INCORPORATING RISK AND UNCERTAINTY INTO ENVIRONMENTAL EVALUATION: AN ANNOTATED BIBLIOGRAPHY

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Evaluation of Environmental Investments Research Program

IWR Report 96-R-9
September 1996

PREFACE

This report was conducted as part of the Evaluation of Environmental investments Research Program (EEIRP). The EEIRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE). It is jointly assigned to the U.S. Army Engineer Water Resources Support Center (WRSC), Institute for Water Resources (IWR), and the U.S. Army Engineer Waterways Experiment Station (WES), Environmental Lab (EL). Mr. William J. Hansen of IWR is the Program Manager, and Mr. H. Roger Hamilton is the WES Manager. Program Monitors during this study were Mr. John W. Bellinger and Mr. K. Brad Fowler, HQUSACE. The field review group members that provide complete Program direction and their District or Division affiliations are Mr. David Carney, New Orleans District; Mr. Larry Kilgo, Lower Mississippi Valley Division; Mr. Richard Gorton, Omaha District; Mr. Bruce D. Carlson, St. Paul District; Mr. Glendon L. Coffee, Mobile District; Ms. Susan E. Durden, Savannah District; Mr. Scott Miner, San Francisco District; Mr. Robert F. Scott, Fort Worth District; Mr. Clifford J. Kidd, Baltimore District; Mr. Edwin J. Woodruff, North Pacific Division; and Dr. Michael Passmore, WES EL. The work was conducted under the Incorporating Risk and Uncertainty into Environmental Evaluation Work Unit of the EEIRP. Mr. L. Leigh Skaggs of the Technical Analysis and Research Division (TARD), IWR and Mr. Richard Kasul of the Natural Resources Division (NRD), WES are the Principal Investigators.

The work was performed by the Greeley Polhemus Group, Inc. (GPG) under Task Order No. 28, Contract No. DACW-72-90-D-0002, managed by Mr. Leigh Skaggs. Dr. Charles Yoe was the principal investigator.

Valuable review comments and suggestions were received from Mr. John Bellinger, HQUSACE; Mr. Jim Henderson, WES EL; Dr. David Moser, IWR; Mr. Bill Werick, IWR; and Dr. Justin Williams, IWR.

The report was prepared under the general supervision at IWR of Mr. Michael R. Krouse, Chief, TARD; and Mr. Kyle E. Schilling, Director, IWR; and at EL of Dr. Robert M. Engler, Chief, NRD and Dr. John W. Keeley, Director, EL.

At the time of this writing, Mr. Kyle E. Schilling was Acting Director of WRSC and Dr. Robert W. Whalin was Director of WES. Commander of WES was COL Bruce K. Howard, EN.

EXECUTIVE SUMMARY

This report was prepared to provide assistance to the U.S. Army Corps of Engineers (Corps) in beginning to assess risk and uncertainty in the evaluation of environmental investments. The literature review presented in this report was developed as an initial effort for the "Incorporating Risk and Uncertainty into Environmental Evaluation" work unit of the Corps' Evaluation of Environmental Investments Research Program (EEIRP). The products of the EEIRP provide Corps planners with methodologies and techniques to aid in developing supportable environmental restoration and mitigation projects and plans.

This literature review is primarily for Corps personnel, but it has two audiences. It serves as both a primer on the generic risk analysis literature that will help planners find the tools they need to do risk analysis, as well as a gateway to help more experienced personnel find their way into the environmental resource risk analysis literature.

The first task in this research was to review the Corps' existing risk analysis guidance to determine how it may be useful in crafting the future development of risk and uncertainty analysis guidelines for evaluating environmental investments. The review begins with an introduction to the concept of ecosystem restoration. To provide a contextual approach to the review, the generic notion of uncertainty is considered in the ecosystem restoration planning process. A taxonomy of uncertainty is offered as a starting point for understanding the types and sources of uncertainty encountered in environmental resources planning.

The context begins with a review of two different ways to look at probabilities. Next, there is a generic discussion of the types of quantities encountered in ecosystem restoration planning that can be uncertain. The different types of quantities that are uncertain can have different sources of uncertainty, so a discussion of the sources of uncertainty follows. The contextual information looks at possible sources of uncertainty that may be encountered in an ecosystem restoration planning framework. The remainder of Chapter Two comprises the review of specific Corps' risk analysis guidance.

Existing Corps guidance for risk analysis tends to consist of two types: 1) general concepts, principles, and tools as discussed in manuals and reports; and 2) detailed and specific guidance as presented in Engineer Circulars (EC's) and Engineer Technical Letters (ETL's). There is much in the former guidance that can be readily incorporated into environmental risk analysis guidance. There is much in the latter guidance to be emulated by environmental risk analysis, but very little that can be directly adapted. Sample analyses, literature reviews, lists of key variables, introductions to the array of techniques and tools available for risk and uncertainty analyses, and models to be followed in structuring any potential future environmental risk analysis guidelines are among the most useful things to be gleaned from the Corps' existing guidance.

Chapter Three contains a review of the professional literature. Fifty-two books, reports, papers or articles have been reviewed at length for this report. They are presented in two sections, following an introduction that describes the review process. The first section contains literature that addresses the general methodology of risk and uncertainty analysis. It introduces readers to the literature that will help them find access to the general tools and techniques of risk and uncertainty analysis. The emphasis here is on introductory level readings,

though not to the exclusion of some intermediate and advanced sources of information. The second section of the professional literature review includes applications of risk analysis to environmental issues.

Each annotation begins with a complete citation of the book, report, paper or article. There follows a section called "applicability", which is intended to help the reader decide whether they are interested in reading the entire review. Following is the "review" portion of the summary, where the content of the item is summarized.

A useful summary of the 52 books and articles is presented in Table 3-1. For each annotated item, the following information is provided: title; year of publication; name of first author; whether the item is a book, a paper from a journal, a government report, or an article from a collection of writings; the type of reader who is likely to find the article most helpful or interesting (planners, analysts, mangers, novices, experts); and the three most important topics or ideas addressed in the item.

In addition to the 52 summaries, there are two more sections of the professional literature review. The third section provides some suggestions to the reader for sources of information worth monitoring for future developments in the literature. The final section of the professional literature provides an extended traditional bibliography of books and articles of potential interest.

The authors arrived at several observations in the course of conducting the literature review. One of the most significant observations is that the language of risk analysis has many meanings. Titles of books and papers, annotations, lists of keywords, and the contents of much that is written indicate a striking lack of uniformity in the language of risk analysis. For example, most of the numerous references to "environmental risk analysis" refer to the quantitative risk assessment of human health effects of projects and actions, a key interest of the Environmental Protection Agency (EPA). Human health or environmental risk assessment estimates the incidence of death and disease to humans resulting from exposure to hazardous agents. "Ecological risk assessment" usually means the estimation of hazardous agent impacts on non-human elements of the environment or the risk associated with chemicals. Very little has been written about risk and uncertainty analysis applied to environmental resource planning as the Corps conducts it.

Other observations include the fact that several federal agencies are actively involved in risk analysis research and development that could be of tremendous interest to the Corps in general and to the environmental program in particular; that there are many talented people doing a lot of good work in risk analysis; that there are many good, if narrowly focused, periodicals available, several of which are listed in the "Literature Sources to Monitor" section of Chapter Three; that risk and uncertainty analysis is everywhere in the literature, but it may be implicit rather than explicit; and, finally, that there is a great deal of good literature from which to choose. Although much of the literature discovered in the course of this review that referred to environmental risk analysis invariably alluded to the EPA paradigm for assessing risks to human health, there is nonetheless much that is of interest to the Corps in the literature, a point made numerous times in this report.

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CHAPTER ONE: INTRODUCTION

INTRODUCTION

This literature review was prepared to provide assistance to the U.S. Army Corps of Engineers (Corps) in beginning to assess risk and uncertainty in the evaluation of environmental investments. To address this and other issues the Corps initiated the Evaluation of Environmental Investments Research Program (EEIRP), intended to provide Corps planners with methodologies and techniques to aid in developing supportable environmental restoration and mitigation projects and plans. The EEIRP has been divided into ten specific study areas or work units. One of these work units is "Incorporating Risk and Uncertainty into Environmental Evaluation". The literature review presented in this report was prepared as an initial effort for this work unit.

TARGET AUDIENCE

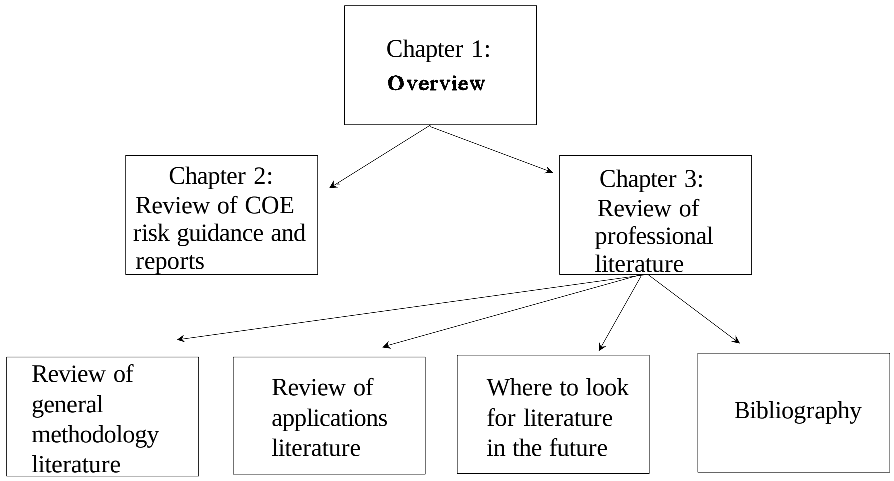
This literature review is primarily for Corps personnel, but it has two audiences. First, it serves as a primer on the generic risk analysis literature that will help planners find the tools they need to do risk analysis. Thus, one audience is the Corps analyst who knows little or nothing about risk analysis, and who will eventually be responsible for conducting the risk and uncertainty analysis for environmental investments. Second, the review is to help more experienced personnel find their way into the environmental resource risk analysis literature. Thus, this review may serve as a gateway to the more detailed and specific risk analysis literature for the Corps' risks analysts, planners, managers, modelers, and environmental experts.

ORGANIZATION OF REPORT

To serve these two audiences the literature review is organized as shown in Figure 1-1. Two main parts follow this overview. First, Chapter Two contains a review of existing Corps guidance and reports on risk analysis. This stands alone as a brief guide to what current Corps guidance on risk analysis might have to offer analysts applying risk analysis to environmental investments. To provide context to this review, it is preceded by an introduction to the generic concept of uncertainty in the ecosystem restoration planning process.

Next, Chapter Three contains a review of the professional literature. Fifty-two books, reports, papers or articles have been reviewed at length for this report. They are presented in two sections, following an introduction that describes the review process and some of its major findings. The first section contains literature that addresses the general methodology of risk and uncertainty analysis. It introduces readers to the literature that will help them find access to the general tools and techniques of risk and uncertainty

Figure 1-1: Organization of Report



analysis. The emphasis here is on introductory level readings, though not to the exclusion of some intermediate and advanced sources of information. The second section of the professional literature review includes applications of risk analysis to environmental issues. It is generally a more demanding literature.

In addition to the 52 summaries provided in these two sections there are two more sections of the professional literature review. The third section provides some suggestions to the reader for sources of information worth monitoring for future developments in the literature. The final section of the professional literature provides an extended traditional bibliography of books and articles of potential interest.

CHAPTER TWO: REVIEW OF EXISTING CORPS RISK ANALYSIS GUIDANCE

INTRODUCTION

Since the inception of the Corps' Risk Analysis for Water Resources Investments Research Program at the Institute for Water Resources there has been an expansion of the application of risk and uncertainty analysis methods to water resources planning. Risk and uncertainty analysis has grown from a fringe concept in the planning process to a mainstream idea on the way to becoming a powerful tool for improving the Corps' decision-making process. During the course of this evolutionary process the Corps has begun to develop guidance on risk analysis evaluation frameworks for flood control, lock and dam rehabilitation and other areas related to the Corps' missions.

This research represents an initial step in the development of a risk analysis framework for environmental investments. The first task in this research was to review the Corps' existing risk analysis guidance to determine how it may be useful in crafting the future development of risk and uncertainty analysis guidelines for evaluating environmental investments.

The review begins with an introduction to the concept of ecosystem restoration. To provide a contextual approach to the review, the generic notion of uncertainty is considered in the ecosystem restoration planning process. A taxonomy of uncertainty is offered as a starting point for understanding the types and sources of uncertainty encountered in the environmental resources planning process.[1] This is provided to aid the reader approaching the notion of uncertainty for the first time with seriousness of purpose.[2]

The context begins with a review of two different ways to look at probabilities. Next, there is a generic discussion of the types of quantities encountered in ecosystem restoration planning that can be uncertain. The different types of quantities that are uncertain can have different sources of uncertainty, so a discussion of the sources of uncertainty follows. The contextual information looks at possible sources of uncertainty that may be encountered in an ecosystem restoration planning framework. The remainder of Chapter Two comprises the review of specific Corps' risk analysis guidance. Items summarized in a literature review in Chapter Three of this report are occasionally referred to in this review of existing Corps' risk analysis guidance. The last name

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[1] Throughout this review the terms environmental resources planning, environmental investment planning, environmental restoration planning, and ecosystem restoration planning are used interchangeably.

[2] For a more detailed investigation of the sources of uncertainty in environmental restoration planning, as well as some of the tools available to address these uncertainties, please refer to another EEIRP product, *An Introduction to Risk and Uncertainty in the Evaluation of Environmental Investments,* IWR Report 96-R-8, March 1996.

of the first author listed and year of publication is cited in parenthetical notes following the mention of selected topics.

ECOSYSTEM PLANNING IN THE CIVIL WORKS PROGRAM

The starting point for discussing the development of risk and uncertainty analysis for environmental investments is the Corps' current framework for such planning. Engineer Circular 1105-2-206, "Ecosystem Restoration Planning in the Civil Works Program", provides the description of the planning framework against which this review of risk analysis guidance proceeds.

The purposes of EC 1105-2-206 are to assure that Civil Works investments in ecosystem restoration will have the intended beneficial effects; are consistent with Administration policy; and will be conducted in the most cost effective manner. Breaking with the environmental mitigation tradition of mitigating damage to fish and wildlife only, studies and projects initiated under the Corps' program to restore ecological resources will be formulated and implemented under principles of ecosystem restoration (see Cairns 1993, Droppo 1993, and Kusler 1990 in Chapter Three). Ecosystem restoration provides a more comprehensive approach for assessing and addressing the problems associated with disturbed and degraded ecological resources. The primary goal of ecosystem restoration is to return an ecosystem's structure, function, and dynamic processes to a less degraded, natural condition.

Ecosystem restoration planning considers the roles of plant and animal species and their habitats in larger community and ecosystem frameworks. Projects developed in this framework are conceived in a comprehensive context that provides aquatic, wetland and upland complexes with the potential for long-term survival as functioning systems.

Overlaying the principles of ecosystem restoration on the Corps' existing plan formulation and reporting processes results in a planning environment that is fraught with uncertainty. In the next section we discuss some of the potential sources of uncertainty in the ecosystem planning process.

UNCERTAINTY AND ECOSYSTEM RESTORATION PLANNING

To discuss uncertainty in the context of ecosystem restoration planning we have to address two significant issues. First, there is the taxonomy of risk and uncertainty analysis. What kinds of uncertainty are there? We need to know something about uncertainty in order to know where and how to look for it. Second, we need to know where in the Corps planning process it might exist. Only then can we turn toward the Corps' existing guidance to see if it can be helpful in the development of risk and uncertainty analysis guidelines for environmental investments.

This section begins with a discussion of the taxonomy of uncertainty that will be used in this report. It is the taxonomy used by Morgan and Henrion in their benchmark 1992 book, *Uncertainty: A Guide to Dealing With Uncertainty in Quantitative Risk and Policy Analysis* (reviewed in Chapter Three of this report and on which much of this section is based). Next, we offer a way to look at the places in the Corps' ecological restoration planning process where significant uncertainties of the types identified in the taxonomy might occur.

RISK AND UNCERTAINTY

Uncertainty describes any situation in which we are not absolutely sure. **Risk** describes a situation in which there is a chance of something bad happening. The chance is often unknown, as are the nature and extent of the "bad" thing that might happen. Risky situations, are, then, characterized by uncertain likelihood of occurrence and uncertain consequences; clearly, a case of uncertainty.[3] For simplicity this section proceeds by considering uncertainty to be inclusive of risk in a rather broad sense (see Glockman 1993).

Uncertainty arises for a variety of reasons: incomplete information, disagreement among experts or data sources, imprecise language, or variability that results from sampling error or the structure of a model. Probability is often used as a measure of uncertain belief. Probability is an appropriate way to express some kinds of uncertainty (for example, the uncertainty concerning the occurrence of a flood), but not others (e.g., uncertainty regarding an appropriate mitigation goal) (see Morgan 1992).

THE NATURE OF PROBABILITY

Probability is the best known way to quantify uncertainty. There are two basic views of probability: the classical or frequentist view and the subjectivist or Bayesian view (see Baird 1989). In ecosystem restoration planning there will be occasions to use both views, so they are discussed briefly below.

Classical View of Probability

The classical or frequentist view of probability (see Megill 1984) defines the probability of an event as the frequency with which it occurs over a very long series of similar trials. Probability can be estimated by the frequency of an event within a sample of that very long series. For example, the probability of a flow of 25,000 cubic feet per second (cfs) or greater is the frequency with which it is observed to occur over a very long period of time. If we have a sample of 100 years of flow data and see that flows equal to or greater than 25,000 cfs occurred 10 times, the frequency of this flow is 10/100 or 0.1, a ten-year event.

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[3] The authors acknowledge that these simple definitions mask distinctions between the terms that may be employed elsewhere. For example, "risk situations" have been described as those in which the potential adverse outcomes can be described in reasonably well-known probability distributions, while "uncertain situations" cannot be described by objectively known probability distributions. The language of risk and uncertainty analysis can be very confusing because many disciplines make use of its tools and methods. The point to be made here is that how we label a situation in the absence of certainty is less important than that we address it. The terms risk analysis, risk and uncertainty analysis, and uncertainty analysis are used as virtual synonyms in this report, less because there is no difference than because the difference is relatively unimportant.

But the frequency of flows in this sample are only an estimate of the probability of flows over 25,000 cfs. Probability is the value to which the long-run frequency converges as the number of trials increases. Suppose the true probability of a flow of 25,000 cfs or more is 0.2. By pure chance, our 100 years of record do not reflect the true probability. As the period of record (i.e., the number of trials, in this case, years of record) gets longer and longer, the observed frequency of these flows will begin to approach the true probability.

In this view, probability is seen as an intrinsic property of the system that generates the events. Flow volume is a function of rainfall, groundwater contributions, and channel and basin characteristics. Over a very long period of time flows greater than or equal to 25,000 cfs can be expected in 20 percent of the years because of the combination of local precipitation probabilities and the fixed characteristics of the basin. Frequentists might observe flows over a period of time and from that data try to estimate the true probability with more or less success, depending on the period of time they monitor, the length of that time period, and it's chance representativeness of the true probability.

The classical and frequentist views can be distinguished by their attitudes toward the probability estimate. The classical view sees probability as an intrinsic property of a system. For example, if we breed two heterozygous plants there is a 0.25 probability that an offspring will exhibit the recessive characteristic. This is a probability in a classical sense. The value 0.25 is an intrinsic property of the system of two heterozygous plants.[4] The frequentist view is demonstrated in the stream flow example above where we have flow data from a period of record and observe how often the event of interest has occurred. The resulting frequency is based on what we have observed and not necessarily on what is intrinsic to the system we are observing.

The frequentist view of probability will arise often in ecosystem restoration. The pure classical view of probability will be observed less often.

Subjective View of Probability

The subjective/ personalist/ Bayesian view of probability is quite different from the classical/ frequentist view. The subjective view of the probability that an event will occur is the degree of belief that a person has that it will occur, given all the information currently available to and known by that person. Probability depends not only on the event itself but also on the state of information about that event.

In symbols we would write a classical probability for event X occurring as P(X). The subjective probability would be P(X|e) where X is the event and e is the person's state of information upon which the strength of his or her belief is conditioned.

Implicit in this view of probability are at least three important points. First, since different people may have different states of information and/or different strengths of belief that something will or will not happen, it is quite normal that different people would estimate different probabilities for the same event. Second, because

[4] A heterozygous plant has one dominant and one recessive gene, Rr. When two such plants are bred the offspring can be RR, Rr, Rr, or rr. There is one chance in four of observing the recessive characteristic, rr.

the same person can acquire new information over time the same person may change his or her estimate of the probability of an event occurring. Third, following from these first two points we conclude that there is no such thing as "the" probability of an event. This is very different from the classical view that holds that probability is an intrinsic property of the system from which the event of interest is generated.

In ecosystem restoration planning, many of the probabilities will be subjective in nature. Given the substantial scientific uncertainty attending this emerging field it will not be uncommon to see probabilities expressed as an expert's degree of belief that an event will or will not occur (see Baird 1989, Clemen 1990, Megill 1984, and Morgan 1992). The very notion of an adaptive management approach to planning, the approach recommended in EC 1105-2-206, is conceptually aligned with the subjectivist view of probability. As additional information is obtained probabilities are revised in the subjectivist view. As additional information is obtained management techniques are refined in the adaptive management approach. Hence, there should be little philosophical difficulty with the notion of subjectivist probabilities.

