is taxation instead of subsidization. On the page below, please provide your predicted values of the following indicators for the five year intervals listed. The indicators are number of beds (BD), winter occupancy rate (WO), and number of people unable to find work in the village (NW)

	Control A			Control B			Control C		
	NB	WO	NW	NB	WO	NW	NB	WO	NW
1975									
1980									
1985									
1990									
1995									
2000									

In the data package you were given an objective function and some sample total utilities derived from exemplary time streams of indicators. In the space provided below, please estimate the expected total utility of the three management options.

	Control A	Control B	Control C
Expected total Utility	________	________	________

Section III. Research Recommendations

To give the case study coordinators an idea of insight provided by your assessment technique, would you please list below the five variables on which you think information about the current starting conditions is most sorely needed.

1.

2.

3.

4.

5.

Would you please list the 5 most needed pieces of information regarding specific variable interactions (e.g. how tourists respond to eroded land).

1.

2.

3.

4.

5.

Would you please comment below on the time and effort required in the use of the technique. How well was your understanding able to fit into the computational framework of the technique, how many new ideas did the technique generate, etc.?

II.2. APPENDIX III

Final output format from experimental testing design.

Each case study -- level of information combination could be summarized by a table like the one below.

The qualitative and quantitative ratings put in this table will have to be designed as data become available from assessment groups. See performance criteria section.

IMPACT ASSESSMENT TECHNIQUE

Performance Criteria	A (Leopold Matrix)	B (KSIM)	C (GSIM)	D (simple simul.)
Qualitative policy impact table	.5 (moderate)	.0 (poor)	.3 (some)	.6 (good)
Quantitative analysis of time series	.2 (poor)	.3 (poor)	.5 (mod.)	.6 (mod.)
Insight provided	.1 (some)	0. (none)	.2 (some)	.8 (lots)
Correct "optimal" policy	No	Yes	No	Yes

II.2.

APPENDIX IV

POLICY IMPACT TABLE

Policy Act	A	B	C	D	E	F	. . . . *m*
1	+	-	+				
2	0	0	+				
3	0	+	0				
4	-	+	0				
5	0	0	-				
6	-	-	+				
. . . . . .							
n							

The Assessor fills in +, 0, or - in the upper corner of each box to indicate a positive, negligible, or negative effect, respectively, of policy *i* on state variable or indicator *j*. The case study coordinator knows what impacts the full simulation model predicts and fills in the bottom corner of each box afterward for use in part of the evaluation of a technique's performance.

II.3 TECHNIQUE CRITERIA

INTRODUCTION

The purpose of this subgroup (and, we hope, this paper) is to put some order into the search for techniques which this group is to examine. Although we make a rough pass at categorising a few familiar techniques, this is for illustrative purposes and is not intended to prejudge future performance testing. We adopted this approach to create a framework which would allow a rational screening for proposed techniques and the identification of missing pieces. We begin by proposing that techniques can be classified according to the location on a qualitative-quantitative scale as well as their order (mathematical complexity). We classify potential case studies by their pre-impact system behaviour and by their inherent number of variables and quantity of data. The techniques and cases are united through an estimate of the forecasting potential and insight gained. The main conclusion is -- not surprisingly -- that one can not separate the technique selected from consideration of the data available, the system behaviour, and the information desired.

(1) An illustrative set of techniques is given in Appendix A. This set is deliberately incomplete, but has the advantage of

permitting easy presentation in categories and classifications that provide some degree of insight. It has the disadvantage that a critical pathway may be overlooked in the following analysis. In Appendix A, the "0" category is decisive for any large data set, but we do not consider it explicitly further here. This technique is to be one of the major topics for the next meeting. As the group adds further examples to the technique list, they should be incorporated into the following framework to test its usefulness.

