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ENVIRONMENTAL PLANNING AND ECOLOGICAL POSSIBILITIES[a]

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INTRODUCTION

Strategies and Tactics.—When considering plans and approaches to solutions of environmental problems, it is useful to borrow two terms from military science related to planning levels, i.e., strategy and tactics. Strategies are concerned with the comprehensive employment of power (resources) while tactics are concerned with the immediate or local employment of power (resources) (3). Two important principles regarding these planning levels are that (3): (1) Tactical plans and actions are subordinate to strategic plans; and (2) strategic plans are limited by tactical capabilities. Failure to observe these two principles could well lead to military disaster.

In elaborating the military definitions to accommodate environmental problems, it is necessary only to consider the words comprehensive and immediate as having spatial, temporal, and organizational (ecological and social) dimensions, and the work power to relate to the total management resources available. In the area of environmental management, strategic and tactical planning levels have not been clearly defined and as a result, the preceding two principles are often violated. Comprehensive environmental plans will be defined herein as environmental strategies and decisions based on these plans will be defined as strategic decisions. Immediate environmental plans will be defined herein as environmental tactics and decisions based on these plans will be defined as tactical decisions. There are planning levels in which distinction between these types is difficult.

Environmental engineering and management literature has been nearly exclusively dominated by subjects of a tactical nature. The relatively few ex-

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ceptions that have described environmental strategies (as defined herein) have not been further analyzed and developed in the literature with the same degree of technical aggressiveness as subjects of a more tactical nature. As a result, tactical decisions have often been made in a strategic vacuum.

It is often expressed that strategies are solely of a social and political nature and that technical people should merely develop tactics to pursue such strategies. This view is an obvious violation of a second principle stated herein; moreover, this view could hardly explain the relative absence of environmental strategies from the technical literature. This absence is more likely the result of a historical hangover. Historically man has lived in an environment in which the scope of his own activities has been relatively small. Unfortunately, this condition has long been passed and man can no longer afford the luxury of completely localized decisions.

Strategy of Reduced Growth.—It is possible to attribute many of the currently perceived environmental problems to excessive growth in the number of humans, in the utilization of resources, or in environmental demands. A number of authors have addressed this question, and one can readily find just about any position expressed in the literature. Without getting involved in the standard arguments, which become highly emotional and value system oriented, it is possible to identify several elements of the strategy which fall within the focus of this paper.

The faster a population is growing, the shorter the time available to correct a recognized problem. The faster a population is growing, the greater the shift in role structure due to change in age distribution when the population is stabilized. The faster a population is growing, the greater the demands made on technological capacity in order to maintain a standard of life quality. Similar comments can be made with regard to technological growth and economic growth. The faster the rate of growth, the greater the trauma of adjustment and the greater the difficulty of achieving a satisfactory adjustment.

These arguments against rapid relative growth can be augmented by arguments against absolute growth or even by arguments for an optimal stable level, but most of these are less well defined. Peterson (7) has argued that, under a reasonable set of assumptions, it is impossible for technology to continue to effectively clean up the by products if the population continues to grow exponentially (at a constant specific rate). Forrester (4) has an even more damning argument. His analysis, also following reasonable model assumptions, indicates that decreased population growth is not adequate to prevent deterioration of "quality of life," but rather, it must be accompanied by what amounts to decreased per capita demand, or technological impact.

A major difficulty in applying the strategy of reduced growth lies in the organization of social systems. Social systems are organised into competing units (e.g., competing countries). A universal reduction is not likely to occur unless prompted by an immediately impending catastrophe which is universally perceived. Unilateral reduction by one or several units would be resisted by members of these units because of the resulting competitive disadvantage. Moreover, a reduction by one or several units might merely result in an increase of growth in the remaining units.

In summary, it appears that the strategy of reduced growth in some form is necessary (particularly for population) but not likely sufficient to solve environmental problems, and further, will itself present some tremendous problems which will require additional strategies.