The Union of the Two Views

In theory, when there is sufficient data for the frequentist to estimate a probability, the subjectivist's assessment of his or her probability will converge to the frequentist's estimate of "the" probability of the event. In other words, they will tend to agree as information becomes available.

UNCERTAINTY AND GENERIC QUANTITIES IN ECOSYSTEM RESTORATION PLANNING

It has been suggested that probability can be used to express uncertainty and that subjective probabilities can be helpful in expressing uncertainty about quantities. Planning models contain many different types of quantities and not all of them are amenable to probabilistic analysis. In general, only empirical quantities should be represented in probabilistic terms. To see why this may be so we need to consider some of the types of quantities that may be encountered in ecosystem restoration planning models (see Morgan 1992). Table 2-1 presents a summary of the generic types of quantities that can be encountered in the planning framework.

Empirical parameters or **chance variables** are empirical quantities that represent measurable properties of the resources and factors that can be measured in the planning process. They include quantities in the domains of all the disciplines involved in the study, such as population counts for significant species, water temperatures, stream flows, and quantity and cost estimates, for example.

In principle, all empirical quantities should have a single, true value that is empirically measurable. For example, the white tail deer population could, in theory, be measured exactly by counting. There is a

TABLE 2-1: Generic Types of Quantities in the Planning Framework

Type of quantity	Example	Treatment of uncertainty
Empirical parameter or chance variable	Mortality rate, stream discharge	Probabilistic, parametric[5]
Defined constant	Gallons per acre-foot	Certain by definition
Decision variable	Level of protection, mitigation goal	Parametric
Value parameter	Discount rate, value of life	Parametric
Index variable	Acreage, longitude & latitude	Certain by definition
Model domain parameter	Study area, planning horizon, base year	Parametric
Outcome criterion	Benefit/ Cost ratio, incremental costs	Depends on treatment of inputs

single true value for the white tail deer population at a given place and point in time. Whether we can actually determine that true value is another matter.

One type of quantity is always certain: **defined constants**. There will always be 43,560 square feet to an acre, 326,000 gallons of water in an acre-foot. These values are true by definition and we never have to worry about their uncertainty.

Decision variables are quantifiable achievement levels; they are set by the planning team. They are sometimes called “control variables” or “policy variables”. We may be uncertain about whether we have chosen the best level of protection for a flood damage reduction project or the best level of environmental mitigation. It makes no sense, however, to be uncertain about the "true" value of level of protection or environmental mitigation because these quantities have no true values. These are decision variables. Their values are selected by the planning team. To represent them as probabilistic variables detaches them from the decision process. It is generally more appropriate to vary decision variables parametrically, i.e., to use a sensitivity analysis.

It is important to bear in mind that decisions are made throughout the planning process. Planners may be required to make a choice and select one course of action over another at various points in the planning

[5] Parametric variation, also known as sensitivity analysis, is a process in which a number or parameter that is treated like a constant in the analysis is varied systematically over a range of values to examine its impact on the decision or result.

process. It may be desirable to test the sensitivity of the results of the planning process to the alternative courses of action in more cases than it is possible to do so.

Value parameters represent the preferences of the planning team or the people they represent, e.g., the general public, resource agencies, higher authority. The discount rate is an example of a value parameter. Historically, there has been considerable debate about the proper discount rate. In recent ecological literature the debate has been revisited. Congress has made a value judgment about what the discount rate should be and has prescribed a methodology for calculating it.

It is not unusual for a value parameter to be treated as an empirical quantity and represented by a probability distribution. This, however, is usually a mistake, sometimes a serious one. The key point about value parameters is that they are value judgments. If the decision-maker is not sure what he prefers, it would rarely be helpful to leave the value judgment to chance, as would be done if it's treated like an empirical quantity. If the planning team is not sure about a value parameter it is better to vary the values parametrically, i.e, first try one, then another, and so on. This allows the team to learn how changes in the parameter's value affect the outcomes in which we are interested.

Value parameters often tend to be those people are least sure about and they may contribute significantly to the uncertainty about the best alternative. If these quantities are treated as probabilistic it may mask the effect of the different value choices on the planning objectives. A systematic sensitivity analysis can be far more illuminating and can help decision-makers better understand and refine their preferences.

Index variables are used to identify and locate information in a model. For example, the base year, project year 10, grid cell 230, 90○50' longitude and 30○42' latitude. There is no reason to be uncertain about the value of an index variable. Although we may have considerable uncertainty about matters of space and time - when and where something might happen - it makes no sense whatsoever to design an indexing system that we are uncertain about.

Model domain parameters specify the scope of the study. We identify the Potomac watershed as the study area and a 50-year planning horizon. Values like these define the extent of the study. The planning horizon delimits the temporal domain of the study, the study area delimits the spatial domain. Considering levee heights in two-foot increments and habitat units in increments of 100 are examples of other model domain parameters.

It would be quite normal to be uncertain about what domain values are appropriate. As with the value parameters, however, there are no true values and it would be inappropriate to represent these model domain parameters with probability distributions. The choice of the domain values is up to the planning team. In many cases these decisions have been made and are set forth in the various sources of planning guidance. Nonetheless, it can often be useful to vary these values parametrically to determine the sensitivity of study results to different model domains.

The use of parametric sensitivity analysis (see Clemen 1990, Morgan 1992) in ecosystem restoration planning would appear to be a most valuable tool. In the first blush of excitement with risk and uncertainty analysis, many Corps planners have leapt to embrace Monte Carlo simulation models[6] (see Allardyce 1985, Clemen 1990, Davis 1982, Morgan 1992, and Newendorp 1976). While these models are undeniably useful in many settings, they are not appropriate in all settings.

Planners involved in ecosystem restoration have espoused an adaptive management approach. The success of this approach is predicated on planners becoming more informed about ecosystem restoration as the results of completed projects are monitored. Risk and uncertainty analysis can help inform planners about ecosystem restoration. The techniques can reveal insights as they improve decisions. It is usually easier to see the implications of value and domain choices, for example, by parametrically varying these values in a sensitivity analysis. Only in this way can we learn such basic things we need to know as what planning horizons make sense and what discount rates are most appropriate.

The **outcome criteria** are the variables we use to rank or measure the desirability of possible outcomes. The Corps has traditionally used the benefit-cost ratio (BCR) in its planning studies. When possible, the BCR is equally useful for environmental investment planning. Incremental costs are another outcome criteria in common usage for environmental resources planning. These outcome criteria will be deterministic if there is no uncertainty in the inputs used to develop them and there is an unambiguous analytical method to develop the criteria. However, if the inputs are probabilistic or there are no analytical methods for estimating the criteria, the outcome criteria will be probabilistic (see Bishop 1978 and Templet 1994).

Table 2-2 presents some generic environmental investment study tasks and concepts and attempts to indicate the nature of the quantities that might be encountered in these tasks. Many have more than one entry because the items in most cases could be broken down into numerous specific tasks, each of which could involve a different type of quantity. A table of this type could be a useful device for helping analysts think about the types of quantities they are working with and the subsequent methods for addressing their uncertainty.

[6] The Monte Carlo process is frequently used in computer simulation models in which values for random variables are generated based on one or more specific probability distributions (e.g., normal, lognormal, or uniform distributions). The process works as if the user specifies a type of probability distribution and its parameters and a number is randomly selected from that distribution. The random numbers generated by a Monte Carlo process can represent a sample of potential results in the process under consideration.

TABLE 2-2: Environmental Investment Study Tasks/Concepts

	Types of Quantities						
Study Task/Concept	**Empirical**	**Constant**	**Decision**	**Value**	**Index**	**Domain**	**Outcome**
Investment costs	X	-	-	-	-	-	-
Beneficial impacts	X	-	-	-	-	-	X
Watershed	-	-	-	-	-	X	-
Indicator species	-	-	X	-	-	-	-
Antecedent ecological condition	X	X	X	X	X	-	-
Role of species in ecosystem	X	-	X	-	-	-	-
Resource significance	X	-	X	X	-	-	-
Restoration objectives	-	-	X	-	-	-	-
Inventory	X	X	-	X	X	X	-
Forecast	X	-	-	-	-	-	-
Influencing factors	X	-	X	X	-	-	-
Ecological interactions	X	-	-	-	X	X	-
NED impacts	X	-	X	X	-	X	X
Experimental technology	X	-	X	X	-	-	-
Probability of success	X	-	-	-	-	-	-
Consequence of failure	X	-	-	-	-	-	-

SOURCES OF UNCERTAINTY

To this point we have concentrated primarily on the uncertainty that resides in empirical quantities. That is perhaps the most familiar kind of uncertainty but it may not be the most important. Model uncertainty is another type of uncertainty that can be more important in many cases (see Morgan 1992).

Using the habitat evaluation procedures (HEP), we can envision many kinds of empirical uncertainty. There will be considerable uncertainty about the choice of indicator species, the data, and so forth. It is not difficult to envision uncertainty about the values of the quantities that have to be entered into the HEP model. It is much more difficult to try to think about the uncertainty in the model itself. How much uncertainty is there in the form of the model? Are the assumptions underlying the model reasonable? Unassailable? How much uncertainty is there in the validity of identifying an indicator species to represent the functioning of an ecosystem? How much uncertainty is there in tying the future viability of a species to a habitat suitability index? Are these even proper ways to think about the problems?

MODEL FORM UNCERTAINTY

Uncertainty about model form frequently reflects a lack of theory or data, or perhaps a disagreement among experts about the underlying scientific or technical mechanisms at work in the system we are trying to model. Given the evolving art of ecosystem restoration planning there would appear to be substantial model uncertainty present in many environmental investment planning activities. The biological and habitat models currently in use can be a significant source of uncertainty in the evaluation of environmental resources investment plans, and will most likely be investigated as environmental risk assessment research proceeds

UNCERTAINTY ABOUT EMPIRICAL QUANTITIES

Empirical quantities measure properties of the real world systems analyzed or modeled in an environmental investment study. A starting point for most risk and uncertainty analysis would be to identify those key variables and parameters under each of the quantities listed in Table 2-1 (see Morgan 1992 and Canter 1993). Though a useful starting point, merely identifying the key variables does not distinguish the causes of uncertainty in the key variable. Analysts need a way to think about the causes of uncertainty.

Generic sources of uncertainty in empirical quantities are shown in Table 2-3. These can be used to order one's thinking about how to approach the risk-based analysis. By systematically identifying the sources of uncertainty in a study and devising an analysis to address the most significant sources of uncertainty, a good analysis can be assured.

TABLE 2-3: Generic Sources of Uncertainty in Empirical Quantities

- Random error and statistical variation
- Systematic error and subjective judgment
- Linguistic imprecision
- Variability
- Randomness and unpredictability
- Disagreement
- Approximation

Source: Morgan & Henrion 1992

Statistical Variation and Random Error

The best understood source of uncertainty is the **random error** or **statistical variation** that arises from errors in the direct measurement of a quantity. Few measurements are exactly right. Our instruments are not properly calibrated, our powers of observation are imperfect, we are flawed human beings. Our tools and ourselves make mistakes. This kind of uncertainty is commonly expressed through standard deviations and confidence intervals. Examples of this type of uncertainty in environmental investment will include estimates of ground cover and infiltration of water through soil types.

Subjective Judgement and Systematic Error

Subjective judgements are common sources of systematic errors. So-called experts are frequently ignorant of their own biases in estimating or assessing quantitative measures. Experts can sometimes be the last to recognize the limits of their experience and knowledge.

Systematic errors arise due to biases in the measurement instrument or the individual taking the measurement. Attempts to estimate populations from animal excrement counts can lead to errors if the ratio of excrement to organisms is incorrect. Estimating values with inappropriate or poorly calibrated tools yields systematic errors. Systematic error or bias is defined as the difference between the true value of the quantity being measured (the actual number of animals) and the value to which the mean of the measurements converge as more observations are collected (the estimated population based on our counting method).

A good analyst is careful to identify and eliminate all sources of systematic error. If systematic error is recognized it can generally be eliminated. When systematic error is not recognized it can present a serious problem. Estimating the size of a systematic error that is merely suspected is a difficult and often subjective task. It is much easier to underestimate the existence or effect of systematic errors than to overestimate them when quantifying uncertainties. Unfortunately, systematic error is not reduced by more observations.

Systematic errors can occur in any values that have to be physically measured with equipment that needs periodic calibration (e.g., hand-levels, the length of a person's pace, flow meters) or that are estimated by people unaware of their imprecision (e.g., habitat suitability indices). The solutions to these types of uncertainty are well-calibrated equipment in sufficient quantity for all analysts and rigorous training in data collection techniques. New analysts, contractors with minimally trained field personnel, and inflexible experts are common sources of such errors.

Linguistic Imprecision

Language is frequently an imprecise vehicle for communication. The stated objective of an environmental project of “restoring aquatic plant beds for fish and wildlife habitat” may sound like a perfectly clear planning objective to some planners, but what aquatic plants does it refer to? What fish and wildlife habitat would benefit from the restoration of aquatic plant beds? The natural environment would be restored to what level?

In many cases, a bit of clear thinking and precise language can clear up most uncertainty stemming from imprecise communication. Unfortunately, when a new jargon is developing as it is with the environmental investments and ecosystem restoration program there is going to be considerable imprecision in the language and considerable uncertainty about its meaning. There is a great deal of variation in the way different people interpret words and phrases and their interpretation is very context-dependent.

Even words in common usage like ecosystems, resources, and functioning have clouded meanings in new contexts. What is a functioning ecosystem? Would lumbermen give the same answers as an Audubon Society spokesperson when describing the functions of the forests of the Pacific Northwest? That linguistic imprecision that permits two people to give widely varying and honest definitions to the same terminology is a significant source of uncertainty.

Fortunately, linguistic imprecision can be relatively easily avoided once its potential existence is recognized. It is imperative that environmental planners recognize that there is considerable potential for such uncertainty in the early years of environmental planning as a new formal planning activity. Pains should be taken to assure that all stakeholders have a clear, specific and similar understanding of all important terms, concepts, tools, and quantities encountered in the planning process.

Variability

Variability has been called sampling error in the traditional textbooks. Analysts need to know the difference between uncertainty and variability. Uncertainty, in this current context, results from incomplete scientific or technical knowledge; variability results from sampling from a population.

Suppose we want to model the uncertainty about the average size of striped bass. We could catch, weigh, measure, tag, and release every bass in the study area. Or, we could take a sample of striped bass, weigh and measure them, and make some inferences about the population. Our uncertainty with the sample has two components. One is the uncertainty about the distribution of the population (uncertainty that arises from incomplete knowledge) and the other is the uncertainty that results from sampling from this distribution (variability).[7]

When we take a sample and calculate the sample mean it's reasonable to expect the sample mean to differ from the population mean by some amount. When a sample is drawn, sample statistics estimated, and confidence intervals constructed, the analyst is treating the variability in the data. This is only one source of uncertainty in the data. Although it was common to address only this type of uncertainty in early risk analyses, it is rarely adequate. The other sources of uncertainty are often far more significant.

Generally, variability can be reduced by disaggregating or increasing the sample size. Stratifying the sample or sampling more units may help. On the other hand, uncertainty can only be reduced by further research that increases our knowledge of the uncertainty modeled.

Inherent Randomness and Unpredictability

Inherent randomness is often defined as uncertainty that is impossible to reduce. Some would debate this point, saying that such indeterminacy is not a matter of principle but only the result of our limited understanding of the world. The practical issue for the analyst is, "Is the uncertainty reducible in practice?" A quantity that is random to one person who does not understand the systems at work may be deterministic for

[7] This uncertainty may be expressed in terms of probability distributions for the frequency distribution's parameters such as its mean, standard deviation, and median.

another person who knows the underlying process that generated the quantity. The planner should try to distinguish uncertainty that can be reduced by further study from that which is inherently random, for the latter can't be reduced. Taking full advantage of the expertise present in the interdisciplinary study team can help reduce this type of uncertainty to the maximum practical extent.

An economist may not understand the computed water surface profiles, and conclude the uncertainty here cannot be reduced further. A hydraulic engineer, on the other hand, may readily be able to reduce the uncertainty. Uncertainty about the cost of constructing structures can often be reduced by more detailed estimating techniques. Uncertainty about the years in which future floods will occur cannot be reduced by any practical means and it is not worth trying to do so.

Disagreement

Different people can view the same problem from very different perspectives. For example, is the problem flooding or is it developed floodplains? Two experts can look at the same evidence and draw different conclusions. The levees have prevented millions in dollars of damages. The levees have destroyed thousands of acres of wetlands. Which side is right? It's quite possible the two sides might disagree.

When experts disagree, the nature of the **disagreement** should be explained. Sometimes the opinions can be combined using some weighting system. This is usually best when the differences are insignificant for planning purposes. If the disagreements have implications for the planning effort it is better to keep them separate and perform a sensitivity analysis.

Approximations

Models are abstractions of real systems. They inevitably simplify real events and interdependencies. Tradeoffs between model complexity and computation costs dictate that most model results yield mere **approximations** of the actual values. One way to estimate the uncertainty introduced by the approximation is to increase the resolution of the model and measure the difference between the two models. Approximation uncertainty can be difficult to ascertain, but it is most often addressed by sensitivity analysis.

Habitat models are used to estimate changes in environmental resources. How good are the approximations? The only way to tell is to compute the losses with a better model. This is rarely possible. If a better model were available it would have been used.

Occasionally, the best models are not used because they are too expensive. A WET evaluation may be used for the reconnaissance report when a HEP evaluation may have been better. In a case like this the uncertainty due to approximation can be estimated in subsequent studies by using the more sophisticated HEP evaluation.

POTENTIAL SOURCES OF RISK IN ECOSYSTEM RESTORATION PLANNING

Table 2-4 identifies items taken from EC 1105-2-206 and offers a very preliminary attempt by the author to identify the types of uncertainty that might be encountered at each step in the planning process.[8] The table offers several overview broad patterns. First, disagreement would appear to be a potential source of uncertainty at virtually every stage of the planning process. Environmental investment is a frequently contested project purpose attended by substantial scientific uncertainty. The existing uncertainty ensures that there is ample room for disagreement. The controversial nature of the plans suggests these differences may be exploited frequently. An open planning perspective that gives full voice to all points of view may be the best response to these differences. From an analytical process, the differences found most worthy of consideration can be addressed in a parametric manner.

Second, there is a potential problem with communication. Much of the jargon and many of the concepts are new and still evolving. In these circumstances there are likely to be a substantial number of communication problems among study stakeholders. Information and education are the best ways to reduce this type of uncertainty when it is encountered.

Random and systematic errors will be encountered most often during the collection of data and the analytical work of the study. In the field of environmental issues where ideology often plays a strong role in the definition of issues we must remain aware of the potential for systematic errors resulting from biases on the part of various stakeholders. Variability will likewise be encountered most often during the data collection tasks where samples must be relied on for information about the population.

The random errors and variability can be dealt with through traditional probabilistic and statistical methods including Monte Carlo simulation, as appropriate. Systematic errors cannot be addressed by larger samples and can dominate the overall error in some cases. The danger with these uncertainties is that they are often not recognized and they go untreated. When the tools are poorly calibrated but yield consistent readings it is difficult to recognize the error. Likewise, poorly designed tools are often the best available and the error goes undetected. Models can be unintentionally systematic in the uncertainties they introduce to an analysis. Institutional or human bias is by its nature rarely acknowledged and can be difficult to detect. Once detected it should be systematically removed from the data or planning process.

Unpredictability can be a problem throughout the planning process. This includes those things we simply do not know, like how an ecological system functions or what the system would have been like had a reservoir not been built 60 years ago. It also includes those things we don't know because we lack the expertise needed to understand them. Some of this type of uncertainty can be removed by further research - more or better data or additional expertise. Other examples of this uncertainty are irreducible because they are fundamentally unknowable.

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[8] Both generic and specific sources of uncertainty in environmental restoration planning are covered in greater detail in IWR Report 96-R-8, *An Introduction to Risk and Uncertainty in the Evaluation of Environmental Investments*, March 1996.

TABLE 2-4: Types of Uncertainty (EC 1105-2-206)

Item	Random Error	Systematic Error	Linguistic Imprecision	Vari-ability	Unpredict-ability	Disagree-ment	Approx-imation
Purpose	-	-	X	-	-	X	-
Applicability	-	-	X	-	-	-	-
Philosophy	-	-	X	-	-	X	-
Definitions	-	-	X	-	-	X	-
Resource significance	X	X	X	X	X	X	X
Non-Federal partner	-	-	-	-	-	X	-
Ecosystem context	-	X	X	-	X	X	X
Operational effectiveness	-	-	X	-	X	X	X
Recon considerations *	X	X	-	X	X	X	X
Scoping *	X	X	X	X	X	X	-
Inventory *	X	X	-	X	X	X	X
Forecasting *	X	X	-	X	X	X	X
Measurement *	X	X	-	-	-	X	X
Techniques *	X	X	-	X	X	X	X
Problem ID *	-	X	X	-	-	X	-
NED role *	X	X	-	X	X	X	X
Compare plans *	-	-	-	-	-	X	X
Cost effectiveness & ICA*	X	X	X	-	-	X	X
Adaptive management	-	X	X	-	X	X	X
Monitoring	X	X	-	X	X	X	X
O&M requirements	-	-	-	-	X	-	-
Decision-making criteria	X	X	-	-	-	X	X
Report requirements	-	-	X	-	-	X	-

* Related to reconnaissance and feasibility phase studies

With these overview remarks in mind, the following sections suggest how some of the different sources of uncertainty might arise for the various items presented in Table 2-4.