(2) This note is an assessment of techniques and as in any assessment, presentation in matrix form is an obvious first step and is used here. The characteristics of techniques are assumed to have two main components:

(i) a qualitative/quantitative axis

- (a) sign or direction of influences (+,0,-)
- (b) small set of discrete values (1,0,-1)
- (c) relative values (scaled 0 to 1)
- (d) absolute values (mass, length, time units)

(ii) the order of the equations (stated explicitly or implicitly)

- (a) linear
- (b) quadratic (or bilinear)
- (c) pre-defined functions
- (d) specific functions (to portray particular relationships)

(3) Our set of techniques (Appendix A) is tentatively located on the matrix of these categories in Appendix B. Their position in this matrix (or graph) can often be quite variable; the chosen position is based on our sub-group's consensus on the potential of the technique. For example, matrices (Technique II) may be purely quantitative but the essential feature is the ability to handle in an explicit numerical manner large quantities of data (with the sometimes implicit assumptions that the relationships between the variables are linear).

(4) It is apparent that the matrix (B) can be fairly full. We suggest that the position (a,a) is the least satisfactory and (d,d) the most useful for a final assessment. However, it will normally be necessary to attempt to proceed from (a,a) to (d,d) by some path through B. The choice of this path is not an inherent property of particular techniques but is determined by the nature of the problem, particularly by the structure of the system before the impact.

We place the system into one of three categories (Fig. 1). These structures are not to be considered as basic properties of systems in a general sense but as a convenient categorisation to be used in a particular assessment. Thus on time and space scales, different from those used in a particular assessment, a system represented as (γ) may have to be transformed into a representation in the form (α). It should also be remembered that an apparently simple (α) system may be composed of large numbers of complex (γ) parts at other scales of time and space. In more detail:

(5) (α) represents the assumption of a steady state (e.g., James Bay) relative to rates of change of the effects of the proposed impacts. In theory, small perturbations from the steady state can be represented by linear approximations. (The need to assume steady state is likely to have arisen from the nature of the problem -- a large number of state variables with relatively poor information about interrelations.) In this case, it may be useful to use matrix techniques to provide: (i) a test (validation) of the interactions proposed to represent the system since the eigenvalues should all be negative; (ii) an estimate of the direction (-,0,+) that variables will take after impact; (iii) an indication of the stabilising or destabilising effects of the impacts. This could be done either from the linear (community) matrix or through consideration of only the critical interactions (i.e., using a quadratic approximation). In particular, global stability criteria can be examined, though not rigorously concluded.

(6) (β). Although many ecological situations may be represented as a steady state over same time and space scales, economic or social variables before impact are more typically in a state of change (e.g., Obergurgl). If these rates of change are constant, a linear approximation is still possible; if not, then some higher order representation is necessary. This may be quadratic or some specific pre-defined functions. The aim, in many cases, is to indicate the nature of the future steady state;

the reasons why a desired state cannot be achieved; and the actions necessary to circumvent this. These factors would suggest that techniques using pre-defined functional relationships might be appropriate.

(7) (γ). Systems which display complex cycling (or outbreak) behaviour (e.g., budworm) present the most difficult conceptual problems. Technically, it appears that representation of these systems requires terms of order 3 or more (Jones, Ludwig). As long as one essential variable displays the "γ" effect, the whole system should be put in this category. Qualitative insights can be gained through certain formulations such as catastrophe theory. (In one sense, catastrophe theory is a set of "pre-defined functions" of order (3+)). However, it may be the nature of these systems that a small number of state variables is relevant.

(8) Each of the above categories of system structure will have its own path through the matrix of techniques (Appendix B). Consideration of the available techniques suggests that the pathways are as shown in Figure 2.

(9) The validation of any technique is a critical aspect of its use. One criterion is the ability of the technique to portray pre-impact system behaviour. Given knowledge of the initial state of the system (to some degree of reliability), validation implies the ability of the assessment technique to describe the characteristic rates of change. Thus, for

(α) the system should display positive stability;
(β) the system should give the pre-impact rates of change;
(γ) the system should cycle at the pre-impact frequencies.