Purpose of this Paper.—The purpose of this paper is to develop an environmental strategy that prevents conditions which would significantly destroy the quality of life as perceived by this and future generations. The indeterminant changing value systems of society are recognized and thus no attempt will be made to precisely define "quality of life." This strategy will not apply to catastrophes resulting from failure of man-made systems; such failures must continue to be avoided through appropriate safety factors incorporated into the system design.

Herein, conditions and events which significantly destroy the quality of life will be defined as catastrophes. Such a definition is not limited to sudden events which result in large losses of life, nor is it limited to those conditions and events which are identifiable to specific causes. The strategy developed herein is distinctly different from the strategy of reduced growth previously mentioned. The following analysis is concerned with all influences of man on the environment and is not limited to those influences normally included in the definition of pollution.

ENVIRONMENTAL PREDICAMENT

Man has at his disposal the technological tools that enable him to drastically change his environment. The basic analytical approach which has given man this technological power is largely based on the developments in the physical sciences during the 17th, 18th, and 19th centuries. During this period, methods of quantitatively analyzing simply organized systems were developed (11). The design and development of complex systems since that time has been possible by decomposing complex systems into simply coupled subsystems which can be mechanistically analyzed. Though technology has drawn considerably upon scientific advances since the 19th century, the assumption of the decomposability of complex systems has been so widely accepted that it is seldom listed or even recognized along with other stated assumptions. Even the more holistic design approaches have relied in some way on the decomposability of the complex system under design.

While the approach of decomposition has enabled man to design and construct highly complex systems, this same approach is of limited value when applied to the study of man's effect on ecological systems. Ecosystems have continuously adjusted over geological time to environmental changes by a process of introductions and survival tests of numerous species and systems of species. To survive, a species must be able to compete successfully within the system for necessary resources. In addition, systems of species which cannot effectively withstand the perturbations and extremes of their environment are eliminated and succeeded by systems of greater durability, resilience, or stability. Thus, ecosystems have been modified and tested at all levels of organization so as to continuously select systems of greater survivability. The result, at any given time, is a complex net of interlocking (highly coupled) systems selected on the basis of past survival from a large number of less durable possibilities.

The technological advances of man have enabled him to produce significant environmental changes. Ecosystems will adjust to these changes. However, some species will not be able to compete successfully within these newly adjusted ecosystems and thus these species will be eliminated. Because man-caused changes occur over extremely short periods of geological time, evolutionary processes do not have time to operate and instabilities are to be expected.

For his own interests, man hopes to qualitatively predict the ecological changes that would develop as a result of a given set of actions by man. Such predictive ability would enable man to control his actions in a manner that would preserve and even enhance ecological systems for the benefit and survival of man. One would think, at first, that the same powerful analytical tools and approaches that have enabled man to develop significant environmental changes could be used to predict the resulting ecological responses. The necessary assumption of decomposability, however, makes such use questionable. The resistance of certain species to environmental conditions imposed by man, e.g., is often studied by isolating a given species from its system. Such an approach assumes the decomposability of ecological systems, yet, because ecological systems are relatively nondecomposable, this approach cannot be used to answer the relevant question concerning what ecosystem states will develop in response to man's activities. One cannot make such determinations by detaching selected species from an ecosystem for study any more than one can determine the response of social systems by detaching individuals from society. Ecosystems and social systems are both strongly coupled and are thus essentially nondecomposable; yet, decomposability is a fundamental technological assumption. Thus man has the technological tools that enable him to produce ever greater environmental changes; yet these same tools are of limited value in predicting the ecological significance of such changes.