PURPOSE, APPLICABILITY, PHILOSOPHY, DEFINITIONS

The purpose, applicability, philosophy and definitions of environmental investments are primarily policy-based. They define a new subfield of water resources planning and introduce new initiatives, goals, concepts and language. As such, there is bound to be considerable uncertainty about this new program purpose. Even seemingly straightforward terms like "investments" and "ecosystem restoration" that are so basic to this new endeavor are fraught with uncertainty. It can be expected that there will be confusion and disagreement about what all of this means. The uncertainty here arises less from more classical sources of uncertainty than from the imprecision of language. Ecosystem restoration may conjure visions of the Garden of Eden to some and a simple halt to an imminent loss to others.

RESOURCE SIGNIFICANCE

Another crucial aspect of environmental investment planning is the establishment of resource significance needed to prove a Federal interest in the project. There will be communication issues about what constitutes a resource and what makes it significant (linguistic uncertainty). The relationships between the resources and project outputs can be full of unpredictability, often due to a lack of information and understanding. As above, data measurement may result in random and systematic errors. Sample data will lead to variability. The models relating resources and outputs will be full of approximations. Once again, with such an obvious lack of certain knowledge, disagreements over what constitutes a significant resource seem likely.[9]

NON-FEDERAL PARTNER

Given the nature of cost-sharing arrangements it is wise to expect the non-Federal partner to give more credence to scenarios (i.e., parameter choices for decision and value quantities) that lead to lower cost shares for the non-Federal partner. This may conflict with other expert opinions about quantity values.

ECOSYSTEM CONTEXT

Plans are to consider the role of ecological resources in the larger context of the ecosystem and its plant and animal communities. It's not yet clear that anyone can do this in a deterministic fashion. Insofar as these appear to be value quantities the uncertainty is more likely to be systematic than random. Once again, language can be expected to be a problem when the terminology is so new and its precise meaning so distant. Much of this uncertainty stems from a lack of information and unpredictability. The models used to establish the role of resources in a larger context must be approximate and disagreement among experts is to be expected.

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[9] IWR Report 95-R-10 (June 1995), *Resource Significance: A New Perspective for Environmental Project Planning*, discusses the concept of resource significance in terms of scientific, institutional, and public criteria, and provides detailed summaries of selected programs that assist in determining environmental significance.

OPERATIONAL EFFECTIVENESS AND O&M REQUIREMENTS

The reliability of environmental investments, i.e., their ability to perform the purpose for which they are intended in a reliable fashion, is one of the fundamental uncertainties attending environmental investment planning. The extent of required operation and maintenance activities may well be unknown until we develop some experience with ecosystem restoration and other projects.

RECONNAISSANCE AND FEASIBILITY CONSIDERATIONS

Items marked with an (*) in Table 2-4 relate to reconnaissance and feasibility phase studies. Most of these tasks are currently part of existing water resource planning studies in the reconnaissance and feasibility phases of study and have been recognized as exercises in uncertainty for some time.

The new nature of environmental investment planning and its sometimes hotly contested issues add a different dimension to the ordinary planning tasks. There may be greater difficulty in getting agreement on such things as problem identification. One group may see anything less than full restoration as unresponsive. Another group may not even recognize the existence of a need for a contested resource. Both may be supported by the same data and different perspectives. At other times they may rely on their own data sets. Models are likely to be more approximate because the science is not as developed and holistically integrated. Disagreements are more likely, in part as a result of linguistic imprecision and in part because of a realistic basis for different points of view.

ADAPTIVE MANAGEMENT AND MONITORING

An interesting and foresighted concept, adaptive management is another in a series of evolving concepts. It will take some time before people begin to get comfortable with the idea of adaptive management. The very notion of adaptive management arises from an enlightened acknowledgment of the uncertainty that exists in this planning arena.

In essence, adaptive management says you formulate the best plan possible considering the range of possible results. The plan is implemented as formulated but it is carefully monitored. As additional information is obtained about the ecosystems you are concerned with and the performance of the project, you tinker with the project/ management plan to adapt to the new information you are gaining. Adaptive management is learning by doing. In time risk and uncertainty analysis will help planners consider the range of results that could be realized from a unique or experimental plan. This prior knowledge should lead to better formulated adaptive management plans.

DECISION-MAKING CRITERIA

Cost effectiveness, incremental cost analysis, identifying environmental outputs and valuing them where possible are among the decision-making criteria that could be used. These will be subjected to random and systematic errors if the data and analysis that goes before them were subjected to these errors. Because the models used to generate the input data for these decision criteria are approximations, the criteria will be as well. Disagreements over data, models, methods and assumptions can always be expected.

The criteria supporting plan justification include acceptability, completeness, efficiency, effectiveness, and restoration measure applied. This adds a criterion to the four used for more traditional planning purposes. It also weakens the efficiency criteria by providing for a quantitative assessment of the costs of the projects only. There will rarely be a quantitative assessment of the value of the outputs produced by the plan. This makes the selection of an efficient project even more uncertain than usual.

REVIEW OF EXISTING CORPS RISK ANALYSIS GUIDANCE AND REPORTS

The preceding sections presented a discussion of the types of quantities that can be uncertain as well as the nature of the different kinds of uncertainty that are most commonly found with empirical quantities. In an abbreviated review of some environmental investment planning issues we have attempted to identify some of the potential sources of uncertainty in primarily, but not entirely, empirical quantities that will be encountered in environmental investment planning.

With the different types of quantities that can be uncertain in mind, the types of uncertainty and a general idea of where uncertainty may be encountered in environmental resource planning, we can begin to consider existing Corps guidance on risk and uncertainty analysis to learn if it may be helpful in the development of risk analysis guidance for environmental investment planning.

In the following sections selected existing risk analysis guidance used by the Corps of Engineers are reviewed. The review begins with a complete citation of the guidance and proceeds in a narrative fashion to describe the applicability of that guidance to the development of risk analysis guidance for environmental investment planning. Chapter Two of this report concludes with a summary discussion of the guidance reviewed.

Engineer Circular 1105-2-205 *Risk Based Analysis for Evaluation of Hydrology/Hydraulics and Economics in Flood Damage Reduction Studies*

The purpose of the EC is to provide "...guidance on the evaluation framework to be used in Corps of Engineers flood control and flood damage reduction studies." The EC itself is four pages in length and is accompanied by 54 pages of extended examples in three appendices. This EC represents detailed, specific, and directed guidance for field personnel. It is an excellent example of directive guidance.

The EC's *Background* material is as applicable for environmental investment planning as it is for flood damage reduction studies. It states that risk and uncertainty are intrinsic in water resources planning issues; best estimates of key variables and sensitivity analysis are to be used; and, risk analysis can be advantageous to the planning process. These are important principles, well worth repeating for any planning context.

The structure of the guidance (*Purpose, Applicability, References, Background, Definitions, Key Variables in a Risk-Based Analysis, Policy and Required Procedures,* and *Examples of Risk-Based Analysis*) provides an excellent model for future detailed guidance. The definitions are important for limiting uncertainty that results from an imprecise language. The emphasis placed on key variables illustrates the importance of this task. It is perhaps the single-most important first step on which any environmental investment planning risk analysis should focus. Preliminary identification of the key variables is essential so that the nature of the uncertainty can be discerned and potential techniques for addressing it developed.

The details in the *Policy and Required Procedures* are too specific to the estimation of flood damage reduction expected annual damages to warrant any detailed review here. Once again, however, the EC provides a valuable model for future detailed guidance. There is a clear directive to use risk-based analysis followed by a statement of the ultimate goal of that analysis that includes a statement of the minimal requirements for a risk analysis. The EC prescribes that the results of the analysis present the expected value and the distribution of NED benefits. Considerable attention is given to the issue of how to handle what was once called "freeboard".

The *Appendices*, particularly *Appendix A*, provide excellent examples of possible directions for any future environmental investment planning program risk analysis guidance. It also provides some examples of what to avoid.

Appendix A explains the nature of the plan formulation problem for flood damage reduction studies in a coherent, overview fashion. This "big-picture" view of the problem is an essential starting point. In environmental investment planning a similar effort will be needed to tie the uncertainties inherent in the biological models with the engineering and economic uncertainty. Environmental planning efforts are too unique and varied to lend themselves easily to representation by any one simple model. Nonetheless, a generic model of the basic elements of the decision problem would be a unifying structure for analysts to formulate their risk analysis about. A framework that is a corollary to the hydroeconomic model of Figure A-1 in the EC, showing how the major components of the analysis relate to one another, would be an invaluable aid to the development of future risk analysis procedures and guidance.

The “Risk-Based Strategy for Project Formulation” section in the EC is a good idea in principle. The disadvantage of this and other sections of the *Appendix A* example for environmental investment planning is that it relies more on the Monte Carlo process and simulation than the risk and uncertainty analyses for environmental investment planning might. Section II and subsequent sections of the *Appendix* provide detailed discussions of the uncertainty attending relationships presented in the basic risk-analysis problem. This format is a good one. It would be appropriate to discuss habitat model uncertainty, environmental output uncertainty, structure performance uncertainty, and cost uncertainty separately when, and if, guidance is developed for environmental risk analysis. The structure used in this EC is exceptional.

While much of the content of the EC is far too specific to flood damage reduction to be usefully reviewed here, there is much of general interest. Section III includes a section titled "Stage Uncertainty Factors and Issues", which provides a list of the specific quantities that can give rise to different types of uncertainty. Table A-4 in Section III does the same in more detail. One option is to use and build upon the presentation of Table A-4, incorporating the structure provided by Morgan and Henrion's (1992) taxonomy.

The far right column of Table A-4 provides a somewhat comprehensive list of key variables.[10] We think two additional columns identifying the type of quantity and the source of uncertainty in the context established by Morgan and Henrion (1992) presented earlier in this report would be useful. With this additional data we would have a better idea how we might appropriately go about addressing the uncertainty inherent in these key variables.

Guidebook for Risk Perception and Communication in Water Resources Planning, Part I Underpinnings and Planning Applications **and** ***Part II An Annotated Bibliography*****, IWR Reports 93-R-13 and 14, October 1993**

The *Guidebook* provides a review of the major observations and theories found in the literature about how people perceive risk. It sets forth the maximization of expected utility as the normative model, then proceeds to identify the limitations to this model. In subsequent chapters the guidebook develops the limitations to the normative model in substantial detail. The limitations discussed include: the filters that risk information must penetrate; cognitive problems with risky decisions; and the role of social pressure and amplification in communication.

The major contribution of the guidebook is Chapter VI, which presents guidelines intended to assist water resource planners and managers in their efforts to communicate with the public and decision-makers about situations in which risk is important.

While there is little in the *Guidebook* that is specific to environmental investment planning, there is a great deal that could be useful in minimizing or eliminating the uncertainty that results from linguistic imprecision and disagreement, two likely, common sources of uncertainty in the environmental investment planning program. Communication is the key to addressing both these sources of uncertainty. The guidebook presents a set of guiding principles when the objective is to get people to understand an uncertain situation and another set of principles when getting people to take action is the goal. These principles are reproduced in Figure 2-1.

[10] This list provides a good example of one of our most serious concerns about such lists. Field personnel looking for direction that will help them satisfy the analytical demands of their higher authority can tend to take ECs as gospel rather than guidance. Lists can be dangerous when they are not comprehensive and it is very difficult to be comprehensive. For example, personal experience with sensitivity studies has indicated that the lowest ground elevation at which flood damages begin, sometimes called the zero damage point or ground elevation, is the single most important variable in expected annual damage calculations in areas with frequent flooding. This variable does not appear in the list and may never be investigated.

Though the orientation of the *Guidebook* seems to be toward communicating physical risks to the public, there is much insight that is useful to anyone involved in risk analysis. It describes such common phenomena as denial, which is frequently encountered in environmental studies. "The method chosen for coping with uncertainty in many planning and policy-making contexts is simple if not very defensible: those involved pretend it does not exist" (p.1). About environmental management, the *Guidebook* says, "...ecological-modeling capability may reflect substantial ignorance of how relevant systems, such as wetlands, actually function in the larger context, as well as a serious lack of historical data on inputs and end points" (p. 3). In presenting examples of problems public agencies face that do not fit the normative model, the guidebook provides useful insight into environmental risk analysis in the following quotation:

> "Ultimately, the Secretary of the Army's position on the permit will have to be based, in part, on the expert judgment of ecologists about the probabilities of various types and levels of harm. But there is no requirement that even entirely rational citizens should accept these judgments."

This last point is an excellent example of the need for clear and concise communication about all matters of risk and uncertainty, because they are a hard sell under the best of circumstances.

While the *Guidebook* is full of useful insights, examples and suggestions, there appears to be little that could be explicitly adapted from the *Guidebook* to draft risk guidance for environmental investments. The annotated bibliography that constitutes Part II of the *Guidebook* was used in the preparation of the bibliography that accompanies the literature review in Chapter Three of this report.

FIGURE 2-1: Guiding Principles in Communicating Uncertainty

When Understanding the Uncertainty Is the Objective

- Uncertainty should be expressed in a variety of ways. Care should be taken to avoid encouraging thinking of independent events as cyclic, with fixed return intervals.
- Disagreements among experts should be made explicit and not concealed. If possible, the range of options should have probability weights attached to alternative possibilities.
- The decision problem outcomes should be framed in at least two ways, one stated as losses from best case and one as gains from worst case.
- Stress the analogy of the project to an insurance policy against catastrophic loss whenever this is appropriate.
- Provide information that allows the audience to assess the risk of the contemplated project relative to other activities and programs, both individual and collective.

When the Objective is to Take Action About the Uncertainty

- The campaign should effectively convey a message about the seriousness of the risk.
- The program should provide social reinforcement of risk reduction behavior especially at the local level.
- The campaign should make an attempt to convince the consumers that their actions aimed at reducing risk will help to mitigate risk impacts.
- Risk Reduction efforts requested by the campaign should be equitable.
- The specific strategies of the campaign should rely, to the extent possible, on providing a feedback on risk reduction efforts and providing economic and social incentives for doing so.

Note: Adapted from Summary p. 73.

***Guidelines for Risk and Uncertainty Analysis in Water Resources Planning Volume I Principles with Technical Appendices*, IWR Report 92-R-1, March 1992**

Volume I of the *Guidelines* provides a discussion of basic principles of risk and uncertainty analysis that provide a relevant and concise context for the development of risk analysis principles for environmental investment planning. The basic concepts presented in Chapter 2 are somewhat dated in that there is now a widely accepted interchangeable use of the terms uncertainty and risk, a position not taken in the March 1992 report. Uncertainty is used as the comprehensive term that describes situations of risk (i.e., an unwanted consequence and its probability of occurring), as well as the full range of uncertainties discussed earlier in this report.

Risk analysis is described as consisting of an assessment and a management function. The distinction between the **assessment of risk**, the technical analysis required to develop results, and the **management of risk**, what decision-makers do with those uncertain results, is still a valuable one. Any risk analysis guidance should pay particular attention to the duality of the risk analysis. It consists of an assessment stage that includes technical analysis and a management stage that includes the evaluation of the results of the assessment in the broader planning context. These two components will be substantially different in terms of their foci, stakeholders and techniques. For example, model uncertainty may be a substantial assessment issue, while expert disagreement could dominate the risk management phase of the analysis.

Chapter 3 on "Risk and Uncertainty Analysis in the Planning Process" provides a good starting point for any new risk analysis guidance. If the initial guidance is to avoid reliance on specific techniques and models it should, at a minimum, provide guidance in the explicit context of the environmental investment planning process.

Suggestions that multiple "without project condition" scenarios be developed, that key variables at each stage of the planning process be identified, and that the risk analysis transition gradually through the planning process from an emphasis on assessment to an emphasis on management are as relevant for environmental investment planning guidance as they are for the general planning process. The guidebook stresses the need to be open and above board about the uncertainty analysis. This is even more important with ecological uncertainty.

Chapter 5 on "Techniques for Dealing with Risk and Uncertainty" is particularly important because it presents some of the range of techniques that can be used in uncertainty analysis. Ecological restoration planning has the opportunity to embrace a broader range of analytical tools than have been adopted so far. Flood damage reduction studies and lock and dam rehabilitation studies have appropriately emphasized simulations. Environmental investment planning may require a broader range of tools. This chapter provides a good place to start identifying possible tools.

Chapter 6 on risk communication has been more fully developed in IWR Reports 93-R-13 and 14. Nonetheless, some useful distinctions are made between internal and external communication of risk issues. The chapter provides a good summary of the most significant risk communication issues.

The outline presented in Chapter 7, "A Risk and Uncertainty Analysis Outline", provides a useful model that might be emulated by those doing environmental investment planning. The chapter makes a fundamental point that today's analysts must understand: "There is no formula for conducting a risk and uncertainty analysis." Even so, a systematic approach to any risk and uncertainty analysis can and should be developed prior to the initiation of the study. The outline presented in the chapter presents a viable example of how this might be done.

The Technical Appendices of *Volume I* provide considerable useful information for those unfamiliar with the basic tenets of risk analysis. The bibliography in Appendix A provides an excellent cross-sectional summary of the general risk literature prior to 1992. Little of direct use to those interested in explicit applications of risk analysis techniques to environmental issues will be found in these volumes, however.

Excerpts from the *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (also called the "Principles and Guidelines" or "P&G"), relating to risk and uncertainty are reproduced in Appendix B.

The basic concepts of probability are presented in Appendix C. The presentation is conventional and a bit dry. It would provide an adequate review of anyone seeking a concise brush-up on principles of probability but offers little real insight to those who are far removed in time from their formal training in probability.

Appendix D, "Distributions", provides a handy overview of several key aspects of probability distributions. Following some rather stiff definitions of random variables, probability density functions (PDF), and cumulative distribution functions (CDF), the appendix contributes some useful insights for the non-statisticians. The relationship between the PDF and CDF is developed so the reader can understand that there are different ways of presenting the same information. The appendix pays attention to the role of parameters in determining the shapes and locations of distributions and this too is useful to new risk analysts. The appendix concludes with a discussion of distribution fitting that provides a good introduction to the topic. Understanding probabilities and distributions is essential for any risk analysis, whether assessment or management, and Appendices C and D are helpful starting points for this purpose.

Appendix E, "Sampling Techniques", addresses a useful topic. Though it presents a useful introduction to concepts like simple random samples, stratified random samples, and cluster samples, it is far too superficial to be very useful.

Expected utility theory is addressed in Appendix F. This is a very important concept in the field of risk analysis. The differences among risk-adverse, risk-neutral, and risk-seeking attitudes are illustrated with a flood damage reduction example. These risk attitudes are essential to understand for the risk management phase of a risk analysis.

Risk-adverse people tend to be willing to pay more than the expected damages they could incur in order to eliminate the possibility of those damages destroying their property or security. For example, we might pay $300 annually in fire insurance to avoid a fire loss with an expected value of $50 per year. A risk neutral person would only pay $50 to avoid this fire risk. A risk-seeking individual would pay less than $50 to avoid the potential fire loss. These are concepts risk analysts need to understand to access the risk literature and to address people's perceptions of risky situations. The appendix also presents a couple of alternatives to the expected utility criteria for judging risks.

The forecasting overview in Appendix G provides a reasonable overview of the components of time series data and some simple time series forecasting methods. The value of this appendix lies in the range of topics it covers, including qualitative forecasting methods which may be very important for environmental investment planning.

Simulation is the topic of Appendix H. Brief discussions of when to simulate as well as the advantages and disadvantages of simulation are presented. A cursory overview of the Monte Carlo process is provided. The material in this appendix is most rudimentary. Many of the simulation languages cited are now defunct. There are far better introductions to the Monte Carlo process contained in the users manuals of @RISK and Crystal Ball, two commercially available products.

Appendix I, "Decision-Making Under Uncertainty", is a useful reference to those new to the field of risk analysis. The decision criteria presented in this appendix include: partial probabilities, LaPlace criterion, maximin criterion, maximax criterion, dominance criterion, Hurwicz criterion, and the minimax criterion. One or more of these criteria may be very useful to the risk management stage of a risk analysis because they are simple methods of addressing multi-criteria decision methods. The criteria allow analysts or decision-makers to make value judgments about the uncertainty faced in the evaluation of project outcomes. Inasmuch as traditional benefit-cost analysis will not be practical in many environmental investment planning efforts, alternative decision criteria may be of considerable interest.

Appendix J presents a simple introduction to the most basic notions of Bayesian inference. The example presented provides an excellent introduction to the notion of how subjective probabilities can be incorporated into the assessment phase of a risk analysis. The danger of this example, however, is that it could leave the reader seriously underestimating the complexity of more sophisticated Bayesian analysis. Bayesian analysis is a technique that could be expected to be very useful in and important to risk analyses of environmental issues. Generally, these techniques are beyond the capability of most field personnel and require the support of experts. Generally, we assume no one would pay $500 for a $300 television. Why pay more than something is worth? This reasoning serves us well in most circumstances. However, in situations involving risk this reasoning may no longer be useful. The insurance industry is able to function because people are willing to pay more in premiums than the damages they as a group will incur over the long-run.

Guidelines for Risk and Uncertainty Analysis in Water Resources Planning Volume II Examples, IWR Report 92-R-2, March 1992

This report presents hypothetical example risk analyses for a flood control and a navigation project. The examples are replete with helpful examples of how to incorporate risk analysis into the traditional planning process. The examples range from suggestions about how to remove the guise of determinant knowledge from the report language to the first developed example of how uncertainty can be incorporated into the estimation of benefits.