This criterion is critically dependent on knowledge of the rates, which in turn is very dependent on the data available. It depends especially on its quantity in terms of two aspects:

(a) number of components (state variables,
(b) data per component (especially the distribution in time and space).

Once again, these can be represented in a matrix; Figure 3. We tentatively suggest that it might be possible to map this matrix onto that in Appendix B. This emphasises the connection between nature of data and choice of techniques.

(10) The discussion of these techniques, as described thus far, has been concerned with the pre-impact system. Impacts and their effects will need to be represented by additional (or altered) terms within the context of the technique. For example, in matrices, impacts must be represented by extra columns (rows) or altered elements; for pre-defined functional models the impact must be expressed within these functional forms; for graphical forms impacts require extra loops. These aspects form another (and possible the most important) parameter in the choice of technique.

(11) The final requirement of this assessment of techniques (as of any assessment) is performance criteria. Two of these criteria are: (a) the insight provided, and (b) the forecasting ability (Figure 4). The scores given here are again a consensus of the sub-group. Further development requires a more formal scoring procedure and comparative testing between groups. Another criterion in relation to further use is the transferability of the method. This is especially important for assessment where time and facilities are limited. In relation to Figure 4, there is a roughly inverse relation between generality and simplicity. Simple linear techniques score low on both insight and forecasting, while simulations score high.

(12) These notes on techniques can be taken as a paradigm of the methods themselves. Given limitation in time and data, a qualitative, linear (matrix) approach has been used. It may provide some insight and some indication of directions but it is very poor in providing detailed quantitative advice. Particularly, it has inadequately represented the interactions between the state variables (data, order, performance, etc.). It is obviously necessary to validate these conclusions before applying them.

RECOMMENDATIONS

1. To test the validity of the pathways proposed in Figure 2.

For example, there should be at least one, and preferably two, representatives of:

(α) James Bay + 1

(β) Obergurgl + 1

(γ) Budworm + 1

These should be tested against as many as possible of the methods, but especially the main aspects of matrix B, i.e., (a,a); (a,d); (d,a) (d,d) and (c,c).

2. There is a need to give greater consideration to the problems of data reduction.

3. The results of any testing should be aimed at indicating the generality of techniques in relation to particular data problems.

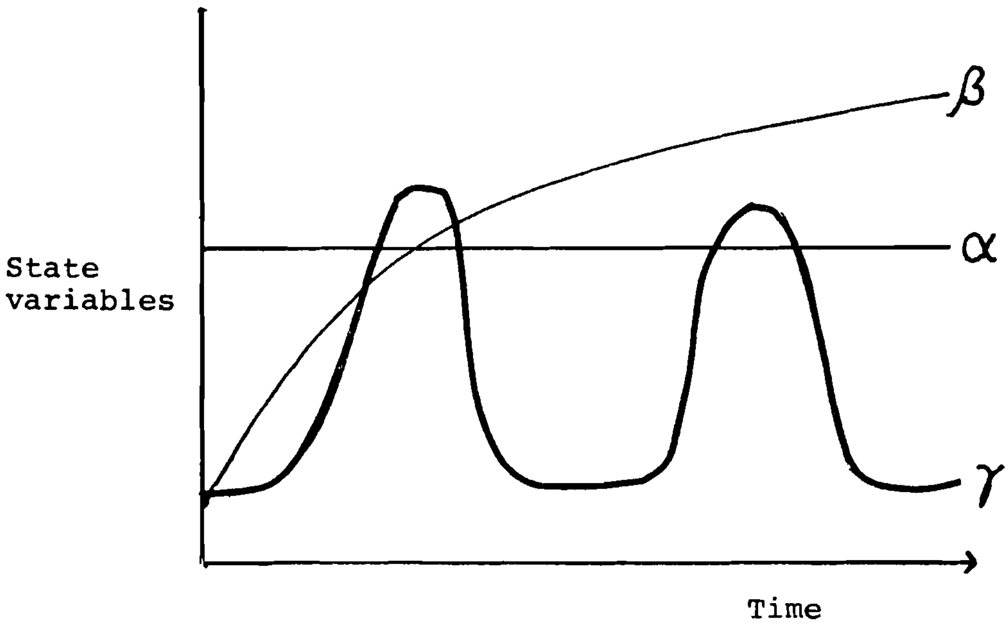


FIGURE 1: Three basic structures used in this assessment of techniques.