Fundamental methods of analyzing complex organized systems (which cannot be decomposed into simple systems) are currently being studied in many fields of science (1,8,12). The evidence to date, however, indicates a continuing difficulty in understanding complex systems. There will, no doubt, be significant advances in the environmental sciences. The relevant point, however, is not that the environmental sciences will significantly advance but rather that it is unreasonable to expect that this advance can keep pace with the more rapid expansion of man-made systems. Man is faced with an environmental predicament which can be stated as follows: Man's ability to modify the environment will increase faster than his ability to foresee the effects of his activities. This predicament rests not on man's lack of interest in his environment (though this is a contributing factor) but on his relative inability to understand complex organized ecosystems, i.e., the environmental predicament rests ultimately on man's capacity rather than on his will. Failure to recognize this predicament can occur because of the engineer's underestimation of the relative complexity of ecosystems and the ecologist's overestimation of the relative complexity of man-made systems. As an illustration of this predicament, consider the basic manuals available to both the engineer and the ecologist. There are no ecological manuals comparable in simplicity, generality, utility, and availability to engineering design manuals [such as the Manual of Steel Construction (5) and The Reinforced Concrete Design Handbook (10)] and there will likely never be such manuals, not because ecologists are backward or unimaginative, but because ecological systems are too complex. It is extremely unlikely that a major breakthrough will occur in the environmental sciences such that the environmental predicament will be removed. Thus, environmental strategies must be based on a recognition of this predicament.

The environmental predicament is also highly relevant to the needs (not limited to physical needs) of man himself. The difficulty of understanding man's complex needs is further compounded by the dual role of man as both the investigator and the object of the investigation. With regard to this aspect, the environmental predicament might also be expressed as: man's ability to change his environment will increase more rapidly than his ability to anticipate his changing environmental needs.

LEVELS OF DECISION STRATEGIES

General.—In consideration of decision making strategies, one can identify four levels, depending on the scope and kind of information available to the process. Specifically the following cases are identified: (1) The certain outcome case; (2) the uncertain outcome, probability specified, case; (3) the uncertain outcome, probability unspecified, case; and (4) the unspecified outcome case.

The general decision problem can be structured as follows. There is an action space, A, containing two or more possible actions, an outcome space, O, containing two or more possible outcomes, a utility function, $U(o, a)$, defined over $A \times O$, representing the utility of action a in the event of outcome o. A low utility will be defined as one of large magnitude and negative sign, a high utility as one with large magnitude and positive sign. Lastly, a probability function on O is defined for each a:

$$0 \leq P(o|a) \leq 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Thus, the model for decision consists of

$$\left.\begin{array}{l} A = \{a_1, \ldots\} \\ O = \{o_1, \ldots\} \\ \left.\begin{array}{l} U(o, a) \\ P(o|a) \end{array}\right\} (o, a) \in O \times A \end{array}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

It should be stated that some details which must be accommodated in practice have been eliminated in this account, as they are not essential to the argument. The four identified levels of decisions are defined in terms of restrictions on this model.

Case 1: Certain Outcome Case.—For each $a \epsilon A$, let

$$\left.\begin{array}{l} P(o|a) = 1 \text{ for some } o \epsilon O \\ \qquad\quad = 0 \text{ otherwise} \end{array}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

That is, for each action, a, there is one certain outcome, o_c, which may vary or not among the $a \epsilon A$. Then, let $U(o_c, a)$ be the utility of the certain outcome given a. If one chooses that action, a, for which $U(o_c, a)$ is greatest, then utility is maximized. Note that this is a special case of the second case.

Case 2: Uncertain Outcome, Probability Specified Case.—Calculate the expected utility for each $a \epsilon A$ by

$$E(U(a)) = \sum_{o \epsilon O} P(o|a)\, U(o, a) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

then choose that action, a, such that $E(U(a))$ is greatest; maximizing $E(U)$ by appropriate choice of a.

This is the conventional form of formal decision theory. The role of experimentation and observation is to sharpen $P(o|a)$ and to determine $U(o, a)$ and the essence of the decision process is contained in the preceding description.

Case 3: Uncertain Outcome, Probability, Unspecified Case.—Suppose that $P(o|a)$ is not completely specified; i.e., suppose that one can write down the possibilities, $o \epsilon 0$, but that some of the probabilities are not known. In this case it is impossible to calculate $E(U(a))$ for at least some $a \epsilon A$ and necessary to devise an alternate scheme.

The relevent consideration herein is that for a utility value sufficiently great, relative to others, the action which potentially provides that utility value will be chosen under almost all possible positive values of P, so that it is not necessary to know P to make the best decision. Conversely, for utility value sufficiently low the action associated with that value will be rejected under almost all possible positive values of P, so that again it is not necessary to know P in order to eliminate this possible decision. This idea is related to the concept of factor of safety in engineering design. It is similar, philosophically, to the min-max rule and to the notion of admissibility, but is unique in several important respects.

