INTERNATIONAL COMPARISONS OF ENVIRONMENTAL HAZARDS:

Development and evaluation of a method for linking environmental data with the strategic debate management priorities for risk management

by

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ABSTRACT

This paper describes and evaluates a method for comparing environmental hazards within and between countries. The method is intended for use by international institutions, nongovernmental organizations, and governments and that are involved in setting national environmental agendas or developing environmental programs that require international coordination. The core of the method is a common set of indicators that can be used to characterize any environmental problem. The indicators are designed to reflect both causes and consequences of environmental problems, and to pose realistic demands on available data. We show that by analyzing indicator data in various ways, the method can help to identify sets of "similar" hazards, to flag unusual or outlier hazards that might otherwise be ignored, to show which countries have common environmental problems, and to assign management priorities among hazards. We recognize the central role of values in structuring such analyses. Because the method addresses the value question directly, it can be used to illuminate the implications of preferences that (for example) emphasize present as opposed to future impacts, health as opposed to ecosystem effects, or pollution emissions as opposed to their consequences. Application of the method is demonstrated and evaluated through country studies of India, Kenya, the Netherlands, and the United States.

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1. INTRODUCTION

The past decade has witnessed a growing awareness of not only the severity, but also the diversity of environmental problems. Global environmental concerns such as ozone depletion and climate change have captured the attention of high level international meetings. Regional and local problems such as acid rain, renewable resource depletion and drought have been the subject of public debate and governmental action. An increasing number of environmental problems are competing for places on political agendas, for the attention of regulatory agencies and international governmental bodies, and for the limited resources available for environmental management.

This rapid proliferation of environmental concerns poses a number of challenges for the strategic design of good public policy. Most obviously, to quote a former administrator of the U.S. Environmental Protection Agency, "In a world of limited resources, it may be wise to give priority attention to those pollutants and problems that pose the greatest risk to our society." (U.S. Environmental Protection Agency, 1987). More broadly, as senior officials of the UN Environmental Program (UNEP) have long argued, we need a systematic understanding of how the severity and nature of environmental problems vary from place to place around the world. This need can only become more pressing as bilateral and international negotiations increasingly take on environmental dimensions.

By and large, today's world is poorly equipped to meet these strategic challenges. True, we have more data on environmental problems than ever before. A variety of international and national compendia are now available, and are being updated on a regular basis[2]. Moreover, a great deal of progress has been made in recent years towards identifying policy instruments that should improve the effectiveness and efficiency with which specific environmental problems are managed[3]. In practice, however, these important advances have left the strategic task of setting priorities among environmental problems largely unaddressed. Indicators vary from country to country. Some focus on sources of environmental degradation, some on effects, and some on the state of the environment per se. As one result, meaningful comparisons are generally impossible. Resource allocation sporadically tracks successive "problems of the month," responding more to media attention and political grandstanding than to any more fundamental criteria[4]. The lack of common definitions and metrics has left the UN's 1992 Conference on Environment and Development (UNCED) hardly more able to conduct systematic international comparisons of environmental problems than was its forerunner in Stockholm 20 years before. [5]

Much needs to be done in order to mitigate these shortcomings of present practice. The methodological framework proposed in this paper is intended as one modest contribution to the required effort. In brief, we have attempted to design a framework that can help both to define the data most relevant for priority setting and international comparisons among environmental problems, and to structure those data in a way that

makes them usable by a variety of participants in the policy making process. Experience in a number of other policy fields, most notably macro-economics, suggests that such strategically defined data frameworks constitute essential foundations for long term improvements in management performance (Hutchison, 1977).

Reflecting the general recognition of this fact, several efforts have already been conducted to develop strategic frameworks for evaluating priorities in environmental policy. As part of a retrospective assessment of the world's environment ten years after the first World Conference on Environment and Development in Stockholm, Gordon Goodman developed a set of indicators for characterizing and ranking at an aggregate global level environmental problems around the world (Goodman, 1980). At roughly the same time, scholars at Clark University's Center for Technology, Environment and Development (CENTED) began their seminal research on the characterization of health and environmental hazards arising from the use of technology (Kates et al., 1985). At a national level, in 1986 the U.S. Environmental Protection Agency (EPA) began an effort to compare the risks posed by over 30 environmental problems faced by American society (U.S. Environmental Protection Agency, 1987). In a review and follow-on study, the Science Advisory Board of the U.S. EPA, highlighted and worked to overcome several of the shortcomings of the original study (Science Advisory Board, 1990)[6] Other recent comparative hazard assessment efforts have characterized regional patterns of environmental degradation within nations, as illustrated by the recent "Green Index" comparing environmental problems and policies among America's 50 states (Hall and Kerr, 1991). Local assessments have also begun to appear (City of Seattle, 1992).

Much light has been shed on the priorities problem through this work. But none of the existing approaches are directly applicable to developing countries where the needs for priority setting are arguably greatest while the scarcity of data is the most problematical.
And none allow international comparisons to be carried out in the face of the vast differences among nations - both in the importance of specific environmental hazards and in the values relevant to their evaluation. The approach presented here is an effort to begin constructing a framework for characterizing environmental hazards that addresses these unmet needs, and thus complements existing efforts.

The remainder of the paper is organized as follows. Our framework for comparing hazards is outlined in Section 2, with emphasis on its logical structure, the set of environmental hazards covered, and the indicators used to characterize them. Section 3 then presents an application of the framework to the characterization and comparison of hazards in four countries. Here the emphasis is on alternative ways of incorporating values in the aggregation and comparison of indicator values. Our tentative conclusions regarding the framework, its strengths and limitations, and its possible applications are given in Section 4. Our principal purpose in presenting this approach in its present preliminary state of development is not to suggest definitive rankings among problems or countries. Rather, it is to encourage the use and further development of the comparative hazard approach by others who will have both

different knowledge and better understanding of particular countries and cases. Put somewhat differently, we are more interested in producing a useful tool and an illustration of what can be built with it, than in the particular demonstration piece we construct along the way. We therefore include with this paper a set of appendices that provide sufficient details to allow independent application and evaluation of this comparative hazard approach.

2. THE METHOD

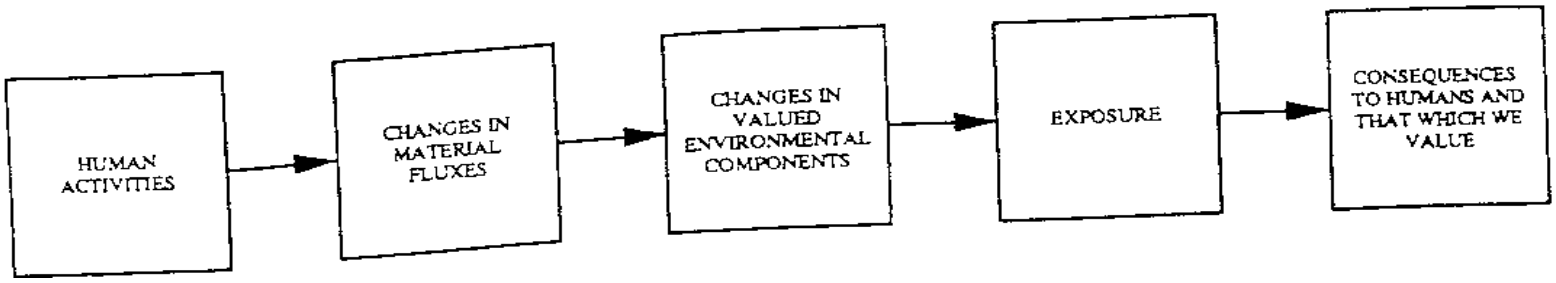
2.1 An Overview

Early efforts at comparative hazard assessment were often based on single measures of hazardousness, such as human mortality. Such simple characterizations proved to be of limited use in promoting productive debates on public policy for at least two reasons. First, data on consequences in general, including mortality, are often much less available and more controversial than data about other dimensions of a hazard -- for example emissions or exposure. Second, empirical studies have shown that even when consequence data are available, many people give strong weight to other aspects of hazardousness in their informal assessments. Analytic approaches that neglect these "other aspects" have often found it difficult to establish their relevance to or legitimacy in the formulation of public policy. In recent years we have therefore witnessed a trend towards the adoption of a more varied and complex set of measures for comparative hazard assessment (Covello, 1991; Hohenemser et al., 1983). Unfortunately, the potential benefits of this variety have been offset by its apparent arbitrariness -- complex sets of indicators have had little obvious rationale or cohesion.

A rich but systematic approach that largely avoids these difficulties was developed for comparing technological hazards by the Center for Technology, Environment and Development, CENTED (Kates et al., 1985). We have adapted CENTED's approach, particularly its "causal taxonomy" of hazard, for the comparative environmental assessment presented here. In the following sections, we present a detailed discussion of our causal taxonomy for environmental hazards and its advantages over simpler approaches to hazard assessment. First, however, it may be helpful to introduce our approach by providing a broad outline of its basic components.

We began with a simple linear model of hazard causation, anchored at one end by the human activities or natural events that perturb the environment, and anchored at the other by consequences of those perturbations for people and the things they value. This "causal model" is presented in Figure 1[7]. It provides the "backbone" against which we define a number of key characteristics of environmental hazard: for example, persistence of a pollutant in the environment, the population exposed, and health consequences. For each of these characteristics, we next defined specific measurable "descriptors", and normalize them on a scale of 1 to 9. We have developed a total of 18 descriptors which are used to characterize each environmental hazard. The same model structure and descriptor definitions are applied to all hazards characterized through the framework. [8]

FIGURE 1: CAUSAL STRUCTURE OF ENVIRONMENTAL HAZARDS



Next, we identified the specific set of potential environmental problems to be characterized. These were selected based on three criteria: (1) that they be understandable and meaningful to policy-makers and other non-specialists, (2) that they be comprehensive, such that virtually all the potentially significant environmental problems faced by any nation are included, and (3) that they be defined at a level of resolution yielding a list neither too general nor too complex for practical utility. A group of 28 problems was ultimately selected for characterization in this study, ranging from biological contamination of freshwater to depletion of stratospheric ozone.

Finally, for each hazard, in each country or other region evaluated, available data were used to assign each descriptor a score. The method therefore results in a matrix of 18 by 28 scores -- 504 in all -- for each country studied. Such a large set of numbers is not particularly informative by itself. Rather, useful interpretation requires that descriptors be aggregated. The choice of how to weight or group descriptors is essentially a choice about what aspects of hazardousness will be used for comparing and prioritizing environmental hazards. The crucial input to the aggregation process is not scientific data but human values. How should future consequences be weighted relative to current ones? How should degree of perturbation to natural cycles be weighted relative to known impacts on human health? Our approach does not attempt to answer such value-laden questions. It does provide a transparent and flexible method that can help users to evaluate the implications of alternative value assumptions for the ranking of environmental hazards. Examples of several value positions often adopted in debates on environmental priorities are explored in the text.

We turn next to a more detailed discussion of the approach outlined above.

2.2 The Causal Structure of Environmental Hazards - A Framework for Analysis

Based on the causal structure of environmental hazards as illustrated in Figure 1, any environmental problem is characterized by a sequence of events that can be summarized as follows: natural factors or human activities (eg. energy production) lead to changes in material and energy fluxes (eg. sulfur dioxide release), which in turn lead to changes in components of the environment that society values sufficiently to single out for concern (eg. precipitation acidity), which in turn leads to exposure of, and consequences for, humans and things they value (eg. forest die-back). The actual ontogeny of real environmental problems is of course a much more complex affair, replete with feedbacks and other nonlinearities. For purposes of the present framework, however, it turns out that the simpler model suffices.

The model starts with natural phenomena or **"human activities"** that are the initial sources of changes in the environment. The human activities are defined by both the choice of technology and its level of use.

Human activities or natural phenomena lead to measurable changes in chemical flows or in other physical or biological components of the environment, that are

together described as **"changes in the material fluxes".** In the case of pollution based environmental problems, this refers to an increase (or decrease) in chemical constituents. In the case of renewable resource depletion, this describes a decrease (or increase) in the stocks of plants or animals. And for natural hazards, this describes a change in the accustomed or usual flow of materials or energy, noting that the accustomed flow may be zero.

Changes in these material fluxes then lead to changes in **"valued environmental components (VECs)"** which are most simply described as those attributes of the environment that humans choose to value. [9] In general, we value these components not in and of themselves (although this point would be debated by the deep ecologists), but because changes in them might lead to downstream consequences more directly bearing on human or ecosystem welfare.

"Exposure" is the pathway by *which* changes in VECs inflict downstream consequences. For example, pathways of exposure to pollution which cause human health consequences include inhalation, ingestion, and dermal contact.

"Consequences for humans and things we value" are defined here to include increased risks to human life and human health, to ecological systems, and to productivity and the physical infrastructure. In this taxonomy, we have included loss of species as a consequence of value to humans, and thus will not define it separately as an environmental problem. As will be discussed below, we have defined our list of hazards in terms of changes in VECs. Because changes in many different VECs can lead to the loss of species, within the framework of this study loss of species is not considered a single environmental problem.

As an example, the causal structure of stratospheric ozone depletion is shown in Figure 2. This figure demonstrates that in practice the structure may be expanded to include more than one stage of any of the components of the taxonomy. In the case of ozone depletion, a change in one "valued environmental constituent" (increased CFC's in the stratosphere) leads to a change in another (decreased ozone in the stratosphere). The example of ozone depletion also shows that in practice, the taxonomy may look more like a "pitchfork" than a simple chain. In this case, changes in the concentration of several ozone depleting gases lead to a decrease in ozone in the stratosphere, and the change in the valued environmental component of UV radiation on the earth's surface leads to several different consequences.

One of the advantages of using a causal structure as a framework for analysis is that it provides a valuable link between the functions of hazard assessment and hazard management (Kates et al., 1985)[10]. The causal taxonomy clearly delineates the sequence of events that create a hazard, thus providing a guide to available points for intervention. For demonstration purposes, we look once again at the case of ozone depletion, as shown in Figure 3. This diagram shows that environmental problems can be managed through modifying human activities, altering environmental processes, preventing exposure, or preventing consequences. While each of these points of intervention may not be equally viable, the causal taxonomy is a

FIGURE 2: THE CAUSAL STRUCTURE OF STRATOSPHERIC OZONE DEPLETION

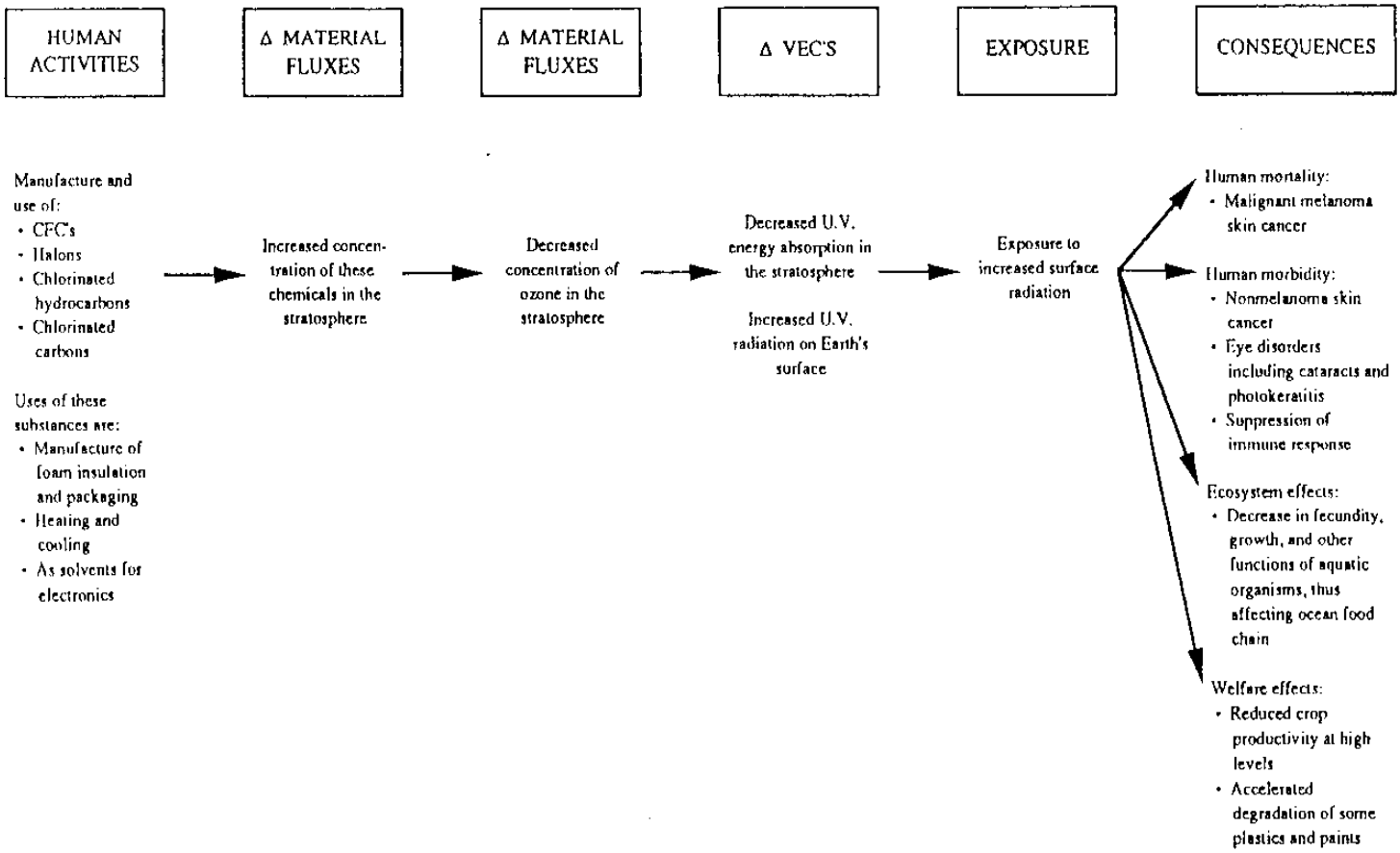
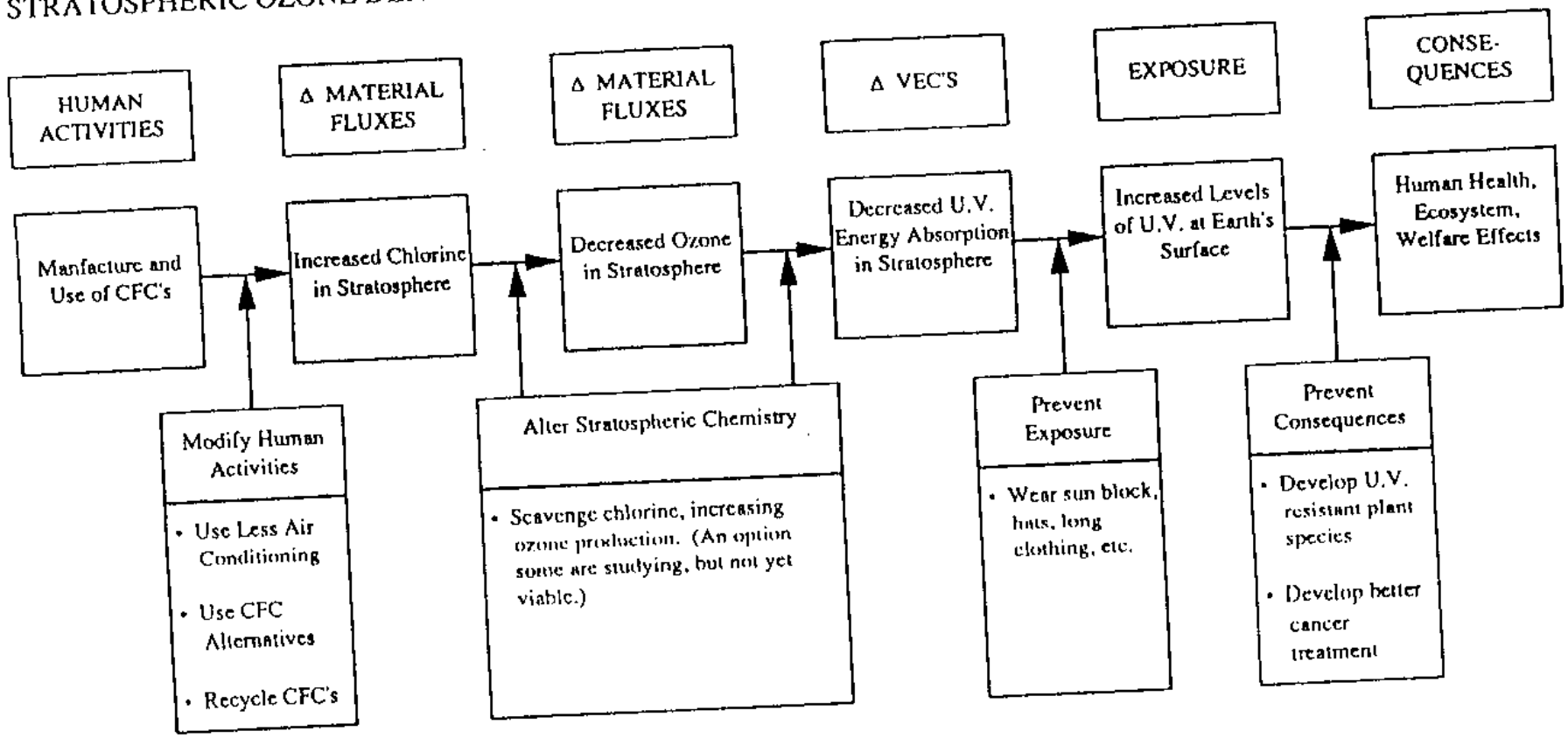


FIGURE 3: RELEVANCE OF CAUSAL STRUCTURE FOR HAZARD MANAGEMENT - THE EXAMPLE OF STRATOSPHERIC OZONE DEPLETION.



valuable aid in conceptualizing the options. We view the further development of this tool to provide more information relevant to management as one of the key next steps (see, for example, Clark, 1991).