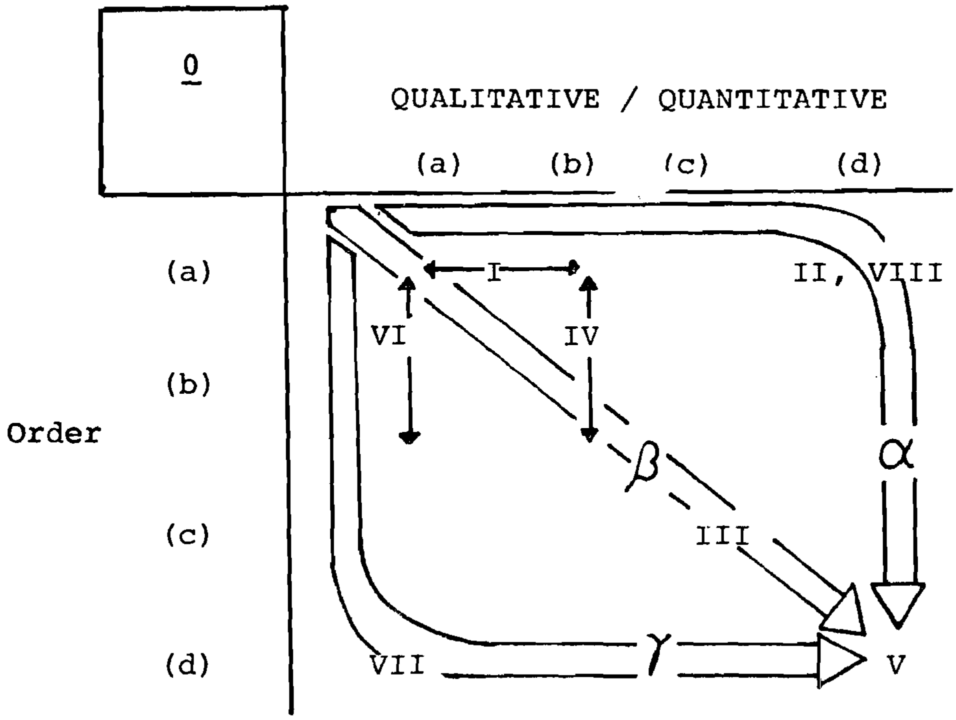


FIGURE 2: Pathways through available techniques from initial inspection to final assessment. The paths α, β, and γ refer to characteristic pre-impact system behaviour.