With regard to the very low utility case, this idea will be expressed as the rule of catastrophic possibility which can be stated: Any action, possibly leading to a catastrophic outcome, will be considered a catastrophic action and eliminated from the action space.

Case 4: Unspecified Outcome Case.—In this case, it is assumed that not all possible outcomes are known for all considered actions, that is, not all $o \epsilon 0$ can be specified at the time the decision must be made. In order to devise a strategy which will accommodate this case, it is necessary to examine the nature of catastrophy, and essentially to adopt guides which unspecifically guard against catastrophic action.

BASIS FOR ENVIRONMENTAL STRATEGY

Selection of Decision Case.—In the past, environmental decisions have generally been made under the assumptions of decision cases 1, 2, and 3. Decision case 1 has been preferred and generally has been assumed at the higher levels of decision making both because of its simplicity and because of the political difficulty of admitting uncertainty or the possibility of undesirable outcomes. Case 1 decisions based on the best available information have been considered adequate despite the overwhelming evidence that the best available information itself is inadequate. Court decisions have also fallen under the requirements of case 1 due to the requirement that guilt (as of environmental degradation) be proven beyond a reasonable doubt. In addition, scientific and technological advances are often considered to result in the increase of predictive abilities and thus greater use of case 1 decisions is often anticipated. Past experience, however, demonstrates that the certain outcome assumption (case 1) was likely not justified at the time of the decision. Hindsight has continuously revealed a host of unforeseen outcomes. Moreover, the environmental predicament examined previously suggests that the unspecified outcome (case 4) situation will increasingly occur; i.e., future decisions will be handicapped to an even greater extent by the inadequacies of available information.

The increased scope of man's possible actions will lead to some outcomes of exceedingly low utility. Few would doubt that man now has the capacity to cause catastrophic events of such magnitude that, if permitted to occur, would far exceed any possible beneficial action that man can take. As an example, nuclear power has provided many benefits to man, yet, this same power has given man the capacity to cause catastrophic events of far greater magnitude than the benefits he has enjoyed. Man has enjoyed in the past and will continue to enjoy in the future the benefits of nuclear power only by carefully taking actions which reduce the probability of such catastrophies to essentially zero.

The traditional decision methods (cases 1, 2 and 3) all can be used to demonstrate the dominance of such catastrophic outcomes on a decision at any given time. Each of these methods, however, requires, as a minimum, that such catastrophic outcomes are recognized as possibilities at the time of the decision as possibilities. However, the environmental predicament, stated previously, forces one to recognize that man's ability to produce changes, of which some may be catastrophic, will exceed his ability to anticipate such changes as possible outcomes of considered actions. A decision strategy, therefore, must be developed which avoids catastrophic events yet does not require that all catastrophic events resulting from considered actions be specified at the time of the decision. Moreover, such a strategy should be reasonably acceptable to society, for any strategy that requires the continued presence of catastrophy or near catastrophy to be accepted by society, will likely not be effective in avoiding catastrophy. In short, man must learn to satisfactorily apply the rule of catastrophic possibility to environmental decisions within the restrictions of decision case 4.

Application of Rule of Catastrophic Possibility.—A general method used in engineering design to satisfy the rule of catastrophic possibility involves the consideration of only those actions for which the probability of catastrophic outcome is reduced to essentially zero. Choice among the considered actions can then be made under decision cases 1 or 2 with case 1 preferred.

As an example, the design load of a passenger elevator might be determined at some level above the maximum weight of people that could possibly fit into the elevator. This choice is made to avoid the possibility of a collapsed elevator (an outcome of low utility). Thus, the design choices would be restricted to those that could at least accommodate this loading regardless of the probability of any group of people ever attempting to attain it.