2.3. The Set of Descriptors

For each stage in this causal structure, we have developed several "descriptors" that characterize environmental problems. The causal structure and descriptors together form a causal taxonomy for the evaluation of environmental hazards, as presented in Figure 4. The descriptors are summarized in Table 1. More in-depth definitions, measurement scales, and application of these descriptors are provided in more detail in Appendix A[11]. Many of our descriptors have logarithmic scales, some in base 2 and others in base 10. As noted in the CENTED study, this is justified on the basis of both the nature of human perception and the uncertainty of measurements (Kates et al., 1985).

This causal structure is a particularly valuable framework for hazard assessment because it reflects the multi-dimensional nature of environmental hazards. Considering first only consequences, we are concerned about human mortality and morbidity, ecosystem damages and material losses. However, these different types of consequences cannot be adequately measured in a common metric. Furthermore, when considering consequences, we care both about current effects and future effects, but the proper valuing of effects occurring now versus those expected in the future is hotly debated. There is much evidence that policy makers would rather be given information about several relevant aspects of a problem than a single number (eg. a cost/benefit ratio) composed of either detailed or unspecified assumptions[12]. It is therefore useful to have a method, such as this, in which these different aspects of consequences are disaggregated, and where any aggregation scheme is transparent.

The discussion above explains the need for a range of consequence descriptors, but still leaves open to question the usefulness of descriptors at each stage in the causal chain. There are three major reasons for including this entire set of descriptors. First, there is considerable uncertainty and ignorance regarding the consequences of environmental hazards. Comparatively speaking, we have a much better understanding of the magnitude of human perturbations of the environment. Thus, we generally have better and more accurate information for the descriptors to the left of our causal chain (the material flux descriptors) than for those to the right (the consequences). In fact, estimates of consequences depend on estimates at each stage of the causal chain, and therefore the errors and uncertainties in each stage are compounded in the measure of consequences (see also Schneider, 1983). It is due to this uncertainty and ignorance that many environmental problems are in fact managed and even assessed in terms of the disruption that they cause to natural processes. One strength of this method is that it allows problems to be compared based both on perturbations to the environment and on known consequences.

TABLE I (p. 1): DESCRIPTORS

MATERIAL FLUX DESCRIPTORS

1. Spatial Extent. Measures the spatial extent of a single release for which there is a significant change in the material levels in the environment.

2. Disturbance to the Environment (Magnitude of Perturbation). Measures the degree to which a change in the material of interest (pollutant or resource) is above or below the background, normal, or long-term average levels.

3. Annual Change in Perturbation Level. Measures the annual change in the perturbation level.

4. Anthropogenic Flux. Measures the extent to which human activities contribute to the total flux of materials into or out of the environment, i.e. compares the anthropogenic flux to the natural flux.

5. Annual Change in Anthropogenic Flux. Measures the annual rate of change in the anthropogenic flux.

6. Persistence. Measures the time period required for the material most directly perturbed in the environment to return to the level existing before the event that caused a flux of that material.

7. Recurrence. Measures the frequency of the event which causes a flux.

EXPOSURE DESCRIPTORS

8. Population Exposed. Measures the percent of current population within a country that is exposed to the change in a valued environmental component NEC).

9. Land Area or Resource Exposed. Measures the percent of land area or resource within a country that is currently exposed to the changed valued environmental component (VEC).

10. Delay. Measures the delay time between the release or altering of materials and the earliest onset of serious consequences.

TABLE 1 (p. 2): DESCRIPTORS

CONSEQUENCE DESCRIPTORS

11. Human Mortality (Current Annual). Measures the average annual percent of population that dies as a direct result of the hazard.

12. Human Morbidity (Current Annual). Measures the average annual percent of population that becomes significantly ill from the hazard.

13. "Natural" Ecosystem Impacts (Current Annual). Describes the impacts to "natural" elements within ecosystems.

14. Material and Productivity Losses (Current Annual). Measures the average annual losses of material and non-labor productivity.

15. Recovery Period. Measures the time period required to recover from the effects of the relevant material or energy flux to the background state of human health, ecosystem and productivity, assuming the causative human activity is stopped.

16. Future Human Health Consequences. Describes the severity of harm to future health caused by today's human activities.

17. Future Ecosystem Consequences. Describes the severity of harm to future ecosystems caused by today's human activities.

18. Future Material and Productivity Losses. Describes the severity of harm to future ecosystems caused by today's human activities.

19. Transnational. Describes the nations where human activities lead to the consequences.

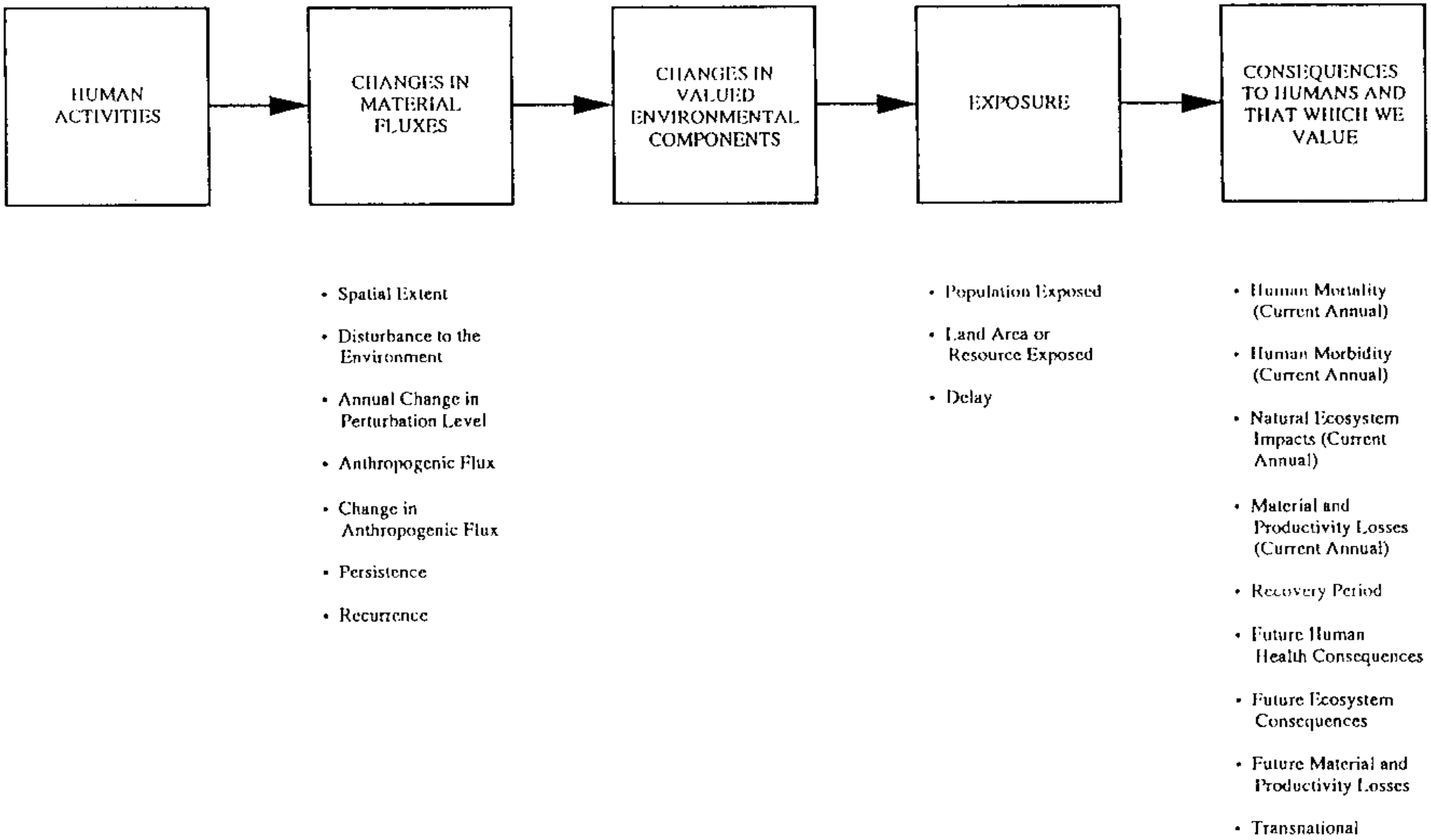
A second reason for using this full causal taxonomy for comparative hazard assessment is that public perception of risk is dependent not only on consequences, but also on factors such as controllability, knowledge, and dread (Slovic et al., 1985). While the method does not describe the full range of variables important in risk perception, several of our descriptors, such as persistence, frequency of occurrence, and spatial extent have direct bearing on these factors. A third reason is that we are interested in characterizing as well as ranking environmental hazards, in order to ascertain if there are particular patterns in the types of environmental hazards which are causing the greatest consequences. Characterization is also important as one moves from hazard assessment to hazard management. The causal structure and its associated descriptors provide a method for the full characterization of environmental hazards.

2.4. The Set of Environmental Problems

In principle, environmental problems can be defined in terms of their manifestation at any point along the causal chain described above. The most conventional approach focusses on important environmental changes per se (e.g. all activities leading to and consequences resulting from the depletion of stratospheric ozone). An alternative approach which in recent years has been advocated by many concerned with environmental management is to define problems in terms of the sectors of human activity that lead to environmental disruption (eg. the environmental problems of energy use). The advantages of this approach have been clearly articulated by the Bruntland Commission, which emphasized that in order to reduce environmental damages, one had to consider environmental consequences when undertaking activities in all sectors of the economy (World Commission on Environment and Development, 1987). For managing a well defined set of priority environmental problems, we side with the Brundtland Commission in advocating the second, or source-oriented approach. But for the more fundamental comparisons and priority setting tasks that are our principal concern here, we have determined that the conventional "environment-centered" is most useful.

As mentioned above, we wanted our set of environmental hazards to be meaningful to the environmental policy debate, do justice to the great variety of environmental concerns expressed around the world, and be defined at a level of resolution that is neither too general nor too complex. Another set of criteria was that they be internally consistent, and justifiable based both on theory and experience. We met these criteria by defining our list of problems by the change in a valued environmental component (VEC), and not by some other point in the causal chain. This key decision is best explained by walking through an example such as climate change, as illustrated in Figure 5. It is not the human activity of, for example, fossil fuel burning, that is the problem. In fact, such activities represent benefits to society as well as sources of environmental problems. Likewise, the change in the carbon cycle is not of concern to us except as it changes a component of the environment we care about -- in this case, the thermal radiation budget. Moving further down the causal chain, exposure is the link between changes in environmental components and the consequences we care about. It holds no promise as a unique

FIGURE 4: CAUSAL TAXONOMY FOR COMPARATIVE HAZARD ASSESSMENT OF ENVIRONMENTAL PROBLEMS



definition of an environmental problem. Similarly, consequences for humans and that which we value are not unique definitions of a single problem. In sum, defining environmental hazards by the VEC allows us to develop a comprehensive yet non-overlapping set of environmental hazards. Of equal importance in our choice to define the environmental hazards by VECs was practical experience in environmental impact assessment. A review of environmental impact assessments in Canada concluded that the most effective assessments were based on an agreement on which aspects of the environment were to be valued, i.e. on a clearly defined set of VECs (Beanlands and Duinker, 1983).

The list of environmental problems finally chosen for this analysis is given in Table 2. This list includes pollution-based hazards, depletion of natural resources, and natural disasters. We recognize that these are often considered to be quite different types of problems which are managed under different legislation or by different agencies. Nonetheless, it is crucial to include all three types of environmental problems because each is likely to be among the most hazardous in some countries. These problems are described in terms of their causal structure in Appendix B**.**

2.5. Interpreting the Data - Aggregation Schemes

As noted above, the application of this method to a single country results in 504 scores - 18 descriptors scored for each of 28 environmental problems. In order for this information to be useful for comparing, ranking and characterizing hazards, some form of data reduction is necessary.

A number of sophisticated data reduction methods are available, some attempting statistically efficient representations of information content, others seeking accurate representations of particular user's concerns and preferences. We employed one such method, Principle Components Analysis (PCA), which can often be useful in interpreting multidimensional data sets. PCA sometimes reveals variable groupings which are not intuitively obvious, but which upon further reflection provide meaningful results. In our case, to the limited extent that the PCA pointed toward tight groupings of descriptors, it largely validated the intuitively meaningful approaches to data reduction that we had previously developed. This result, along with our ultimate concern for usefulness and transparency of the method have led us to adopt some very simple aggregation schemes in the work reported here. The principle components analysis is presented in Appendix E.

In the final analysis, all data reduction or aggregation schemes incorporate value judgments. For example, aggregating consequence descriptors requires one to decide how to value human health, ecosystem, and economic effects in relation to each other. In our interpretation of the country studies in Section 3, we present several aggregation schemes which we found particularly informative. However, interpretation of the data is not limited to these particular aggregations, nor are particular aggregation schemes prescribed by the method. One of the strengths of this method is that it allows other users to explore prioritizations based on their own sets of values, and for those value judgements and their implications to be communicated clearly along with the conclusions. We emphasize that this can and should be a two-way process. Learning

TABLE 2: ENVIRONMENTAL HAZARDS

POLLUTION-BASED HAZARDS

WATER QUALITY
1. Freshwater - Biological Contamination
2. Freshwater - Metals and Toxic Contamination
3. Freshwater - Eutrophication
4. Freshwater - Sedimentation
5. Ocean Water

ATMOSPHERIC QUALITY
6. Stratospheric Ozone Depletion
7. Climate Change
8. Acidification
9. Ground Level Ozone Formation
10. Hazardous and Toxic Air Pollution

QUALITY OF THE HUMAN ENVIRONMENT
11. Indoor Air Pollutants - Radon
12. Indoor Air Pollutants - Non-radon
13. Radiation - Non-radon
14. Chemicals in the Workplace
15. Accidental Chemical Releases
16. Food Contaminants

RESOURCE DEPLETION HAZARDS

LAND/WATER RESOURCES
17. Agricultural Land - Salinization, Alkalinization, Waterlogging
18. Agricultural Land - Soil Erosion
19. Agricultural Land - Urbanization
20. Groundwater

BIOLOGICAL STOCKS
21. Wildlife
22. Fish
23. Forests

NATURAL HAZARDS
24. Floods
25. Droughts
26. Cyclones
27. Earthquakes
28. Pest Epidemics

what our environmental values are and ought to be requires a means of examining and reflecting upon their implications for the ordering of specific real world priorities (Wildavsky, 1979). This method can contribute to the necessary dialectic between general environmental values and specific environmental concerns.

Having pled for useful simplicity, however, it is clear that there is a fine line between the usefully simple and the misleadingly simplistic. With data such as that generated in the scoring of the case studies, it is tempting simply to add the scores for all 18 descriptors of each problem, creating a "total hazard score". We discourage such an approach. A simplistic summation implies that each descriptor merits equal weighting in the determination of rank, an assumption for which there is no basis. There is another fundamental reason for avoiding a simple summation. While for a majority of the hazards, a normalized score of 9 will imply a more hazardous problem than a score of 1, this is not necessarily the case[13]. The representative aggregation schemes we present in Section 3 seek to retain simplicity and transparency without falling into such simplistic traps.

One final note. Throughout the analysis presented below, the method is used to rank problems in three categories: high, medium, or low hazard. Although the problems could be ranked numerically in each category, such a detailed ranking demands of the method more precision than it was designed to deliver, and places more confidence in numerical scores than the data generally justify. Rather than developing an ordinal ranking, we believe the method serves its purpose by distinguishing the problems which present the greatest hazard from those presenting intermediate or low hazards. "High" and "Low" ranked problems are defined, respectively, to approximately reflect the top and bottom quartiles of the 28 item list of potential hazards[14].

2.7. Limitations of the Method

Because this method was developed for hazard assessment rather than hazard management, we stress that it provides only one of the key inputs into the process of allocating resources for managing environmental hazards. In this sense, our effort is similar to the EPA study, Unfinished Business, in that it focuses on characterizing the hazard or harm and does not perform the following tasks which are also required for setting policy agendas and managing hazards: (1) evaluate the economic costs or technical potential for controlling the risks, (2) quantify or list the benefits to society from the activities which cause the environmental risk, (3) evaluate existing governmental efforts which have ameliorated or exacerbated an environmental problem, (4) evaluate the full range of the qualitative aspects important to the publics' perception of risk including voluntariness, familiarity, or equity (U.S. Environmental Protection Agency, 1987). Rather, the method's contribution is its ability to highlight the environmental problems that may be "most" hazardous, and to characterize the key differences in the set of environmental hazards we are facing.

We also emphasize our awareness that the task which we have addressed -- comparing environmental problems within and between countries -- is of such breadth and

complexity that efforts to accomplish it can probably never reach the standards of clarity, certainty and accuracy to which we aspire. Our hope is only that we can help this important task be done better than is now the case. In the course of this project, we made many difficult choices, and the method is neither as simple to apply as we had originally hoped, nor as precise as we might like. Although the method employs a quantitative scoring process based on a seemingly clearly defined set of characteristics of hazards, informed judgment plays a significant role in the method's application. Indeed, assumptions and interpretations enter the process at almost all steps, from scoring the descriptors to choosing aggregation schemes. We therefore want to make certain that potential users of this method understand that it remains an imprecise tool. In order to pass on some of our experience to future users, we have included "tips on applying the method" in Appendix C.

3. APPLICATION OF THE METHOD - FOUR COUNTRY STUDIES

3.1. Choice of Case Studies

In order to demonstrate, evaluate and refine the method outlined above, we have used it to characterize and prioritize the environmental problems in four countries - India, Kenya, the Netherlands, and the United States. The United States was chosen as our first case because of the large amount of information available on environmental hazards and environmental risk assessment. If the descriptors could not be scored well for the U.S. due to lack of information, then we would have little hope of being able to score them for most countries around the world. [15] The other countries were chosen based on two factors: diversity and availability of information. In terms of diversity, these four countries represent a range of climates, population density, levels of economic development, and predominant economic activities. These variables are likely to have significant effects on the type of environmental problems facing a country. In addition, the U.S. and India are both large countries which have tremendous diversity in these variables within their own borders. Applying the method to four countries with major differences in key variables has tested both its scorability and its usefulness as a tool for comparative hazard analysis. The data for each country is presented in Appendix C.

3.2. Comparing Hazards within a Country - Results from the U.S. Case

We begin this section by presenting several different aggregations based solely on the consequence descriptors. We start here because consequences are widely used in hazard assessment, easily understood, and clearly critical variables for comparative hazard assessment. However, as argued in our presentation of the method, there are several characteristics of hazards other than consequences which provide important information for comparative hazard assessment. Therefore, we end this section by presenting several aggregation schemes involving other descriptors in the causal chain, demonstrating how these can also be an aid in priority setting. To make the

discussion easier to follow, throughout the remainder of this chapter, descriptors will be written in italics and aggregation schemes will be in bold type. A summary of all of the aggregation schemes presented in this section is given in Table 3.

Figure 6 shows the rankings of environmental hazards based on three different aggregations of consequences. The first column is the aggregation scheme **Total Human Health Consequences.** This aggregation is the sum of the descriptors relating to current and future health effects *(Human Mortality, Human Morbidity,* and *Future Human Health Consequences).* This is an important aggregation scheme because human health concerns have been and will continue to be one of the main reasons for enacting environmental protection measures.

However, few would argue that health concerns alone should determine environmental priority setting. We therefore present comparable aggregation schemes for ecosystem impacts and material and productivity losses. The second column in Figure 6 presents the aggregation scheme **Total Ecosystem Consequences**, which is the sum of the descriptors *Natural Ecosystem Impacts* and *Future Ecosystem Consequences.* The third column presents the aggregation scheme **Total Material and Productivity** Consequences, which is the sum of the descriptors *Material and Productivity Losses* and *Future Material and Productivity Losses.*

Examination of these three aggregation schemes leads to conclusions similar to those found by CENTED in their study of technological hazards and by the U.S. EPA in their two studies of environmental problems: How a problem is ranked in relationship to other problems depends on what dimensions of the problem or types of effects are being considered. Specifically, when looking only at consequences, what one considers to be the most pressing environmental problems depends on whether one focuses on health or ecosystem or material losses. No problem ranks high in all three categories, and only one problem (Freshwater: Metals and Toxics) ranks high in two of the three consequence aggregations.

An alternative treatment of the method's consequence descriptors is to construct two temporally-based aggregations - **Total Current Consequences** and **Total Future Consequences. Total Current Consequences** is comprised of *Human Mortality, Human Morbidity, Natural Ecosystem Impacts,* and *Material and Productivity Losses,* while **Total Future Consequences** includes *Future Human Health Consequences, Future Ecosystem Consequences,* and *Future Material and Productivity Losses.* These aggregations allow us to compare those environmental hazards that pose the greatest hazard currently to those that are expected to become significantly worse in the next 25 years. This comparison is of particular interest, as determining how to weigh present versus future consequences is one of the most difficult tasks facing policy makers (Weiss, 1989).