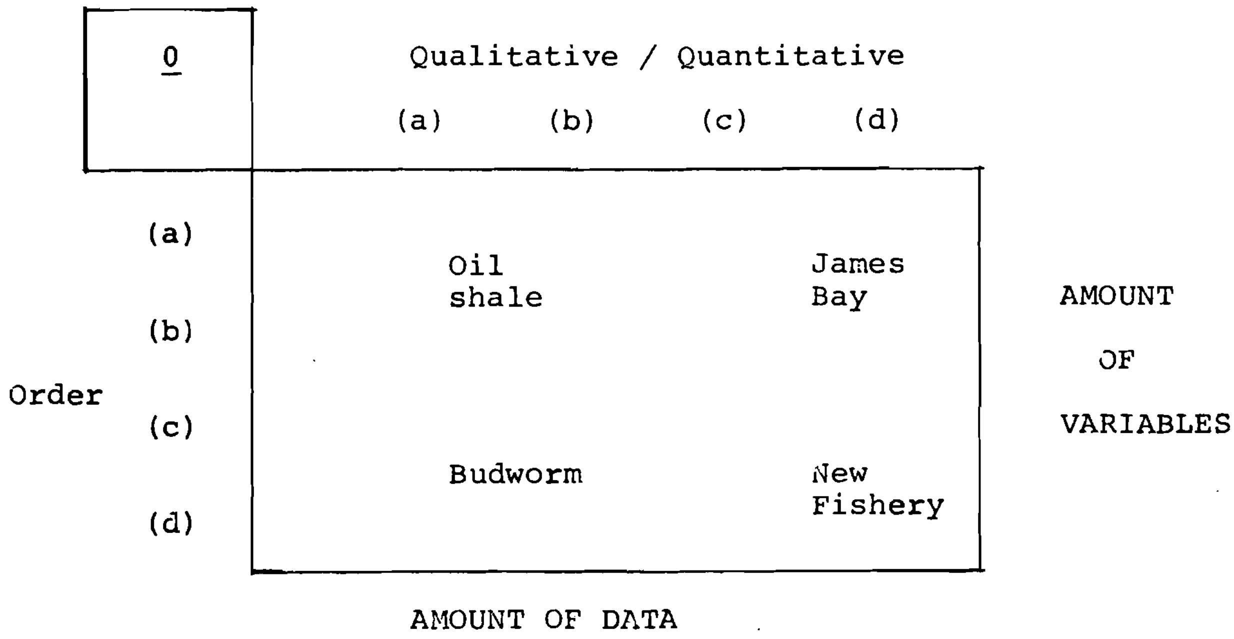


FIGURE 3: Examples of typical assessment cases in relation to the amount of data and state variables involved. The axes are oriented to emphasise the relationship to Appendix B and Figure 2.