The application of the rule of catastrophic possibility to environmental decisions, however, is far more difficult. One is not faced with the problem of selecting a system which must be capable of handling certain specified loadings. Rather, environmental management is faced with the problem of determining the loadings which the system is capable of handling. Moreover, such determinations must be made with incomplete knowledge both of the system, which is exceedingly complex, and of the loadings, which have varied and interdependent influences on the system. The difficulty of such determinations can be appreciated by returning to the example of the passenger elevator. Imagine that one now has an elevator of unknown construction. It is desired to know how many people can be carried in this elevator. Without an adequate knowledge of the elevator construction, the only approach that would lead to a direct answer would be to load the elevator (preferably not with people) until it failed and then, conclude that the loading at failure was above the maximum load limit. One would then recommend that future loadings on all elevators which appear to have similar construction remain significantly below this limit, though in the case of ecosystems influenced by a complex set of loadings, there is far less assurance that such a restriction would prevent future failures. The aforementioned procedure is obviously wasteful, particularly if the number of available elevators is limited. While this determination procedure may seem crude, its approach is essentially identical to that followed in environmental management. Environmental standards have been established largely on the basis of past failures.

In summary, the above analogy of the elevator shows a simple manner in which the rule of catastrophic possibility can be applied to an engineering design. Similar approaches have been common in many areas of engineering design, and thus a precedent for the use of this rule has long been established. Applications of this rule to environmental decisions, however, have generally been on a trial and error basis. The ever increasing technological powers of man will enable him to significantly influence ever larger regions of the entire biosphere. Therefore, environmental determinations will increasingly approach the analogy of a single elevator in which we are all permanent passengers. Thus, while the trial and error approach used in the past has been considered inadequate, its continued use must be considered increasingly catastrophic.

Role of Mathematical Models.—The use of mathematical models in resource management has increased greatly in recent years, and a brief review of the role and limitations of such models is appropriate. In essence, a model of an object is a mathematical structure representing some perceived aspects of that object (but ignoring others). Models have become useful in the study of natural systems because of several features of such study. First, direct observation may require destruction of the object. An example is the determination of the biomass of a living tree. A second feature of concern is the time involved. Changes induced by cultural practice may require many years to develop. An example is the productivity of a forest area. Experimental studies of different methods of logging and stand reestablishment must necessarily be limited to the first few years of the next growth cycle. Evaluation of the effect over the 60-yr-100 yr cycle requires some form of model from which productivity over an extended period can be predicted.

Mathematical models thus provide an essential extension of the experimental method, but the extension is theoretical, rather than experimental, and subject to the concepts on which the model is based. Because such concepts are based on past experiences and observations, the use of mathematical models cannot be expected to remove the possibility of unanticipated outcomes. Moreover, the mathematical expression of concepts can contribute toward an overconfidence in these concepts. Such overconfidence can inhibit the development of new and different concepts. Further, the most coupled model is still an extremely simplified representation of actual ecosystems and absolute validation can be shown to be impossible. Thus, even though models are based on experimental results and have been carefully evaluated and shown to be useful, it is essential that the user remain constantly aware of the limitations. Specifically, e.g., one must not conclude that successful projection of dissolved oxygen concentrations in polluted streams by a particular model validates that model as an adequate description of aquatic ecosystems.

In short, mathematical models are powerful tools that enable man to better understand his environment. As such, they play an important role in the area of environmental management. The limitations of mathematical models, however, must be recognized and environmental strategies must account for such limitations.

Principal of Irreversible Events.—Let the utility measure (as introduced previously) be the index to contribution to quality of life so that the outcomes (catastrophies) to be avoided are those with extremely small utilities. Without becoming involved in the mechanics by which such an index is constructed, it is possible to generalize with regard to the properties of outcomes having extremely small utility. First, such an outcome will be wide in consequence, affecting a large segment of society. Second, it will be uncorrectable, so that upon recognizing the ill, man is unable to correct it. Thirdly, it must rank high in importance in the value system of society. The latter is mentioned only to acknowledge its importance. The following analysis will elaborate the aspects of correctability.