A comparison of these two aggregation schemes is presented in Figure 7 for the U.S. case. The horizontal axis represents **Total Current Consequences,** the vertical **Total Future Consequences.** The lines on the graph correspond to our quartile divisions, used to distinguish the problems ranked high, medium, and low. The "corners" of the graph represent combinations of current and future consequences that are of particular interest. A problem falling into the

TABLE 3: AGGREGATION SCHEMES USE FOR INTERPRETATING DATA

AGGREGATION SCHEME	SUM OF THE FOLLOWING DESCRIPTORS
Total Human Health Consequences	11. Human Mortality (Current Annual) 12. Human Morbidity (Current Annual) 16. Future Human Health Consequences
Total Ecosystem Consequences	13. "Natural" Ecosystem Impacts (Current Annual) 17. Future Ecosystem Consequences
Total Material and Productivity Consequences	14. Material and Productivity Losses (Current Annual) 18. Future Material and Productivity Losses
Total Consequences	11. Human Mortality (Current Annual) 12. Human Morbidity (Current Annual) 13. "Natural" Ecosystem Impacts (Current Annual) 14. Material and Productivity Losses (Current Annual) 16. Future Human Health Consequences 17. Future Ecosystem Consequences 18. Future Material and Productivity Losses
Total Current Consequences	11. Human Mortality (Current Annual) 12. Human Morbidity (Current Annual) 13. "Natural" Ecosystem Impacts (Current Annual) 14. Material and Productivity Losses (Current Annual)
Total Future Consequences	16. Future Human Health Consequences 17. Future Ecosystem Consequences 18. Future Material and Productivity Losses
Pervasiveness	1. Spatial Extent 6. Persistence 8. Population Exposed 9. Land Area or Resource Exposed 15. Recovery Period
Disruption	2. Disturbance to the Environment (Magnitude of Perturbation) 3. Annual Change in Perturbation Level 4. Anthropogenic Flux 5. Annual Change in Anthropogenic Flux
Persistence in Time	6. Persistence 15. Recovery Period
Pervasiveness in Space	1. Spatial Extent 8. Population Exposed 9. Land Area or Resource Exposed
Manageability	7. Recurrence 10. Delay 19. Transnational

FIGURE 5: THE CAUSAL STRUCTURE OF CLIMATE CHANGE

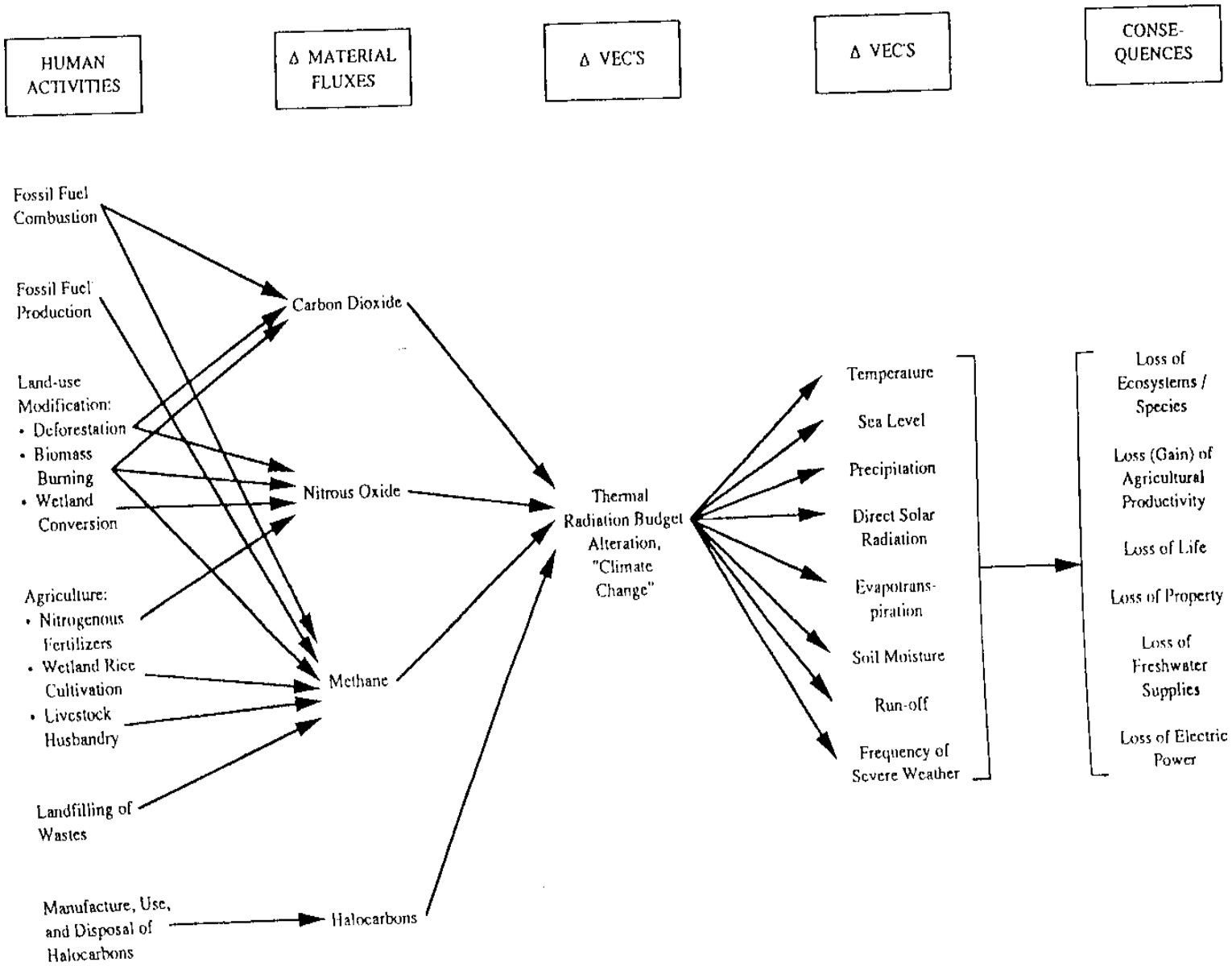


FIGURE 6: HAZARD RANKINGS BY TOTAL CONSEQUENCE AGGREGATIONS FOR USA

Key:

High Hazard	*****
Medium Hazard	***
Low Hazard	*

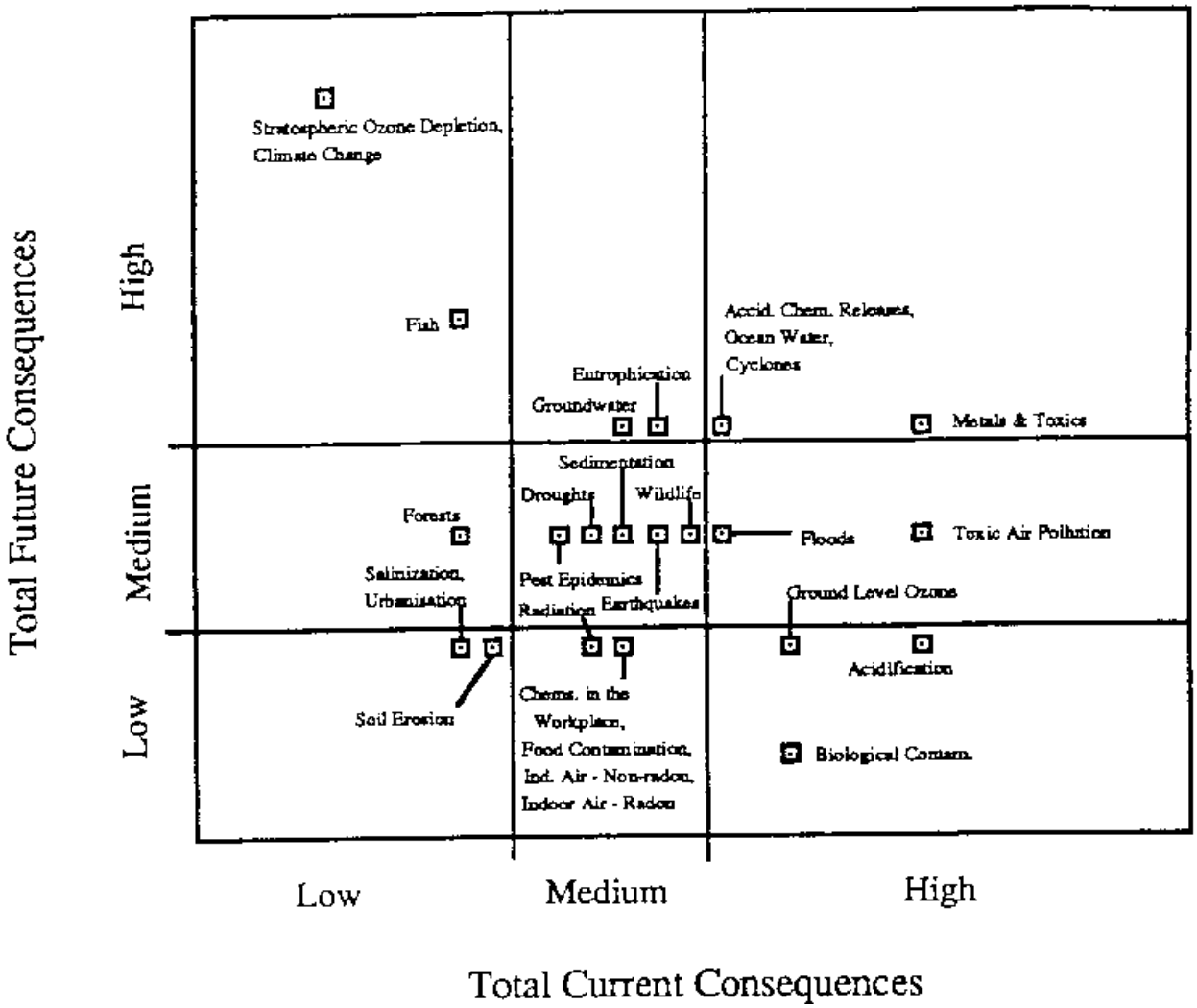
Environmental Problems	Total Human Health Consequences (a)	Total Ecosystem Consequences (b)	Total Mat./Prod. Consequences (c)
1. Freshwater - Biological Contamination	***	***	***
2. Freshwater - Metal and Toxic Contamination	*****	***	*****
3. Freshwater - Eutrophication	***	***	*****
4. Freshwater - Sedimentation	*	***	*****
5. Ocean Water	***	***	*****
6. Stratos. Ozone Depletion	***	***	***
7. Climate Change	***	***	***
8. Acidification	***	***	***
9. Ground Level Ozone Formation	***	***	***
10. Toxic Air Pollution	*****	***	***
11. Indoor Air - Radon	*****	*	*
12. Indoor Air - Non-radon	*****	*	*
13. Radiation - Non-radon	*****	*	*
14. Chemicals in the Workplace	*****	*	*
15. Accidental Chemical Releases	***	***	***
16. Food Contamination	*****	*	*
17. Agric. Land - Salinization, Alk.,Water.	*	*	***
18. Agric. Land - Soil Erosion	*	*	*****
19. Agric. Land - Urbanisation	*	***	*
20. Groundwater	*	***	*****
21. Wildlife	*	*****	***
22. Fish	*	*****	***
23. Forests	*	*****	*
24. Floods	***	*	*****
25. Droughts	*	***	***
26. Cyclones	***	*	*****
27. Earthquakes	***	*	*****
28. Pest Epidemics	***	***	***

(a) Total Human Health Consequences consists of the descriptors 11) Human Mortality (Current Annual), 12) Human Morbidity (Current Annual), and 16) Future Human Health Consequences.

(b) Total Ecosystem Consequences consists of the descriptors 13) Natural Ecosystem Impacts (Current Annual), and 17) Future Ecosystem Consequences.

(c) Total Material and Productivity Consequences consists of the descriptors 14) Material and Productivity Losses (Current Annual), and 18) Future Material and Productivity Losses.

FIGURE 7: COMPARISON OF USA HAZARD RANKINGS
Total Current Consequences vs. Total Future Consequences



upper right corner of the graph ranks high in both these aggregation schemes. Such problems are worthy of special attention, for they are not only among the worst current problems, but are expected to become significantly more severe in the future. In other words, they are problems which are not yet being effectively managed, even to the minimal level of preventing increasing harm. In the United States, Freshwater Metals and Toxics, Accidental Chemical Releases, Ocean Water, and Cyclones fall into this corner. In contrast, the lower right hand portion of the graph contains those problems that are currently severe, but unlike those in the upper right quartile, are expected to improve in the future. This is due to projections that management efforts already underway will successfully reduce the future consequences of this set of problems. For the United States, Biological Contamination of Freshwater, Acidification, and Ground Level Ozone fall into this quartile, due to expectations that these will be controlled under the new Clean Water and Clean Air Acts. A final portion of this graph that is of particular interest is the upper left hand corner. It represents hazards that are not known to have serious current consequences, but are expected to have significant future consequences. Not surprisingly, Climate Change and Stratospheric Ozone Depletion display this characteristic.

A word of caution is in order regarding the use and interpretation of the aggregation **Total Future Consequences,** for two reasons. First, the future consequence descriptors were scored in relation to the current consequences, and thus measure whether a problem is expected to become *significantly* better or worse, with "significant" defined roughly as a doubling or halving of consequences. Thus, the future consequence descriptors and the aggregation **Total Future Consequences** are measures which combine trend and magnitude *information.* Secondly, the expectation of future harm is based roughly on a "business-as-usual" scenario, which takes into account current management activities, *including* those recently enacted that may not yet have produced results. Current policy debates highlight the contentiousness of what constitutes "business-as-usual", and past experience has shown how often "business-as-usual" scenarios prove to be incorrect. Despite our recognition of the limitations of a business-as-usual approach, the alternative, which is to use several future scenarios, would have created too much complexity for a method of this type. It would have defeated our goal of developing a method which could be applied in a fairly short period of time by an informed generalist.

Thus far, the aggregation schemes we have discussed have been based on the consequence descriptors. As argued previously, one of the reasons why it is problematical to depend solely on current or projected consequences to identify priority environmental problems is that there is much uncertainty and ignorance regarding the consequences of actions that perturb the environment. We are therefore interested in aggregation schemes that can give us an indication of the degree of perturbation caused by various environmental problems. The two aggregation schemes presented next involve descriptors from other points in our causal chain which capture this.[16]

The first, Pervasiveness, is intended to capture both the spatial spread and the natural longevity of pollutants or other environmental perturbations. It is comprised of

the descriptors *Spatial Extent, Persistence, Population Exposed, Land Area or Resource Exposed,* and *Recovery Period.* In Figure 8, we compare scores on Pervasiveness to scores on **Total Consequences,** an aggregate indicator created by summing the scores of the **Health, Ecosystem, and Material Consequence** aggregations shown in Figure 6. Not surprisingly, all of the problems that rank high on **Total Consequences** score high or medium for **Pervasiveness.** What is of particular interest in this graph are the hazards occupying its upper left hand portion. They have relatively low known consequences but high pervasiveness. Radiation and Food Contamination fall into this zone for the U.S. [17] We have dubbed such hazards "Red Flag" problems because their high pervasiveness suggest that if turn out to exist currently unknown impacts due to these changed VECS, we could experience unexpectedly high consequences in the future. These are thus problems that call for extra monitoring, and possibly policy action as insurance against surprises.

Two environmental problems that are currently receiving much attention, climate change and stratospheric ozone depletion, are good examples of the relevance of the **Pervasiveness** / **Total Consequences** analysis. Twenty years ago, they would have fallen into the "red flag" zone, as their consequences were poorly understood or altogether unsuspected. Now it is clear that these hazards pose grave environmental risks precisely because the pollutants that cause them are globally pervasive and temporally persistent.

A second aggregation scheme which describes perturbation to the environment is **Disruption.** This aggregation consists of the descriptors *Disturbance to the Environment, Change in Perturbation, Anthropogenic Flux,* and *Change in Anthropogenic Flux.* The **Disruption** scheme identifies those hazards that are causing drastic additions (as in pollution) or extractions (as in harvesting of renewable resources) of materials into or out of the natural environment. **Disruption** versus **Total Consequences** is graphed in Figure 9. Another "red flag" zone appears in the upper left hand corner, identifying problems that have high disruption but low known consequences. Salinization falls in this zone[18]. Again, due to society's ignorance and uncertainty regarding the consequences of severe or rapid disruption of the natural environment, perhaps more attention should be paid to such hazards. The lower right hand corner of this graph is also of interest, as it contains climate change, which scores high for total consequences, but low for disruption. Although human activities are disrupting the carbon cycle at a faster rate than ever before in history, it is still a rather minor disruption when compared to the entire carbon cycle. The reason, of course, is that we believe that small perturbations to the carbon cycle will turn out to be magnified by the earth system into relatively large changes in the distribution of the energy received from the sun, in the climate, and in ecosystem function. This is a consequence of detailed feedback mechanisms missed by the simple "Disruption" index, and serves another warning that no single-dimensioned ranking of environmental problems is likely to be without major shortcomings.

As stated previously, the foregoing aggregation schemes are suggestive, not prescriptive. Several others which we believe can be useful for ranking and

characterizing environmental hazards are described below.

Persistence in Time. This is the sum of the descriptors *Recovery Period* and *Persistence.* It describes the natural longevity of pollutants or perturbations in the environment and is the temporal component of the aggregation **Pervasiveness.**

Pervasiveness in Space. This is the sum of the descriptors *Population Exposed, Land Area or Resource Exposed,* and *Spatial Extent.* It describes the physical reach of pollutants or perturbations in the environment and is the spatial component of **Pervasiveness.**

FIGURE 8: COMPARISON OF USA HAZARD RANKINGS
Total Consequences vs. Pervasiveness

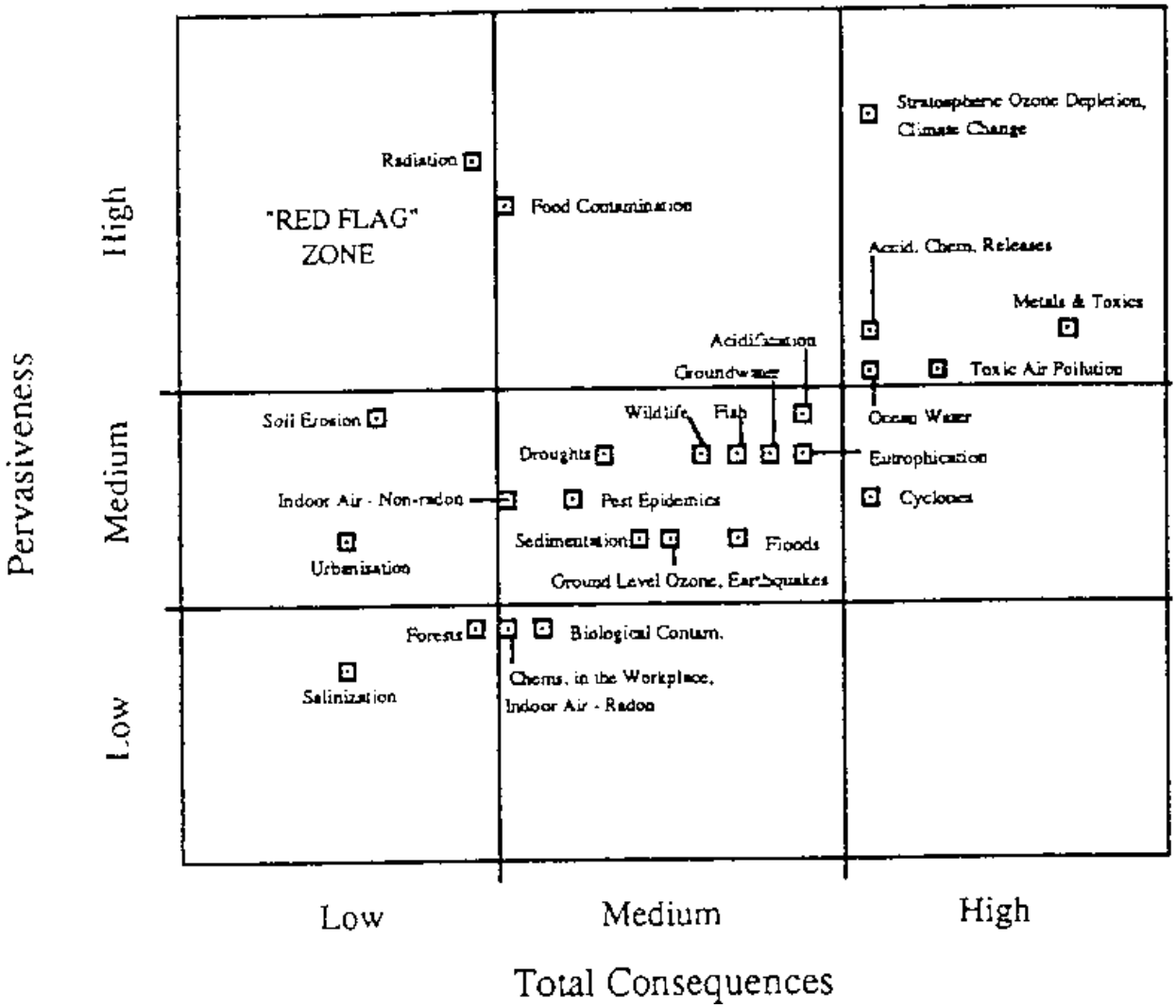
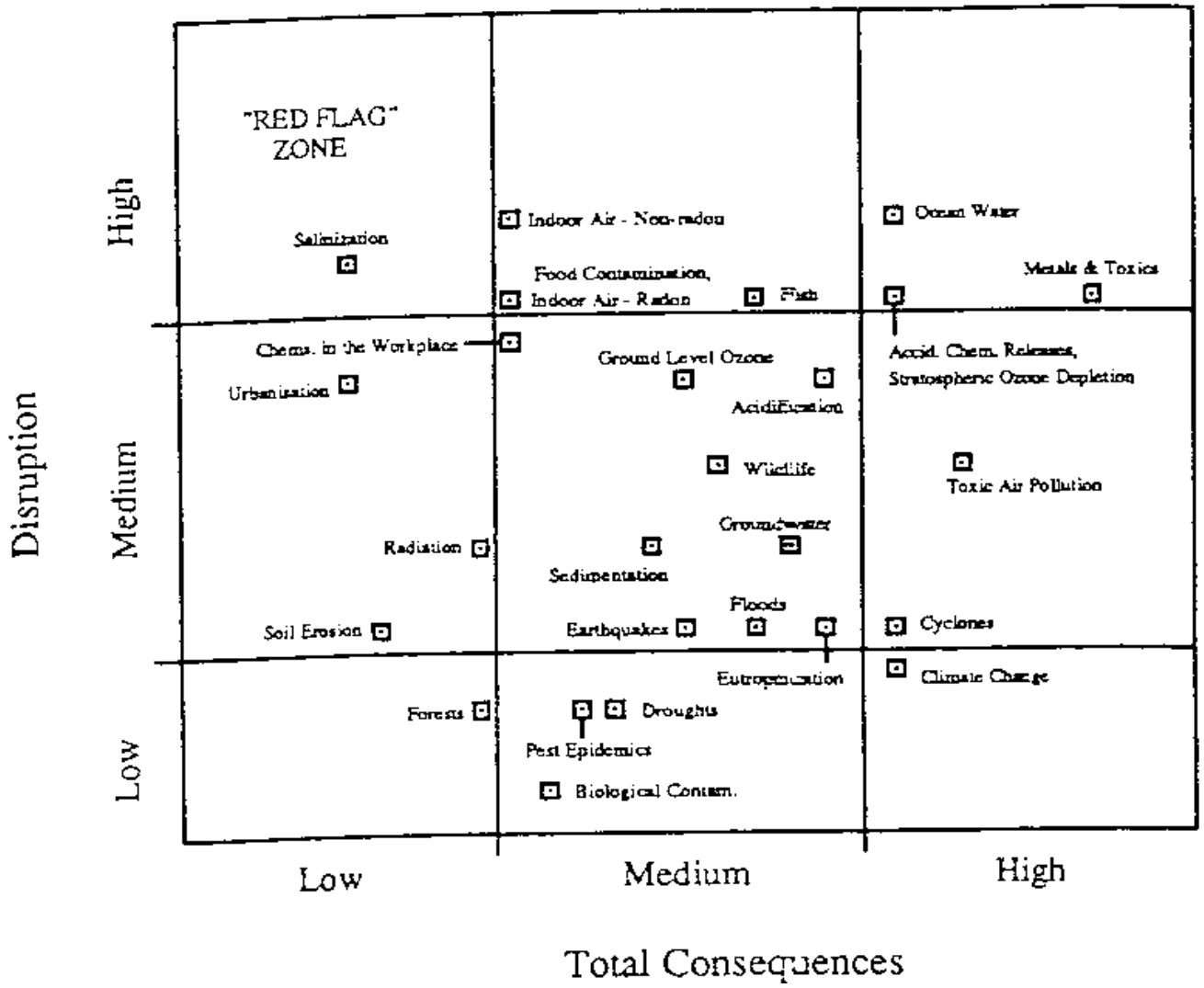


FIGURE 9: COMPARISON OF USA HAZARD RANKINGS
Total Consequences vs. Disruption



Manageability. This aggregation scheme is the sum of the descriptors *Transnational, Delay,* and *Recurrence.* Problems that score high in *Transnational* will be more difficult to manage because the problem is exacerbated by the actions of other countries. Problems that score high in *Delay* will be difficult to manage because they will be out of the public eye for long periods of time and it will therefore be difficult to rally political support to remedy them. And problems that score high in *Recurrence* will be difficult to manage because the less frequently problems occur, the less likely the public will maintain an active awareness of them.