The examples in this volume were seminal works but they have been largely surpassed by more recent work. However, detailed examples such as these serve an extremely useful purpose insofar as they give agency personnel a concrete example of how the application of risk analysis might proceed. They also provide a platform from which refinements of the analysis can proceed. Developing examples that illustrate how risk analysis can be incorporated into environmental investment planning studies would be a most useful future exercise.

***Guidance for Major Rehabilitation Evaluation Reports Fiscal Year 199X*, annual**

This annual guidance memorandum provides general guidance on the preparation of major rehabilitation evaluation reports beginning in fiscal year 1995. As such, it is broader in scope than the other risk-analysis guidance reviewed in this report. For the most part, there is little of direct interest in this annual memorandum to the environmental investment program. The memo addresses major rehabilitations of hydropower and navigation projects with an emphasis on reliability analysis. Nevertheless, there are some terms and concepts of general interest in risk analysis.

The guidance distinguishes major rehabilitations for reliability from those done for improved efficiency. It is significant that considerable care is taken in defining these two mutually exclusive categories of major rehabilitation. There is a clear intention to try to avoid uncertainty that stems form imprecise language in the definitions of terms. This is a virtue to be emulated.

The guidance provides a somewhat detailed description of the contents of a major rehabilitation evaluation report that would appear to be helpful to field personnel. An outline of an environmental investment planning report could be similarly useful in that it would provide structure without constraining creativity.

The document defines the term "base condition" as the alternative which all other plans will be measured against. It goes on to offer some assumptions implied by the term. Because they are unique to the major rehabilitation program they will not be reviewed here. Base condition is a term used in place of "without project condition" in the major rehabilitation planning context. We suggest it may be a term readily adapted to the environmental investment program where issues like ecosystem restoration make without project and with project terminology rather confounding.

The steps identified for portraying the base condition recommend the use of event trees and analytical solutions to problems in deference to the automatic use of simulations. This is an encouraging step inasmuch as it attempts to broaden the array of risk analysis tools used.

The document will be a useful resource for the development of guidance relating to "failure" scenarios. The adaptive management framework recommended for ecosystem restoration recognizes the considerable uncertainty that currently attends our knowledge in this area. One of the early concerns of environmental investment planners is how will different projects perform? Will they succeed or will they fail?

This annual memorandum provides a failure scenario framework that may serve as a starting point for risk analysis. The base condition must address the timing, frequency, and consequences of system disruption. All of these are unknown and must be estimated. The steps showing how this can be done for rehabilitation of projects can be readily adapted for other failure scenarios. To the base condition several alternative plans are compared. Instead of the "with rehabilitation condition" of this guidance an alternative plan scenario might be used and the comparison could proceed conceptually as laid out in the guidance document.

Enclosure 1 presents a conceptual approach to rehabilitation that introduces the useful idea of time paths. In two-dimensional space a time path shows how some variable of interest, usually benefits or costs, vary over a period of time, usually a planning horizon. These ideas could easily be adapted for population, water quality, or other environmental values. Figure 2 on page 18 presents a probabilistic view of time paths that shows how means and variances change over time. It is a well done example that could be readily adapted for other contexts. The time path device is particularly useful for environmental investment planning because it enables the analyst to represent the dynamic and stochastic nature of key quantities.

Enclosure 2 provides an introduction to the assessment of structural reliability. As presented, the concept holds little immediate interest for environmental investment planners. However, there may be reason to investigate reliability theory, beginning with such basic notions as these to evaluate the performance of environmental alternatives.

The basic notion behind the reliability analysis is that of a safety factor. Safety factors are expressed as the ratio of capacity to demand. Perhaps the safety factor notion can be adapted for environmental use. For example, if an acre has vegetative cover (capacity) for 10 organisms and two live on the acre (demand), the "safety factor" is five. In Enclosure 2 a probabilistic approach is used to incorporate uncertainty into the development of safety factors.

Enclosure 3 is an overview of hydropower and navigation benefits of no interest to this report. Enclosure 4 , however, shows an example of how to calculate an expected annual value that could be a very helpful reference for analysts. Virtually all examples of expected annual value computations come from flood damage reduction studies. Enclosure 4 shows examples of expected annual costs and benefits based on alternative streams of benefits and costs over a 10-year period. While the example is good it does not take full advantage of the opportunity to instruct analysts with less experience with risk analysis. For example, Table 2a shows the computation of marginal probabilities, an important concept for environmental risk analysis. Unfortunately, many readers will be unable to follow the example. A simple explanation that the probability of failure is 0.1 in the first year, 0.11 in the second year, 0.121 in the third, 0.133 in the fourth, 0.146 in the fifth, and so on, would help. The example provides all the information needed to figure this out in Table 1 but relatively few will do so with ease. The series presented has a failure probability that begins at 0.1 and grows at 10% a year. The probability of success is, then, one minus the probability of failure. For the first five years these probabilities are 0.9, 0.89, 0.879, 0.867, and 0.854. While we do not suggest this is an adequate explanation, we do suggest explanations such as this and more are critically important if the risk analysis guidance is to help analysts rather than intimidate or frustrate them.

Engineer Technical Letter 1110-2-328 *Reliability Assessment of Existing Levees for Benefit Determination*, 22 March 1993

The purpose of the ETL is to provide "...guidance on the assessment of the structural reliability of existing levees, primarily for the purpose of estimating flood damages for the "without project" condition..." The detailed and technical guidance provided in this ETL provides an excellent example to which potential risk analysis guidance for the environmental investment planning program can aspire. Assessing the reliability of existing levees is the raison d'être for this ETL. Assessing the reliability of structures and other management measures is likely to become an important consideration in an adaptive management approach to environmental planning. Likewise, assessing the reliability of projects to which impacts are linked may become a significant consideration. In either or both cases explicit guidance like that in the ETL may be most helpful.

The ETL directs that the without project condition "...be based on what is most likely to occur if the project is not built". Basing without project conditions on what is most likely to happen in actuality is a significant step forward in the planning process when compared to the prior method of relying on engineering or policy standards.[11] Future risk analysis guidance should adhere to the actual practice standard whenever possible.

The ETL provides a reasonable model to emulate. The procedure for conducting the evaluation of existing levee reliability is outlined in several generic steps beginning in paragraph five. Identifying the known major steps required for an analysis is useful. The ETL directs that these steps be: a) The Preliminary Field Survey; b) Slope Stability Analysis; and, c) Past Performance. The procedure goes on to address the means by which professional disagreements will be resolved: the Joint Field Survey. It is significant and farsighted that the guidance recognizes expert disagreement as an expected and reasonable source of uncertainty. The guidance provides for an orderly resolution of such issues by directing an inclusive process to resolve these differences. We think risk analysis in the environmental investment planning program, where expert disagreement and controversy can be expected, would be well advised to emulate the spirit of this ETL.

A second approach, the Template Method, is also offered in the guidance as an alternative to the model of items a through c above. Though the second method is offered for use when data for the preferred method are unavailable, the fact that alternative methods are presented is desirable. When environmental risk analyses confront model uncertainty, it is advisable that guidance allow and even encourage alternative analytical models and risk models until a broad based consensus on the relative merits of various models begins to build among the environmental community.

The procedure guidance concludes with a straightforward statement about the applicability of the ETL. Attachments to the ETL provide effective illustration of the template method and the procedure described above.

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[11] For example, past policy for levees included ignoring benefits provided by substandard levees even when benefits were known to have accrued. Other examples include the prior reliance on standards for freeboard for levees and flood walls and underkeel clearance for navigation channels.

On balance, the ETL provides a good model of the conciseness and clarity that future detailed guidance should aspire to. The guidance builds in flexibility and an acknowledgment of expert disagreement and a reliance on actual practice that may prove to be useful themes for any future risk analysis guidance.

Engineer Technical Letter 1110-2-XXXX *Uncertainty Estimates for Non-Analytic Frequency Curves*, November 1993

This draft ETL presents a methodology and computer program for computing the uncertainty about non-analytic frequency curves. It provides an excellent example of the type of guidance that is appropriate once an integrated model has been developed. To the extent that flow-frequency information becomes important in environmental resource planning studies, this guidance could be useful, if it is implemented in its current form.

In hydrologic studies analysts either use an analytic distribution of flows, like the log-Pierson III, or they use non-analytic techniques, like graphical fits of ordered data points to a curve. This latter technique is a distribution-free or non-parametric technique. Uncertainties exist in the frequency curves from either analytic or non-analytic methods. The methods used to quantify those uncertainties vary, however. EC 1105-2-XXXX describes the methods to be used to quantify uncertainty in analytic frequency curves. This ETL describes the non-parametric order statistics approach for quantifying uncertainty.

The order statistics approach is based on a straightforward application of the binomial distribution. The ETL is well supported in a technical sense, which of course is the nature of an ETL. However, it is, unfortunately not as reader friendly as risk and uncertainty guidance needs to be if it is to be used and understood by the widest audience possible.

There are limits to how much some of the complex statistical procedures and concepts can be digested for users. There are legitimate arguments about the desirability of even attempting to do that; “a little knowledge being a dangerous thing” chief among them. Nonetheless, when binomial probabilities can be expressed with notation no more complex than a factorial, we question the wisdom of offering an equation like (2) on page 2 that involves the incomplete beta function and integral calculus as “a more convenient...expression”.

The guidance is still well prepared. It proceeds from a mathematical presentation of the order statistics concept to an example that takes most if not all of the sting out of the math presented earlier. The guidance provides sufficient discussion of related issues to satisfy most situations and there are practical guidelines for determining equivalent record lengths. There are numerous useful examples.

On balance, this ETL provides a good example of the type of guidance that constitutes adequate support for an integrated uncertainty model. However, at this point, it is unclear whether or where a single integrated risk model will be used for environmental resource planning. If and when such a model is developed for use, this ETL would serve as a reasonably good example of the type of risk analysis guidance that should accompany it.

SUMMARY

Existing Corps guidance for risk analysis tends to consist of two types: 1) the general concepts, principles and tools as discussed in manuals and IWR reports; and 2) detailed and specific guidance as presented in ECs and ETLs. There is much in the former guidance that can be readily incorporated into environmental risk analysis guidance. There is much in the latter guidance to be emulated by environmental risk analysis but very little that can be directly adapted.

At this point when we speak of environmental risk guidance we are not talking about ECs and ETLs. We are speaking more about introducing this relatively new concept of risk analysis to the evolving subfield of water resources and environmental planning. The most reasonable and modest goals for the initial guidelines would include: identifying basic theories, techniques and concepts used in risk and uncertainty analysis; applying them to representative or commonly encountered environmental planning situations; taking a first cut at identifying key quantities/variables; developing some precision in the language of environmental investment planning; establishing procedures for dealing with expert disagreement and public controversy; encouraging model reviews and development of new models; and fostering an exchange of ideas among agency, academia and public interests.

Sample analyses, literature reviews, lists of key variables, introductions to the array of techniques and tools available for risk and uncertainty analyses, and models to be emulated in structuring future environmental risk analysis guidance are among the most useful things to be gleaned from the Corps existing guidance. At this writing there were several additional examples of risk analysis guidance under preparation. Upon their completion they warrant review as well.

CHAPTER THREE: REVIEW OF PROFESSIONAL LITERATURE

OVERVIEW AND OBSERVATIONS

INTRODUCTION

The main feature of this chapter is a summary of 52 books, reports, papers and articles related to risk analysis. It is by no means the only feature of this chapter. In this overview section we briefly describe the review methodology. Of particular interest in this section are some general findings we have culled from the literature review and present as a series of observations. The next two sections contain the 52 reviews presented in two parts: general methodology of risk analysis and applications of risk analysis to environmental issues.

The fourth section is written for analysts who will want to continue to keep abreast of developments in environmental risk analysis in the professional literature. It is not an exhaustive list of sources. Instead, it is a guide to some of the most promising sources of information that are likely to be of most interest to Corps analysts. A more complete list of potential sources can be obtained from the 52 summaries, the references included among the books, papers and articles cited in the works summarized, and the bibliography that follows in the fifth and final section of Chapter Three.

LITERATURE REVIEW METHODOLOGY

Risk and uncertainty analysis for environmental investments must address issues at both the watershed and project-specific levels. The emphasis of this literature review was clearly focused on the environmental aspects of the program as opposed to the economic or engineering aspects of risk analysis. We were also interested in including the uncertainty attending biological modeling tools currently used by the Corps. There were hopes, for example, that habitat evaluation models like Habitat Evaluation Procedure (HEP), Wetlands Evaluation Techniques (WET), and others listed in EC 1105-2-206, had been reviewed and evaluated in the literature. Unfortunately, that has not been the case. There was also considerable hope for the promise of articles that explicitly reference environmental risk analysis in their titles. As will be seen in the reviews, these articles generally relate to the U.S. Environmental Protection Agency's (EPA) risk analysis paradigm. The EPA paradigm is important, but does not provide what we had hoped the articles would reveal.

Despite these apparent disappointments the review has revealed a great deal of information of interest and value to Corps planners. Thus, it is important to understand how the 52 items reviewed were selected.

The outset of this research could be called a "fishing expedition". Library searches were begun at three libraries, each with access to different online search services. Online searches of environmental citations were also conducted. Some of these resources will be described subsequently. Several authors prominent in the fields of risk analysis or environmental resource planning were contacted for their suggestions about literature relevant to this review. In addition, several days were spent perusing journals and books at two major research libraries at the University of Maryland (College Park and Baltimore County campuses) and Johns Hopkins University. Other public and college libraries were investigated as well.

From this initial search a preliminary list of 50 books, reports, and articles was compiled. From preliminary review of the 50 sources it became evident that there was considerable overlap and redundancy in the subject matter of many of the items. The truth is that very little has been written about environmental resource planning as the Corps conducts it. Most of the environmental risk literature actually refers to human health impacts, a key interest of the EPA. While some redundancy was welcomed a decision was made to revise the list of 50 articles as the literature arrived.

The additions to the reading list were developed from continuing searches as described above. However, the best leads were developed from new resources suggested in the literature that was being reviewed. New online services were discovered, new authors to contact were identified, and references to items provided fresh new journals to investigate. Thirty-two items from the original list of 50 and 20 new items, for a total of 52, comprise the reviewed items.

HOW TO USE THIS REVIEW

The items summarized for this literature review have been divided into two sections. Within each section, the articles are organized alphabetically, by author. First are the materials on general methodology, numbered G-1 through G-16, which cover the generic tools and issues of risk and uncertainty analysis. Second are the materials on applications of risk and uncertainty analysis to environmental resources issues, numbered A-1 through A-36, which address risk and uncertainty analysis in the explicit arena of environmental issues.

Many readers will be interested in a more refined division of the items reviewed. There are many ways in which these items can be subdivided and none of them will prove satisfactory to all readers. Thus, we start from the premise that our system is flawed. Given its flaws, we have at least endeavored to keep the system simple.

The articles are summarized in Table 3-1. The title of each item is offered as the first level delineation of subject matter (the numbers in the first column correspond to our numbering system for the annotations). The year of publication is also listed. Only the first author listed is noted in the table. The third column indicates whether the item is a book, a paper from a journal, a government report, or an article from a collection of writings.

We have also attempted to indicate the type of reader who is likely to find the article most helpful or interesting. We have grouped all readers into one of three functional groups. "Planners" are those who are interested in the planning process and the broader aspects of the risk analysis, understanding it, and weighing appropriate trade-offs, for example. "Analysts" are those who will have something to do with conducting the risk analysis. They may do the actual assessment of the risks or they may monitor a contract in which a contractor does the assessment. "Managers" are study and program managers who will direct and approve work and may be called upon to manage risks estimated in the assessment.

At times we have distinguished the skill level of the reader. Items that are clearly written as an introduction to a topic are indicated to be suitable for "novices". Items that are a bit more difficult to read or that require a more technical background to understand are designated as "expert" reader items. In most cases the skill level of the reader is not a factor worth mentioning.

When it comes to the matter of what is in these items we had a bit more difficulty. They are already summaries. In some cases several hundred pages of text are summarized in two or three. There are limits to how much the information can be reduced. We have decided to provide the reader with some subjective information about the contents of the item in the column labeled "Topics".

During the preparation of this report a list of topics addressed in each item was made. The list was far too long to be useful in any classification matrix. Hence, we have arbitrarily decided to list what we subjectively believe to be the three most important topics or ideas addressed in the item. Generally, we have tried to avoid listing topics that are obvious from the title. Our criteria for determining importance was simply to try to guess what would be of most interest to the Corps reader. Someone else could come up with an entirely different set of topics. The list of topics should not be considered exhaustive or authoritative in any fashion. We have taken the liberty at times of reshaping the author's arguments in the language of the Corps. These topics, then, can be interpreted as the reasons why you, the reader, might be interested in that item.

Each item begins with a complete citation of the book, report, paper or article. There follows a section called "applicability". In that section we do specifically for each article what we're trying to do generically in the summary table. The "applicability" portion of the review is intended to help you decide whether you're interested in reading the entire review. We have tried to restrict our editorializing to this portion of the summary. On occasion it seemed necessary to make editorial comments in the body of the review, however.

The "review" portion of the summary is where we summarize the content of the item. Sometimes the review is very brief. In other cases we have used the author's own words in some detail to deliver important points. The review style was modified to reflect what we felt was most important to convey about that item to the Corps reader. Do not assume the review has successfully conveyed the author's complete argument. It would be impossible to do so in a page or two. The sole purpose of the summary is to help you decide whether it would be useful to you to obtain a copy of the article to read in its entirety.

One last parting bit of advice for using this review is offered. When you are interested in a topic, get the book or article. Whenever you obtain one of the items be sure to carefully review the references the author of the item has used. The references are one of the most valuable aspects of some of these articles.

TABLE 3-1: SUMMARY OF ANNOTATIONS					
Number	**Title & Year of Publication**	**First Author**	**Type**	**Reader**	**Topics**
A1	Risk Analysis as a Project Management Tool 1985	B. Allardyce	Paper	Analyst Novice Expert	•Monte Carlo simulation •sensitivity analysis •fault tree
A2	Problems of Risk Assessment in Water Resources Management 1991	Richard C. Allison	Paper	Manager Planner	•human health •risk assessment •risk communication
A3	On Quality, Peer Review, and the Achievement of Consensus in Probabilistic Risk Analysis 1983	G. Apostolakis	Paper	Manager Analyst	•probabilistic risk analysis •quality assurance •peer review
A4	Risk Assessment Principles in Environmental Impact Studies 1992	M. Carolota Arquiaga	Paper	Planner Manager	•human health risks •policy review •EIS
G1	Managerial Decisions Under Uncertainty: An Introduction to the Analysis of Decision-Making 1989	Bruce F. Baird	Book	Novice Analyst	• Bayesian analysis • probability trees • subjective probability assessment
G2	The Role of Environmental Risk Analysis in the Cost-Effective Development and Operation of Emerging Energy Technologies 1983	Nathaniel F. Barr	Book	Novice Analyst	• Bayesian analysis • probability trees • subjective probability assessment
A5	Ecological Risk Estimation 1992	Steven M. Bartell	Book	Analyst Expert	• ecological risk analysis • probabilities of ecological endpoints • water column model
G3	Unacceptability of Acceptable Risk 1982	A. Bicevskis	Paper	Manager	• zero risk • acceptable risk
A6	Endangered Species and Uncertainty: The Economics of a Safe Minimum Standard 1978	Richard C. Bishop	Paper	Manager Planner	• safe minimum standard • inevitability and uncertainty • option and existence value

TABLE 3-1: SUMMARY OF ANNOTATIONS					
Number	**Title & Year of Publication**	**First Author**	**Type**	**Reader**	**Topics**
G4	The Social Response to Environmental Risk: Policy Formulation in an Age of Uncertainty 1992	Daniel W. Bromley	Book	Manager	• property rights • risk communications • media stories about risk
A7	Risk Assessment in Conservation Biology 1993	M.A. Burgman	Book	Analyst Manager Expert	• population survival • quasi extinction risks • metapopulation dynamics
A8	Ecological Function and Resilience: Neglected Criteria for Environmental Impact Assessment and Ecological Risk Analysis 1993	John Cairns, Jr.	Paper	All	• reference • functional endpoints • ecological restoration
A9	Benefits and Risk of Using Predators and Parasites for Controlling Pests 1980	L. E. Caltagirone	Paper	Manager Analyst Novice	• biological control • risks of biological control
A10	Pragmatic Suggestions for Incorporating Risk Assessment Principles in EIA Studies 1993	Larry W. Canter	Paper	Planner Expert Analyst	• EPA paradigm • rapid risk assessment • dealing with uncertainty
A11	A Risk Analysis Methodology for Assessing Natural Resource Degradation 1990	R. Cincotta	Paper	Analyst Planner	• acceptance limits • failure rate • risk probability
G5	Making Hard Decisions: An Introduction to Decision Analysis 1990	Robert T. Clemen	Book	Analyst Planner	• decision theory • Monte Carlo simulation • multiattribute models
A12	Impact of Discharges as a Basis for Control Measures 1982	R.A. Conway	Paper	Manager Planner	• environmental risk assessment • deterministic models • parametric variation
A13	What is Ecological Economics? 1989	Robert Costanza	Paper	Analyst Planner	• ecological economics • technological optimism • technological pessimism