Ecological correctability must be viewed as consisting of two aspects. An undesirable state of the ecosystem is correctable if the ecological processes can be reversed, so that the system reverts to its former more desirable state. It is also correctable if the system can be manipulated into an equally desirable or more desirable different state, although this may irreversibly preclude return to the first one. The second aspect will be called substitutability.

Most acceptable corrective actions will likely have some reversible properties as a completely substitutive action would be difficult to obtain and might lead to further catastrophy. One can thus be certain of avoiding or at least lessening serious ecological catastrophies only if reversible actions are possible. Likewise, noncorrectable ecological catastrophy can result only if irreversible ecological changes have occurred.

The environmental strategy presented herein is based on the avoidance of large scale irreversible changes. This concept is defined as the rule of irreversible change and can be stated by either of the two following essentially identical statements: (1) No action or set of actions can be taken that leads to large scale irreversible ecological change; and (2) only those actions or sets of actions which essentially preserve ecological options can be taken.

Obviously not all irreversible change can be avoided. The intended meaning of large scale irreversible ecological changes can best be interpreted by examining the following examples:

1. Ecological components such as species, sets of species, habitat types, etc. are eliminated (become extinct) before their importance is recognized and effective action is taken.
2. A harmful condition or set of conditions becomes so widespread, before detection, that effective action by society is impossible.
3. Increasingly catastrophic ecological changes result from system modifications upon which society has become so dependent that removal of these modifications would be catastrophic in itself.
4. Environmental and social damage is such that, by the time it is sufficiently recognized by society, its effect on society results in the loss of capacity to take effective corrective action.

The preceding type 1 of irreversibility implies that readjustments by the ecological system in response to corrective action will essentially proceed on a geological or evolutionary time scale. Type of irreversibility can easily expand into one or all of the remaining types. The last two types 3 and 4, which imply the occurrence of the second type, results, in part, from changes within the social system. An example of type 3 might be the elimination of natural anadromous fisheries due to flood control dams. An example of type 4 might be the expanding use of drugs in society.

STRATEGY OF PRESERVED DIVERSITY

Strategy.—The environmental strategy presented herein proceeds directly and simply from the rule of irreversible change. This strategy calls for the uneven distribution of man's environmental influences so as to preserve environmental diversity including a wide range of essentially untouched ecosystems. Such preservation of diversity maintains ecological options and thus substantially reduces the probability of unanticipated large scale irreversible change. The strategy of preserved diversity requires that decisions to preserve ecosystems be as definite, final and binding as decisions to develop others. Moreover, this strategy rejects the notion that specific proof is needed for each decision to preserve, for a fundamental basis of this strategy is a recognition of the environmental predicament.

It is reasoned that the essence of the environmental predicament is the essential indeterminancy of the outcomes of environmental actions. If it is impossible to eliminate catastrophic outcomes by anticipating them, then it is necessary to adopt a strategy which will eliminate such outcomes without the requirement of anticipation. This approach follows the principle that strategies must be based on tactical limitations (see introduction). Such a strategy must take the form of diversification as elaborated in the following statements:

1. An action restricted to a part of the system is less likely to lead to a large scale irreversible outcome than is the same action applied to the entire system (spatial restriction).
2. Large scale optimization or specialization with respect to restricted goals or outputs leads to lowered resilience and lowered stability (state or organizational restriction).
3. An action which directly influences a system for a short period of time is less likely to lead to irreversible outcomes than is a comparable action which is more persistent (temporal restriction).

From these statements, a principle of preserved diversity upon which this strategy is based can be stated: The chances for irreversible consequences and environmental catastrophy will be reduced by maintaining environmental diversity in two dimensions, spatial and organizational, and by elimination or constraint of those actions which have a persistent effect.

This principle might just as readily be called the principle of preserved alternatives or the principle of preserved opportunities, because the net effect is to preserve environmental variation and to localize the potentially detrimental effects of man's activities. The strategy based on this principle, however, is not without cost, because the localization of an action of man may be purchased at the price of the localization of a benefit resulting from that action. The choice is made because the potential long term detrimental outcomes of all such actions override the immediate limited benefit of the action. Such a choice recognizes that tactical decisions must be subordinate to strategic decisions.