3.3. Comparing Hazards Across Countries - India, Kenya, the Netherlands, and the United States

This section uses several of the aggregation schemes illustrated above to compare environmental hazards across the four countries. We begin in Figure 10 with a comparison of environmental problems described in terms of their **Total Consequences.** The figure shows that none of our 28 environmental problems rank high for **Total Consequences** in all four countries. Similarly, only three environmental problems -- Freshwater: Metals and Toxics, Ocean Water, and Hazardous and Toxic Air Pollution -- are ranked high for three countries. This result serves as an important reminder for international cooperation that different nations are facing very different sets of severe environmental threats.

It is also instructive to examine shared problems across pairs of countries, as many environmental problems are ranked high across two countries for **Total Consequences.** The Netherlands and the U.S. share 5 out of 7 of their top ranked hazards. This is due to their similar levels and types of industrialization, as well as similarities in their environmental management programs. Comparing India and Kenya, the two developing nations in our study, only two problems ranked high in both for **Total Consequences.** In fact, India shares more top ranked problems with the Netherlands and the U.S. than with Kenya. This is due to the fact that India is a diverse country with major areas of concentrated industrialization, while Kenya has much lower levels of industrial activity. Thus, more of India's top-ranked problems are caused by industrial activities while more of Kenya's are from resource depletion. These results serve as a warning against making the erroneous assumptions that all developing countries face similar environmental hazards, or that there are one set of problems facing industrialized countries and another facing developing countries. Many more case studies would be needed in order to determine if there are meaningful ways of grouping countries in terms of the most severe environmental hazards that they face.

Our second set of cross country comparisons involve the aggregation schemes **Total Current Consequences** and **Total Future Consequences,** as illustrated in Figures 11 and 12. For both aggregation schemes, there are significant differences in the hazards that are ranked

FIGURE 10: COMPARISON OF HAZARDS RANKED AS MOST SEVERE IN TERMS OF TOTAL CONSEQUENCES FOR THE NETHERLANDS, USA, INDIA, AND KENYA (a).

A high ranking hazard is indicated by a *.

Environmental Problems	Netherlands	USA	India	Kenya
2. Freshwater - Metal and Toxic Contamination	*	*	*	
5. Ocean Water	*	*	*	
10. Toxic Air Pollution	*	*	*	
6. Stratos. Ozone Depletion	*	*		
7. Climate Change	*			*
9. Ground Level Ozone Formation			*	*
18. Agric. Land - Soil Erosion			*	*
23. Forests			*	
1. Freshwater - Biological Contamination	*			
3. Freshwater - Eutrophication		*		
15. Accidental Chemical Releases				*
21. Wildlife				*
22. Fish			*	
24. Floods				*
25. Droughts		*		
26. Cyclones				*
28. Pest Epidemics				
4. Freshwater - Sedimentation				
8. Acidification				
11. Indoor Air - Radon				
12. Indoor Air - Non-radon				
13. Radiation - Non-radon				
14. Chemicals in the Workplace				
16. Food Contamination				
17. Agric. Land - Salinization, Alk.,Water.				
19. Agric. Land - Urbanisation				
20. Groundwater				
27. Earthquakes				

(a) The Total Consequences Aggregation consists of the descriptors 11) Human Mortality, 12) Human Morbidity, 13) Natural Ecosystem Impacts, 14) Material and Productivity Losses, 16) Future Human Health Consequences, 17) Future Ecosystem Consequences, and 18) Future Material and Productivity Losses.

FIGURE 11: COMPARISON OF HAZARDS RANKED AS MOST SEVERE IN TERMS OF TOTAL CURRENT CONSEQUENCES FOR THE NETHERLANDS, USA, INDIA, AND KENYA (a).

A high ranking hazard is indicated by a *.

Environmental Problems	Netherlands	USA	India	Kenya
1. Freshwater - Biological Contamination		*	*	*
2. Freshwater - Metal and Toxic Contamination	*	*	*	
5. Ocean Water	*	*		
8. Acidification	*	*		
9. Ground Level Ozone Formation	*	*		
10. Toxic Air Pollution	*	*		
15. Accidental Chemical Releases	*	*		
18. Agric. Land - Soil Erosion			*	*
24. Floods		*	*	
25. Droughts			*	*
28. Pest Epidemics			*	*
3. Freshwater - Eutrophication	*			
4. Freshwater - Sedimentation	*			
12. Indoor Air - Non-radon				*
17. Agric. Land - Salinization, Alk.,Water.			*	
21. Wildlife				*
23. Forests				*
26. Cyclones		*		
6. Stratos. Ozone Depletion				
7. Climate Change				
11. Indoor Air - Radon				
13. Radiation - Non-radon				
14. Chemicals in the Workplace				
16. Food Contamination				
19. Agric. Land - Urbanisation				
20. Groundwater				
22. Fish				
27. Earthquakes				

(a) The Total Current Consequences Aggregation consists of the descriptors 11) Human Mortality, 12) Human Morbidity, 13) Natural Ecosystem Impacts, and 14) Material and Productivity Losses.

FIGURE 12: COMPARISON OF HAZARDS RANKED AS MOST SEVERE IN TERMS OF TOTAL FUTURE CONSEQUENCES FOR THE NETHERLANDS, USA, INDIA, AND KENYA (a).

A high ranking hazard is indicated by a *.

Environmental Problems	Netherlands	USA	India	Kenya
6. Stratos. Ozone Depletion	*	*	*	*
7. Climate Change	*	*	*	*
3. Freshwater - Eutrophication	*	*		*
5. Ocean Water	*	*	*	
9. Ground Level Ozone Formation	*	*		*
2. Freshwater - Metal and Toxic Contamination	*		*	*
8. Acidification	*		*	
10. Toxic Air Pollution	*	*		*
15. Accidental Chemical Releases		*		*
22. Fish			*	
23. Forests	*			*
1. Freshwater - Biological Contamination				
18. Agric. Land - Soil Erosion		*	*	
20. Groundwater		*		
24. Floods				
26. Cyclones				
4. Freshwater - Sedimentation				
11. Indoor Air - Radon				
12. Indoor Air - Non-radon				
13. Radiation - Non-radon				
14. Chemicals in the Workplace				
16. Food Contamination				
17. Agric. Land - Salinization, Alk.,Water.				
19. Agric. Land - Urbanisation				
21. Wildlife				
25. Droughts				
27. Earthquakes				
28. Pest Epidemics				

(a) The Total Future Consequences Aggregation consists of the descriptors 16) Future Human Health Consequences, 17) Future Ecosystem Consequences, and 18) Future Material and Productivity Losses.

high for the different countries, emphasizing that the greatest risks are different for the four countries. However, comparing these two aggregations, we find that more environmental problems are highest ranked across three or more countries in terms of **Total Future Consequences** than in terms of **Total Current Consequences.** Of particular note, Stratospheric Ozone Depletion and Climate change are ranked high for **Total Future Consequences** in all four countries we studied. This suggests that to the extent attention can be focused on problems largely important for their future consequences, there is an internationally shared basis for focusing on these two global hazards.

These shared high future consequence rankings for Stratospheric Ozone Depletion and Climate Change for all four countries also point to one of the limitations of our method. Not all countries are likely to suffer the same magnitude of consequences from a problem like Climate Change. Yet, our future consequence descriptors are not sensitive enough to allow for such distinctions. The complex scenario development needed for that type of analysis, even for problems with better understood consequences, was not compatible with the ease of application we were striving for in our descriptors.

The two figures also illustrate that there are distinct differences between highest ranked problems for **Total Current Consequences** and **Total Future Consequences** in each country. Two factors contribute to these differences. The first is that many of the worst current problems are being managed and therefore are expected to become less severe in the future, such as acid rain and ground level ozone formation in the United States. Secondly, problems that are not ranked among the worst currently may be becoming more severe at a significantly faster rate. This difference between hazards that are top ranked for current and future consequences is most pronounced for Kenya and India, where only 2 problems in each country were ranked high for both current and future consequences. This indicates the existence of many problems that are not currently of great concern that are expected to become significantly more severe in the future. [19]

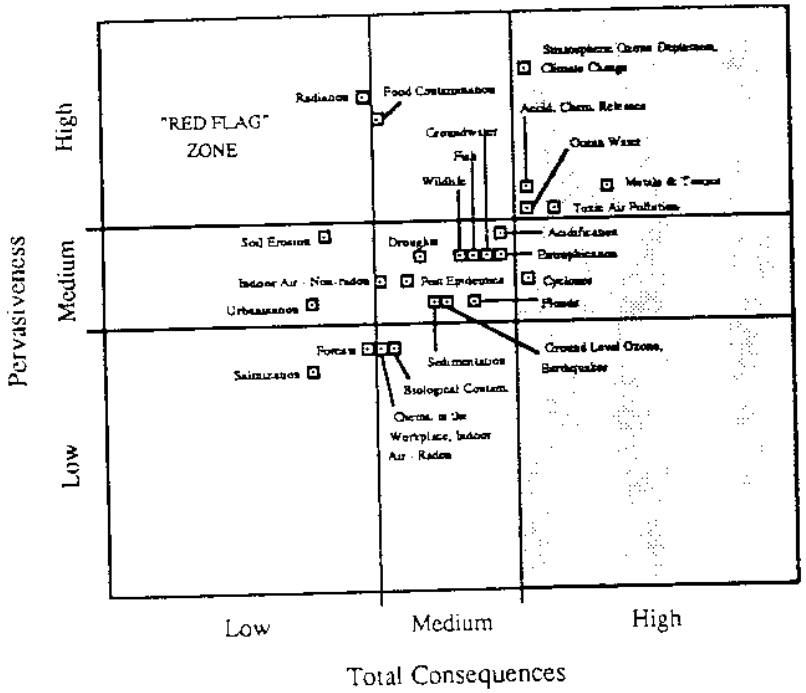
Our final cross country comparison is **Total Consequences** versus **Pervasiveness,** already investigated for the US case in our first "red flag" graph. Figure 13 presents this graph for each of the four countries. Two particularly interesting observations can be made from this figure. First, as discussed for the U.S. case, problems that fall into the upper left hand corner of this graph (the "red flag" zone) have high **Pervasiveness** and low Total (known) **Consequences.** Figure 13 demonstrates that each of the four countries of our study has two problems in common that are in or very near the "Red Flag" zone: Radiation-Non-Radon and Food Contamination. This across-the-board outcome serves as a warning that if there are unknown but severe consequences from these problems, they are likely to be experienced globally. Again, they may be compared to Climate Change and Stratospheric Ozone Depletion, which if scored twenty years ago, would have been plotted in this zone.

The second point of interest on this graph is to look at the shaded portion of the diagram. So far in this paper, we have been comparing each country in terms of its

own quartiles, and ranking problems as high, medium, or low. We now shift to comparisons based on total scores.

FIGURE 13 - PART 1: CROSS-NATIONAL COMPARISONS OF HAZARD RANKINGS
Total Consequences vs. Pervasiveness

USA



INDIA

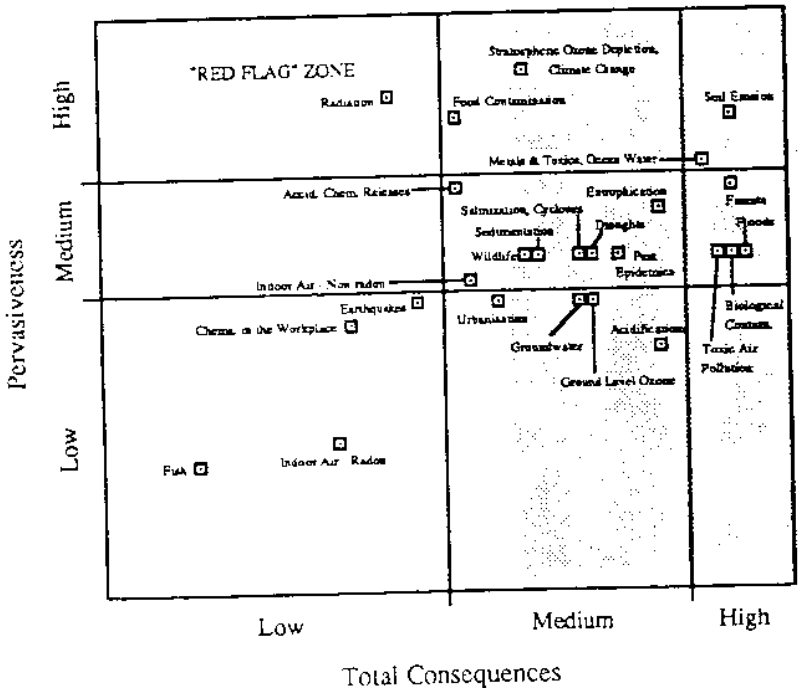
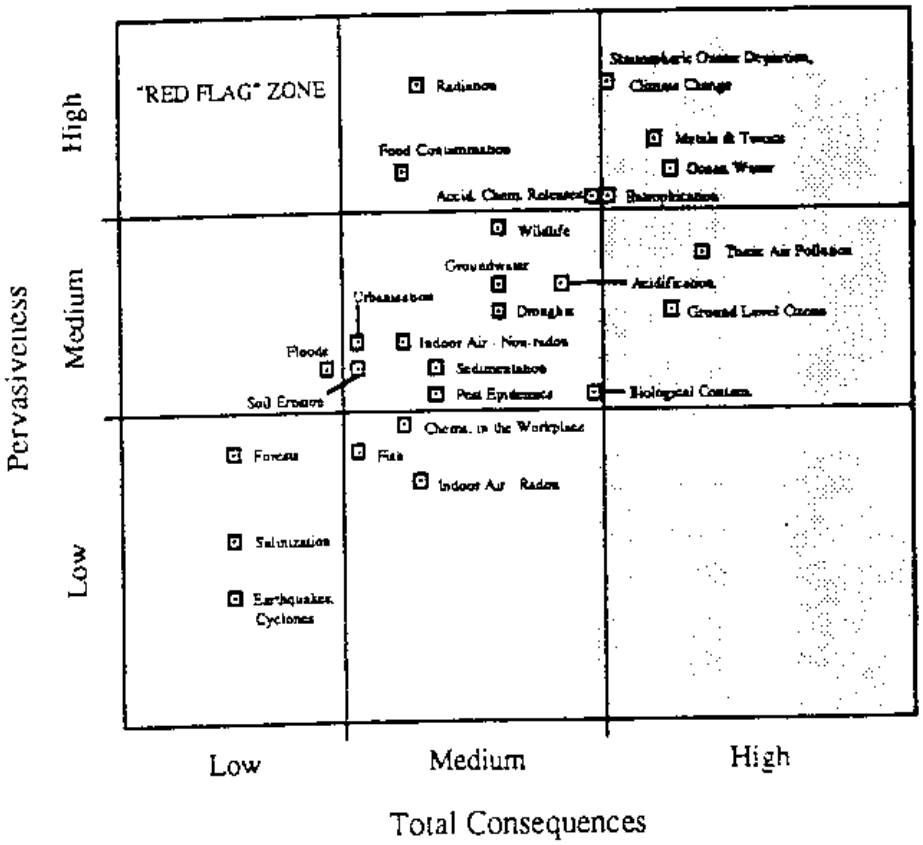
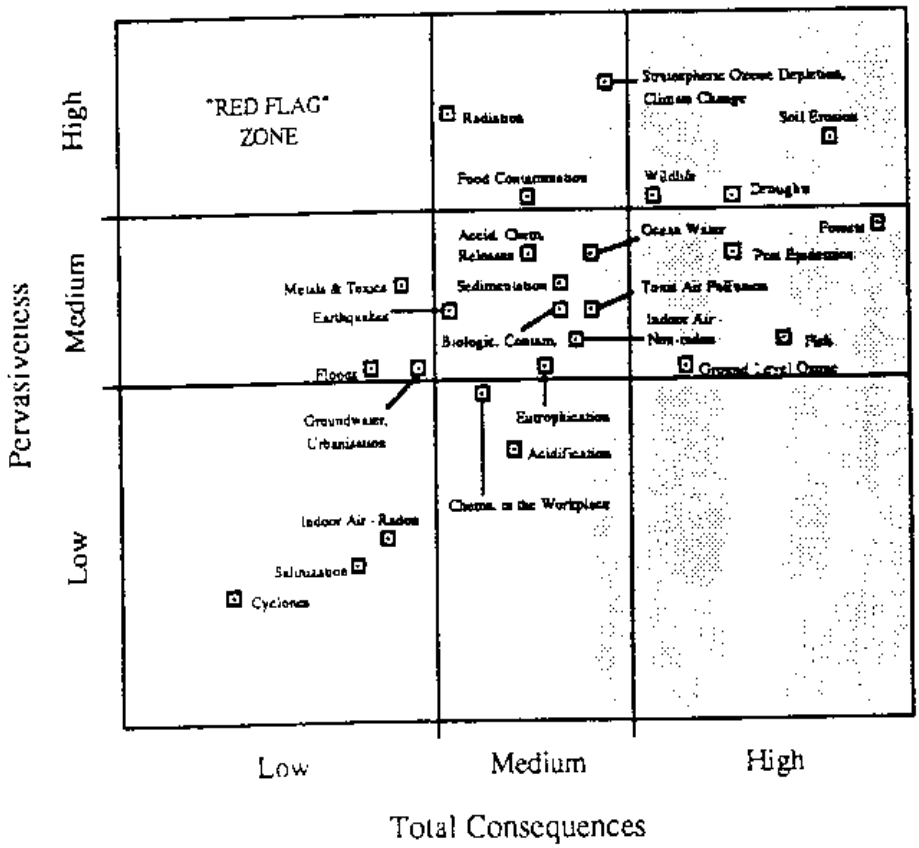


FIGURE 13 - PART 2: CROSS-NATIONAL COMPARISONS OF HAZARD RANKINGS
Total Consequences vs. Pervasiveness

THE NETHERLANDS



KENYA



The shaded regions in the figure are defined to include all problems with **Total Consequence** scores equal to or greater than those characterizing the upper quartile (i.e.. high-ranked problems) in the US case. For the U.S., a score of 30 or greater is needed to rank in the top quartile for the aggregation **Total Consequences.** The Netherlands has nearly the same number of problems with scores greater than 30, 8 compared to 7. In contrast, there are 11 problems in Kenya and 19 in India with scores greater than 30. This result emphasizes that the environmental challenges being faced by Kenya and India are in general much more hazardous than those faced by the U.S. and the Netherlands. Put somewhat differently, many of the "medium" ranked problems of India and Kenya almost certainly pose greater threats to those countries' peoples and ecosystems than even the "high" ranked problems of the US and Netherlands pose to theirs.

4. CONCLUSIONS

The case study evaluations presented here have convinced us that this method can successfully contribute to the difficult task of comparative environmental hazard assessment, both within and across countries. Our goal has been not to present one final set of rankings, but rather to demonstrate how the method can be used to accomplish this task. The case studies have also demonstrated the complexity of an endeavor of this sort, and emphasized the importance of the assumptions and judgments required to make comparisons in the face of limited and uncertain data. In addition, we have discussed our difficulties in developing and scoring descriptors for the important category "future consequences".

A method of such admitted liabilities should lead one to ask the obvious question: Why use it at all? Our justifications are twofold. First, the arguments for conducting some sort of environmental hazard comparison are compelling; thinking of environmental risks in isolation from each other and then drawing policy conclusions independently is extremely shortsighted. Despite the limitations of EPA's Unfinished Business report, its great contribution to policy making was its fundamental demonstration that effective environmental protection should not and need not be based on ad hoc responses to hazards.