TABLE 3-1: SUMMARY OF ANNOTATIONS					
Number	**Title & Year of Publication**	**First Author**	**Type**	**Reader**	**Topics**
A14	Prospect Risk Analysis Applied to Ground-Water Reservoir Evaluation 1982	George H. Davis	Paper	Novice Analyst	• identifying critical variables • Monte Carlo simulation • expert panel • subjective probability estimation
A15	Risk Computation for Environmental Restoration Activities 1993	J. G. Droppo, Jr.	Paper	Analyst Manager	• DOE paradigm • environmental restoration • risk screening tools (MEPAS)
G6	Summary Report on Issues in Ecological Risk Assessment 1991	Eastern Research Group	Report	All	• stress response rates • human health risk assessment • ecological risk assessment
G7	Risk Assessment and Management: Framework for Decision-Making 1984	U.S. EPA	Report	Manager	• risk assessment • risk management • human health risk assessment
A16	Application of Environmental Risk Analysis to Groundwater Protection 1988	M.O. Ettala	Paper	Planner Analyst Novice	• environmental impairment • risk analysis team • qualitative risk scales
G8	The Greening of Risk Assessment: Towards a Participatory Approach 1993	Frank Fischer	Article	Manager Expert	• acceptable risk • quantitative risk assessment • participatory risk assessment
A17	Valuing Environmental Resources Under Alternative Management Regimes 1991	A. Myrick Freeman, III	Paper	Analyst Expert	• open access fishery • perfect regulations • value of wetlands
A18	Public Policy and Environmental Risk: Political Theory, Human Agency, and the Imprisoned Rider 1992	John Martin Gillroy	Paper	Expert Analyst Planner	• imprisoned rider • human agency • risk benefit analysis
G9	Readings in Risk 1993	Theodore S. Glockman, Ed.	Book	All	• risk assessments vs. risk management • zero risk • heuristics

TABLE 3-1: SUMMARY OF ANNOTATIONS					
Number	**Title & Year of Publication**	**First Author**	**Type**	**Reader**	**Topics**
G10	Graphical Communication of Uncertain Quantities to Nontechnical People 1987	Harold Ibrekk	Paper	Analyst Planner	• cumulative distribution function • risk communication • tukey box
A19	Risk Analysis, Fuzzy Logic and River Basin Management 1984	P. W. Jowitt	Paper	Analyst Expert	• water pollution • fuzzy logic • differential equation systems
A20	Wetland Creation and Restoration: The Status of the Science 1990	Jon A. Kusler, Ed.	Book	All	• wetland creation • adaptive management • wetland restoration
G11	Simulation Modeling and Analysis 1991	Averill M. Law	Book	Analyst Expert	• simulation • random number generators • modeling
A21	Application of Event Tree Risk Analysis to Fisheries Management 1987	Ernst Linder	Paper	Analyst Expert	• event trees • discretized continuous distributions • recovery and survival
A22	Risk Analysis for Conservation Biologists 1991	Lynn A. Maguire	Paper	Analyst Manager	• conservation biology • risk analysis • decision tree
A23	Risk Analysis of Multiple Environmental Factors: Radiation, Zinc, Cadmium, and Calcium 1986	Junko Matsubara	Paper	Analyst Expert	• multiple logistic model • multiple risk factors • mortality rate
G12	An Introduction to Risk Analysis 1984	Robert E. Megill	Book	Analyst Novice Expert	• probability • opinion analysis
A24	The Marginal Cost of Species Preservation: The Northern Spotted Owl 1994	Claire A. Montgomery	Paper	Planner Analyst Expert	• probability of survival • marginal cost • northern spotted owl

TABLE 3-1: SUMMARY OF ANNOTATIONS					
Number	**Title & Year of Publication**	**First Author**	**Type**	**Reader**	**Topics**
G13	Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis 1992	M. Granger Morgan	Book	All	• uncertainty types sources • subjective probability assessment • risk communication
A25	Fuzzy Multigroup Conflict Resolution for Environmental Management 1994	B.G. Munda	Article	Analyst Expert	• game theoretics • fuzzy set theory • coalition formation theory
G14	A Method for Treating Dependencies Between Variables in Simulation Risk-Analysis Models 1976	P.D. Newendorp	Paper	Analyst Expert	• Monte Carlo simulations • dependent variable • what-if scenarios
A26	The Values of a Habitat 1990	Kelly Parker	Paper	Planner Expert	• pragmatic environmental thinking • adequacy and significance • preservation/development conflicts
A27	Characterization and Evaluation of Uncertainty in Probabilistic Risk Analysis 1981	G. W. Parry	Paper	Expert Analyst	• subjective probability • event and fault trees decomposition • rare events
G15	The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies 1989	Dennis J. Paustenbach, Ed.	Book	Analyst Expert Manager	• EPA paradigm • health risk assessment • superfund risk assessment
A28	First Things First: Needed - A Genetics Risk Analysis Science 1985	Jeremy Rifkin	Paper	Manager Planner	• biotechnology • genetic engineering • risk assessment
A29	COMPARE: An Integrated Tool for Hazard Assessment and Risk Analysis 1993	G. Rinaldi	Paper	Analyst Expert	• risk analysis models • GIS • industrial hazards
G16	Reducing Risk: Setting Priorities and Strategies for Environmental Protection 1990	Science Advisory Board	Report	Manager	• EPA paradigm • environmental risk • relative risk

TABLE 3-1: SUMMARY OF ANNOTATIONS					
Number	**Title & Year of Publication**	**First Author**	**Type**	**Reader**	**Topics**
A30	Risk Sharing in the Design of Environmental Policy 1986	Kathleen Segerson	Paper	Analyst Expert	• ex ante constraints • ex post constraints • expected utility
A31	Environmental Risk Analysis: An Overview 1991	M.P. Singh	Paper	Analyst Planner	• EPA paradigm • three-tiered buffer zone • risk liability insurance
A32	Ecology and Design: An Introduction 1988	Ian R. Smith	Paper	Manager Planner	• design criteria • ecological design • ecological units
A33	Risk Analysis for the Concho Water Snake 1989	Michael E. Soulé	Paper	Planner Analyst	• subjective risk assessments • decision trees • risk of extinction
A34	Ecological Risk Assessment: Its Role in Risk Management 1992	David James Stout	Paper		• ecological risk assessment • contaminated sediments • hazard ratios
A35	Ecological Risk Assessment 1993	Glenn W. Suter, II	Book	Analyst Expert	• EPA paradigm • regional risk management • retrospective risk assessment
A36	The Complementarity Between Environmental and Economic Risks: An Empirical Analysis 1994	Paul H. Templet	Paper	Analyst	• emissions-to-jobs ratio • toxic release inventory • environmental and economic risk

OBSERVATIONS

One cannot read as much literature as this review required without coming up with a few observations. One begins to notice things time and again in the literature. Though not a primary or even an anticipated part of this literature review, we offer some of the more significant of these observations for the consideration of the Corps' reader.

The first observation is that the language of risk analysis has many meanings. Titles of books and papers, annotations, lists of keywords, and the contents of much that is written indicate a striking lack of uniformity in the language of risk analysis. Or is it uncertainty analysis? Or is it risk and uncertainty analysis?

Risk and uncertainty analysis, as the Corps defines it, is applied in many different contexts. It belongs to no one discipline but is used by many. As a result, a vast and varied jargon has arisen. The Corps says risk analysis comprises the two steps of risk assessment and risk management. EPA says risk assessment comprises the two steps of risk analysis and risk management. The specific meanings of these terms are flip-flopped. There are numerous similar examples in the literature.

Initially, we were buoyed by the numerous references to environmental risk analysis. This is one of the names given to the quantitative risk assessment (as defined by EPA) of human health effects of projects and actions. Human health or environmental risk assessment estimate the incidence of death and disease to humans resulting from exposure to hazardous agents. Ecological risk assessment is a term that is coming to mean the estimation of hazardous agent impacts on non-human elements of the environment or the risk associated with chemicals. Others in the literature suggest that human health and ecological risk assessments are subsets of a broader field called environmental risk assessment.

Risk analysis is routinely applied to many disciplines: human health/environment; ecology; conservation biology; reliability of project performance (the most common context in which it is applied in the Corps); safety; natural disasters; accidents; insurance; business profit and loss; and numerous other applications. Each discipline, each government agency, and each program has adopted its own language to describe what they do and what it means.

As the Corps seeks to integrate the use of risk and uncertainty analysis into the evaluation of environmental resource investment projects it is going to need a language in which it can communicate clearly and unambiguously. As the review of Corps guidance in Chapter Two indicates, there is already a substantial investment in the development of language that would be foolishly ignored. Nonetheless, there remains a need to develop new language carefully.

For example, what should the type of risk and uncertainty analysis that this entire review is about be called? To distinguish it from the very specific work of the EPA related to human health effects, "environmental risk assessment," would probably not do. "Environmental risk analysis" is too close a term and would cause confusion in the literature. Besides, reference to risk alone seems to deny the importance of that larger class of problems and issues called uncertainty. Perhaps "environmental resource uncertainty analysis" would be descriptive enough to succeed. It does not, unfortunately, flow easily from the lips.

At some point, as risk analysis becomes more widespread and common, the need to standardize the language may reach a critical mass among all the disciplines that lay claim to a piece of risk analysis. Until that time, however, we in the Corps should strive to develop a language that is clear and unambiguous as it becomes necessary to define terms and describe procedures and results.

A second observation is that other federal agencies are actively involved in risk analysis research and development that could be of tremendous interest to the Corps in general and to the environmental program in particular. Much of the literature reviewed in this report was prepared by, for, or as a result of the programs of other federal agencies. These include the U.S. Environmental Protection Agency (EPA), the Department of Energy (DOE), the Nuclear Regulatory Commission (NRC), the Food and Drug Administration (FDA), the Occupational Safety and Health Administration (OSHA), and the Consumer Product Safety Commission (CPSC). The National Academy of Sciences (NAS) plays a prominent role in the history of much of this literature as well.

There are obvious differences in authorities, programs, applications, paradigms, and terminology among the various agencies. But there are important similarities as well: lack of data, evolving science and theory, the need to train employees, the need to develop and integrate models, the need to communicate with the public, the need to communicate with other risk analysts, and the need to stretch research budgets, for example. This would provide a rationale for dialogue and cooperation among the agencies. The related nature of certain missions means that inevitably analyses of the Corps and, for example, EPA will overlap with one another. The agencies thus have a clear need to become aware of what each is doing in the area of risk analysis.

A third observation is that there are many talented people doing a lot of good work in risk analysis. Though 52 items are summarized here, we had the opportunity to review far more than that during the course of this research. One very clear message is that there are a great many talented people doing very good work in the areas of risk analysis and environmental resource planning. The authors of these reports should be considered resources.

The fourth observation is that there are many good, if narrowly focused, periodicals available. In the "Literature Sources to Monitor" section of this chapter we offer the names of 28 periodicals that would be worth monitoring to stay abreast of future developments in the application of risk analysis to environmental resource planning problems. We expect more and more risk analysis applications of interest to Corps analysts in the years ahead. A one-time literature review like this may help but it does not provide that continual update that analysts need in such a rapidly developing field.

Another observation is that risk and uncertainty analysis is everywhere in the literature. It may be explicit or implicit. The most natural place to begin to look for information about risk and uncertainty in the literature is in the titles of the items. The title search will most likely lead to explicit treatments of risk and uncertainty analysis, but a great deal of good work could be overlooked in the implicit treatments of uncertainty.

Uncertainty is so pervasive that it can be found in virtually every journal article. Option values and existence values are concepts developed in attempts to address fundamental notions of uncertainty regarding resource values. Articles that discuss future conditions of resources are addressing issues of uncertainty found everywhere. In searching for treatments of risk and uncertainty, it is important not to limit one's self to a title search that might overlook implicit treatments of uncertainty.

A final observation is that there is a great deal of good literature from which to choose. As this literature review began, we had hoped that we would find attempts to incorporate risk and uncertainty analysis into, for example, the use of habitat evaluation models and evaluations of environmental resource management measures. The literature that referred to environmental risk analysis contributed to soaring hopes for a rich literature that we only had to tap into. Those hopes were quickly dashed. The environmental risk analysis invariably referred to the EPA paradigm for assessing risks to human health. The habitat models and management measures have, thus far, been overlooked in the literature.

Although we would be the first to admit that our search of the literature should not be considered exhaustive, we feel somewhat confident in saying there is little in the literature that pertains to risk analysis applied to environmental issues that would be immediately applicable to the Corps' program. Nonetheless, there is much that is of interest to the Corps in the literature, a point made numerous times in these observations.

In this review, the emphasis has been more on the application of risk analysis to environmental resource investments than on the general method of risk analysis. There is a great deal of material available regarding the general methods of risk analysis. However, if an office or an individual were interested in starting a library of introductory source material for risk analysis there are a few books that stand out. All are summarized in this report. Morgan and Henrion's 1992 book (reference number G13) has one of the best overall introductions to the essence, concepts, and practice of risk and uncertainty analysis that exists. The Clemen (1990) text has a masterful presentation of decision theory (reference G5). As a pure bonus it provides excellent sections on modeling uncertainty and preferences as well. Glockman's 1993 collection of readings is valuable for the range of topics it covers in a collection of seminal readings in the field (reference G9). The Science Advisory Board's 1990 report for EPA (reference G16) provides a short overview of that agency's risk assessment program. Baird's text (1989) provides a good introduction to Bayesian analysis (reference G1). This is not the first topic a new analyst will want to tackle, but sooner or later he or she will have to learn something about this topic. The Law book (1991) is helpful for users who will want to build simulation models (reference G11).

GENERAL METHODOLOGY LITERATURE

G1: Managerial Decisions Under Uncertainty: An Introduction to the Analysis of Decision-Making. By Bruce F. Baird. New York: John Wiley & Sons, 1989. pp. xiii, 530. Thirteen chapters, six appendices, solutions to selected problems. ISBN 0-471-85891-9.

Applicability

Though risk and uncertainty analysis is a field that continues to evolve, there are some topics with which every analyst should be familiar. Bayesian analysis is one of these topics. Many environmental planning analysts are likely to be unaware of the differences between Bayesian and classical views of probability. Bayesian analysis provides a whole new set of tools for approaching problems that may not lend themselves well to classical analysis.

This book was selected to provide an accessible reference book that introduces the reader to a broad range of Bayesian probability and Bayesian decision analysis techniques. It is broad ranging in content, sacrificing some detail and depth for breadth. This is a real plus for the novice reader. While there are many Bayesian statistics texts they may be too difficult for beginners. Traditional texts may offer a chapter or two on Bayesian analysis at best. This text is a good introduction to Bayesian analysis and is replete with examples. It is highly recommended to anyone seeking an introduction to Bayesian analysis. Its many examples are well worth the time it takes to follow them.

Review

Baird's book proceeds from the notion that the era of successful intuitive decision-making is over. The goal of the book is to "..improve decision-making skills in realistic situations and do it in reasonably nonmathematical fashion." We think he succeeds on both counts. The primary focus of the book is Bayesian decision theory but it does far more than that.

The book begins with some fundamental concepts that define decision-making processes in an effective manner. The first chapter is a good basic introduction to the nature of decision theory. The next three chapters deal with probability. First, Baird offers a treatment of elementary probability theory that indeed does succeed at a nonmathematical level. The strength of this chapter is that it covers all the probability concepts important to decision-making without getting bogged down in theory or prolonged numerical examples. A priori and empirical objective probabilities are defined and illustrated. Simple, conditional, joint and marginal probabilities are clearly defined. Probability trees illustrate examples of each of these probabilities. Baird glides through the elements of probability in a manner sure to be appreciated by non-statistician professionals.

In the third and fourth chapters he discusses random variables and probability distributions. Baird offers more detail and more examples than the Morgan and Henrion (1992) text reviewed elsewhere (reference G13).

The detail may be a bit much for some, but most analysts entering or reentering the field of risk analysis will find it just right or nearly so. The first four chapters do very well what some texts take considerably more pages to do less effectively.

In Chapter 5 Baird discusses decision theory and inference. Inference is a conclusion or judgment about the nature of some uncertain quantity, for example a point or interval estimate of a population mean. We cross over from inference to decision theory when actions must be taken as a result of our judgments. Both inference and decision theory can be classical or Bayesian. Section 5.1 provides a masterful overview of the differences between Bayesian and classical approaches.

He offers an example of the difference between the two schools using a 95% confidence interval about a sample mean:

> "We are 95 percent confident that the mean battery life of the population lies within 30 and 42 months. This statement does not mean that the chance is 0.95 that the mean life of all our batteries falls within the interval established from this one sample. Instead it means that if we select many random samples of this sample size and if we calculate a confidence interval for each of these samples, then in about 95 percent of these cases, the population mean will lie within the interval" (p. 137).

The Bayesian finds this too restrictive and would prefer to say the interval 30 to 42 months contains the population mean with a probability of 0.95.

With clear examples like this Baird proceeds to build a good intuitive feel for the major differences between the two schools of thought. Simple and straightforward discussions of decision criteria like the maximax and minimax, for example, are just a bonus in this chapter.

Elementary Bayesian concepts are presented in Chapter 6. Beginning with conditional values, Baird develops an effective inventory model to effectively introduce a number of concepts that could become useful in risk analysis of environmental resource plans. These concepts include expected value of perfect information (EVPI), expected profits under uncertainty (EPUC), expected loss (EL) , critical ratios, and value of perfect information problems. The use of inventory models may itself have some value for environmental resource planners if they can find some legitimate parallels between the problem of having an optimal quantity of goods on hand under conditions of uncertain demand and determining optimal levels of environmental resources.

The construction of multilevel decision diagrams is discussed in Chapter 7 in a rather informal and easy-to-follow way. The essential elements of the Clemen (1990) text, reviewed elsewhere in this report (reference G5), are effectively presented and illustrated with examples in a single chapter.

The essence of Bayesian analysis is addressed in Chapter 8 on information and the revision of probabilities. An introductory discourse on the nature of information effectively characterizes the "data overload/information shortage" confronting analysts and decision makers alike. In a fun and effective challenge of the readers knowledge of facts, Baird makes some effective points about degree of belief, an essential Bayesian concept. He offers five commonly known "facts", like the mention of an apple in the Biblical story of Adam and Eve, and then debunks them to capture the readers interest and attention. This intuitive approach is found throughout the book and it is quite effective.

It is in this chapter that Bayes' theorem is presented. In essence it is: “joint probability/simple probability = conditional probability.” He follows this simple definition with an example that both illustrates Bayes' theorem and drives home the difference between Bayesian and classical approaches to probability. His treatment of prior probability, likelihood and posterior probability is effective in the example that shows an apparently obvious decision that proves to be incorrect. In the remainder of the chapter priors[12] are revised using different kinds of distributions and conjugate priors are discussed in a simple manner, features not found in most texts that give a cursory review of Bayesian probability/decision theory.

The remainder of the book is devoted to a variety of topics of interest to risk analysts. Probability assessments based on both historical data and personal assessment are described. Utility theory is developed effectively, as are sensitivity analysis and multicriteria decision problems. The treatments of these latter concepts are consistent and effective. The use of examples continues and some of the latter chapters are a bit more mathematical, but the math rarely goes beyond algebra. The many graphs are helpful, once one gets used to the idiosyncrasies of Baird's decision tree style. Though done well, some of these topics are treated more effectively in other books and articles reviewed in this report.

Appendix VI offers a very valuable probability assessment calibration that could be useful to analysts planning to become involved in subjective probability assessments. Calibration is explained by Baird, who offers a series of 75 questions that can be used to calibrate the subjective tendencies of so-called experts along with a scoring rule. These questions reveal whether a person tends to be over confident, over cautious or "just right" in estimating probabilities of uncertain events. This appendix could come in handy for analysts who eventually begin to do probability assessments except for one surprising and annoying flaw: the answers are not included!

[12] “Priors” refer to prior or original probabilities, or beliefs about the value of a parameter held “prior to” or before additional information is collected through sampling or testing. Prior probabilities combined with information from a test or sample yield posterior probabilities, i.e., probabilities that incorporate prior beliefs and test results.

G2: "The Role of Environmental Risk Analysis in the Cost-Effective Development and Operation of Emerging Energy Technologies." By Nathaniel F. Barr. In Annals of Nuclear Energy, Vol. 10, No. 3/4, 1983. pp. 187-194.

Applicability

This article was selected to inform Corps personnel about the risk analysis experience of another federal agency. It recounts the efforts of the Department of Energy in an astoundingly frank assessment of the DOE environmental risk program. This article was written when risk analysis was fighting the battle for respectability and acceptance. There may be lessons to learn from the efforts of DOE in the early days of its risk analysis program. It bears noting that this article was written in 1983 and it is unclear how long the programs described persisted.

Review

This article begins with the intent of using risk analysis to guide the acquisition and application of environmental data to reduce uncertainty regarding the potential environmental impacts of emerging energy technologies. At the time of this article there was a great divergence of views regarding the potential utility of risk analysis in resolving issues of environmental acceptability of existing, much less emerging, energy technologies. DOE was thwarted by the often encountered problem of a lack of data. This lack of information is considered the greatest source of uncertainty.

At this point the article takes a turn away from a technical analysis of the risk analysis issues toward an assessment of DOE's risk research program. This shift in emphasis provides an alternative model for organizing an agency's risk research.

DOE's Office of Health and Environmental Research (OHER) is part of the Office of Energy Research. One of OHER's principle functions was to conduct a research program that would provide information needed to reduce uncertainties regarding the potential health and environmental impacts of emerging energy technologies. Around 1981 OHER initiated a Health and Environmental Risk Analysis Program (HERAP).

The strategy of HERAP was to support analyses that describe what is known and what is unknown about potential health and environmental impacts of emerging energy technologies. The results of this program were presented annually in a technology-specific Health and Environmental Effects Document (HEED). The principle product of these analyses was understood to be a description of the nature, magnitude and sources of uncertainty regarding potential health and ecological impacts.