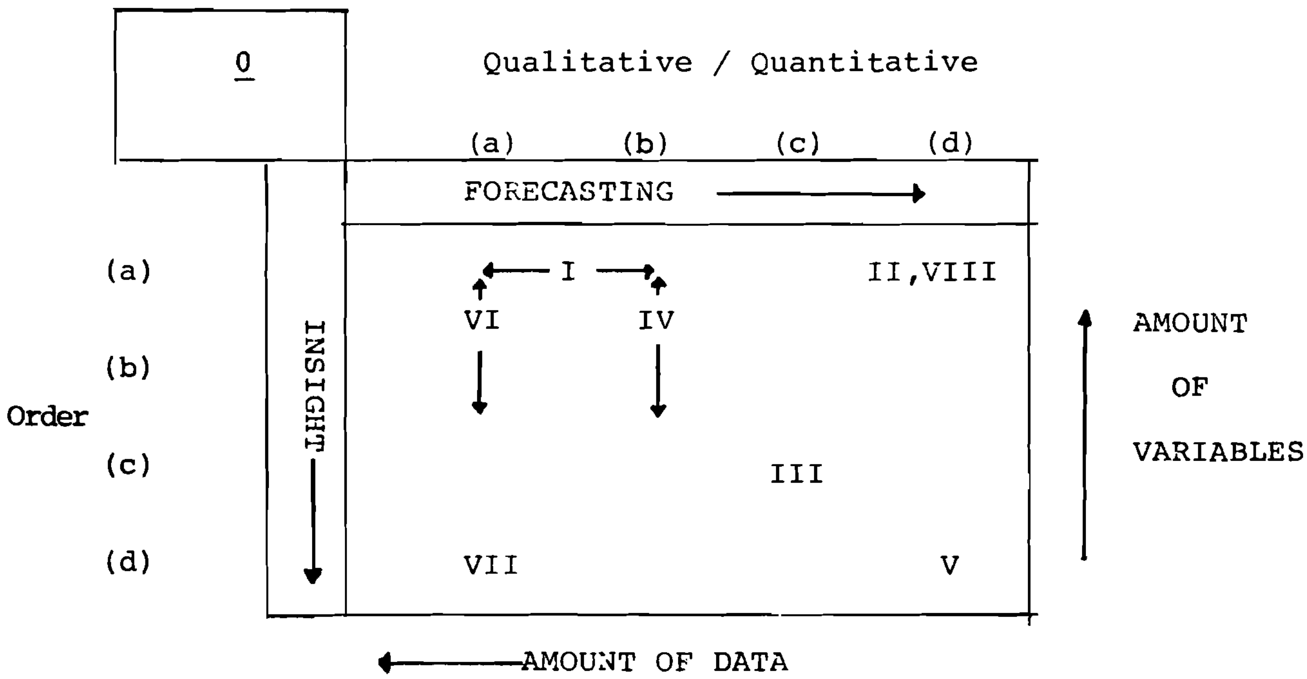


FIGURE 4: The relative value of techniques in relation to forecasting ability and insight provided. Compare with Figures 2 and 3.

II.3 APPENDIX

A. LIST OF TECHNIQUES

0 Data reduction (Borden)

I Check lists (Leopold Gross) -- overlays, etc.

II Matrices (Community matrices) (Steele)

III KSIM (Kane)

IV GSIM (Gallopin)

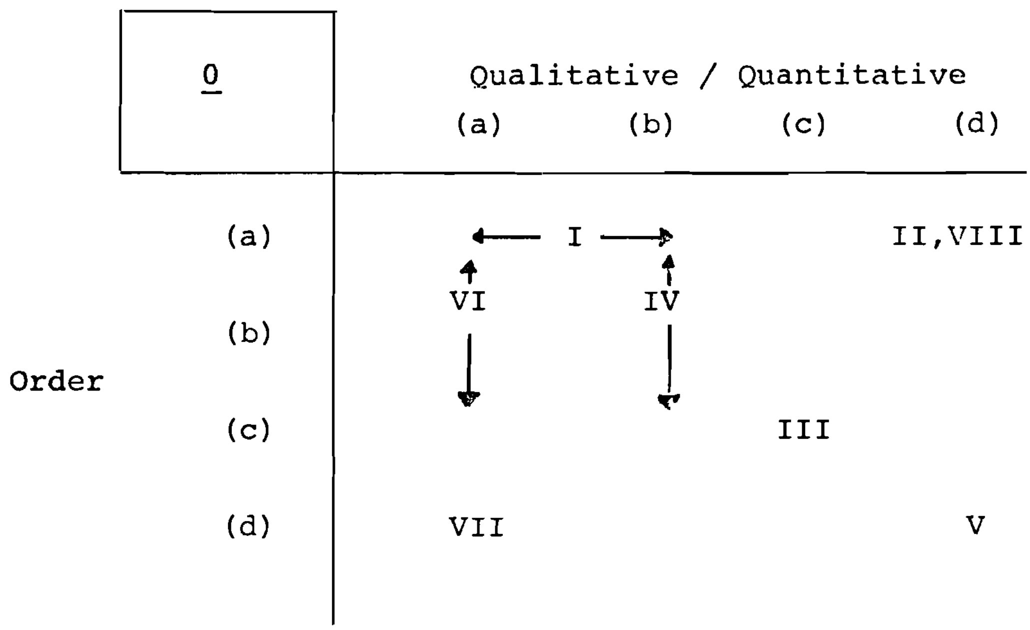
V Models: Walters -- large sim & small sim
Ludwig -- analytical

VI Graph Theory (Loop analysis, Levins)

VII Qualitative theory of differential equations (e.g., catastrophe theory. D. Jones, A. Bazykin)

VIII Markov (Leslie, life tables)

B.



III. TECHNIQUES AND METHODOLOGIES

One of the tasks of this group will be to make a broad feasibility survey of possible techniques and methodologies that might have use in environmental impact assessment. The final report and recommendations will be limited to a smaller set of well documented techniques. In order to arrive at that set in 18 months' time, the preliminary list below was constructed.