As for the second justification, we simply do not know of any alternative mechanisms for international comparative assessment of environmental hazards that are any more satisfactory than the one we have sketched here. Despite its many shortcomings, the use of a causal taxonomy for comparative hazard assessment allows a full characterization of environmental hazards. This allows for hazards to be ranked based both on their consequences, and on other important characteristics such as disruption to the environment, pervasiveness, and manageability. By focusing on aggregation schemes that are chosen by the user and can be clearly communicated to others, the method makes transparent the value judgments inherent any scheme for comparing and ranking hazards. This is of particular importance when ranking hazards that cause different types of consequences, whose consequences occur over different time frames, and that appear in very different perspectives in different parts of the world. Lastly, this method provides clear links between the two distinct

but interrelated tasks of hazard assessment and hazard management.

In short, we are at least as aware as any of our readers that the method presented here is only a beginning, and a highly imperfect one at that, for the urgent and complex task of comparing environmental hazards in international context. We can only hope and believe that it is a beginning upon which others will be motivated and able to build.

ENDNOTES

1. The study reported in this paper was conducted at the Center for Science and International Affairs at Harvard University's John F. Kennedy School of Government from 1988 to 1991. The work was carried out as part of the Center's larger program on global environmental risks, led by Prof. William C. Clark. Vicki Norberg-Bohm, a doctoral candidate at the School, directed the study. The other authors contributed in the course of their graduate training at the institutions listed below: JoAnne Berkenkamp, Marc D. Koehler, and Jennifer A. Marrs (Kennedy School of Government, Harvard University); Bhavik Bakshi, Chris P. Nielsen and Ambuj Sagar (Massachusetts Institute of Technology); Sherry Bishko (Tufts University). All authors can be reached care of Prof. Clark at the Kennedy School, 79 Kennedy Street, Cambridge MA, 02138 USA.

The study was supported by The Stockholm Environment Institute (SEI), The Rockefeller Brothers Fund through a grant to SEI, and the United Nations University. The early formulation of the study benefitted greatly from meetings with Roger Kasperson, Chris Hohenemser, Robert Kates and their colleagues at Clark University's Center for Technology, Environment and Development (CENTED). The grounding of our approach in CENTED's earlier work on hazard assessment is acknowledged in the text, but bears special mention here. CENTED contributed substantially to the subsequent development of our study through hosting a critical review meeting on an earlier draft and, through the Center's librarian Jeanne X. Kasperson making available their unparalleled collections of source materials. Other critical feedback was provided by members of the European Policy Unit at the European University Institute in Florence, and by students in Clark's classes on Comparative Environmental Policy at the Kennedy School, and by anonymous reviewers of an earlier version of the work presented by SEI to the Second World Climate Conference. To all, our sincere thanks.

An earlier version of the method presented here was published as Norberg-Bohm et al., 1990.

2. E.g. World Resources Institute, 1990; World Resources Institute, 1992; United Nations Environment Program, 1991; Parker and Hope, 1992.

3. E.g. Pearce, et al., 1989; Project 88 - Round II, 1991; Project 88, 1988; Repetto and Gillis, 1988.

4. " EPA's budget and priorities have been shaped more by 'what the last phone call from Capitol Hill or the last public opinion poll had to say' than by a scientific assessment of risk, says Frederick Allen of EPA's office of policy analysis. ... Now, Reilly *has* asked *his* Scientific Advisory Board to tell him which problems pose the biggest environmental or public health threats. The board's analysis ... reveals that the environmental problems that dominate public concerns - and EPA's budget - are often not those that Reilly's scientific advisers deem the biggest threats." (Robert, 1990). For further discussion of the differences between the results from the EPA risk assessments, public perception, and legislative and budgetary priorities, see also (Morgenstern and Sessions, 1988) and the two EPA comparative risk assessment reports, U.S. Environmental Protection Agency (1987) and Science Advisory Board (1990).

5. A review of the state of the environment 10 years after the Stockholm conference evaluated the severity of the major environmental problems around the world (Holdgate et al., 1982). More recently, there have been a number of important studies which make systematic comparisons of the severity of environmental problems in different parts of the world (e.g. National Geographic Society, 1988; Lean, et al., 1990). However, there is still a great need for research which identifies what are the biggest problems in different parts of the world.

6. Although our work proceeded simultaneously, we have found that in developing the method presented in this paper, we also identified and tried to overcome many of the same shortcomings and concerns which have been identified by the SAB (Science Advisory Board, 1990). These included: the inconsistencies created by basing environmental problem definitions on legislation and programmatic organization; limiting hazards to those under the jurisdiction of the EPA and thus not addressing the full range of environmental hazards; the need to emphasize the important role that values play in risk comparisons; and the importance of considering temporal and spatial dimensions of hazards in an analysis of relative environmental risk.

7.This model derives from the "causal taxonomy" of Kates et al., 1985. Similar models have long been used in environmental impact assessment, eg. Covello, 1985.

8. There are in fact a few technical exceptions to this generalization, necessitated by differences in the ways that pollution-based hazards, hazards involving renewable resources, and natural hazards are defined for certain indicators. The conceptual unity is maintained, however, in that each descriptor can be applied to each hazard, independent of type. See Appendix A for details.

9.The important concept of "valued environmental components" was articulated by Beanlands and Duinker (1983) in their retrospective review of environmental impact assessment experience in Canada. They argued that successful assessments had forsaken the early "checklist" objectives of assessing "everything important" about the environment in favor of much shorter lists of especially valued components of the environment. They emphasized that these "valued environmental components" or VECs were ultimately social, rather than scientific, constructs. That is, they reflected particular aspects of the environment -- sometimes but not always highlighted by scientific research -- that people choose to value. Where society has been unwilling to chose a modest number of such environmental components on which to focus its management attention -- or where environmental assessment procedures have made such focus impossible -- Beanlands and Duinker show that effective policy has seldom evolved. In practice, VECs turn out to be the largish categories of environmental problems that appear on the table of contents of national "state of the environment" reports, or as the subject of debates on the floor of parliaments.

10. In choosing to use the phrase "hazard assessment and hazard management" rather than "risk assessment and risk management", we are drawing on the distinctions between these concepts that were made by Hohenemser et al. (1985). "We define hazards as

threats to humans and what they value and we define risks as conditional probabilities of experiencing harm." For example, urban ozone (smog) is a hazard that can adversely affect human health. The risk posed by urban ozone is the probability that a particular individual will become ill. In this hazard assessment project, risk assessment can be considered an important part, but not the totality, of the effort.

11. Wherever possible we have chosen and defined descriptors along lines used by the previous comparative hazard assessments of Goodman (1980), CENTED (Kates et al., 1985), and the U.S. Environmental Protection Agency (1987).

12. See, for example, the excellent review in chapter 11 of Ezrahi (1990).

13. This is particularly true for Recurrence and Delay. For example, there is no inherent reason to believe that a problem which recurs more frequently is more hazardous than one which recurs less frequently. In our interpretation of the case studies, we will show how these particularly tricky characterizing descriptors can nonetheless be useful components of aggregation schemes.

14. In defining quartiles, if several problems had tied scores at the 25% cut-off, we used the following rules: For the upper quartile (problems ranked "high") we included all hazards tied at the 25 % cut-off line. For the lower quartile (problems ranked "low") we excluded all hazards tied at the 25 % cut-off line. There is one exception to this. For the aggregation scheme **Total Ecosystem Consequences,** the aggregate scores divided into 3 groups. For example, in the U.S. case, three problems have aggregate scores of 14, fourteen problems scored 10, one problem scored 6, and ten problems scored 2. In this case, the above defined rule for "cut-off" points for quartiles would lead to identifying 17 problems as highest ranked, a rather meaningless categorization. Similar results were found in the other country case studies. Therefore, for the aggregation scheme Total Ecosystem Consequences, we chose to define high, medium and low by the break points in the scoring: a score of 14 or above indicates a high hazard, a score of 6 or 10 is a medium hazard, and a score of 2 is a low hazard. This points to one of the shortcomings of the method - the fact that the descriptors for ecosystem consequences could not differentiate with the degree of sensitivity we would like. Further development of ecosystem descriptors that can both provide greater differentiation and remain scorable would contribute greatly to efforts for comparative hazard assessment.

15. The opposite does not hold; the ability to score a descriptor for the U.S. is not a reliable indicator of its scorability for other countries.

16.These aggregations would be of particular interest to those who consider anthropogenic changes to nature to be intrinsically alarming, regardless of their eventual consequences.

17. Radiation ranks high for the aggregation **Pervasiveness** for the following reasons: *Spatial Extent* scores "9" for all countries due to the potential for nuclear accidents like Chernobyl to carry radioactive particles long distances. The two temporal descriptors, *Persistence* and *Recovery Period,* scored "9" for all cases because of the longevity of

isotopes in nature and the generational time required for carcinogenic effects to run their course. *Population* and *Land Area or Resource Exposed* were scored high based on extrapolations from Netherlands data which showed that external radiation from building materials accounted for 40% of the anthropogenic exposure. Scorers assumed this to be a significant source of radiation in the U.S. as well.

While food contamination has only a moderate *Spatial Extent,* it ranks high for the aggregation **Pervasiveness** because of high scores for the other 4 descriptors which compose this aggregation scheme. *Persistence* and *Recovery Period* both score a "9" due to the longevity of some pesticides in the environment. *Population Exposed* and *Land Area or Resource Exposed* both score "9" because pesticides and other chemicals are used in most agriculture and livestock production, and thus most of the population is exposed to pesticides, hormones, or other contaminants through the food they eat. In addition these agricultural chemicals leach into water supplies.

18. Salinization ranks high for the aggregation **Disruption** for the following reasons: Some U.S. farmland has a salinity that is 3 to 4 times the natural amount, leading to a score of "7" for the descriptor *Disturbance to the Environment.* Furthermore, salinization from irrigation is a completely anthropogenic phenomenon, although it is somewhat ameliorated by rainfall. This leads to a score of "9" for the descriptor *Anthropogenic Flux.* Salinity tends to increase on a given land with repeated irrigations, and the hectarage of land which has been salinized in the U.S. is also growing. Specific quantitative data on the rates of growth was limited. Assumptions based on the rate of growth of irrigated acreage led to scores of "6" and "7" for the descriptors *Change in Perturbation Level* and *Change in Anthropogenic Flux,* respectively.

19. We previously commented that for the aggregation scheme Total Consequences, India and Kenya shared only two top-ranked hazards. In contrast, they share five top-ranked hazards for Future Consequences and 4 top-ranked hazards for Current Consequences. Because currentconsequential problems are often not also future-consequential, the result of the Total Consequence aggregation will be determined by small differences in a number of the scores. This serves as a reminder of the importance of value judgments and weighting schemes in the formation of aggregation schemes. A different weighting of current versus future consequences could give quite different results as an aggregation of total consequences.

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APPENDIX A
THE DESCRIPTORS[1]

Summing: Any given environmental problem may have a variety of components which score differently for the same descriptor. For example, in the case of Stratospheric Ozone Depletion, persistence of some CFC's are 10 years while others are 110 years. As a result, a summing rule has been chosen for each descriptor as noted throughout and explained below:

1. Total: Add up over all components.
2. Highest Significant Score: Give the highest score for which a significant portion of the problem would score. Significant portion is defined as about 20%.
3. Weighted Average: Take a weighted average over all components of the problem.

MATERIAL FLUX DESCRIPTORS

1. Spatial Extent

Measures the spatial extent of a single release or event for which there is a significant change in the material levels in the environment. The quantitative scale is based on lineal dimensions while the categorical scale on common geographical units.

Pollution-based hazards: This measures the distance from a source for which a single release or event contributes to a change in material levels.
Renewable Resource depletion: This measures the area (scored as the longest lineal distance) in which local harvesting effects the quantity and/or quality of the resource.

Natural Disasters: This measures the area (scored as the longest lineal distance) affected by a single occurrence.

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[1]Many of these descriptors were inspired by the work of Goodman (1980), CENTED (Kates et al., 1985), and the U.S. Environmental Protection Agency (1987). Several descriptors are modifications in name, scale or interpretation, but are nonetheless quite similar to those used by CENTED, including: Spatial Extent, Magnitude of Perturbation, Persistence, Recurrence, Recovery Period, Population Exposed, Delay, and Human Mortality. The scale for Spatial Extent is the same as that used by Goodman.

Score	Distance Scale	categorical definition
1	< 10 km	Small Region
3	10 - 100 km	Region
5	100 - 1000 km	Subcontinental
7	10^3 - 10^4	Continental
9	> 10^4	Global

Notes on scoring: The objective here is to distinguish between local, national, multi-national within a region, and global problems. A score of "1" or "3" will be within a nation for all countries. While theoretically a score of "5" could be within a nation for the largest nations, we have not been able to think of an example where this is the case (e.g. acid rain in the U.S., Canada, U.S.S.R., and China would be scored "5", and would be a multi-national regional problem). Thus, it is safe to say that a score of "1" or "3" indicates the problem occurs within a nation, while a score of "5" or over indicates it is multinational. An exception to this is Australia where a score of 5 is both continental and within a nation.

In general, scores for this descriptor are determined by the nature of the hazard, and thus for a given hazard will typically score the same for all countries. There are a total of four such "problem-specific" descriptors in the taxonomy and are each identified as such in their Notes on Scoring section.

Summing rule: Highest significant score.

Notation for the material flux descriptors 2 through 5: The next four descriptors give a characterization of the material or energy changes due to human activities or natural forces. We are interested here in both **current levels or stock** (how much of the material is in the environment compared to background, normal or long-term average levels), and **flows** (how much of the material is being added to or extracted from the environment on an annual basis). We are also interested in how stocks and flows are changing over time. In other words what are the trends - are we perturbing the environment more or less than we were 5 to 10 years ago? This helps to assess whether the problem is getting better or worse.

Descriptor 2 characterizes the current level or stock while descriptor 3 characterizes how the current level or stock is changing over time. Descriptor 4 characterizes the flow, while descriptor 5 characterizes how the flow is changing over time. In all four descriptors, the values are normalized in relationship to a background, normal or long-term average in order to make scores comparable across the different hazards.

The notation below will be used to explain how to calculate the scores for these descriptors.

B = "natural" background levels

M_j = material or energy levels in year j

$$= B + \int_0^y D\,dt - T\,dt$$

D_j = annual anthropogenic flux of materials or energy (disturbance; discharge or removal) in year j

T_j = annual absorption/transformation of materials or of ecosystems toward the "natural" or undisturbed state

A_j = annual natural flux of materials in year j

y = current year
j = a given year
n = the number of years under consideration.

The measures defined below are used to score the next four descriptors. They are listed below as a summary, and described in more detail in the text which follows.

P: describes the disturbance to the environment or magnitude of perturbation (descriptor #3)

$$P = M_y/B$$

▲P: describes the change in P over time as a fraction of P, i.e. measures the change in the perturbation (descriptor #4)

$$\blacktriangle P = dP/dt = (M_y - M_{y-1}) / M_y \quad \text{or} \quad [(M_y - M_{y-n}) / M_y] / n$$

F: describes the anthropogenic flux in relation to the natural flux(descriptor #5)

$$F = D_y/A_y$$

▲F: describes the change in anthropogenic flux as a fraction of the anthropogenic flux (descriptor #6)

$$\blacktriangle F = dF/dt = (D_y - D_{y-1}) / D_y \quad \text{or} \quad [(D_y - D_{y-n}) / D_y] / n$$

2. Disturbance to the Environment (Magnitude of Perturbation)

Measures the degree to which a change in the material of interest (pollutant or resource) is above or below the background, normal or long-term average levels. In other words, this measures the degree to which the quantity of the material present in the environment has increased (where the environmental problem is caused by net material *flow* into the environment, eg. CO. into the atmosphere) or decreased (where the problem is due to net material *flow* out of the environment, eg. loss of forests) relative to the background levels. The perturbation is estimated by calculating the factor P, where P = current material levels/background levels for *flow* into the environment as in most pollutants, and P = background levels/current levels for *flow* out of the environment as in resource depletion. As a result, increased pollution concentrations and decreased forest cover, for instance, will both have P values greater than 1.

Pollution-based hazards: This measures the level of the pollutant compared to the natural background level (i.e. the level that existed prior to human perturbation). Note that those pollutants that do not occur in nature will necessarily score 9.
Renewable Resource depletion: This measures the long-term average pre-harvest level of the resource or the level to which the system would return to in the long-run if harvesting ceased compared to the current stock of the resource.
Natural Hazards: This measures the level of the material or energy during the natural hazard as compared to background levels.

Score	Scale
1	$P < 1/2$
3	$1/2<P<1$
5	$1 < P < 2$
7	$2 < P < 4$
9	$P > 4$

Notes on scoring: When measuring perturbation, use the change in material quantity nearest to or most affected by the original human perturbation. For example, with stratospheric ozone depletion, measure increase in atmospheric chlorine and not a reduction in stratospheric ozone.

Some hazards have bi-modal distributions. For example, there are average photochemical oxidant concentrations in urban areas that are much higher than the average concentrations in rural areas. Yet there are consequences to these elevated levels in both areas. Decisions on how to score such problems should be made on an individual basis, however, and should be scored for one of the distributions, rather than the average of both.

Summing rule: Weighted average of most significant effect.

3. Change in Perturbation

Measures the annual change in the magnitude of perturbation (i.e. the rate of change of Descriptor #2). The annual change is measured by the factor ▲P. In technical terms, ▲P is the time derivative of M as a fraction of M.

Pollution-based hazards: This measures the change in the pollution level in the environment
Renewable Resource depletion: This measures the change in the stock of the resource.
Natural Disasters: This measures the degree to which the flows have changed in severity or frequency. This will usually score "5" except when human actions combine with natural factors to cause an increase or decrease in the occurrence or severity of natural disasters, as can be the case in floods and droughts.

Score	Doubling/Halving Time	Per cent change per year
	halving time	
1	< 10 years	< -7.0
2	10 - 20 years	-7.0 to -3.5
3	20 - 40 years	-3.5 to -1.7
4	> 40 years	< -1.7
5	no detectable change 0	
	doubling time	
6	> 40 years	< 1.7
7	20 - 40 years	3.5 to 1.7
8	10 - 20 years	7.0 to 3.5
9	< 10 years	> 7.0

Notes on Scoring: Given the way in which the scale is defined, a negative change in perturbation indicates a situation in which there is an improvement in the environment. A positive change in the perturbation indicates a situation where the problem is being exacerbated. The change in perturbation level should reflect an average over the last 5 to 10 years. If there has been a significant change in trend during this time, score for the more recent trend (e.g. if levels in the environment were increasing from 1980 through 1985, but decreasing after 1985 due to the implementation of pollution controls, score for the decreasing trend after 1985). Also take care to eliminate biases due to extremely high or low values for a single year due to random fluctuation.

Summing Rule: Weighted average

4. Anthropogenic flux

Measures the extent to which human activities contribute to the total flux of materials into or out of the environment, i.e. compares the anthropogenic flux to the natural flux. This is measured by the factor F, which measures the ratio of annual human flux to background flux.

Pollution-based hazards: This measures the annual anthropogenic flow of the pollutant compared to the annual natural flow.
Renewable Resource depletion: This measures the annual net extractions of the resource compared to the sustainable yield (i.e. the level of extraction that would result in the highest average annual rate of extraction).
Natural Disasters: This measures the magnitude of the material flow due to human factors as compared to the magnitude of the material flow due to natural factors. These problems will generally score a "1", again with the exception of problems where human actions have intervened to reduce or increase the severity of the material flow. (Note that this is different than human actions which reduce or increase the severity of consequences.)

Score:	Scale
1	$F < 1/2$
3	$1/2 < F < 1$
5	$1 < F < 2$
7	$2 < F < 4$
9	$F > 4$

Summing rule: Weighted average

5. Change in Anthropogenic

Flux

Measures the annual rate of change in the anthropogenic flux (i.e. the rate of change in Descriptor #4). This is measured by the factor ▲F. In technical terms, ▲F is the time derivative of F as a fraction of F.

Pollution-based hazards: This measures the change in the annual anthropogenic additions of the pollutant to the environment.
Renewable Resource depletion: This measures the change in annual extractions.

Natural Disasters: This measures the change in flow due to human factors, in other words, whether human factors are increasing or decreasing the severity or frequency of a natural hazard. This will generally score a "5"

Notes on Scoring: The change in anthropogenic flux should reflect an average over the last 5 to 10 years. If there has been a significant change in trend during this time, score for the more recent trend (e.g. if emissions were increasing from 1980 through 1985, but decreasing after 1985 due to the implementation of pollution controls, score for the decreasing trend
after 1985).

Summing rule: Weighted average

Score:	Doubling/Halving Time	Per cent chance per year
	halving time	
1	< 10 years	< -7.0
2	10 - 20 years	-7.0 to-3.5
3	20 - 40 years	-3.5 to-1.7
4	> 40 years	< -1.7
5	no detectable change	0
	doubling time	
6	> 40 years	<1.7
7	20 - 40 years	3.5 to 1.7
8	10 - 20 years	7.0 to 3.5
9	< 10 years	>7.0

6. Persistence

Measures the time period required for the material most directly perturbed in the environment to return to the level existing before the event that caused a flux of that material. (Note that this is different from the Recovery Period, which reflects the time necessary for all subsequent effects including those on human health, ecosystem or material welfare to be attenuated to background levels.)

Pollution-based hazards: This measures the time period that the material released remains in

the environment, e.g. for acidification, persistence measures the atmospheric lifetime of acid rain precursors as 3-10 days.
Renewable Resource depletion: This measures the time period required to regenerate a specimen of the resource extracted, e.g. the lifetime of a fish caught or of a tree lost to deforestation.
Natural Disasters: This measures the duration of the event.

Score	Time Scale
1	< 1 week
3	1 week - 1 year
5	1 - 10 years
7	10 - 100 years
9	> 100 years

Notes on scoring: In general, this descriptor is defined by the hazard (i.e. it is problem specific), and thus for a given hazard will score the same for all countries. In scoring, consider a 90% return from the perturbed level to be sufficient. If a problem does not exist in a particular country, persistence must nonetheless be scored for the time the environment remains perturbed for that type of hazard.

Summing rule: Highest significant score.

7. Recurrence

Measures the frequency of the event which causes a flux. Use the scale for Persistence.