The cost of environmental protection has been discussed in a somewhat different frame of reference by Odum (6) who identifies two functions of ecosystems, production and protection. He argues that a gain in production results in a loss of protection and a gain in protection results in a loss of production. Historically, man has indulged his need for increased production. Because of man's widespread influence on his environment, he must now recognize and indulge the need for preserving the protective characteristics of ecosystems. Odum argues that "More emphasis needs to be placed on compartmentalization so that growth-type, steady-state, and intermediate-type ecosystems can be linked with urban and industrial centers for mutual benefit." Based on the work of Redfield (9) Odum stresses the need to preserve the open oceans as protective rather than productive regions. These are clearly arguments for preserved diversity and particularly for preservation of some ecosystems which are not optimally managed to produce goods for man's consumption.

Based on the needs of man beyond physical needs, Dasmann (2) pleads for environmental diversity; not only for the preservation of natural diversity but for the creation of man-made diversity. Dasmann's argument stresses the concept that preservation of environmental diversity will significantly contribute to the quality of life by increasing the richness of experience.

Certain broad aspects of historical approaches to pollution control are consistent with the strategy of preserved diversity. The perceived offensiveness of pollutants has been initially minimized by dilution or spreading pollutants over sufficiently wide regions of space and time. This approach changes the distribution in a manner so as to reduce the perceived problems to acceptable levels. When perceived environmental pollutant problems reach a sufficiently high level that dilution will no longer solve the problem, the historical approach has then been one of concentration or localization of serious pollutants. Such localization and concentration (and possible elimination) of pollutants has been usually brought about by technological means, such as waste treatment facilities.

While the strategy of preserved diversity also calls for the concentration and localization of man's activities, this strategy is significantly different from such historical approaches in at least two important aspects. First, the strategy calls for concentration or localization of man's activities before these actions are perceived to lead to serious problems. This requirement is necessitated by the recognition of the environmental predicament.

Second, the strategy of preserved diversity does not rely exclusively on the success of technological corrective methods, but rather is a preventive strategy. Not all of the consequences of man's activities are subject to technological treatment. Moreover, technological treatment is most often based on the unjustifiable assumption of an adequate knowledge of ecological systems. Finally, technological methods which require continued repetitions of positive actions by society should not be considered sufficient because, on a long term basis, social systems are far less durable and stable than ecological systems. The increased dependency of ecological systems upon technological artifacts of social systems must, therefore, be interpreted as a long-term decrease of ecological durability and stability. In short, technological environmental methods are necessary but not sufficient for environmental protection.

Research Priorities.—The strategy of preserved diversity raises many difficult questions. On what specific basis does one select areas (or systems) to be preserved? How large should these areas (or systems) be? How does one measure environmental diversity? What types of human activities should be permitted in the various defined areas? What are the legal and economic constraints of such a strategy? What complimentary strategies might be needed to cope with those activities of man which are difficult or impossible to localize or concentrate? The writers recognize that suitable answers to many such questions are not easily available, and that the answers involve considerations far beyond those usually afforded the choice of parks and wilderness areas.

One might conclude that the lack of available answers to these questions demonstrates the extreme difficulty in applying this strategy and thus is sufficient reason for its rejection. This conclusion is unacceptable; it must be recognized that the present availability of answers to such questions depends on the nature of the questions that have been asked in the past; i.e., information that is now available depends to a large extent on past research priorities. It is pertinent, therefore, to briefly review the general nature of past research priorities in the area of environmental protection, and more particularly in the environmental engineering field.

In general, environmental research priorities have been largely influenced by a high probability (near one) of occurrence of outcomes to be researched; i.e., high priority is given to those projects which investigate problems which have already occurred or which are anticipated as likely to occur. Such an attitude is considered reasonable and practical in view of pressing environmental problems. This attitude reflects the notion that decision case 1 (described previously) is the best basis for making decisions, and that, at worst, case 2 may be invoked. The writers have argued with this position in an earlier portion of this paper. The reality of the situation is that the most important problems may at any time be unperceived so that the primary goal of environmental research must be to identify problems, on the one hand, and gain a better understanding of system dynamics on the other.