At the time of this article the Third Annual Contractor Meeting had been held in 1982. These contractors had to date prepared 13 technology-specific HEEDs. A footnote indicates that these and future HEEDs may be obtained from the author at the U.S. Department of Energy, ER-73 (GTN), Washington, D.C. 20545.

In an evaluation of the HERAP the author finds the HEEDS deficient in several areas of vital importance. First, they were incomplete in their coverage of potential environmental impacts. The analyses were found to lack sophistication and data. In addition they are very site-specific and unique. The HEEDs had provided little of value for guiding ecological research.

With regard to health impacts, the HEEDs did not make it clear how individual uncertainties contribute to overall uncertainty. This was to have been addressed by development and use of more uniform procedures for dealing with uncertainty.

Of potential interest to the Corps as it develops risk analysis for environmental programs is the HERAP review process. HEEDs were reviewed by a community of experts with broad responsibilities for the management of environmental issues. At the time the article was written DOE intended to expand the review of their work to include the National Academy of Sciences/National Research Council. The NRC was to undertake an independent review and critique of the HEEDs.

Overall, DOE experience indicated that risk analysis was most effective as an integral part of the decision process, rather than an add-on. Additionally, they found:

> "..science as well as public policy are better served by timely organization and display of current uncertainty to support decisions than are served by delay and avoidance while attaining greater certainty regarding potential environmental impacts" (p. 193).

G3: "Unacceptability of Acceptable Risk." By A. Bicevskis. *Search.* Vol. 13, No. 1-2, February/March 1982. pp. 31-34.

Applicability

How do we determine when the risk created by an action or the risk remaining after an action is acceptable to the general public? If zero risk is not a viable option, how much risk is acceptable? There is no simple answer to this question. This article does little to clarify the issues.

Review

The author's view on acceptable risk is never in doubt in this article: "..the chimera of an 'acceptable' risk has led to a series of subsequent developments in risk analysis attempting to quantify a concept which has no right of existence in the first place" (p. 34). Bicevskis offers a brief history of the concept of acceptable risk as it had developed in the literature to that point in time. This review is interesting to those seeking the historical development of the argument but is of little practical interest today.

Many of the author's arguments do not ring true. For example, the author argues that cost-effective allocations of risk-reducing resources do not even raise the issue of absolute or acceptable risk. We believe that setting the dollar limits on these resources in fact does place us in a de facto acceptable risk range. The acceptable risk becomes what we can afford given our budgets. The fact that there is no explicit discussion of the matter does not obviate the issue.

The author feels strongly that focusing on the acceptable level of risk misdirects public attention and priorities from more important things. He prefers more of a multi-attribute decision process. Perhaps the thrust of this article is best summarized in the author's own words: "..a decision process which aims at promoting the long-term welfare of the community at large should be based on a *holistic* approach considering the combined effect of *all* the factors, whereas the concept of an acceptable risk deflects public concern to one specific area which may militate against the best overall solution" (p. 34).

G4: The Social Response to Environmental Risk: Policy Formulation in an Age of Uncertainty. Edited by Daniel W. Bromley and Kathleen Segerson. Boston, MA: Kluwer Academic Publishers, 1992. pp. ix, 216. Eight articles.

Applicability

This book, written primarily by economists and decision scientists, claims to be a retrospective assessment of what is known about environmental risk. The book falls well short of this stated purpose. It does not define basic terms, present the four step environmental risk assessment model, or address many of the other issues central to environmental/health risk. It does, however, provide thoughtful yet relatively easy to read articles that elaborate on the fact and theory of public response to risk. The view taken by the book is a big picture view of environmental risk as a body of public policy. This makes it somewhat unique among the titles reviewed here.

Review

"Entitlements and Public Policy in Environmental Risks" by David Bromley argues that property rights in environmental policy determine which party in a dispute receives protection form the state. People expect to be informed about some risks, protected from others, and compensated for still others. "Better safe than sorry" seems to be a commonly accepted maxim that, as the Paustenbach (1989) book reviewed elsewhere (reference G15) indicates, can be quite costly to the range of policy options considered. Alternative entitlement or rights structures are not likely to appear in the near future and institutional setups will err on the side of caution where ecological and health effects are probabilistic.

"Environmental Risk Perception and Valuation: Conventional Versus Prospective Reference Theory" by V. Kerry Smith is an article for economists interested in the theory of why risk perceptions and neoclassical economic models often do not match one another. Smith reviews a number of potential explanations for the misalignment of perceptions and value favoring the prospective reference theory of Kip Viscusi. Smith suggests three ways that public policies could be designed to account for the differences between perception and values. The article is of limited use to most practitioners.

"Risk Perception and the Perceived Public" by Lola L. Lopes addresses some fundamental questions with which every risk manager should be familiar. How much do people know about risk? This question provides the entree into a cursory review of some of the classical literature on this topic. What needs to be known and by whom? Here the author dips her toe into the vast waters of risk communications but she does not wade in very far. The discussion is largely anecdotal and cursory.

"The Media and Public Perceptions of Risk: How Journalists Frame Risk Stories" by Sharon Dunwoody looks at the role of the media in presenting stories about risk. Studies find that the media coverage of risks does not mirror reality and that risk stories contain very little risk information. The article offers a series of findings related to this thesis. For example, events are emphasized over processes in story selection. Such insights may be valuable to some, but the article concludes with the observation that we know precious little about how journalists construct stories regarding scientific and technological risk.

"The Policy Response to Risk and Policy Perceptions" by Kathleen Segerson categorizes environmental risks into three categories: 1) internalized risks caused by the person facing the risk; 2) market-based risks associated with product and workplace safety where there is a market relationship between the risk generator and the victim; and, 3) externalized risks where the risks are involuntary to the victim. There is a potential role for government for each type of risk and the role varies with the nature of the risk. Segerson also finds a number of different approaches for managing the risks. These include: privatizing risk management; ex ante economic incentives (taxes and deposits); regulation; legal liability; and victim compensation funds. Significantly, the author concludes that because risk management is likely to have multiple goals no one policy instrument is likely to suffice.

"Decision-Making About Biotechnology: The Costs of Learning From Error" by E. J. Woodhouse and Patrick W. Hamlett discusses the risks posed by biotechnology. They conclude that there are more than economic and environmental risks. Chief among these are the deliberate damage that could be done by humans using successful technologies; and the risks of intentional deployment of lethal pathogens.

"Gaining Acceptance for Noxious Facilities With Economic Incentives" by Howard Kunreuther and Douglas Easterling applies an old concept to a new context. What if we offered a benefit package to the NIMBY (not in my backyard) and LULU (locally unwanted land use) crowds that was sufficient to overcome their resistance to a project? Might that not help break the impasse on at least some siting issues? The basic problem with siting noxious facilities is that the benefits of such facilities are perceived to be general in nature while the costs seem to fall most heavily on the community in which they are sited. The authors suggest any number of benefit packages that might overcome local resistance provided the risks of the site are perceived to be acceptably small. They conclude with an emphasis on the need to mitigate risks to assure that an acceptable compensating benefits package can be found.

"Occupational Safety and Health in the 1990s" by W. Kip Viscusi offers a critique of the Occupational Safety and Health Administration (OSHA) . The article focuses on a critique of the use of standards to control behavior offering alternative economic incentives like an injury tax.

G5: <u>Making Hard Decisions: an Introduction to Decision Analysis</u>. By Robert T. Clemen. Boston, MA: PWS-Kent Publishing Company, 1990. pp. xviii, 557. Seventeen chapters, six appendices. ISBN 0-534-98444-4.

Applicability

One of the best books to read to learn how to model decisions is this one by Clemen. Based on anecdotal evidence gathered at risk conferences, Clemen's book is the book of choice for introductory decision theory classes. It's well written, clear, and full of good examples. The book takes work, however, because it is a rather complete introductory treatment of the theory. Though it can be used as a reference book and read selectively it is best treated as a text and read from start to finish, at least from start to finish of the major sections.

The section on modeling decisions is highly recommended to Corps analysts and planners. Better than any one source, it will teach the basics of influence diagrams and decision trees. These are going to be important tools in applying risk analysis to environmental resources. Though this text has been selected primarily for its explication of decision theory it has extremely useful sections on modeling uncertainty and preferences. This book is a must for anyone's basic risk analysis library.

Review

Clemen's book is divided into three sections: modeling decisions; modeling uncertainty; and modeling preferences. The first section may be of most value to Corps analysts. It begins with the elements of decision problems and introduces the reader to the jargon and essential concepts of decision theory including sequential decisions, uncertain events, outcomes, values, and the time value of money. He then proceeds to an extremely well done discussion of how to structure decisions that relies primarily on influence diagrams and decision trees. Numerous examples are presented to show the reader how to use these tools to make choices.

A chapter on sensitivity analysis effectively presents strategies for approaching sensitivity analysis of decision problems as well as graphic devices (tornado diagrams) for displaying the results of these analyses. The final chapter on decision modeling is entitled "Creativity and Decision Structuring". This interesting chapter offers insightful advice on how to think about alternative actions.

The second section of the book deals with modeling uncertainty. It begins with the basics of probability that packs a great deal of easy to process information into a single chapter. The chapter on subjective probability is extremely well done and is well worth the reader's time. Clemen uses intuitively appealing examples to illustrate what often appear to be very dense concepts in other texts. The chapter uses probability wheels, computer outputs, decision trees and a variety of functions to effectively illustrate his discussion.

Clemen's chapter on theoretical probability models is one of the best around. He describes the distributions with a mix of intuition and rigor that is very effective. The case studies on overbooking, earthquake prediction, and municipal solid waste are effective capstones to this chapter. The chapter on using data to construct probability distributions is brief but it's an effective introduction to some basic concepts. The second half of the chapter introduces some Bayesian concepts.

Monte Carlo simulation is the subject of one chapter. With reference to the spreadsheet environment, the author introduces the basics of Monte Carlo simulation. The explanation of how random numbers can be generated for various distributions using a simple random number generator is a good introduction to an important programming skill that is taken up at greater length in the review of the Law and Kelton (1991) book (reference G11).

The last section of the book deals with preference modeling. The discussion of risk attitudes will be of general interest. Much of what follows on expected utility and its axioms will be of interest only to experienced analysts and those with a serious interest in risk analysis.

The chapters on trade-off analysis and multiattribute utility models are a bit more esoteric than most. They do, however, present good, basic, and understandable introductions to topics that may well prove of considerable interest to risk analysts dealing with environmental resource issues. Overall, Clemen's book is an invaluable reference.

G6: **<u>Summary Report on Issues in Ecological Risk Assessment</u>. By Eastern Research Group for the Risk Assessment Forum of the U.S. Environmental Protection Agency. Washington, D.C.: U.S. EPA, February, 1991. Three sections and eight appendices. EPA/625/3-91/018.**

Applicability

In 1986 the U.S. Environmental Protection Agency published a series of guidelines for carrying out human health risk assessments. Recently EPA's Risk Assessment Council has asked the Risk Assessment Forum to organize a program to develop ecological risk assessment guidelines for agency-wide use. This has been an on-going process. EPA, with this report, "..embarked on a multi year effort to develop ecological risk assessment guidelines that will foster consistency in the Agency's approach to evaluating not only the risks posed by conventional stresses such as toxic chemicals, but also other anthropogenic stresses such as habitat loss and global climate change."

The summary is an excellent introduction to ecological risk assessment issues. There is also ample review of the human health risk assessment paradigm. The document is extremely reader friendly. It is highly recommended to those with responsibility for conducting or introducing risk and uncertainty analysis to environmental resource planning. It is also highly recommended to all analysts seeking to understand risk analysis issues related habitat loss, global climate change and other non-chemical ecological stresses.

Review

In 1983 the National Academy of Sciences (NAS) published *Risk Assessment in the Federal Government: Managing the Process (National Research Council, 1983).* This report recommended that federal agencies establish guidelines for risk assessments. In 1986 EPA published risk assessment guidelines related to human health risks. The U.S. EPA is currently developing a similar set of guidelines for conducting ecological risk assessments.

While human health assessments focus on a single species (humans), ecological risk assessments involve multiple endpoints at different levels of biological organization, from single species to communities of organisms to entire ecosystems. There are also different types of assessments. Human health assessments tend to all be predictive. Ecological assessments are predictive, retrospective and monitoring studies concerned with multiple stresses, both anthropogenic and natural, chemical and non-chemical.

Selection of an appropriate risk assessment paradigm is a critical focus of the EPA effort and the subject of the early sections of the report. The human health paradigm recommended by the NAS, described in several publications reviewed in this report, comprises: I) hazard identification; ii) dose-response assessment; iii) exposure assessment; and, iv) risk characterization. It has been generally agreed that a modified version of the NAS paradigm could be used for the ecological risk assessment.

Hazard identification of the ecological paradigm is complex. Defining the scope of the problem, identifying chemical and non-chemical stresses, the type of ecosystem(s) involved, spatial and temporal scaling factors and identifying the endpoints are critical steps. Instead of dose-response it has been suggested that stress-response may be a better term. It better conveys the range of stresses.

For human health an exposure assessment refers to the magnitude, frequency and duration of exposure and the human populations subject to exposure. In an ecological context, exposure more frequently refers to the concentration or magnitude of a contaminant or stress in the environment. The recent *Relative Risk Reduction Strategies Reports (U.S. EPA* SAB-EC-90-021 and SAB-EC-90-021A) clearly identified nonchemical stresses from human activities as posing the highest risks to the environment. This finding moves EPA's interests much closer to the Corps as far as environmental resources planning is concerned.

The risk characterization for ecological risk assessments does not always have to be quantitative. Relative rankings of ecological risks are considered potentially useful in this new area of endeavor. Interestingly, the report's first recommendation on the choice of paradigm is that terminology be clearly defined.

In subsequent sections, uncertainties in each of the four components of the risk assessment paradigm are described in enlightening detail. Population modeling is discussed in Section 2.4. This section describes matrix projection models, natural population time-series models, ecotoxicity population models, and others. The references in this report are an invaluable treasure. Following section 1 is a comprehensive list of EPA guidelines found in the Federal Register. Section 2 is followed by extensive references to the risk assessment literature.

The appendices provide a mixture of background papers and written summaries of colloquium sessions during which the content of this report was discussed and debated.

G7: "Risk Assessment and Management: Framework for Decision-Making." By United States Environmental Protection Agency, EPA 600/9-85-002. Washington, D.C., December 1984. pp. 35.

Applicability

This is the earliest EPA document addressing risk assessment and management. It was chosen on the basis of its historical interest to Corps policy and risk assessment. Risk analysis has been a major thrust of the EPA, much more so than it has been for the Corps. It needs to be noted, of course, that the types of risk analysis and its role in the agencies' missions vary markedly. Nonetheless, the EPA model for addressing risk analysis - both institutionally and analytically - deserves review and scrutiny by the Corps, to learn by the successes and failures of EPA.

Review

The purpose of this document was to develop the outline of a strategy that would allow EPA to act constructively, despite the uncertainty they face, to improve the condition of the environment, to reduce risks to human health, and to protect and enhance the quality of natural ecosystems. The report clarifies EPA's risk jargon by distinguishing risk assessment and risk management. In part it says:

> "Scientists assess a risk to find out what the problems are. The process of deciding what to do about the problems is risk management" (p. 3).

The advantages of separately identifying the assessment and management steps were identified as follows: 1) risk assessment and risk management help set priorities; 2) risk management provides a context for balanced analysis and decision-making; and 3) risk assessment and management produce more efficient and consistent risk reduction policies.

The emphasis of this early document rests clearly on reducing the damaging effects of pollution. The risk assessment focus was on human health risk assessment. The discussion makes it clear that risk assessment does not enjoy the status of incontrovertible scientific agreement. Despite its uncertainties, however, risk assessment is appreciated for being the only tool available for discriminating among environmental health problems. The risk assessment done by EPA was seen as a literal risk assessment. An example is estimating the probability of developing cancer as a direct result of chemical exposure.

The report describes population risks from toxic pollutants as a function of two measurable factors: hazard and exposure. To cause a risk, a chemical has to be toxic (it presents a hazard) and present in the human environment at some significant level (human exposure). Risk assessment judges whether an adverse effect will occur as a result of the hazard and exposure. The total effects of the risk are quantified to the extent possible. The basic approach to risk assessment is described in the document in four steps, which have come to be identified as the environmental risk assessment paradigm.

Hazard identification involves weighing the available evidence and deciding whether a substance exhibits a particular adverse health effect. Once a chemical is identified as a hazard, its potency is determined. In a *dose-response assessment* the analyst determines the response to various levels of exposure (dose). The *exposure assessment* determines the likely degree of human exposure to the chemical of concern. In the final step, *risk characterization,* the risk associated with the exposures are estimated. The final calculations are straightforward, exposure times potency or unit risk. However, presentation of the assessment is problematic because of the copious uncertainties associated with the assessment.

EPA identified several significant uncertainties. First, most risk assessments depend on animal tests. Extrapolating results to humans leads to a weight of evidence problems in hazard identification. Because it is not entirely clear that safe levels or thresholds exist for toxic chemicals there are uncertainties in dose-response assessments. Uncertainty in exposure assessment stems from data and measurement limits in monitoring exposure.

As the EPA struggled with the development of principles and guidelines for risk assessments it confronted issues of terminology and the degree to which procedures can be appropriately standardized. In Chapter 2 of the document, reference is made to numerous EPA documents that may be of interest to those interested in the evolution of the agency's risk analysis policies and practices and those interested in human health risk assessments. At the time this document was prepared EPA was in the process of completing or revising guidelines on carcinogenicity, mutagenicity, reproductive effects, systemic effects, assessment methods for chemical mixtures, and exposure assessment. A Risk Assessment Forum was established at this time.

Chapter 3 addresses the goals and applications of risk management. EPA identifies a duality of this management initiative that may or may not materialize for the Corps in the area of environmental resource planning. Individual risk management decisions may be seen as balancing risk reduction against resources. On the other hand, the program as a whole is designed to balance risk against risk. That is, it is essential to address the worst and most controllable risks first. To do otherwise means we reduce less risk than we could.

The primary elements of risk management are setting priorities among risks and choosing reduction measures for the risks selected. The three major components of risk management that have to be balanced are: 1) the harmful effect of the pollutant; 2) cost; and 3) confidence. The effects factor is not easy. It can be quantified as a risk calculation but benefits of reducing effects are not easy to quantify. Costs are the costs of reducing the hazard and they may be explicit or implicit. The enormous range in uncertainty makes the measure of confidence a particularly difficult issue.

To analyze the relationship between cost and effect several tools were identified. These are: benefit-cost analysis; risk-benefit analysis; and, cost-effectiveness analysis. The agency's risk management initiatives at the time the document was prepared were: building the information base; using risk management tools; and, strengthening the role of communication in risk management. Although the document is basic and somewhat dated, for its historical and epistemological lessons, it is worth reading.

G8: "The Greening of Risk Assessment: Towards a Participatory Approach". By Frank Fischer. pp. 98-115. In Business and the Environment: Implications of the New Environmentalism. Edited by Denis Smith. New York: St. Martin's Press, 1993. ISBN 0-312-09518-X hardcover.

Applicability

This article is applicable to anyone involved in project management or public participation programs. Environmental resource risk assessments can be expected to be emotional, controversial, and contested issues in many studies. Fischer provides a convincing argument for a participatory approach to risk assessment that may well become an essential element of environmental resource risk assessments in the future. The article, though directed to the Environmental Protection Agency's programs, is a well referenced non-technical argument to do risk assessments differently. EPA's reliance on a scientifically based quantitative risk assessment is basically the same approach used by the Corps of Engineers today. Fischer says this method can sometimes make matters worse. Fortunately, he offers enough of a hint of a solution to give Corps managers and analysts a direction in which to go.

Review

> "The number of people who believe that we live in the riskiest of times has increased dramatically over the past two decades. For those people, particularly those of the green persuasion, the world is on the brink of an ecological disaster" (p. 98).

With these two sentences Fischer captures the essence of what project managers may find to be the attitude of many environmental resource study stakeholders. His arguments have merit, as the quests for safety and environmental protection have emerged as paramount political issues.

Fischer recounts how emerging environmental philosophies appeared to verge on opposing any project or technology that was not risk free. The primary response to this development has been to shift the resulting political discourse to the search for an "acceptable risk". During the 1980s the EPA instituted a scientifically based risk assessment as the mandated criterion for risk related decision-making. This process was to provide a technically rational basis for centralized regulatory decision-making.

Briefly, the process generally requires complex systems to be broken down into various measurable components; measuring the statistical probabilities of failures or other outcomes; examining crucial variables that might cause or exacerbate a failure/outcome; and modeling this entire process. The result was intended to be the replacement of risk "perceptions" of technically uninformed stakeholders with objective statements of risk. The method has largely failed to reassure the public. Fischer suggests that this has been because managers and decision makers have failed to see large-scale technological systems as social phenomenon.

Risk assessment in a democratic society cannot be based on the a priori findings of experts explained to groups of passive public participants.

> "The first step towards a solution is to be found in the theoretical redefinition of large-scale technological systems. Rather than a complicated set of nuts and bolts, we must recognize such systems to be a special type of social phenomenon" (p. 103).

Post mortems of recent disasters such as Bhopal, Chernobyl, Three Mile Island, Challenger, Exxon Valdez, and innumerable plane crashes reveal organizations and managerial systems to be at fault. This engenders considerable distrust of experts, government organizations, and management systems. The public's trust in our ability to ensure personal and environmental protection have been inexorably shaken. "Rather than being a technical issue plagued by social perceptions, the risk problem turns out to be as much a social question related to technical issues."