Notes on scoring: Within the pollution and resource depletion category, we will not expect to get a wide range of scores as most of the relevant events are continual and will therefore score "1". However, accidental releases, chemical or nuclear accidents, and natural disasters will rank differently.

In general, this descriptor is defined by the hazard (except natural hazards), and thus for a given hazard will score the same for all countries.

Summing rule: Highest significant score.

EXPOSURE DESCRIPTORS

8. Population Exposed

Measures the percent of current population within a country that is exposed to the change in a valued environmental component (VEC).

Score	% of population
1	< 1%
3	1%-10%
5	10% -30%
7	30% -70%
9	> 70

Notes on scoring: "Exposed" population should be broadly interpreted to mean all people who are currently exposed to a changed valued environmental component (VEC). For example, for atmospheric problems such as acidification or smog, the per cent of the population exposed would include all inhabitants of an affected area, not just those individuals, whose respiratory systems are unusually sensitive to such conditions. For accidental chemical spills, per cent exposed should include all inhabitants in the relevant vicinity of a potential accident. First order effects should only be considered. Indirect effects, such as malnutrition from crop losses should not constitute population exposed.

Summing rule: Total.

9. Land Area or Resource Exposed

Measures the percent of land area or resource within a country that is currently exposed to the changed valued environmental component (VEC).

Score	% of land area
1	< 1%
3	1%-10%
5	10% - 30%
7	30% -70%
9	> 70

Notes on scoring: Interpret broadly, as described in the notes on scoring for descriptor #8. Summing rule: Total.

10. Delay

Measures the delay time between the release or altering of materials and the earliest onset of serious consequences. The goal here is to measure the time delay between human actions and the first evidence that these actions are causing consequences.

Score:	Time Scale
1	< 1 week
3	1 week - l year
5	1 - 10 years
7	10 - 100 years
9	> 100 years

Notes on scoring: In general, this descriptor is defined by the hazard (i.e. it is problem specific), and thus for a given hazard will score the same for all countries. As with Persistence, if a problem does not exist in a particular country, delay must nonetheless be scored for the time between changes in material fluxes to the onset of consequences for that type of hazard.

Summing rule: Earliest onset of first significant consequence.

CONSEQUENCE DESCRIPTORS

11. Human Mortality (Current Annual)

Measures the average annual percent of population that dies as a direct result of the hazard. Indirect effects, such as malnutrition from crop losses, should not be included.

Score	% of population
1	$< 10^{-6}$%
2	10^{-6} - 10^{-5}
3	10^{-5}- 10^{-4}
4	10^{-4} - 10^{-3} %
5	.001-.01%
6	.01- .1%
7	.1 - 1%
8	1%-10%
9	> 10%

Notes on Scoring: Note that the scale is based on percentages of the population, not fractions.

Summing rule: Total.

12. Human Morbidity (Current Annual)

Measures the average annual percent of population that becomes significantly ill from the hazard. Significantly ill is defined as a permanent injury or injury that interferes with normal activity.

Use the scale for human mortality.

Summing rule: Total.

13. "Natural" Ecosystem Impacts (Current Annual)

Describes the impacts to "natural" elements within ecosystems. As a result, this descriptor does not take into account resources within ecosystems which are managed predominantly for the purpose of harvesting food or materials (i.e. crops or timber). These are captured in descriptor #14 below.

Score	categorical definition
1	No significant effect
5	Significant declines in productivity or local species extinctions
9	Regional or global extinction of significant species.

Summing rule: Total.

14. Material and Productivity Losses (Current Annual)

Measures the average annual losses of material and non-labor productivity as a percentage of national GNP.

Damages to be included are: material damages to both public and private capital stocks, crop losses, losses to recreation, and natural resource damages.

Not to be included are reductions in labor productivity from lost days of work (or lost human lives), the costs of management or control measures (including equipment, managerial efforts, and health care), nor aesthetic loss valuations.

Score	% of GNP
1	$< 10^{-6}$
2	10^{-6} - 10^{-5}
3	10^{-5} - 10^{-4}%
4	10^{-4} - 10^{-3}
5	.001 -.01%
6	.01 - .1%
7	.1-1%
8	1%-10%
9	> 10%

Notes on Scoring: Note that the scale is based on percentages of GNP, not fractions.

Summing rule: Total.

15. Recovery Period

Measures the time period required for the VEC to recover from the effects of the changed material or energy flux to the prior state of human health, ecosystem and productivity assuming the causative human activity is stopped. Assume no change in trends of management activities to ameliorate consequence.

Score	Time Scale
1	< 1 week
3	1 week - 1 year
5	1 - 10 years
7	10 - 100 years
9	> 100 years

Notes on scoring: It is important to note that the assumption here is not "no management change", but rather "no change in trends of management". This means, for example, that if a nation has been improving its sewage treatment at a certain rate, and it appears likely that this will continue, then assume that rate of improvement when scoring. For management activities that have been holding steady, we assume this won't change. To the extent that a nation has a credible action plan for ameliorating a problem,

this should be taken into consideration. As a result, recovery periods for any given problem may be shorter in countries where greater effort is currently made in aiding environmental recovery than in countries where this is not the case. As with Persistence, consider a 90% recovery to be sufficient.

Summing rule: Highest significant score.

16. Future Human Health Consequences

Describes the severity of harm to future human health caused by today's human activities. Assumes current trends in management activities to ameliorate consequences, i.e. use a business as usual scenario.

Score	categorical definition

Using a business-as-usual scenario, future consequences are most likely to be:

1	Significantly smaller than current consequences
5	Not radically different than current consequences (more than half or less than twice as large)
9	Significantly greater then current consequences

Notes on scoring: The term "future" means the next 25 years. Take the Annual Change in Perturbation Level and extrapolate out 25 years. Then look at the political situation, economic situation, etc. and attempt to factor the non-quantifiable trends into the 25 year extrapolation. Use this to determine if the effects of the considered activity will be more than half or less than twice as large as the current consequences.

If the problem does not cause significant consequences for a given country and is not expected to in the next 25 years, score 1. In other words is no future consequences are expected, score 1.

Summing rule: Total

17. Future Ecosystem Consequences

Describes the severity of harm to future ecosystems caused by today's human activities. As with descriptor #15, harm to resources managed predominantly for harvesting of food or material should not be reflected here. Assume current trends in management activities to ameliorate consequences, i.e. use a business as usual scenario.

Score: Use scale for #16.

Notes on scoring: See notes under descriptor

#16. Summing rule: Total

18. Future Material & Productivity Losses

Describes the magnitude of future material and productivity losses caused by human activities today. Assumes current trends in management activities to ameliorate consequences, i.e. use a business as usual scenario.

Score: Use scale for #16.

Notes on scoring: See notes under descriptor

#16. Summing rule: Total.

19. Transnational

Describes the nations whose activities lead to

consequences.

Score	Categorical Definition
1	Consequences are caused mainly by own activities
5	Consequences are caused by neighbors activities and own activities
9	Consequences are caused by activities around the world

Summing rule: Highest significant score.

Notes on scoring: Interpret this in the narrow sense, as describing the nations whose release or alterations of the environment lead to the consequences. For natural disaster, always score 1 unless the consequences of the disaster are exacerbated by activities of other nations, e.g., if flooding is worse due to deforestation in a neighboring country.

APPENDIX B
ENVIRONMENTAL PROBLEMS

POLLUTION-BASED HAZARDS

WATER QUALITY

Note: Freshwater includes both surface water and ground water.

1. Freshwater - Biological Contamination

Human Activities: Human and animal waste disposal.

Changes in material fluxes: levels of bacteria, viruses, and parasites in surface and/or groundwater.

Changes in Valued Environmental Components: Reduction in quality of freshwater supplies. Particularly relevant for drinking water.

Exposure: Ingestion of water. Ingestion of contaminated food. Dermal contact.

Consequences: Results in human mortality and human morbidity. Diseases carried include: diarrhea, cholera, sleeping sickness and guinea worm infestation. Loss of recreation through closing of waterways, beaches, etc.

2. Freshwater - Metals and Toxic Contamination

Human Activities: The use of pesticides, fossil fuel combustion (deposition from the atmosphere into water, or onto land surfaces and then run-off), industrial activities (including releases of chemicals, waste disposal, accidental releases and underground storage), mining, consumer (municipal) waste disposal, urban run-off.

Changes in material fluxes: Increased pollutants in surface waters and groundwater. Toxic chemicals including heavy metals, inorganic compound and volatile organic compounds, herbicides, insecticides, fungicides.

Changes in Valued Environmental Components: Reduction in quality of water supplies. Increased toxicity of water.

Exposure: Human exposure through ingestion of contaminated water and food, dermal contact. Aquatic life exposed to increased pollutants in water.

Consequences: Human mortality and human morbidity. Some pollutants are carcinogenic and/or mutagenic. Damage to aquatic ecosystems such as reproductive deformities to animals which depend on these aquatic ecosystem, including birds and mammals. Crop losses from decreased biological productivity due to contaminated irrigation water.

3. Freshwater - Eutrophication

Human Activities: Use of fertilizers in agriculture, animal husbandry, forest clearing, municipal waste disposal.

Changes in material fluxes: Increased nitrates and phosphates in water.

Changes in Valued Environmental Components: Initial changed VEC is increased nutrient loading in water. This leads successively to increased algal growth, to decreased clarity and increased particulate organic levels in the water, settling of particulate organic material into deep water, overabundant bacteria which consume oxygen and produce hydrogen sulfide, and a decrease in oxygen levels in deep water.

Exposure: To fish, through inhalation, lack of oxygen. For vegetation and other shellfish, ingestion of bacteria, reduced sunlight.

Consequences: Unsafe levels of nitrates can cause methemoglobinemia in infants, hypertension in children, gastric cancer in adults and fetal malformations. Nitrates may be carcinogenic or mutagenic. Eutrophication can kill or displace fish and other aquatic life. Contamination of fish supply and losses to tourism.

4. Freshwater - Sedimentation

Human Activities: Agricultural practices leading to erosion from cropland, silviculture practices or deforestation leading to erosion from forestland (or formerly forested land), animal husbandry leading to erosion of rangeland, construction activities.

Changes in material fluxes: Increased sediments in river water, increased sedimentation in waterways.

Changes in Valued Environmental Components: Reduction in quality **of** water supplies. Increased toxicity of water. Decreased navigatability of waterways.

Exposure: Through ingestion and use of riverways for transportation.

Consequences: Harm to aquatic life, decreased river navigation, destruction or decreased efficiency of hydroelectric projects.

5. Ocean Water

Human Activities: Off-shore oil drilling, oil transport, shipping in general. Disposal of industrial, consumer, commercial and public wastes. Discharges of pollutants from rivers, direct coastal outfalls, and coastal urban and agricultural runoff.

Changes in material fluxes: Increased concentrations of oil, plastics, microbial/organic concentrations, and toxic chemicals.

Changes in Valued Environmental Components: Decreased ocean water quality, increased ocean water toxicity. Disruption of marine food chains.

Exposure: Entanglement by marine life. Ingestion by marine life including shellfish, fish, marine mammals, birds, plankton, algae, etc, sometimes several steps removed on the food chain. Ingestion of contaminated seafood by humans. Dermal contact. Visual contact.

Consequences: Human health and morbidity from exposure to toxins (especially through contaminated seafood) including carcinogenic and mutagenic effects as well as more immediate digestive disorders. Ecosystem damage, especially local effects from locally high concentrations. Loss of recreation, losses to tourism, and loss of food supplies.

ATMOSPHERIC QUALITY

6. Stratospheric Ozone Depletion

Human Activities: Manufacture, use and disposal of halocarbons, including chlorofluorocarbons (CFCs), halons, chlorinated hydrocarbons, and chlorinated carbons. These substances are used in the manufacture of foam for insulation and packaging, as propellants, as heat transfer fluids in heating and cooling systems, as solvents, especially in the electronics industry, and in fire extinguishers.

Changes in material fluxes: Increased concentration of CFCs, halons, chlorinated hydrocarbons, and chlorinated carbons. Through a series of chemical reactions this leads to decreases in the concentration of ozone (0_3) in the stratosphere.

Changes in Valued Environmental Components: Increased ultraviolet (UV) radiation on the earth's surface. A reduction in the ozone shield leads to more radiation reaching the earth's surface.

Exposure: UV radiation contact on skin, eyes, ecosystems.

Consequences: Increased human mortality from malignant melanoma skin cancer. Increased human morbidity from non-melanoma skin cancer, and eye disorders, including cataracts and acute photokeratitis (snow blindness). Suppression of immune response system of humans and animals, slower growth and higher mortality among plant and animals. May aggravate nutritional deficiencies, infectious diseases, and autoimmune disorders. At high levels, may reduce crop productivity. Causes decrease in fecundity, growth, survival and other functions of aquatic organisms, and thus affects ocean food chain. Accelerated degradation of some plastics and paints. Crop productivity losses due to UV radiation, and secondary losses due to increased tropospheric smog.

7. Climate Change

Human Activities: Fossil fuel production, distribution, and combustion. Production, consumption and disposal of halocarbons (CFCs, halons, and chluorocarbons). Wetland rice cultivation. Livestock husbandry. Use of nitrogenous fertilizers in agriculture. Landfilling of wastes. Land use modification including deforestation, biomass burning and wetland conversion.

Changes in material fluxes: Increases in several chemical constituents in the stratosphere including: Carbon dioxide (CO) from fossil fuel consumption, deforestation and biomass
burning; halocarbons; Methane ($CH_,$) from landfills, fossil fuel production and distribution,
wetland rice cultivation, livestock husbandry and biomass burning. Nitrous oxide (N_20) from fossil fuel consumption, use of nitrogenous fertilizer, deforestation and biomass burning.

Changes in Valued Environmental Components: Thermal radiation budget alteration leading to climate change. This in turn will lead to other changes in key environmental components including: temperature, sea level, precipitation, storm patterns including frequency and severity, direct solar radiation, evapotranspiration, soil moisture, and run-off.

Exposure: Humans and ecosystems exposed to changed climate.

Consequences: Consequences are likely to vary significantly from one region to another. They include: Severe disruptions of natural ecosystems with species loss. Losses (or gains) to agricultural productivity. Disruptions to human settlements and infrastructures, including property losses and loss of electric power. Loss of life. Loss of freshwater supplies.

8. Acidification

Human Activities: Fossil fuel combustion and use. Industrial activities including use of smelters and paper manufacture.

Changes in material fluxes: Increased sulfur oxides (SO_X) and nitrogen oxides (NO_X) in the troposphere.

Changes in Valued Environmental Components: Acidity of atmosphere. Through dry and wet deposition, acidity of soil and freshwater (lakes and streams).

Exposure: Inhalation of SOx and NOx by humans. Ecosystems exposed to lower pH.

Consequences: Fish kills and loss of aquatic life in acidified lakes. Forest dieback (from combined problems of acidification and elevated ozone). Possible human health effects include reduced lung function and possible water contamination. Premature mortality for sufferers of cardiac and respiratory problems. Materials damage including degradation of iron, steel, zinc, paint and stone.

9. Ground Level Ozone Formation

Human Activities: Fossil fuel combustion, biomass burning, industrial processes including use of organic solvents, surface coatings, chemical manufacture and petroleum refining..

Changes in material fluxes: Increased nitrogen oxides (NO_t) from fossil fuel combustion. Increased volatile organic compounds (VOCs, also called reactive hydrocarbons) from solvents and gasolines, highway vehicles, surface coating, organic solvents, solid waste disposal, chemical manufacturing and petroleum refining.

Changes in Valued Environmental Components: Photochemical oxidant formation, i.e. increased ozone. This is formed through the reaction of VOCs and NOx in the presence of sunlight.

Exposure: For human health, through inhalation.

Consequences: Damage to crops. Eye irritation. Decreased lung function including coughing, shortness of breath, possibly long-term lung damage such as premature aging of lungs. Degradation of works of art. Forest dieback (in conjunction with acidification).

10. Hazardous and Toxic Air Pollutants

Human Activities: The full spectrum of industrial activities involved with the manufacture, use and disposal of chemicals including: petroleum handling, pesticide

application, waste disposal sites, waste incineration, metallurgical industries, chemical production and manufacture. Combustion of fossil fuels. Use of motor vehicles. Municipal sewage disposal, wastewater treatment.

Changes in material fluxes: Level of toxic chemicals in the atmosphere. There are hundreds of different toxic chemicals released to the atmosphere.

Changes in Valued Environmental Components: Toxicity of air.

Exposure: Inhalation by human and non-human life.

Consequences: Increased human morbidity and mortality, including both cancer and non-cancer health effects. Ecosystem effects.

QUALITY OF THE HUMAN ENVIRONMENT

11. Indoor Air Pollutants - Radon

Human Activities: Naturally occurring radiation which enters surrounding air and/or water in human structures. The nature of some structures and ventilation systems allows for the accumulation of radon.

Changes in material fluxes: Uranium-238 and radium-226 are present in most soils and rocks in widely varied concentrations. Radon gas forms from the decay of radium-226 (the fifth daughter of uranium-238).

Changes in Valued Environmental Components: Increased radiation level in human habitats.

Exposure: Inhalation by human beings.

Consequences: Lung cancer.

12. Indoor Air Pollutants - Non-Radon

Human Activities: Combustion of fuels inside buildings. Use of chemicals in buildings including cleaning solutions, pesticides, office supplies. Materials used to construct buildings. Level of ventilation in buildings is key factor in determining levels of indoor air pollutants.

Changes in material fluxes: Increased levels of nitrogen oxides from combustion of fuels. Increased levels of chemical contaminants.

Changes in Valued Environmental Components: Quality of air inside buildings.

Exposure: Inhalation by human beings.

Consequences: Increased morbidity and mortality.

13. Radiation - Non-radon

Human Activities: Medical exposure, operation of nuclear power plants, constructing nuclear weapons, disposing of nuclear waste. Only anthropogenic sources of radiation are included, not background levels of radiation.

Changes in material fluxes: Medical X-rays. Radioactive particles carried downwind from nuclear power plants and weapons plants, radioactive water leaks within the nuclear power plants and weapons plants, radioactive particles seeping into land and water from nuclear waste sites.

Changes in Valued Environmental Components: Increased radiation in land, water and air.

Exposure: Inhalation, ingestion through food supplies and water, absorption through the skin.

Consequences: Human mortality and morbidity. Damage to ecosystems.

14. Chemicals in the Workplace

Human Activities: Use of chemicals (including pesticides) and biological pathogens in the workplace.

Changes in material fluxes: Increased levels of chemical contaminants in work environment.

Changes in Valued Environmental Components: The safety of the occupational environment is reduced.

Exposure: Inhalation, ingestion, absorption through the skin.

Consequences: Human mortality and morbidity.

15. Accidental Chemical Releases

Human Activities: Use, storage, and transport of chemicals.

Changes in material fluxes: Release of toxic chemicals to the environment. This usually entails a high concentration release over a short period of time.

Changes in Valued Environmental Components: Toxicity of atmosphere, land and/or water.

Exposure: Humans and ecosystems exposed to chemicals.

Consequences: Human mortality and morbidity. Ecosystem damage. Commercial losses due to shut downs, clean ups and reduction in quality of resources.

16. Food Contaminants

Human Activities: Use of herbicides and pesticides in agriculture; disposal of industrial chemicals, radionuclides, inorganic compounds, hormones in meat such as chicken or beef.

Changes in material fluxes: Increase in herbicides, pesticides and toxins in soil and on food, impure fish due to contamination by chemical and heavy metals.

Changes in Valued Environmental Components: Decrease in purity of food or increase in toxicity of food.

Exposure: Ingestion.

Consequences: Increased cancer and other health problems in humans. Possible damage to wildlife that consume human foods.

RESOURCE DEPLETION HAZARDS

LAND

17. Agricultural Land - Salinization, Alkalinization, Waterlogging

Human Activities: Irrigation.

Changes in material fluxes: Excess irrigation water percolates down, raising the water table. Capillary action pulls near-surface water up, and evaporation results in increased saline and alkaline salt deposition. Also, if the water table is raised high enough, it can waterlog crops by depriving their roots of needed air.

Changes in Valued Environmental Components: Increased salinity, alkalinity and waterlogging, leading to decreases in soil productivity.

Exposure: For humans, decreased food supplies. For crops, exposure to changed soil conditions.

Consequences: Decrease in productivity of land or complete loss of productive land, leading to crop losses. This may cause hunger which in turn leads to increased human morbidity and mortality.

18. Agricultural Land - Soil Erosion

Human Activities: Land clearing (deforestation, burning or harvesting). Cultivation of marginal lands. Overgrazing. Cultivation techniques such as furrowing and mechanization.

Changes in material fluxes: Degradation or loss of vegetative cover which leads to increased soil erosion.

Changes in Valued Environmental Components: Reduction in soil productivity which leads to a reduction in the food supply (crop losses).

Exposure: For humans, decreased food supplies. For crops, exposure to changed soil conditions.

Consequences: Reduction in crops and livestock produced on land. This may cause hunger which in turn leads to increased human morbidity and mortality.

19. Agricultural Land - Urbanization

Human Activities: Urbanization.

Changes in material fluxes: Land is removed from agricultural production and put to use for human settlements, industry and commercial purposes.

Changes in Valued Environmental Components: Loss of agricultural land which leads to a reduction in the food supply.

Exposure: Human exposure to reduced food supply.

Consequences: Productive losses in agriculture. This may cause hunger which in turn leads to increased human mortality and morbidity.

20. Groundwater

Human Activities: Irrigation, drinking water extraction, industrial use.

Changes in material fluxes: Groundwater is extracted at rates greater than recharge leading to depletion.

Changes in Valued Environmental Components: Decreased supplies of groundwater.

Consequences: Losses to agriculture, industry. Significant material and productivity effects.

BIOLOGICAL STOCKS

21. Wildlife

Human Activities: Hunting, poaching (including subsistence hunting).

Change in material fluxes: Quantity of wildlife decreases.

Changes in Valued Environmental Components: Wildlife populations decrease.

Consequences: Loss of species, reductions in human food supply, loss of recreation, secondary effects on the viability and population of other wildlife and vegetation.