The list is separated into two arbitrary parts: ordering and organising the problem and then system articulation and evaluation. The separation follows Figure 2 of the SCOPE report which disaggregates system, action, and impact variables. Even in the event of adopting a revolutionary new strategy, many of the first category will still be required.

For the most part, the items in the list are meant to be specific techniques rather than general fields of study. The "source" is to further pin down the item and serve as a preliminary reference.

Responsibility. The person places as "charge" has volunteered to look into the potential of that technique. As soon as possible, each technique should be placed somewhere on a spectrum of

- -- dropped without consideration,
- -- not recommended but to be fully analysed,
- -- promising for further group consideration,
- -- recommended to be fully documented.

The final statement does not need to be given at the next meeting, but each member of the group should have looked at the assignments and be prepared to discuss in some detail at least <u>two</u> new items.

Feel free to amend and subdivide the list as required. If possible, think about how a particular technique fits into the framework of section II.3 "Technique Criteria."

	Source	Charge
1. Ordering and Organising		
Bounding the problem	Holling	Holling
Qualitative data analysis	Tukey	Borden Austin
Leopold matrix	Leopold	Greve Sonntag
Cross impact		Greve Fleming
The Gross chart	Gross	Gross
Polyhedral dynamics	Casti	Clark
Clustering techniques		Borden Austin
Separating act/variables/impacts	SCOPE	Holling
Linear vs. bilinear effects	Steele	Steele
Impact indicator selection	Clark/Bell	Clark
Evaluation of indicators		IRE, Walters Clark
Design of adaptive policies		Walters

	Source	Charge
2. System Articulation and Evaluation		
Selecting state variables from indicators	Walters	Holling Walters
Protocol for selecting first order impacts		Walters Holling
Linear system stability	May	Jones
Perturbation of the equilibrium matrix	Steele	Jones
Non-linear input/output	Leontief	Sonntag
Qualitative stability of matrices	May	Jones Gallopin
Loop analysis	Levins	Gallopin Jones
GSIM	Gallopin	Gallopin Jones
KSIM	Kane	
FREESIM	Jones	Jones
Interactive workshop	Walters	Walters
Simple simulation		
Large simulation	IBP	Gross
Analytic models	Ludwig	Ludwig
Qualitative system theory	Bazykin	Bazykin
"Manifold analysis" (Catastrophe theory)	Jones	Jones
Multivariate statistics		Borden
Markov (transition probabilities)	Fiering	Sonntag

III.1. INVESTIGATION OF TECHNIQUES

Many members of this group have had considerable experience with particular techniques. Some of these were described in modest detail in the October workshop. John Steele talked about some of the problems and assumptions of using matrix techniques. Carl Walters discussed the construction and use of simple simulation models. Alexander Bazykin, Don Ludwig, and Dixon Jones presented their ideas on the qualitative theory of differential equations and topology. The substance of these reports can be found in the references.

In addition, two techniques were subjected to a working demonstration. The techniques used were KSIM, developed by Julius Kane, and GSIM, developed by Gilberto Gallopin. The procedure used was for a "technique expert" (Bill Thompson and Gilberto Gallopin respectively) to guide the construction of a simulation model from the information supplied by the "problem consultant" (Dixon Jones). The spruce budworm/forest ecosystem was used in both cases. Summaries of the steps taken and the conclusions reached will be written up at a later date.