What clearly arises from Fischer's article is the conclusion that the solution to public acceptance of risky projects and technologies is not a well executed quantitative risk assessment carefully communicated to the public. Technical knowledge coupled with improved communications of empirical findings cannot, alone, answer the questions posed to planners and decision makers in the social and political world. The solution, Fischer suggests, is participatory risk assessment.

According to Fischer, the risk assessment process must be opened up to non-experts. There must be a full discussion of the social and institutional issues upon which the risk assessment depends. Laypersons need a role in this discourse from the outset of the analysis. A wider range of stakeholders needs to be incorporated into the initial problems of what the risk problems are or are perceived to be. The advantages of this approach are twofold.

> "First, it builds into the analytical process the stakeholders' pragmatic experiential knowledge about technical and institutional risks; and, second, it addresses the essential issues of public legitimation and motivation" (p. 107).

The rewards are credibility and acceptance for the risk assessment as stakeholders become cooperative participants in the formation of scientific arguments, rather than passive listeners.

Risk assessment is a product of a bureaucratic system. It is a tool designed to guide hierarchical decision-making. As such, scientist/analysts can be expected to be reluctant to admit non-experts, for a variety of reasons; the outrageous unscientific nature of such participation chief among them. However, no decision process that hopes to succeed in a democratic society can long ignore the voice of those affected by the decisions. Fischer provides a compelling argument for including all stakeholders in the risk assessment from the very beginning.

G9: Readings in Risk. Edited by Theodore S. Glockman and Michael Gough. Washington, D.C.: Resources for the Future, 1993. pp. xiv, 262. Nineteen articles. ISBN 0-915707-55-1.

Applicability

This book comprises 19 reprinted papers authored by 34 experts in 13 different journals. The articles were assembled to provide a basic reader for a course in risk analysis. The articles are all self-contained. The topic begins with the first sentence and ends with the last. The reader need not have any sophisticated technical background although some math appears from time-to-time. The selection of articles represents the broad range of disciplines that deal with risk, for example, biostatistics, chemistry, toxicology, epidemiology, economics, engineering, operations research, psychology, physics, and communications.

The book is organized into six parts: 1) basic concepts (four articles); 2) risk comparisons (three articles); 3) regulatory issues (three articles); 4) health risk assessment (three articles); 5) technological risk assessment (three articles); and, 6) risk communication (three articles). For the reader who is approaching the topic of risk for the first time this is a valuable book. It presents basic definitions, fundamental concepts, seminal arguments, and informed discussion with uniform quality. It is recommended for the generalist reader interested in a broader background in the basics of risk analysis.

Review

The *Basic Concepts* section offers articles that help develop the terminology and concepts of basic risk considerations. "Probing the Question of Technology-Induced Risk" by M. Granger Morgan first poses the question, "How safe is safe enough?" In defining exposure processes and effect processes he defines a way to systematically think about technological risks. Briefly exploring some of the rules of thumb that people use to think about risks, he concludes that overconfidence in our own thought processes may be a major pitfall.

In a follow-up article, "Choosing and Managing Technology-Induced Risk," Morgan expounds on the distinctions between risk assessment and risk management. He offers four generic categories for developing risk abatement strategies: 1) modify the natural or human environment; 2) avoid or modify exposure processes; 3) avoid or modify effects processes; 4) mitigate or compensate for effects. Morgan presents the well known loss function modified to show how a theoretical optimal level of risk can be arrived at. This optimal level does, of course, allow for the trade-off between risk losses and the cost of risk abatement. Several tools for quantitative risk analysis are mentioned and a useful probabilistic risk assessment example is presented in a sidebar.

"Defining Risk" by Fischoff et al. essentially concludes that there is no one definition of risk that serves all purposes adequately. The authors explore the dimensions of the risk definition controversy and offer examples of risk indices.

"Risk Analysis: Understanding 'How Safe is Safe Enough?'" by Derby and Keeney treats one of the most fundamental conclusions of the early literature. There is no such thing as a risk free solution. Zero risk is not a viable option for society. Furthermore, there is no single answer to "how safe is safe enough?" because there is no single problem. "The problem appears in many different contexts and solutions for each case are context and problem specific."

Putting risks in perspective requires that they be compared with other risks. In the second section, *Risk Comparisons*, the selection of articles offers insights into the basics of comparing risks. In Wilson's "Analyzing the Daily Risks of Life," the author presents a humorous view of some trivial activities with equal risks. For example, eating 40 tablespoons of peanut butter is as risky as canoeing for six minutes. His tongue-in-cheek point seems to be that we worry so much about trivial risks because we have been so successful in alleviating many of the bigger ones.

"Rating the Risks" by Slovic et al. is one of the classics in the literature and is a must read for anyone who wants to understand how we mortals think about risks. Introducing the heuristics of availability, overconfidence, and the desire for certainty the authors provide keen insight into our judgmental biases. The review of an expert panel's assessment of relative risks is revealing. The nine risk characteristics presented have been reproduced time and again. This is one of the more interesting and more important articles in the basic literature.

"Ranking Possible Carcinogenic Hazards" by Ames et al. compares quantitative estimates of the risks of cancer from natural and man-made chemicals. The authors must rely on animal tests to identify carcinogens and argue there is no reliable method for extrapolating high dose animal tests to low dose exposure for humans or other species. They propose that carcinogens be ranked on the basis of the ratio of human exposure to each substance to the dose that causes cancer in animals. Interestingly, they conclude naturally occurring chemicals in foods are a greater threat than man-made chemicals.

Regulatory Issues are the subject of part three. "Risk, Science and Democracy" was written by former EPA chief William D. Ruckleshaus. He points out the solutions EPA offered to the pollution problems of the 1970s, only to have those problems surpassed in complexity by the toxic substances appearing in our waste streams. The author argues that it is essential to keep risk assessment and risk management separated. The science that supports risk assessment must continue to advance. Ruckleshaus concludes that regulation decisions are best made at the local level, within broad bounds that are set at higher government levels.

Wildavsky argues in "No Risk is the Greatest Risk of all" that government erred when it took responsibility for risk management away from individuals. He sees a successful society paralyzed by a fear of risk that has been fostered by government assumption of the responsibility for risk management. Risks cannot be reduced for everyone, he argues. The desire to protect us from all risk has reduced us to the politics of prevention. Wildavsky would prefer a society that can seek gains as well as avoid losses and he would prefer that the responsibility and authority to do either rest with society and not the government. A no risk society is neither desirable nor within reach.

Kelman in "Cost-Benefit Analysis: An Ethical Critique" says cost-benefit analysis is simply systematic thinking about decision-making. Beyond this opening tribute it would be difficult to consider Kelman a strong proponent of cost-benefit analysis. His basic conclusions about cost-benefit analysis and its application to environmental, safety, and health regulations are: 1) a certain decision may be right even though its costs outweigh its benefits; 2) there are good reasons to oppose monetization of non-market benefits and costs; and, 3) given these first two objections it is not wise to devote many resources to the generation of benefit-cost calculations. He opposes the further spread of the cost-benefit "gospel".

Part four features *Health Risk Assessment*. The basic model comprises four steps. First, identifying chemicals that are health hazards (hazard identification). Second, using biological or mathematical models to estimate the risks associated with doses below the doses that produced the laboratory effects observed in laboratory animals or human beings (dose-response). Third, measuring or estimating the amount of these chemicals to which people/wildlife are exposed (exposure assessment). Fourth, the risk assessor must characterize the risks by specifying the underlying assumptions and uncertainties attending the quantitative estimates (risk characterization).

In "Application of Risk Assessment to Food Safety Decision-Making" Rodericks and Taylor highlight the differences in assessing risks for carcinogens and non-carcinogens. Noncarcinogens are generally assumed to be threshold phenomena. That is, there is assumed to be a dose below which no toxic response will occur. Carcinogens, on the other hand are treated as if any dose, no matter how small, is potentially harmful. The authors find that data for risk assessment are often very limited and assessments compensate for the lack of data by relying on "worst-case" scenarios that intentionally avoid understating the risks. Not said is that there is an unintentional result of frequently overstating the risk.

Hattis and Kennedy in "Assessing Risks From Health Hazards: An Imperfect Science" argue that despite EPA's efforts to rely on an authoritative, scientific risk assessment, there is no such thing. Scientific uncertainties remain, perhaps even abound. There are considerable difficulties in linking cause and effect in an unassailable manner. Dose-response relationships are highly suspect in some cases. Using animals to develop such relationships presents a whole slew of extrapolation problems. The authors conclude there is a need for risk assessors to do a better job of identifying, assessing, and communicating the uncertainties to policy makers.

In "A Quantitative Estimate of Leukemia Mortality Associated With Occupational Exposure to Benzene" authors White, Infante and Chu present a model linking leukemia to benzene exposure. This analysis was responsible for OSHA reversing a policy on benzene exposure of workers.

Part five addresses *Technological Risk Assessment*. Assessing the risks of large and complex modern technological systems can be a formidable task, especially when the technology is new. In "Social Benefits Versus Technological Risks" Starr argues for an economic decision criteria, "maximum benefit at minimum cost". From a series of examples, he is able to derive five "exploratory" rules of thumb about how the public weighs risk benefits and costs.

"The Application of Probabilistic Risk Assessment Techniques to Energy Technologies" by Rasmussen provides an example of how probabilistic risk assessment techniques are applied. Faults trees and event trees are introduced quite effectively. The simple calculations reveal the complexity that can underlie even seemingly straightforward risk assessments. This article provides a good introduction to some useful tools.

Keeney et al. in "Assessing the Risk of an LNG Terminal" provide a very readable example of a risk assessment. Examining the shipping of liquid natural gas (LNG) they conclude that release of a vapor cloud could be catastrophic. However, the analysis shows that despite the nature of this low probability high consequence event, LNG is still less risky than conventional means of generating electricity.

The last part deals with *Risk Communication*. In "The Emergence of Risk Communication Studies: Social and Political Context," Plough and Krimsky indicate that both the federal government and citizens use or abuse risk research for their own ends. Government officials too often draw selectively from the research to support their points while citizens frequently brush the research aside in favor of more politically expedient means to their ends. Of even greater importance to the breakdown in communications is the disconnect between the "technical rationality" of risk assessors and the "cultural rationality" of the citizenry. The authors suggest that the experts must recognize the validity of citizens concerns if risk communication is ever to be a two-way process.

"Getting to Maybe: Some Communications Aspects of Siting Hazardous Waste Facilities" by Sandman focuses on the conflicts encountered among three parties involved in siting hazardous waste facilities. Knowing the community can halt the siting process by saying "no" through legal or political means, proponents of the site would be wise to acknowledge the community's power. Such a concession would enable the community to come out from the corner it feels backed into by the experts and enable them to say "maybe".

Johnson et al. report on the effectiveness of five different booklets and a one page fact sheet used to inform people about the risks of radon in the home in "Informed Choice or Regulated Risk?". Various ways of presenting the same information have decidedly different effects on learning, risk perception, and mitigation behavior. The extent to which people learned about risk, changed their risk perceptions, and formulated advice for their neighbors about radon were probed to establish these preliminary research results.

G10 "Graphical Communication of Uncertain Quantities to Nontechnical People." By Harald Ibrekk and M. Granger Morgan. Risk Analysis: An Official Publication of the Society for Risk Analysis. Vol. 7. No. 4. 1987. pp. 519-529.

Applicability

Effectively communicating the results of complex risk analysis to decision makers and the public is going to be a major concern of Corps analysts. This article presents the results of an experiment in which two groups of people were provided information in a variety of formats. One group was composed of nontechnical people, the other was a group of semitechnical people. The authors describe their experimental design in sufficient detail for the reader to appreciate the task and the subsequently reported results.

This article can provide an education to Corps analysts in that it may suggest some communication measures of which they are unaware. It is also useful to those already familiar with these graphical techniques because it provides some preliminary evidence of what works best before and after people receive some simple explanations.

The reader is well advised to keep in mind that this 1987 article is somewhat dated in that statistical and presentation graphics computer software has made these graphics and many more very easy to reproduce. Nonetheless, the article is clear, concise, accessible and practical.

Review

Without effective risk communication the best analysis is worthless. This paper examines the question, "What is the best way to communicate, in graphical form, quantitative information about the value of an uncertain quantity to semitechnical and nontechnical people?" It additionally considers how accurately the information can be communicated.

An empirical evaluation of nine graphical techniques is presented. In the first test, 45 volunteers were provided a scenario in which they were going to a mountain cabin and were concerned about the possibility of snow. They were presented information in nine "pictures" that included: an error bar, a histogram, a pie chart, a probability density function, the mirror image of a density function at half its height, dotted horizontal bars, horizontal bars with vertical lines, a tukey box (box and whisker), and a cumulative distribution function. Without any explanation of the graphs they were asked the forecaster's best estimate of the chances there would be more than 2 inches of snow, and the chances there would be 2 to 12 inches of snow. In the second half of the test the people were given an explanation of the graphs and then were asked to make some predictions about water depth in a flood from a new set of graphs.

Results were evaluated in a number of ways. Estimates of best estimates, i.e., means, were most accurate with error bars and tukey boxes. Explanations of the graphs seemed to have a weak effect. For the question about the probability of obtaining a result greater than some value (e.g., snow greater than 2 inches) the pie chart and cumulative distribution function (CDF) gave the most accurate answers. The CDF also gave the best answers for the question of the probability of obtaining a result between two values (e.g., 2 to 12 inches of snow). The authors offer a thorough analysis of the accuracy and confidence people had in the use of these different graphics. Among the interesting findings was that "..a "rusty knowledge" of statistics, a graduate degree, or use of information about uncertainty on the job, do not significantly improve subject performance." This does not bode well for analysts who must communicate with these and "less well trained" people.

The authors offer several useful conclusions, the first of which is that more study is needed in this area. The performance of a display depends on the information you're trying to convey. If means are important you might use one display. For probability intervals you would use another. There are also some handy insights offered. For example, when asked to identify a best estimate people tend to choose the mode rather than the mean. This leads us to the simple solution of marking the mean on a graphic when it is the value of interest. To convey probability intervals the authors recommend using a CDF printed directly above its probability density function. Until more work is done, and probably well beyond that, the best strategy seems to be to combine displays to obtain the best features of each.

G11: Simulation Modeling and Analysis. By Averill M. Law and W. David Kelton. New York, NY: McGraw-Hill, Inc., 1991. pp. xxii, 759. Thirteen chapters, one appendix. ISBN 0-07-036698-5.

Applicability

Simulation modeling has been one of the principal tools of risk analysis as practiced by the Corps of Engineers. It seems this review would not be complete without at least one book devoted to simulation. The Law and Kelton text is a good one. A helpful feature at the beginning of each chapter suggests what you should read the first time you read this book. You'll have to read this book carefully and more than once. This is a book for people who are getting ready to start or who are already doing some simulation modeling. It's not for people looking for information about simulation modeling. It's a rigorous text, full of detail, yet with amazingly little of the complex mathematics that confounds so many readers. This is a text for modelers and programmers. For them, it's a great text and is highly recommended. All others should look elsewhere.

Review

This is a no-nonsense book that should be the companion of every simulation modeler. The analyst using a simple spreadsheet simulation won't need it, but if integrated risk analysis models are going to be developed, or if simulations are going to be written in a "C language" or visual basic, this is the book you want.

The first and second chapters on basic and complex system modeling will exhaust the reader. They are complete treatments with ample examples and sample programs. The two chapters consume 234 pages. The writing is good, the graphics copious, but the detail is draining. It takes careful reading to follow the authors extremely helpful detailed discussions of subroutines. Reading about sample programs takes an uncommon effort to focus on the context of the problem being discussed. The effort is, however, well rewarded.

Chapter 3 on simulation software provides a helpful overview of simulation languages and general purpose languages. It presents discussions of GPSS/H, SIMAN/Cinema, SIMSCRIPT II5, and SLAMII . Table 3.2 provides a useful comparison of these simulation languages not found in other such texts.

Following the overview presentations of the first three chapters the authors take a few steps back and begin to fill in the details. There is a basic review of probability and statistics that is nothing special but it does offer a few nuggets of useful information, for example, why one should not replace a distribution by its mean.

The primary reason this book was selected for this review is because of the material in Chapters 5 through 8. This material is not always easy but it provides the best and most complete discussion of random numbers for programmers and modelers to be found anywhere.

Chapter 8 is worth the price of the book. Using a simple uniform random number generator over the interval 0 to 1, the authors show how to generate random numbers for twelve continuous distributions, seven discrete distributions, three correlated distributions, and three arrival processes. This is very useful information for people who are unable to rely on distribution functions provided by software packages like @RISK and Crystal Ball.

Chapter 9 addresses model outputs. It presents numerous display methods and a complete discussion of topics like transient and steady-state behavior and measures of performance. The remainder of the text becomes considerably more complex. It describes methods for comparing alternative system configurations, a technique that may ultimately be of considerable interest in the development of integrated risk analysis models for the Corps. Variance reduction techniques, experimental design and optimization methods are also presented.

Law and Kelton offer a text that should meet many of the basic needs of Corps simulation modelers. It is complete and documented with a great variety of references. If you can't find what you want in the text, it can almost certainly be found in one of the references.

G12: An Introduction to Risk Analysis. Second edition. By Robert E. Megill. Tulsa, OK: Penn Well Publishing Co., 1984. pp. xiv, 274. Nineteen chapters and three appendices. ISBN 0-87814-257-6.

Applicability

This is an introductory level book on risk written with an oil well exploration orientation that does not limit its applicability to environmental planners. The material is presented at such a basic level that it is easily accessible by any analyst. It is chock full of rules of thumb that many will find helpful. The oil well orientation may prove interesting to analysts who are comfortable with reasoning by analogy, for there are many analogies to environmental planning issues that can be seen throughout the text. This is a good supplemental text for those who want to understand some of the probabilistic nature of risk better. It is recommended.

Review

The goals of this book are, in the author's own words, "...(an) effort to make simple a few of the basic fundamentals in the analysis of risk". At this, the author succeeds. Megill does an admirable job of providing a truly introductory and frequently intuitively appealing explanation to several important methods or concepts in risk analysis. Perhaps the only criticism of the book is that he did not go further in either breadth or depth.

In a workman-like fashion, the author introduces one basic idea at a time. He begins with the histogram in Chapter 1. In Chapter 2 he introduces the binomial and normal distributions. The chapters are illustrated with effective, if somewhat dated looking, graphics. One of the strengths of this book is that the references include many of the classic articles in the literature. A weakness is the flip side: there are far too few modern references to the material treated.

The author does a superb job of introducing the reader to fundamental concepts. If you don't remember what a measure of central tendency is or if you've forgotten what a variance is, Megill is your author. He provides a simple and straightforward explanation devoid of the statistical formulas and examples that come with the modern statistics textbooks that treat much of the same material found in Megill's early chapters.

One of the many useful things about this book is its frequent reference to handy little rules of thumb, such as that the mean deviation of a normal distribution is about 80 percent of the standard deviation. You won't find these handy little "factoids" in many texts anymore. Part of the book's genius is its simplicity. For example, when explaining the lognormal distribution, Megill offers the beautifully simple definition as "Lots of little values and not many big ones". In the context of his example, everything just falls into place. In this chapter as in many others he relates some aspect of the chapter's main subject matter to oil and/or gas fields.

Another pleasant surprise and useful feature of this book is the author's attention to the little historical details. He points out things like how the ancient Greeks were the first to give us abstract concepts using numbers. They were the first to add 5 + 3 to get 8 without worrying about what physical things they were adding. Does material like this help you learn how to do risk analysis? Not in the least, but it makes for an eminently readable book and it provides a real alternative to readers seeking an interesting review of probability and statistics.

Chapter 5 on "The Shape of Distributions" may be the best in the book. If you never understood the difference between a pdf (probability distribution function) and a cdf (cumulative distribution function), you must read this chapter. Using plain talk and effective graphics the author will have you understanding more about these concepts in 12 pages than you did in a whole semester. Considerable space is devoted to the binomial and triangular distributions. Here you may get more detail than you wanted from an introductory course, but you will understand these distributions.

In a style reminiscent of a favorite rambling professor Megill jumps back and forth among topics somehow without annoying the reader because there is always a subtle and ultimately convincing logic to the way the book is arranged, another of its unique strengths.

Several chapters are devoted to opinion analysis and subjective probability. Subjective probability involves decisions where very little information is available, he says with characteristic simplicity. The example on subjective probability provided in Chapter 12 leaves us woefully short of something that constitutes a really useful example for environmental resource planning. But is it fair to expect more from a book that says it is an introductory text?

Parallels with environmental problems abound in the examples and case studies. For example, Chapter 12 presents a situation that requires the analyst to place a value on four different tracts of land that little is known about. We know they are similar to other tracts of land that have produced gas and oil and that only a few geologists know anything more about them. The land may have alternative uses. With only a little imagination the gas and oil become habitat values the geologists become environmentalists and we can pretty much follow this example to its conclusion with some insight into how to pursue subjective probabilities for a restoration or mitigation project, for example.

By the time this 19 chapter book hits chapter 14 it is pretty heavily involved with oil and gas field examples that might cause the novice to nod off or see no relevance. Even then there are nuggets for those who persist. Looking for insight, rules of thumb and shortcuts? If you're not concerned about depth of overall understanding and the details of design, this is your book.