22. Fish

Human Activities: Fishing (including subsistence fishing).

Changes in material fluxes: Quantity of fish decreases.

Changes in Valued Environmental Components: Fish populations drop below minimum

sustainable levels.

Consequences: Loss of species, food supply, recreation.

23. Forests

Human Activities: Agroforestry, firewood cutting, burning of forests for conversion to agricultural uses, forest fire.

Changes in material fluxes: Quantity and quality of forests decrease.

Changes in Valued Environmental Components: Forest productivity declines.

NATURAL HAZARDS

24. Floods

Human Activities: Although caused by natural fluctuations in weather patterns and seasonal weather patterns (e.g. monsoons, hurricanes, and other storm systems), human activities which alter the flow of water can influence flooding. The activities of importance include construction of dams and levees, wetlands conversion, modifications of coastline and coastal areas, and irrigation. In addition, human settlement patterns help determine the magnitude of losses due to flooding.

Changes in material fluxes: Increased water flow in rivers and lakes. Change in physical environment along shorelines.

Changes in Valued Environmental Components: Increased or decreased flooding.

Exposure: For human beings, ingestion of contaminated food and water. For human

Consequences: Human morbidity due to ingestion of contaminated food and water. Human mortality due to increased morbidity and drowning. Welfare losses from damage to crops and agricultural land, food and water supplies, and physical infrastructure.

25. Droughts

Human Activities: Although caused primarily by natural fluctuations in weather patterns,

human activity such as deforestation can contribute to changes in the average level of rainfall (i. e. can affect local climates) while a range of activities (annual husbandry, water management) can influence the susceptibility of land and crops to drought.

Changes in material fluxes: Decreased or more erratic rainfall.

Changes in Valued Environmental Components: Decreased quantities of water in lakes, rivers and reservoirs, decreased moisture in soil.

Exposure: Dehydration of vegetation, crops, livestock, wildlife and human beings. Drying and hardening of soil and increased susceptibility to the processes of desertification.

Consequences: Loss of crops and livestock populations. Hunger and thirst leading to increased human morbidity and mortality. Reduced function of hydro-electric facilities. Damage to agricultural and natural land.

26. Cyclones

"Cyclones" is defined generically to include hurricanes, typhoons, and tornadoes.

Human Activities: N.A.

Changes in material fluxes: Increased rainfall, wind movements.

Changes in Valued Environmental Components: Stability of atmospheric conditions.

Exposure: Exposure to rising water and high velocity winds, unsanitary conditions, contaminated drinking water and loss of food supply.

Consequences: Loss of human life, property. Adverse effects to local environment.

27. Earthquake

Human Activities: N.A.

Changes in material fluxes: Change in terrestrial environment.

Changes in Valued Environmental Components: Stability of land.

Exposure: Proximity to human structures undergoing damage (e.g. buildings and roads), secondary exposure to ensuing fires, unsanitary conditions and contamination of drinking water.

Consequences: Loss of human life and property, ecosystem effects.

28. Pest Epidemics

Human Activities: Due to changes in natural environment, or an environment that is always hospitable to large pest population. Can be influenced by agricultural practices such as use of pesticides, irrigation, and cropping practices that are favorable to pests (e.g. monocultures).

Changes in material fluxes: Natural changes: changes in water and temperature. Anthropogenic changes: increases in standing water, increases in food sources for a given species, decreases in predators for a given species, increases in species resistance to pesticides.

Changes in Valued Environmental Components: Improved pest breeding grounds and increased pest susceptibility of ecosystem. This leads to growth of pest population, pest epidemic.

Exposure: Insect bites for humans and animals. Insects ingest or otherwise destroy crops.

Consequences: Loss of crops. Increased human mortality and morbidity from pest carried disease or hunger due to loss of crop

APPENDIX C: TIPS ON APPLYING THE METHOD

The following is a list of suggestions which will aid in making the process of scoring easier.

1. During the scoring process there was often insufficient data. This was a problem for each of the four countries scored. Often this required much judgement and extrapolation on the part of the scorers. We suggest seeking as much expert knowledge as possible so that scoring time is not spent agonizing over problems that have "no available data".

2. Although we have made every effort to clearly define the descriptors, there will be a tendency for different users to develop different interpretations and rules for scoring. Therefore, if more than one person is involved in the scoring process it is important to discuss the descriptors and be certain that you are using a common interpretation for each and that they are being applied in a similar manner to the various environmental problems. Such communication should occur before scoring begins and also throughout the entire scoring process as interpretation of the descriptors and their application is an ongoing process. We suggest, before scoring begins, that the scorers sit down together and do a practice scoring or a "dry run" for a pollution-based problem, a resource-based problem, and a natural hazard.

3. It is difficult but important to be consistent in interpreting and scoring descriptors across countries and across different environmental hazards. Due to differences in data availability, there is a tendency to fit the interpretation of descriptors to the available data. During the scoring process, one must be aware of this problem and attempt to uniformly use the correct descriptor definition regardless of the information available about a specific hazard or for a specific country.

4. When scoring, it is important to pay careful attention to the shift in logic that must be made when scoring pollution-based problems, resource-based problems, and natural hazards. This holds specific importance for the material flux descriptors.

5. In many instances, scores will be rendered based on qualitative judgments of the scorer. For example, for the future consequence descriptors, a scorer extrapolates available "trends data" from the descriptor Change in Perturbation out 25 years and from this is able to discern if the problem will get more than half and less than twice as large as in the past. Before deciding on such a score, however, the scorer must take into account the political climate, laws that may be enacted or have been enacted but have not yet had any effects, etc. It is beneficial, especially in a team scoring situation, to discuss these judgments with another member of your scoring team in order to get feedback and double check your logic.

6. It is important to remember to annualize when scoring the current consequence descriptors for the natural hazards. The data that you will use will generally be for specific occurrences, e.g. deaths due to an earthquake in 1989. This information must be annualized if this is the only earthquake that has occurred for many years.

7. If there is no history of a hazard in a particular country, but the hazard poses an immediate threat, you must score based on the risk that you perceive. An example of this is accidental chemical releases in Kenya. A major accidental chemical release has never occurred in Kenya. There is no historical data on which to base a score. There is, however, a great potential for such a release in light of increased industrialization. Thus, scores must take into account the risk that Kenya is facing.

8. When a country did not have a particular resource-based environmental problem, there were difficulties scoring the problem for specific descriptors. For example, India does not have a problem with its stock of fish. There is no net overfishing in the country. For descriptors such as persistence, a score of 5 was given because it takes 1-10 years for a fish to reach maturity. Similarly, in the United States for stock of forests, there is net reforestation, yet persistence scored a 7 because it takes up to 100 years for a tree to reach maturity. One may be inclined to score a 1 for persistence if a problem does not exist in a particular country. However, in using the definition of persistence, the approach to scoring in these examples makes sense because they do reflect the "time period required to regenerate a specimen of the resource extracted".

9. The scale for the Natural Ecosystem Impacts descriptor provides very little resolution. Unfortunately, we were unable to design a descriptor with greater resolution that could be scored across the range of hazards.

APPENDIX D - DATA FROM CASE STUDIES: INDIA, KENYA, THE NETHERLANDS, AND THE U.S.

TABLE D1: INDIA
HAZARD TAXONOMY SCORES
part 1

ENVIRONMENTAL HAZARDS	1 SPATIAL EXTENT	2 DIST. TO ENV.	3 CHANGE PERTURB	4 INANTHRO. FLUX	5 CHANGE IN ANTHRO FLUX	6 PERSIS	7 RECURR	8 POPUL EXPOSED	9 LAND EXPOSED	10 DELAY
1. Freshwater - Biological Contamination	5	9	7	9	7	3	1	9	9	1
2. Freshwater - Metal & Toxic Contaminatio	5	9	6	9	6	9	1	7	7	1
3. Freshwater - Eutrophication	5	7	8	7	8	7	1	7	7	1
4. Freshwater - Sedimentation	5	7	8	7	8	3	1	7	7	3
5. Ocean Water	5	9	8	9	8	9	1	7	7	1
6. Stratospheric Ozone Depletion	9	9	8	9	2	9	1	9	9	5
7. Thermal Radiation	9	5	7	1	6	9	1	9	9	7
8. Acidification	5	9	8	3	9	1	1	5	7	1
9. Ground Level Ozone Formation	5	9	8	9	9	1	1	7	7	1
10. Toxic Air Pollution	5	9	8	9	8	3	1	7	7	1
11. Indoor Air - Radon	1	9	5	9	5	3	1	1	1	7
12. Indoor Air - Non-radon	1	9	5	9	5	1	1	9	9	1
13. Radiation - Non-radon	9	5	6	3	6	9	1	9	9	7
14. Chemicals in the Workplace	1	9	6	9	6	3	1	5	7	1
15. Accidental Chemical Releases	5	9	5	9	5	7	5	9	7	1
16. Food Contamination	5	9	8	9	8	9	1	9	9	3
17. Agric. Land - Salinization, Alkalinize	1	5	6	9	5	7	1	5	7	1
18. Agric. Land - Soil Erosion	5	5	6	5	6	9	1	9	9	1
19. Agric. Land - Urbanisation	1	5	6	9	6	9	1	3	3	1
20. Groundwater	5	5	6	1	6	3	1	5	7	1
21. Wildlife	5	5	7	5	7	9	1	3	3	1
22. Fish	3	1	5	3	5	5	1	1	1	1
23. Forests	5	7	8	9	8	7	1	9	7	1
24. Floods	5	9	8	9	8	3	3	7	5	1
25. Droughts	5	7	5	1	5	5	5	7	7	3
26. Cyclones	5	9	5	1	5	1	3	9	9	1
27. Earthquakes	5	9	5	1	5	1	3	7	7	1
28. Pest Epidemics	5	9	5	1	5	3	5	7	7	1

TABLE D1: INDIA
HAZARD TAXONOMY SCORES
part 2

ENVIRONMENTAL HAZARDS	11 CURRENT MORTAL	12 CURRENT MORBID	13 CURRENT ECOSYS	14 CURRENT MATERIAL PRODUCT	15 RECOVERY PERIOD	16 FUTURE HEALTH	17 FUTURE ECOSYS	18 FUTURE MATERIAL PRODUCT	19 TRANS-NATIONAL
1. Freshwater - Biological Contamination	7	8	5	3	3	9	9	5	1
2. Freshwater - Metal & Toxic Contaminatio	6	7	5	7	9	9	5	5	1
3. Freshwater - Eutrophication	5	6	5	2	7	9	9	5	1
4. Freshwater - Sedimentation	1	1	5	6	7	1	9	9	5
5. Ocean Water	3	5	5	4	9	9	9	9	1
6. Stratospheric Ozone Depletion	1	1	1	1	9	9	9	9	9
7. Thermal Radiation	1	1	1	1	9	9	9	9	9
8. Acidification	4	5	1	4	3	9	9	9	1
9. Ground Level Ozone Formation	1	6	1	1	5	9	9	9	1
10. Toxic Air Pollution	4	5	5	4	7	9	9	9	1
11. Indoor Air - Radon	4	4	1	1	7	5	1	1	1
12. Indoor Air - Non-radon	5	6	1	4	7	5	1	5	1
13. Radiation - Non-radon	4	4	1	1	7	9	1	1	1
14. Chemicals in the Workplace	4	5	1	1	7	5	1	1	1
15. Accidental Chemical Releases	3	4	1	3	7	5	5	5	1
16. Food Contamination	6	7	1	1	9	9	1	1	1
17. Agric. Land - Salinization, Alkaliniza	5	7	5	7	9	5	1	5	1
18. Agric. Land - Soil Erosion	6	8	5	8	9	5	9	5	1
19. Agric. Land - Urbanisation	5	7	5	1	9	5	5	1	1
20. Groundwater	1	1	5	5	5	9	9	5	1
21. Wildlife	1	1	9	5	9	1	9	5	1
22. Fish	1	1	1	1	1	1	1	1	1
23. Forests	3	5	5	6	7	9	9	9	1
24. Floods	4	5	5	6	9	9	9	9	1
25. Droughts	4	6	5	6	5	5	5	5	1
26. Cyclones	4	5	1	6	5	5	5	9	1
27. Earthquakes	3	3	1	5	5	5	1	5	1
28. Pest Epidemics	5	6	5	7	7	5	5	5	5

TABLE D2: KENYA
HAZARD TAXONOMY SCORES
part 1

ENVIRONMENTAL HAZARDS	1 SPATIAL EXTENT	2 DIST. TO ENV.	3 CHANGE PERTURB	4 INANTHRO. FLUX	5 CHANGE IN ANTHRO FLUX	6 PERSIS	7 RECURR	8 POPUL EXPOSED	9 LAND EXPOSED	10 DELAY
1. Freshwater - Biological Contamination	5	9	5	9	5	3	1	9	9	1
2. Freshwater - Metal & Toxic Contaminatio	5	9	6	9	6	9	1	5	3	1
3. Freshwater - Eutrophication	5	7	8	7	8	7	1	3	3	1
4. Freshwater - Sedimentation	5	9	6	9	6	3	1	7	9	3
5. Ocean Water	5	9	7	9	7	9	1	5	5	1
6. Stratospheric Ozone Depletion	9	9	8	9	2	9	1	9	9	5
7. Thermal Radiation	9	5	7	1	6	9	1	9	9	7
8. Acidification	5	5	6	3	6	1	1	5	5	3
9. Ground Level Ozone Formation	5	9	6	9	6	1	1	7	7	1
10. Toxic Air Pollution	5	9	6	9	6	3	1	7	7	1
11. Indoor Air - Radon	1	9	5	9	5	3	1	1	1	7
12. Indoor Air - Non-radon	1	9	5	9	5	1	1	9	9	1
13. Radiation - Non-radon	9	5	6	1	6	9	1	9	9	7
14. Chemicals in the Workplace	1	9	8	9	9	3	1	5	7	1
15. Accidental Chemical Releases	5	3	5	5	5	7	9	7	7	1
16. Food Contamination	5	9	8	9	8	9	1	9	7	3
17. Agric. Land - Salinization, Alkaliniza	1	3	5	3	5	7	1	1	1	1
18. Agric. Land - Soil Erosion	5	5	6	5	6	9	1	9	9	1
19. Agric. Land - Urbanisation	1	5	6	9	6	9	1	1	5	1
20. Groundwater	5	3	6	5	8	3	1	5	7	1
21. Wildlife	5	7	6	7	6	9	1	7	7	1
22. Fish	5	7	9	7	9	5	1	5	7	3
23. Forests	3	7	7	7	7	7	1	9	9	1
24. Floods	5	9	6	5	6	3	7	5	3	1
25. Droughts	5	5	5	1	6	5	5	9	9	3
26. Cyclones	5	3	5	1	5	1	9	1	1	1
27. Earthquakes	5	9	5	1	5	1	7	9	9	1
28. Pest Epidemics	5	9	5	1	5	3	5	9	9	1

TABLE D2: KENYA
HAZARD TAXONOMY SCORES
part 2

ENVIRONMENTAL HAZARDS	11 CURRENT MORTAL	12 CURRENT MORBID	13 CURRENT ECOSYS	14 CURRENT MATERIAL PRODUCT	15 RECOVERY PERIOD	16 FUTURE HEALTH	17 FUTURE ECOSYS	18 FUTURE MATERIAL PRODUCT	19 TRANS-NATIONAL
1. Freshwater - Biological Contamination	6	9	1	1	3	5	5	1	5
2. Freshwater - Metal & Toxic Contaminatio	2	3	1	1	9	5	5	1	1
3. Freshwater - Eutrophication	1	1	5	1	7	9	9	1	1
4. Freshwater - Sedimentation	1	1	5	6	7	1	5	9	1
5. Ocean Water	2	4	5	4	9	5	5	5	1
6. Stratospheric Ozone Depletion	1	1	1	1	9	9	9	9	9
7. Thermal Radiation	1	1	1	1	9	9	9	9	9
8. Acidification	1	2	1	2	3	9	1	9	1
9. Ground Level Ozone Formation	1	6	1	1	5	9	9	9	1
10. Toxic Air Pollution	3	4	5	3	7	5	5	5	1
11. Indoor Air - Radon	4	4	1	1	7	5	1	1	1
12. Indoor Air - Non-radon	6	7	1	4	7	5	1	5	1
13. Radiation - Non-radon	4	4	1	1	7	9	1	1	1
14. Chemicals in the Workplace	4	6	1	1	7	9	1	1	1
15. Accidental Chemical Releases	1	2	5	3	7	5	5	5	1
16. Food Contamination	6	7	1	1	7	9	1	1	1
17. Agric. Land - Salinization, Alkaliniza	1	1	1	1	1	5	1	5	1
18. Agric. Land - Soil Erosion	6	8	5	7	9	5	9	5	1
19. Agric. Land - Urbanisation	1	1	5	1	9	1	9	1	1
20. Groundwater	1	1	1	1	5	1	9	5	1
21. Wildlife	2	3	9	5	9	5	5	5	5
22. Fish	2	3	5	5	5	9	9	9	5
23. Forests	4	6	5	6	7	9	9	9	1
24. Floods	3	4	1	1	9	5	1	1	1
25. Droughts	5	7	5	7	9	5	5	5	1
26. Cyclones	1	1	1	1	1	1	1	1	1
27. Earthquakes	2	3	1	4	5	5	1	5	1
28. Pest Epidemics	5	6	5	8	7	5	5	5	5

TABLE D3: THE NETHERLANDS
HAZARD TAXONOMY SCORES
part 1

ENVIRONMENTAL HAZARDS	DESCRIPTORS 1 SPATIAL EXTENT	2 DIST. TO ENV.	3 CHANGE PERTURB	4 INANTHRO. FLUX	5 CHANGE IN ANTHRO FLUX	6 PERSIS	7 RECURR	8 POPUL EXPOSED	9 LAND EXPOSED	10 DELAY
1. Freshwater - Biological Contamination	5	9	1	9	1	3	1	5	7	1
2. Freshwater - Metal & Toxic Contaminatn.	5	9	1	9	1	9	1	9	9	1
3. Freshwater - Eutrophication	5	9	6	9	6	7	1	9	9	1
4. Freshwater - Sedimentation	5	7	5	7	5	3	1	5	7	3
5. Ocean Water	5	9	5	9	1	9	1	7	9	1
6. Stratospheric Ozone Depletion	9	9	8	9	2	9	1	9	9	5
7. Thermal Radiation	9	5	7	1	6	9	1	9	9	7
8. Acidification	5	9	2	9	3	1	1	9	9	3
9. Ground Level Ozone Formation	5	9	5	9	6	1	1	9	9	1
10. Toxic Air Pollution	5	9	5	9	5	3	1	9	9	1
11. Indoor Air - Radon	1	9	6	9	6	3	1	3	3	7
12. Indoor Air - Non-radon	1	9	4	9	4	1	1	9	9	1
13. Radiation - Non-radon	9	7	4	5	4	9	1	9	9	7
14. Chemicals in the Workplace	1	9	4	9	4	3	1	3	7	1
15. Accidental Chemical Releases	5	9	5	9	5	7	7	9	9	1
16. Food Contamination	5	9	7	9	6	9	1	9	9	3
17. Agric. Land - Salin., Alkin., Wtrlog.	1	5	5	9	5	7	1	1	1	1
18. Agric. Land - Soil Erosion	5	5	5	3	5	9	1	1	1	1
19. Agric. Land - Urbanisation	1	5	6	9	6	9	1	3	5	1
20. Groundwater	5	5	6	5	8	3	1	7	9	1
21. Wildlife	5	7	6	7	6	9	1	3	9	1
22. Fish	5	5	7	5	7	5	1	1	3	3
23. Forests	3	7	4	1	4	7	1	1	1	1
24. Floods	5	7	4	1	4	3	7	7	7	1
25. Droughts	5	5	5	3	5	5	5	7	7	3
26. Cyclones	5	3	5	1	5	1	9	1	1	1
27. Earthquakes	5	3	5	1	5	1	9	1	1	1
28. Pest Epidemics	5	9	4	1	4	3	5	1	7	1

TABLE D3: THE NETHERLANDS
HAZARD TAXONOMY SCORES
part 2

ENVIRONMENTAL HAZARDS	11 CURRENT MORTAL	12 CURRENT MORBID	13 CURRENT ECOSYS	14 CURRENT MATERIAL PRODUCT	15 RECOVERY PER100	16 FUTURE HEALTH	17 FUTURE ECOSYS	18 FUTURE MATERIAL PRODUCT	19 TRANS-NATIONAL
1. Freshwater - Biological Contamination	2	4	5	4	3	5	5	5	5
2. Freshwater - Metal & Toxic Contaminatn.	5	5	5	4	9	5	5	5	5
3. Freshwater - Eutrophication	4	5	5	2	7	5	5	5	5
4. Freshwater - Sedimentation	1	1	5	2	5	1	5	5	5
5. Ocean Water	5	6	5	4	9	5	5	5	5
6. Stratospheric Ozone Depletion	1	1	1	1	9	9	9	9	9
7. Thermal Radiation	1	1	1	1	9	9	9	9	9
8. Acidification	3	4	9	5	7	1	5	1	5
9. Ground Level Ozone Formation	1	7	5	7	5	5	5	5	5
10. Toxic Air Pollution	5	6	5	6	7	5	5	5	5
11. Indoor Air - Radon	5	5	1	1	7	5	1	1	1
12. Indoor Air - Non-radon	4	5	1	1	7	5	1	1	1
13. Radiation - Non-radon	5	5	1	1	9	5	1	1	9
14. Chemicals in the Workplace	4	5	1	1	7	5	1	1	1
15. Accidental Chemical Releases	2	4	5	4	7	5	5	5	5
16. Food Contamination	4	5	1	1	7	5	1	1	5
17. Agric. Land - Salin., Alkin., Wtrlog.	1	1	1	1	3	1	1	1	5
18. Agric. Land - Soil Erosion	1	1	1	5	9	1	1	5	1
19. Agric. Land - Urbanisation	1	1	5	1	9	1	5	1	1
20. Groundwater	1	1	5	6	7	1	5	5	1
21. Wildlife	1	1	9	2	9	1	5	5	1
22. Fish	1	1	5	1	5	1	5	1	5
23. Forests	1	1	1	1	7	1	1	1	1
24. Floods	1	1	1	3	3	1	1	5	1
25. Droughts	1	1	5	6	5	1	5	5	1
26. Cyclones	1	1	1	1	1	1	1	1	1
27. Earthquakes	1	1	1	1	1	1	1	1	1
28. Pest Epidemics	1	1	5	2	7	1	5	5	1