The prevailing view of applied research is quite different. It is commonly held that applied research must by definition deal with recognized problems and only those recognized problems having high probability. It is further a commonly held belief that science (technology) can solve any problem once it is recognized and there is even evidence that some scientists do not consider a problem appropriate unless one knows how to go about its solution. All of these views are undesirable in light of the arguments presented herein, and one is forced to define the primary goals of research to be the study of relationships and events; in brief, the basic relationships of the natural system of which man's culture is an integral part and the events on which man can exercise some degree of control.

In most circles, this would be considered basic research, as opposed to applied research, and the general attitude is that basic research is somehow aimless and of practical value only by rare chance. However, from the point of view of the decision process and the arguments presented herein, it is clear that the study of the fundamental relationships of the world system is absolutely required for fulfillment of the management strategies dictated by the level of decisions which are made necessary by the nature of the problem. This applied research will also address recognized problems, but will do so within the broad perspective of the entire system, and the research structure must reflect the knowledge that as yet unrecognized problems may be more important than those commonly recognized.

In consideration of problems of allocating research effort and resources it is reasonable again to use the decision making structure presented earlier. Clearly the same four cases apply as does the subsequent argument. In making a decision with regard to research strategies, it is essential to recognize the logical status of the probabilities used in the decision process. The probabilities are really degrees of belief having strong subjective aspects, and only rarely will reflect the more objective basis, frequency of occurrence. Since degree of belief is strongly influenced by the orientation and perception of the believer, it is clearly possible for two scientists to have quite different view of research needs from exactly the same scientific superstructure.

In this view, the probability of occurrence is primarily a property of the person establishing the priorities and not a property of the actual events which might occur. These degrees of belief, and thus the established priorities, are based on past experiences. Priorities based on past experiences determine future experiences and thus they tend to impose the same beliefs on future priorities. The process continues with the result that research tends to remain involved in those areas of greatest experience. The process is partially disrupted by a dramatic demonstration of the importance of some other area; e.g., the recent interest in mercury. The probability of occurrence (the degree of belief) of an environmental mercury problem went from near zero to essentially one, largely as a result of demonstrations of importance. The toxicity of mercury and the factors effecting the distribution of mercury did not dramatically change at this time, rather it was the beliefs of the observers that changed.

The arguments presented herein disagree with a research priority system dominated by the probability of occurrence (which is really a degree of belief). Moreover, the absence of immediate answers to questions raised by the strategy of preserved diversity is likely the result of significant differences between the basic principles and concepts upon which this strategy is based and the basic principles and concepts which have been used in establishing environmental research priorities. The strategy of preserved diversity suggests a quite different environmental research priority system. The study of global systems and those influences of man which are difficult or impossible to localize would receive a high research priority under such a system.

In short, the arguments presented previously reinforce the need for a high level research strategy which transcends the formal decision structure and which not only accommodates the unperceived consequences but also accommodates the great variation in degree of belief in the perceived consequences. It will obviously be necessary for a large research effort to continue along the path of highest probability, but it is clear that an appropriate effort must be simultaneously directed to this high level of orientation.

CONCLUSIONS

It is concluded that man faces an environmental predicament caused by the essential indeterminancy and unpredictability of outcomes of man's actions. It is further concluded that existing strategies of environmental management are poorly defined and inadequate to accommodate this predicament. An environmental strategy is presented herein which calls for the preservation of environmental diversity. It is reasoned that such a strategy has the potential of reducing the chances of unanticipated environmental catastrophies. Finally, it is concluded that a set of such strategies which can sufficiently cope with the environmental predicament is essential to adequately prevent outcomes of man's actions which significantly destroy the quality of life as perceived by this and future generations.

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APPENDIX I.—REFERENCES

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APPENDIX II.—NOTATION

The following symbols are used in this paper:

A = action space;
a = specific action;
$E(U(a))$ = expected utility of action a;
O = outcome space;
o = specific outcome;
$P(o|a)$ = probability of outcome o given action a; and
$U(o, a)$ = utility value of outcome o and action a.