IV. RECOMMENDATIONS AND TASKS

SHORT TERM RECOMMENDATIONS

		Responsibility
1.	More myths to be given to Clark	All
2.	Examples of real world belief in myths and consequences	All
3.	Re-write Process section	Clark
4.	Re-draft Technique Critera	Steele
5.	Critique of Technique Criteria and re-write for draft 2	Bazykin
6.	Review of tests of GSIM and KSIM at workshop	Jones
7.	Re-write Experimental Design section	Peterman
8.	Send 6 information packages including forms from UBC to Rabinovich and Gallopin	Hilborn
9.	Send 6 information packages from Rabinovich to UBC	Rabinovich
10.	Cross impact handbook	Gross
11.	Send all material to Bigelow for circulation to the group	All
12.	Conceptual paper	Peterman, Jones Clark, Holling Hilborn
13.	Description of case studies with the following headings: Problem - social and economic - behaviour State of knowledge Kinds of acts Anticipated impact areas Institutional setting re power	Rabinovich and IRE
14.	Key papers relating to methodology and EIA.	All

LONG TERM RECOMMENDATIONS

1. Conceptual - unknown, surprise
   - option foreclosure
2. Art vs. science, i.e., transferability
3. Critical evaluation of using simulation models as a representation of the real world
4. Retrospective analysis of existing EIAs re constraints of our proposal (perhaps this could be the focus for the final conference)
5. Arrange to have Edmondson (Seattle) retrospective case study of Lake Washington assessment and clean-up considered for third workshop.

ISSUES FOR SECOND WORKSHOP

1. Impact indicators
2. Evaluation of indicators
3. Adaptive policies
4. Qualitative data analysis
5. Dealing with the unknown
6. Communication and information hierarchies

APPENDIX

LIST OF PARTICIPANTS

Alexander Bazykin
Chief, Laboratory of Mathematical Ecology
Research Computing Centre
142292 Pushchino
Moscow Region
USSR

Ulrike Bigelow
Institute of Resource Ecology
University of British Columbia
Vancouver, B.C.

Steve Borden
Institute of Resource Ecology
University of British Columbia
Vancouver, B.C.

Pille Bunnell
Institute of Resource Ecology
University of British Columbia
Vancouver, B.C.

William C. Clark
Institute of Resource Ecology
University of British Columbia
Vancouver, B.C.

Gilberto Gallopin
Departamento de Recursos Naturales y Energia
Fundacion Bariloche
Casilla 138
San Carlos de Bariloche
Rio Negro
Argentina

Wulf Greve
Institute of Animal Resource Ecology
University of British Columbia
Vancouver, B.C.

Jack Gross
U.S. Fish and Wildlife Service
Ft. Collins, Colorado
USA

List of Participants continued

Ray Hilborn
Institute of Resource Ecology
University of British Columbia
Vancouver, B.C.

C.S. Holling
Institute of Resource Ecology
University of British Columbia
Vancouver, B.C.

Dixon D. Jones
Institute of Resource Ecology
University of British Columbia
Vancouver, B.C.

Donald Ludwig
Department of Mathematics
University of British Columbia
Vancouver, B.C.

Randall M. Peterman
Institute of Resource Ecology
University of British Columbia
Vancouver, B.C.

Jorge Rabinovich
Instituto Venezolano de Investigaciones Cientificas
Departamento de Ecologia
Apartada 1827
Caracas 101
Venezuela

N. Sonntag
Institute of Animal Resource Ecology
University of British Columbia
Vancouver, B.C.

John H. Steele
Marine Laboratory
Victoria Road
P.O. Box 101
Torry Aberdeen AB9 8DB
Scotland

List of Participants continued

Carl J. Walters
Institute of Resource Ecology
University of British Columbia
Vancouver, B.C.

R. Fleming
Institute of Resource Ecology
University of British Columbia
Vancouver, B.C.

LIST OF RELEVANT PAPERS

A.D. Bazykin, Structural and Dynamic Stability of Model Predator-Prey Systems. 1975. IRE paper R-3-R.

John Casti. 1975. Polyhedral Dynamics-I: the relevance of algebraic topology to human affairs. IIASA WP-75-30.

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W.A. Thompson, W.J.C. Tomlinson, I. Vertinsky, N.J. Wilimovsky, J. Kane. International Management of the Oceans: a preliminary cross impact simulation model of fisheries and other management systems. IIM.

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