TABLE D4: UNITED STATES
HAZARD TAXONOMY SCORES
part 1

ENVIRONMENTAL HAZARDS	1 SPATIAL EXTENT	2 DIST. TO ENV.	3 CHANGE PERTURB	4 INANTHRO. FLUX	5 CHANGE IN ANTHRO FLUX	6 PERSIS	7 RECURR	8 POPUL EXPOSED	9 LAND EXPOSED	10 DELAY
1. Freshwater - Biological Contamination	5	9	2	3	2	3	1	5	5	1
2. Freshwater - Metal & Toxic Contaminatio	5	9	5	9	5	9	1	7	5	1
3. Freshwater - Eutrophication	5	5	5	5	5	7	1	3	5	1
4. Freshwater - Sedimentation	5	5	6	5	6	3	1	3	5	3
5. Ocean Water	5	9	6	9	6	9	1	5	5	1
6. Stratospheric Ozone Depletion	9	9	8	9	2	9	1	9	9	5
7. Thermal Radiation	9	5	7	1	6	9	1	9	9	7
8. Acidification	5	9	4	9	4	1	1	9	9	3
9. Ground Level Ozone Formation	5	9	4	9	4	1	1	7	7	1
10. Toxic Air Pollution	5	9	3	9	3	3	1	9	9	1
11. Indoor Air - Radon	1	9	5	9	5	3	1	5	5	7
12. Indoor Air - Non-radon	1	9	6	9	6	1	1	9	9	1
13. Radiation - Non-radon	9	7	5	5	5	9	1	9	9	7
14. Chemicals in the Workplace	1	9	4	9	5	3	1	3	7	1
15. Accidental Chemical Releases	5	9	5	9	5	7	3	9	7	1
16. Food Contamination	5	9	5	9	5	9	1	9	9	3
17. Agric. Land - Salinization, Alkaliniza	1	7	6	9	7	7	1	1	3	1
18. Agric. Land - Soil Erosion	5	5	6	5	4	9	1	3	5	1
19. Agric. Land - Urbanisation	1	5	6	9	6	9	1	1	5	1
20. Groundwater	5	5	6	5	6	3	1	5	7	1
21. Wildlife	5	9	6	5	4	9	1	3	3	1
22. Fish	5	7	7	7	7	5	1	3	7	3
23. Forests	3	7	4	3	4	7	1	1	3	1
24. Floods	5	9	5	1	5	3	3	7	5	1
25. Droughts	5	7	5	1	5	5	5	7	7	3
26. Cyclones	5	9	5	1	5	1	1	9	7	1
27. Earthquakes	5	9	5	1	5	1	3	7	7	1
28. Pest Epidemics	5	9	4	1	4	3	5	5	7	1

TABLE D4: UNITED STATES
HAZARD TAXONOMY SCORES
part 2

ENVIRONMENTAL HAZARDS	11 CURRENT MORTAL	12 CURRENT MORBID	13 CURRENT ECOSYS	14 CURRENT MATERIAL PRODUCT	15 RECOVERY PERIOD	16 FUTURE HEALTH	17 FUTURE ECOSYS	18 FUTURE MATERIAL PRODUCT	19 TRANS-NATIONAL
1. Freshwater - Biological Contamination	2	5	5	6	3	1	1	1	1
2. Freshwater - Metal & Toxic Contaminatio	5	6	5	6	9	5	5	5	5
3. Freshwater - Eutrophication	1	2	5	6	9	5	5	5	5
4. Freshwater - Sedimentation	1	1	5	6	9	1	5	5	1
5. Ocean Water	2	3	5	6	9	5	5	5	5
6. Stratospheric Ozone Depletion	1	1	1	1	9	9	9	9	9
7. Thermal Radiation	1	1	1	1	9	9	9	9	9
8. Acidification	5	6	5	6	7	1	5	1	5
9. Ground Level Ozone Formation	1	6	5	6	5	1	5	1	1
10. Toxic Air Pollution	5	6	5	6	7	5	5	1	1
11. Indoor Air - Radon	5	6	1	1	7	5	1	1	1
12. Indoor Air - Non-radon	5	6	1	1	7	5	1	1	1
13. Radiation - Non-radon	5	5	1	1	7	5	1	1	1
14. Chemicals in the Workplace	5	6	1	1	7	5	1	1	1
15. Accidental Chemical Releases	2	4	5	5	7	5	5	5	1
16. Food Contamination	5	6	1	1	9	5	1	1	5
17. Agric. Land - Salinization, Alkaliniza	1	1	1	5	7	1	1	5	1
18. Agric. Land - Soil Erosion	1	1	1	6	9	1	1	5	1
19. Agric. Land - Urbanisation	1	1	5	1	9	1	5	1	1
20. Groundwater	1	1	5	6	9	1	5	9	1
21. Wildlife	1	1	9	4	9	1	5	5	5
22. Fish	1	1	5	1	9	1	9	9	5
23. Forests	1	1	5	1	7	1	9	1	1
24. Floods	3	5	1	7	5	5	1	5	1
25. Droughts	1	1	5	5	5	1	5	5	1
26. Cyclones	3	5	1	7	5	5	1	9	1
27. Earthquakes	3	4	1	6	5	5	1	5	1
28. Pest Epidemics	1	3	5	2	7	1	5	5	5

APPENDIX E - PRINCIPAL COMPONENT ANALYSIS

1. A Brief Introduction to Principle Component Analysis (PCA)[1]

PCA is a method for expressing multi-dimensional data as new variables which are mutually uncorrelated, linear combinations of the original variables. These new variables are called principle components (PCs). The specific aims of performing PCA on data are:

1) Reducing dimensionality: If some variables are correlated, then the effective dimensionality may be decreased by expressing their information content in their PCs. If the first few PCs account for most of the variation in the original data, then the rest of the PCs may be neglected, reducing the effective dimensionality of the problem.

2) Arranging variables into meaningful groups: It may be possible to interpret or assign meaning to the set of variables contributing significantly to the more important PCs. The PCs may also be rotated to maximize the difference in loadings between variables. Rotation modifies the PCs without altering their underlying structure to allow easier determination of the significant variables in each PC and better interpretation.

3) Discardinq redundant variables: Some variables may be redundant and may therefore be discarded. PCA gives a method for systematically identifying variables with the least contribution to the overall variability in the data.

4) Using the components in subsequent analysis: PCA reduces the effective dimensionality of the data. For example, if the first two components account for a large proportion of the total variation, then the data may be plotted in two dimensions. This can be used for classification and cluster analysis.

2. Results

The results presented below are based on a PCA of the descriptors. After identifying the important PCs, they were rotated using the technique of varimax rotation in an effort to improve interpretation of the PCs. Data generated by all four case studies was used in this analysis.

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[1] Most texts on multivariate statistics discuss this method. Two which we used are: Mardia, K.; Kent, J.; and Bibby, J., Multivariate Analysis (London: Academic Press, 1980) and Harris, R.J., A Primer of Multivariate Statistics (London: Academic Press, 1975).

2.1 Correlations

The correlation matrix of the descriptors is shown in Table El. Listed in Table E2 are all the pairs that have correlations greater than 0.5. Of particular note are the first two pairs which have correlations greater than 0.85. For these two pairs, in future analysis, one descriptor may suffice.

At least part of the explanation for the high correlation between Current Morbidity and Current Mortality is a lack of data, particularly on morbidity. Thus, morbidity was most often estimated based on mortality data, and generally assumed to be one order of magnitude greater. Better data could determine if this correlation describes the actual relationship between these two indicators of human health consequences, or if it is simply an artifact of our scoring inferences. Without better data, it is probably valid to drop the Current Morbidity Descriptor.

In contrast, the correlation between population and land area exposed likely corresponds to the actual characteristics of environmental hazards. Thus, from the viewpoint of reducing dimensionality, a single descriptor would suffice. From the viewpoint of characterizing hazards, there may be some argument for including both.

2.2 Principal Components

The principal components are shown in Table E3. The 19 PCs are presented in order of increasing importance from left to right. The first 19 numbers in each column are the component correlations (or factor loadings). The final number is the cumulative percentage of variance explained by the PCs. We see that the first 6 PCs account for nearly 80% of the variance in the data. This is not a surprising result; it is quite usual for data sets of these dimensions to result in 6 factors describing most of the variance.

The magnitude of the component correlations for a given PC indicates the relative contribution of the descriptor to that PC. It is difficult to pick the most relevant descriptors to each PC, since the component correlations decline rather steadily. I.e., for each PC there is not an obvious cut-off point; there are not a few descriptors with high component correlations, while all others have low correlations. We therefore next performed a varimax rotation in order to maximize the difference in loadings between variables.

2.3 Varimax Rotation

The results of the varimax rotation are presented in Table E4. As mentioned above, the first 6 components account for about 80% of the variance. In addition, selecting more than the first 6 components did not modify the results of the rotation. Therefore, we present only the rotation using the first 6 PCs. Although the varimax rotation improves the distinctiveness of the factors when compared to the PCA without rotation, the problem of cut-off points remains. The analysis has still not provided a strong set of descriptor groupings.

Table E5 lists the descriptors that have component loadings greater than 0.5. The first four PCs lend themselves to meaningful interpretation, and are also quite similar to the simple aggregation schemes which we developed without the aid of PC analysis, in other words, to aggregation schemes that are intuitively meaningful. The last two PCs are difficult

to interpret.

PC1 is almost identical to the aggregation "Pervasiveness in Space". PC2 is identical to the aggregation "Current Human Health". As we have discussed above, the two descriptors composing PC2 are highly correlated.

PC3 is perhaps the most interesting result. The heaviest loading is on the descriptor Annual Change in Perturbation Level. Continuing in order of decreasing importance, the next three descriptors include all but one of the consequence descriptors which describe the future (Future Human Health Consequences, Future Ecosystem Consequences, Recovery Period). The last two descriptors with loadings greater than 0.5 are two more material flux descriptors (Anthropogenic Flux, Recurrence). This suggests that an aggregation called "Trends" may be worth investigating in addition to or as a replacement for the aggregation "Future Consequences". In such an aggregation, the material flux descriptors could serve as a balance to the business-as-usual scenarios by including descriptors which characterize current trends in pollution releases and trends in the perturbation of natural environmental cycles, rather than only those based on assumption laden future scenarios. We had considered a similar approach as one of our aggregation schemes but chose not to present it in the final report due to lack of space, its relative complexity compared to the other aggregation schemes, and the fact that the results were quite similar to those we obtained from the aggregation "Future Consequences".

PC4 suggests that current ecosystem and material losses are more likely in problems in which consequences have long delays.

2.4 Conclusion

When compared to the simple aggregation schemes we first developed for data analysis, the PCA did not add significantly to our ability to interpret the data, for the following reasons:

1. The PCA, even after varimax rotation, did not result in strongly differentiated factors.

2. The first several factors were similar to the aggregation schemes that we had previously developed.

3. Only the first 4 factors lent themselves to meaningful interpretation.

This is not to imply that the analysis was completely without merit. First, we did identify 2 pairs of highly correlated variables, suggesting places where we could reduce our number of descriptors in the future. (However, a simple analysis of pair-wise correlations would give the same result.) Second, we were encouraged to consider using a "Trends" aggregation, which would be based on both current trends and expected future trends. While this would be more complex than the aggregation scheme "Future Consequences which we used in this analysis, its expanded definition may help overcome some of the difficulties of relying on business-as-usual scenarios.

TABLE E1: CORRELATION MATRIX FOR DESCRIPTORS

Descriptor #

Descriptor #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1.00																		
2	-0.04	1.00																	
3	0.21	-0.07	1.00																
4	-0.34	0.45	0.16	1.00															
5	-0.13	-0.17	0.67	0.05	1.00														
6	0.30	-0.21	0.29	0.14	-0.03	1.00													
7	0.08	-0.17	-0.22	-0.47	-0.12	-0.28	1.00												
8	0.49	0.40	0.09	0.10	-0.06	0.03	-0.06	1.00											
9	0.41	0.36	0.06	0.13	-0.07	0.02	-0.15	0.85	1.00										
10	0.43	-0.06	0.18	-0.10	-0.09	0.24	-0.18	0.19	0.15	1.00									
11	-0.19	0.41	-0.08	0.29	0.05	-0.03	-0.16	0.44	0.35	0.02	1.00								
12	-0.19	0.50	-0.10	0.35	0.08	-0.16	-0.15	0.50	0.39	-0.14	0.88	1.00							
13	-0.01	0.00	-0.07	0.14	0.04	0.15	-0.06	-0.04	0.09	-0.33	-0.08	-0.01	1.00						
14	0.03	0.12	-0.16	-0.12	-0.01	-0.16	0.05	0.27	0.21	-0.37	0.15	0.25	0.49	1.00					
15	0.15	0.18	0.26	0.32	0.01	0.60	-0.35	0.20	0.28	0.21	0.15	0.05	0.26	0.08	1.00				
16	0.33	0.27	0.51	0.16	0.25	0.18	-0.23	0.51	0.38	0.29	0.36	0.39	-0.26	0.17	0.16	1.00			
17	0.39	-0.03	0.46	0.10	0.23	0.23	-0.20	0.21	0.28	0.00	-0.21	-0.12	0.44	0.13	0.27	0.30	1.00		
18	0.42	0.06	0.43	-0.12	0.15	0.02	-0.07	0.33	0.34	0.03	-0.26	-0.17	0.11	0.34	0.14	0.36	0.60	1.00	
19	0.55	0.10	0.11	0.04	-0.33	0.33	-0.16	0.31	0.33	0.44	-0.16	-0.19	0.01	-0.14	0.27	0.20	0.33	0.30	1.00

TABLE E2 - HIGHLY CORRELATED DESCRIPTORS

Descriptors	Corr. Coeff.
Current Morbidity (11) and Current Mortality (12)	0.88
Population Exposed (8) and Land Exposed (8)	0.86
Persistence (6) and Recovery Period (15)	0.60
Spatial Extent (1) and Transnational (19)	0.55
Change in Perturbation (3) and Future Health Consequences (16)	0.51
Population Exposed (8) and Future Health Consequences (16)	0.51
Disturbance to Environment (2) and Current Morbidity (12)	0.50
Population Exposed (8) and Current Morbidity (12)	0.50

TABLE E3: RESULTS OF PCA FOR DESCRIPTORS
COMPONENT CORRELATIONS (FACTOR LOADINGS)

Principle Components

Decreasing Importance

PC 19	PC 18	PC 17	PC 16	PC 15	PC 14	PC 13	PC 12	PC 11	PC 10	PC 9	PC 8	PC 7	PC 6	PC 5	PC 4	PC 3	PC 2	PC 1	
0.033	-0.020	0.160	-0.050	0.047	-0.160	0.046	0.237	0.241	-0.070	0.019	-0.060	0.063	-0.140	0.065	0.049	-0.480	0.506	0.548	1
0.021	0.000	-0.070	0.052	-0.100	0.020	-0.110	0.113	0.226	-0.240	-0.140	0.278	0.157	0.462	-0.120	-0.010	-0.090	-0.580	0.397	2
-0.040	0.064	-0.080	-0.230	-0.070	-0.030	0.009	0.141	-0.090	-0.030	-0.100	0.098	0.107	0.005	0.442	-0.130	0.549	0.371	0.470	3
0.045	-0.030	0.068	0.015	0.049	-0.080	0.317	0.074	-0.130	0.104	-0.050	-0.090	0.159	0.377	-0.350	-0.200	0.501	-0.410	0.299	4
0.041	-0.050	0.046	0.186	0.027	0.032	-0.110	0.150	-0.030	-0.040	-0.270	-0.110	-0.050	-0.170	0.594	0.065	0.658	0.067	0.113	5
0.035	0.018	-0.070	0.112	-0.160	0.038	0.040	0.106	0.044	0.145	0.231	0.117	0.180	-0.450	-0.450	-0.270	0.256	0.387	0.360	6
0.035	0.005	0.000	0.030	-0.010	0.002	0.108	-0.090	-0.160	-0.120	-0.150	0.102	0.594	-0.200	0.294	0.249	-0.450	0.075	-0.400	7
-0.180	-0.060	-0.100	0.071	0.032	-0.010	0.089	0.072	0.000	0.203	-0.110	-0.070	0.034	-0.090	0.131	0.120	-0.400	-0.280	0.774	8
0.132	0.048	-0.010	-0.060	-0.050	0.105	-0.060	-0.090	0.018	0.327	-0.260	-0.180	-0.040	-0.020	0.002	0.177	-0.330	-0.220	0.745	9
0.012	0.032	-0.050	0.047	-0.060	0.011	0.217	-0.120	-0.030	-0.330	-0.230	-0.070	-0.300	-0.120	-0.010	-0.600	-0.280	0.322	0.343	10
0.019	-0.150	0.049	-0.100	-0.130	-0.070	-0.080	-0.070	-0.110	-0.140	0.097	-0.070	-0.010	-0.330	0.059	-0.180	0.008	-0.790	0.341	11
-0.030	0.192	0.072	0.064	0.011	-0.090	-0.040	0.001	-0.070	-0.100	0.156	-0.100	0.025	-0.170	0.127	0.000	0.023	-0.850	0.361	12
-0.060	0.006	0.059	-0.050	-0.040	0.216	0.062	0.024	0.078	-0.240	-0.070	-0.280	0.072	-0.130	-0.460	0.681	0.293	0.039	0.095	13
0.081	-0.010	-0.110	-0.010	0.083	-0.050	0.123	0.152	-0.120	-0.100	0.069	0.248	-0.290	-0.210	-0.060	0.798	-0.060	-0.240	0.134	14
-0.030	0.001	0.062	-0.020	0.160	-0.050	-0.120	-0.200	0.000	0.000	-0.250	0.350	0.047	-0.260	-0.510	-0.080	0.301	0.090	0.538	15
0.035	-0.030	-0.010	-0.020	0.173	0.227	0.071	-0.090	0.100	-0.080	0.320	0.068	0.100	0.010	0.437	-0.260	0.064	-0.070	0.707	16
0.025	-0.020	-0.120	0.044	0.011	-0.210	-0.060	-0.240	0.067	-0.110	0.125	-0.290	0.119	0.166	0.007	0.398	0.277	0.431	0.551	17
-0.030	0.000	0.152	0.060	-0.160	0.026	0.057	-0.150	-0.120	0.056	0.113	0.281	-0.140	0.269	0.269	0.454	-0.020	0.400	0.528	18
0.009	-0.010	0.000	0.027	0.056	0.062	-0.210	0.170	-0.360	-0.130	0.072	-0.110	0.048	0.232	-0.330	-0.160	-0.350	0.411	0.516	19
100.0	99.6	99.2	98.6	97.8	97.0	95.9	94.3	92.5	90.6	88.0	85.1	81.8	78.1	72.4	62.6	51.0	39.3	22.4	

Descriptor #

% Variance Explained, Cumulative

TABLE E4: RESULT OF VARIMAX ROTATION OF FIRST 6 PRINCIPAL COMPONENTS

Principle Components
(After Rotation)

Decreasing Importance ←

PC 6	PC 5	PC 4	PC 3	PC 2	PC 1	Descriptor #
-0.514	0.401	0.142	0.207	0.109	0.699	1
0.727	-0.017	0.012	0.289	0.141	0.286	2
-0.326	-0.113	-0.230	0.690	0.177	-0.213	3
0.537	-0.610	-0.297	0.520	0.144	-0.264	4
-0.140	-0.093	-0.065	0.447	-0.123	-0.496	5
-0.551	-0.488	-0.310	0.441	-0.219	-0.024	6
-0.158	0.530	0.332	-0.575	-0.139	0.168	7
0.207	0.385	0.196	0.441	-0.210	0.752	8
0.188	0.247	0.238	0.454	-0.116	0.677	9
-0.339	0.205	-0.533	0.141	0.048	0.421	10
0.547	0.033	-0.173	0.293	-0.660	0.175	11
0.670	0.068	-0.008	0.318	-0.546	0.174	12
-0.095	-0.525	0.610	0.237	-0.097	-0.197	13
0.111	0.003	0.795	0.081	-0.293	0.123	14
-0.203	-0.566	-0.133	0.615	-0.192	0.032	15
0.071	0.244	-0.267	0.632	-0.026	0.323	16
-0.304	-0.201	0.336	0.614	0.347	0.060	17
-0.229	0.192	0.449	0.438	0.424	0.295	18
-0.256	0.041	-0.088	0.248	0.396	0.574	19
78.20	72.40	62.60	51.00	39.30	22.40	% Variance Explained, Cumulative

TABLE E5: DESCRIPTORS FORMING EACH ROTATED PC. (INCLUDES DESCRIPTORS WITH COMPONENT CORRELATIONS GREATER THAN 0.5)

PC 1 8. Population Exposed 1. Spatial Extent 9. Land Area or Resource Exposed 19. Transnational	PC 2 11. Human Mortality (Current Annual) 12. Human Morbidity (Current Annual)
PC 3 3. Annual Change in Perturbation Level 16. Future Human Health Consequences 15. Recovery Period 17. Future Ecosystem Consequences 7. Recurrence 4. Anthropogenic Flux	PC 4 14. Material and Productivity Losses (Current Annual) 13. "Natural" Ecosystem Impacts (Current Annual) 10. Delay
PC 5 4. Anthropogenic Flux 15. Recovery Period 7. Recurrence 13. "Natural" Ecosystem Impacts (Current Annual)	PC 6 2. Disturbance to the Environment (Magnitude of Perturbation) 12. Human Morbidity (Current Annual) 6. Persistence 11. Human Mortality (Current Annual) 4. Anthropogenic Flux 1. Spatial Extent