G13: **<u>Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis</u>. By M. Granger Morgan and Max Henrion with a chapter by Mitchell Small. New York and Cambridge: Cambridge University Press, 1992. pp. xii, 333. Twelve chapters. ISBN 0-521-36542-2.**

Applicability

This is a must read book for anyone who is trying to understand the reasons for and nature of what has come to be called risk and uncertainty analysis. The book is, for the most part, an easy-to-read and well organized guide to uncertainty analysis, just as its title claims. It is one of the most thorough and best introductory texts on the topic. It is a book that will prove as useful to lower, middle and top level managers charged with the responsibility of managing risk and uncertainty as it will to the analysts charged with assessing it. It is highly recommended.

Review

Does uncertainty really matter? That is the intriguing question the authors ask in the first chapter. They find uncertainty rather accepted in the natural sciences and greatly overlooked in policy research and analysis. This makes the book particularly useful to an environmental risk analysis program that involves so many of the natural sciences and that will be charged with making policy.

The first two chapters are used to motivate the reader of the book by showing that risk and policy analyses are timely and of major significance through a mix of Socratic argument and case study examples. The strength of the book, however, lies in the eight chapters that follow.

Many analysts and managers when attempting something for the first time might like to see an example of that thing done well. Chapters 3 and 4 provide as good an overview of the generic issues attending risk analysis as will be found in the literature today. The chapters are well-written but require careful and thoughtful reading in order for the reader to catch on to the thread of the authors' logic. Once grasped, that logic provides an orderly approach to virtually any risk analysis problem.

Chapter 3 addresses the broad issue of what constitutes good policy analysis. Using elements of the scientific method - empirical testing; documentation and reproducibility of results; explicit reporting of uncertainty; peer review; and open debate about alternative theories - the authors develop arguments for applying the same standards to policy analysis. Decision criteria including utility-based, rights-based, technology-based and hybrid criteria are discussed as potential philosophical frameworks for the analysis. The "ten commandments" of good policy analysis are worthwhile and should be considered in any risk analysis undertaken by any agency involved in public policy decisions. Noting the most frequent approach to uncertainty has historically been to ignore it, the authors conclude with examples of when it may be very important to consider uncertainty.

Chapter 4, "The Nature and Sources of Uncertainty" is one of the best in the book. Getting a handle on this uncertainty business is often one of the most difficult tasks for analysts and managers newly approaching the topic. If they can only find a way to begin to understand what it's all about, perhaps it wouldn't be so difficult to understand after all. Morgan et al. begin with a straightforward and simple explanation of the nature of probability. Though many texts identify the classical, frequentist and subjective views of probability as three distinct ways to look at probability, the authors give little weight to the classical view which they have blended in with the frequentist view of probability. The subjective view is called personalist or Bayesian by the authors. Nonetheless, the treatment is clear, concise and easily understandable.

The real value of this chapter is found in the taxonomy of uncertainty that follows the discussion of probability. First, the authors identify the types of quantities that are encountered in policy models. They include: empirical parameter or chance variable; defined constant; decision variable; value parameter; index variable; model domain parameter; and outcome criterion. Next, the sources of uncertainty encountered in these different empirical quantities are identified. These sources are: statistical variation; subjective judgment; linguistic imprecision; variability; inherent randomness; disagreement; and approximation. If the types of significant quantities encountered in an analysis are identified and the sources of uncertainty attending them can be specified, the techniques for addressing these uncertainties can be more readily addressed.

The chapter concludes with a brief discussion of model uncertainty, perhaps the most important and overlooked source of uncertainty in many instances. Model uncertainty describes the circumstances where we are unsure about the structure or form of the model that best represents the system or problem under analysis. For example, the uncertain quantities and sources of uncertainty attending the use of habitat evaluation models can be identified and analyzed. The theory and structure of the habitat model itself could be a source of greater uncertainty than all the uncertain quantities combined.

Following the development of these basic concepts the authors offer an extremely useful discussion of probability distributions. Eleven common and useful families of distributions are described. These descriptions provide a handy introduction to situations in which each distribution may be appropriately used.

It is inevitable that environmental resource risk analysis will confront many situations where complex systems are poorly understood, theory is not well defined or data are inadequate. In these situations professional judgment will become a most important method for ascertaining potential effects. Subjective estimates of uncertain situations or opinion analysis will have a major role in these risk analyses. In Chapter 6 the authors provide an overview of the major issues encountered in subjective estimates of uncertainty. The chapter provides an excellent review of the range of issues addressed in the professional literature.

The heuristics of availability, representativeness, and anchoring and adjusting are illustrated. Of particular value is the treatment of the psychology, elicitation, and evaluation of subjective probability assessments. This chapter is a "must read" for analysts who will be conducting risk analyses. The literature cited throughout the chapter provides an invaluable base for further exploring this topic that will prove most useful to environmental resource risk analysis.

Chapter 7 presents several examples of subjective probability elicitations. Three different probability assessment protocols are presented in such a clear and direct fashion that the reader will feel well grounded in the basics of these techniques after reading only this chapter. There is a wealth of helpful guidance about what constitutes a good protocol, what to do when experts won't cooperate and how to handle differences of opinion. In short, this chapter is the perfect primer for conducting probability elicitations.

The most mathematically rigorous section of the book is the discussion of analytical and computational techniques for examining uncertainty. Chapter 8 introduces tools like decision trees and Monte Carlo simulation using a modest amount of calculus. This chapter will be too abbreviated and mathematically esoteric for beginners and rather too superficial for experienced analysts.

How does one convey the results of a risk analysis to those who are not risk analysts? That is the question explored in the ninth chapter. The results of numerous studies are reviewed. Probability density functions, cumulative distribution functions, Tukey box plots, discretized versions of the density function, pie charts, density functions at half height with mirror images, error bars, fractile graphs, triangle plots, and probability densities using vertical bars or dot densities are among the tools used to visually display information. Both single and multi-dimensional displays are presented. The chapter concludes that the audience for the information is the most important factor in choosing a communication medium.

Chapter 10 provides an interesting but already dated case study of uncertainty modeling. Guidance on the construction of complex models is presented in Chapter 11. Regulatory models and global system models are among the large models discussed. Pros and cons, as well as caveats, for large models are presented.

The final chapter concludes with an admonition to be aware of the limits to our knowledge and a summary discussion of the intriguing idea of the expected value of including uncertainty (EVIU). EVIU is a concept developed at length by Henrion in other works in the early 1980s. The notion of EVIU helps to answer the question how much better will our decisions be if we consider uncertainty explicitly? The chapter addresses the issue of whether it's better to use the best estimates of uncertain values and arrive at a grand best estimate or is it preferable to use distributions of uncertain values. The author suggests that EVIU be used to determine which approach is better.

Virtually all of this text is derivative of the work of others. That in no way diminishes the value of this text. It is a masterful work of pulling together a coherent treatment of a vast new subject matter. It is done with eminently clear prose, excellent examples and an extraordinary list of references.

G14: "A Method for Treating Dependencies Between Variables in Simulation Risk-Analysis Models". By P.D. Newendorp. *Journal of Petroleum Technology: Official Monthly Publication of the Petroleum Branch, American Institute of Mining and Metallurgical Engineers*, Vol. 28, No. 10, October 1976. pp. 1145-1150.

Applicability

This was one of the few articles found that addressed dependencies between variables in risk analysis. It is anticipated that dependencies among and between variables in environmental resource planning will become a significant issue. Understanding the complex ways environmental variables interrelate has always and will continue to represent a significant issue in environmental resources planning.

This is a useful article. It introduces a method for handling dependencies in a Monte Carlo process. This would seem to be a rather difficult task at first. Newendorp offers a technique so simple and so obvious that he makes you feel smart to see it so clearly. When this article was written in 1976 this must have been singular. Today, commercial Monte Carlo software like @RISK and Crystal Ball do these calculations for you, although the algorithms used by these companies are generally unknown to the user. This paper is well written and fun to read, but we're not sure there is a need for it unless you are writing your own program and want an easy way to handle dependencies among variables.

Review

Newendorp notes that most of the literature on Monte Carlo simulations is written assuming variables are independent of one another. He notes that there are many circumstances in risk and uncertainty analysis in which variables are related in a dependent fashion. The paper discusses two points relating to variable dependencies. First, he offers a technique for determining if random variables are dependent. Second, he shows how to modify the sampling procedures on each iteration of a simulation to account for observed partial dependencies between random variables.

Acknowledging that there are many measures of correlation the author presents a method that is "easier" and "eliminates a lot of statistical theory". His suggestion is simply to plot one variable against another and look at them. A complete dependency, such as a straight line, can be handled by estimating the function that describes the dependency. No relationship means independent variables. Between these two extremes are the partial dependencies Newendorp addresses. A boundary is drawn around the cross-plot of two variables to include all observed X-Y pairs. The variability in Y is expressed as a function of X in a way that allows the boundary to change as X changes. Newendorp uses a normalized probability distribution that represents all possible Y distributions in a dimensionless form. He uses a simple transformation:

$$Y = Y_{\min X} + (Y_{\max X} - Y_{\min X})(Y_{norm})$$

Reading the equation of the lower and upper bound of Y as a function of X is the key to this simple process. Once the value of X is selected by usual methods it can be used to estimate a value for Y.

Newendorp cautions that lack of data is not sufficient reason for ignoring possible dependencies between variables. He advocates the use of "what if" cases to define the boundaries of the dependency. The article provides two extended tables with figures that alone are sufficient to explain his technique in enough detail to adapt it to any programming language that has a simple random number generator.

G15: <u>The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies</u>. Edited by Dennis J. Paustenbach. New York: John Wiley & Sons, 1989. pp. xx, 1155. Thirty-four articles in eight sections. ISBN 0-471-84998-7 hardcover.

Applicability

The title of this and many other books might suggest a great deal of work has already been done in the areas of primary interest to Corps of Engineers personnel involved in environmental resource planning. Unfortunately, that may not be so. Environmental risk assessment or health risk assessment, as it is also known, refers to "the process or procedure used to estimate the likelihood that humans or ecological systems will be affected adversely by a chemical or physical agent under a specific set of conditions" (p. 27). Risk analysis as currently practiced by the Corps refers to a more diverse number of unwanted events, few of which are chemical agents. This book is an excellent documentation of the environmental risk assessment literature.

The interested reader will find its sections on *Basic Principles*, *Assessing Water Contaminants*, *Assessing the Risks to Wildlife, and Risk Management* particularly helpful. Most of the articles will require the reader to find applications by reasoning through analogy. This book is worthwhile for its references alone.

Review

Tome has rarely been used more accurately to describe a book than it is used here to describe Paustenbach's two year effort involving over 50 top scientists in the field of health risk assessment. Risk assessment as practiced by those concerned with health risks as defined above is divided into four major steps: hazard identification, dose-response assessment, exposure assessment, and risk characterization.

> "*Hazard identification*...is defined here as the process of determining whether human exposure to an agent could cause an increase in the incidence of a health condition (cancer, birth defect, etc.) or whether exposure by a nonhuman receptor, for example, fish, birds, or other wildlife, might adversely be affected. It involves characterizing the nature and strength of the evidence of causation...
>
> *Dose-response assessment* is the process of characterizing the relation between the dose of an agent administered or received and the incidence of an adverse health effect in exposed populations and estimating the incidence of the effect as a function of exposure to the agent...
>
> *Exposure assessment* is the process of measuring or estimating the intensity, frequency, and duration of human or animal exposure to an agent currently present in the environment or of estimating hypothetical exposures that might arise from the release of new chemicals into the environment (p. 30).

> *Risk characterization* is the process of estimating the incidence of a health effect under the various conditions of human or animal exposure described in the exposure assessment. It is performed by combining the exposure and dose-response assessment" (p. 32).

This four step process provides the theoretical underpinning for most of the articles found in this book.

In the *Basic Principles* section (seven articles), the reader can find a general introduction as well as some useful examples. The first article, "A Survey of Health Risk Assessment" provides a thorough overview of the basic model in all of its complexity. It is a modern, up-to-date and thoroughgoing introduction to the basic model and issues of environmental risk assessment. The Cox and Ricci article provides a good discussion of basic concepts in quantifying human health risks through presentation and discussion of numerous examples. Subsequent articles address: epidemiology, the science of disease distribution; time-response relationships; physiological pharmacokinetic models, the next generation of dose-response models; superfund risk assessments; and a methodology for assessing risks to humans and wildlife presented by contaminated soils.

Section B, *Assessing Water Contaminants*, (four articles) tends to focus on specific chemical agents (e.g., 1, 1, 1-trichloroethane and cationic surfactants). In so doing, however, they provide an informative discussion of contamination and migration of contaminants as well as methods used to apply the various steps of the four step model. There is considerable scientific detail on toxicity, metabolism, and target organ toxicity.

Assessing Hazardous Waste Sites is the third section (five articles). The articles include an actual risk assessment of a pesticide production facility. A site specific risk assessment, also called an endangerment assessment, is provided for a mine tailings site. This latter article provides a good introduction to the terminology and methodology of the superfund analytical process.

The Maxim article, "Problems Associated With the Use of Conservative Assumptions in Exposure and Risk Analysis" is a particularly insightful article for any analyst or decision maker who, because of uncertainty, complexity or politics, has been tempted to make a conservative assumption about inherent risks. Though the article is oriented specifically toward exposure analysis its seven suggestions for improving risk and exposure analyses are sufficiently broad and general to be of use in any situation. The other articles round out the treatment of the four step model when applied to hazardous waste sites.

The fourth section is *Assessing Air Contaminants* (three articles). The Gammage and Travis article is one of many in this book that treats the low-dose extrapolation problem. One of the principle analytical difficulties encountered in the health risk assessment field is how to use data from high dose exposures on selected animal species to infer knowledge about lower doses and effects on other animal or human species. Such issues may have a parallel in the consideration of species survival in environmental resource studies. The Harley article provides a good example of a risk assessment for lung cancer risk. It is particularly strong in presenting risk projection models.

Section E, *Assessing Occupational Hazards*, (five articles) presents articles particularly useful for understanding the dose-response and exposure assessment steps of the risk assessment process that drives this volume. The hazard assessment discussions of these articles remain their strong points, however. The focus is on toxicity levels for humans of various chemical agents. The use of animal data and next generation physiological pharmacokinetic models in different articles provide a view of the many approaches and problems with assessing toxicity of agents for humans.

Assessing Potential Hazards to Consumers (two articles) is the title of he next brief section. Methyl mercury in fish and the presence of di-2-ethylhexyl phthalate (DEHP) in baby pacifiers and toys are the subjects of two risk assessments.

Section G, *Assessing the Risks to Wildlife* (three articles) turns the emphasis from humans to wildlife. Ecotoxicology, assessing unreasonable risks to the environment, is a field of inquiry of considerable interest to the Corps in its dredging program. It is a field of inquiry that may become of increasing interest as involvement with environmental resources planning develops. Ecological risk assessment is complicated by the fact that we are concerned with a myriad of species and not just a single chemical but a host of chemical and non-chemical elements that interact in complex ways in aquatic and terrestrial communities.

The Rand article addresses some general ecotoxicology concerns such as chemical identification, metabolism and mammalian toxicology, and the environmental fate of chemical agents. This is done in the context of a case study of carbofuran's effect on birds.

Keenan et al. examine the effect of sludge produced by a pulp and paper mill used for mine reclamation on the health of animals. The article illustrates the calculation of a lifetime average daily dose (LADD) for dermal contact, inhalation, and soil uptake; three routes of exposure to 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin (2, 3, 7, 8-TCDD) are considered. The article provides example calculations showing how the LADD can be used to estimate TCDD uptake through consumption of game that have ingested TCDD. It is one of the better articles for illustrating cancer risks for individual scenarios of exposure to chemical agents.

The Gandy article presents a hazard assessment for a bald eagle population near a superfund site. The study struggles with the lack of critical data in a manner with which many Corps analysts will identify. The case study comprises a site overview, identification of indicator chemicals, and a hazard assessment. It is one of the few articles in the entire collection to address potential hazards to wildlife habitat.

The articles in the last section, *Risk Management*, as a body provide a good review of the basic management issues encountered in quantitative risk assessments of health hazards. The findings are sufficiently general to be of considerable value to any risk manager. The articles generally provide good examples of the quantitative risk assessment techniques criticized in the Fischer article (reference G8) reviewed elsewhere in this literature review. The Cox and Ricci article provides a helpful introduction to concepts like voluntariness of risk, equity of risk, and procedural legitimacy. They conclude quite rightly, we believe, that acceptability of risk is context sensitive. What is acceptable risk today may no longer be tomorrow.

The Krewski et al. article provides a framework for evaluating risk management strategies that parallels the Principles and Guidelines planning framework in spirit, though not in fact. The framework is illustrated with an example that is a bit underdeveloped.

The article by Ames et al. confronts the interesting problem of how to rank possible carcinogenic hazards. They develop a scale, not of risks to humans, but rather of priorities for concern, an approach that could be profitably mimicked in other contexts as well.

The final article on nonpessimistic risk analysis returns to Maxim's topic of conservative risk estimation from the viewpoint of risk management rather than risk assessment. It likewise finds substantial problems with worst-case assumptions standing in for better analysis.

G16: "Reducing Risk: Setting Priorities and Strategies for Environmental Protection". By Science Advisory Board (A-101), SAB-EC-90-021. The Report of the Science Advisory Board: Relative Risk Reduction Strategies Committee to the U.S. Environmental Protection Agency. Washington, D.C.: USEPA, September 25, 1990. pp. v, 26.

Applicability

This document was selected to assure an awareness of EPA policies regarding environmental protection. It provides a summary of the EPA's recommendations and findings for its risk analysis program as of 1990. Though somewhat dated, this is still a valuable reference document for Corps personnel interested in learning from the experience of other federal agencies. This is a short and easy-to-read document containing findings are specific, helpful and directive. Though the recommendations are less applicable to the Corps because of differing agency missions, they may still facilitate awareness and understanding of EPA procedures.

Review

Despite annual public and private expenditures to protect the environment on the magnitude of $100 billion, many national environmental goals have not been attained. In retrospect our efforts have been inconsistent, uncoordinated, and less effective than possible. The fragmented nature of our approach to environmental problems is evident in our laws, programs and tools, all of which have been rather ad hoc and somewhat shortsighted. It is critical that U.S. environmental policy must become more integrated and more focused on opportunities for environmental improvement than it has been in the past.

> "One tool that can help foster the evolution of an integrated and targeted national environmental policy is the concept of environmental risk. Each environmental problem poses some possibility of harm to human health, the ecology, the economic system, or the quality of human life. That is, each problem poses some environmental risk. Risk assessment is the process by which the form, dimension, and characteristics of that risk are estimated, and risk management is the process by which the risk is reduced. The concept of environmental risk, together with its related terminology and analytical methodologies, helps people discuss disparate environmental problems with a common language. It allows many environmental problems to be measured and compared in common terms, and it allows different risk reduction options to be evaluated from a common basis. Thus the concept of environmental risk can help the nation develop environmental policies in a consistent and systematic way" p. 2.

EPA, in this document, describes itself as a reactive agency that has seen problems as separate. There has been little correlation between work effort and resources dedicated to environmental problems and the risks posed by those problems. The question of relative risk was faced for the first time in 1986. About 75 managers and staff compared the relative risks of 31 environmental problems. They addressed the residual risks after then-current controls were implemented. The results of that effort were published in *Unfinished Business: A Comparative Assessment of Environmental Problems*. This report was a watershed event for EPA, but it also showed that "business-as-usual" was no longer an option for dealing with environmental risks of the 1990s and beyond.

The Science Advisory Board (SAB) formed the Relative Risk Reduction Strategies Committee (RRRSC) in response to the *Unfinished Business* report. The RRRSC was divided into three subcommittees: Ecology and Welfare; Human Health; and Strategic Options. The combined efforts of the RRRSC were to: 1) critically review *Unfinished Business*; 2) merge the evaluations of cancer and non-cancer risk and ecological and welfare risks; 3) provide strategies for reducing environmental risk; and, 4) develop a long-term strategy for improving risk assessment/analysis methodologies. This report highlights the most important policy-oriented findings and recommendations from the three subcommittee reports.

Ten recommendations are offered on policy matters that include targeting future efforts, expanding the scope of risk-based priorities to strategic planning and budgetary processes, among other matters. Eight major findings are reported in the document. These were: 1) the importance of *Unfinished Business*; 2) problems in ranking risks; 3) the extraordinary value of natural ecosystems; 4) time, space, and risk; 5) the links between risk and choice; 6) public perceptions of risk; 7) relatively high-risk environmental problems; and, 8) strategy options for reducing environmental risk.

The findings provide a useful survey of the basic problems Corps analysts can expect to encounter. They range from things like lack of data and methodological inadequacies to the inadequacy of the willingness to pay concept in risk analysis. The findings address issues of intrinsic, moral values that are quite different from the P&G planning framework the Corps uses.

The document is only a summary but it is an effective one. It provides a snapshot of the state of EPA risk analysis policy as of 1990. The mission of EPA is different from that of the Corps, but the lessons learned by EPA can be very helpful to Corps analysts and decision makers. We find this and other EPA documents useful reading for Corps personnel. An awareness of the experience of other agencies can be an important component of the development of the Corps' risk analysis procedures for environmental resources planning.

APPLIED RISK ANALYSIS LITERATURE

A1: "Risk Analysis as a Project Management Tool". By B. Allardyce and G.M. Pottinger. <u>The Journal of Canadian Petroleum</u>. Vol. 24, No. 2, pp. 54-59, April, 1985.

Applicability

This article provides a good example of a general risk analysis as it was conducted in the 1980s. The authors used Monte Carlo simulation and sensitivity analysis, still two of the more popular tools for risk analysis. Their method is rather straightforward and simple. They did several independent risk analyses for project components and used a fault tree to combine the results. Their decision criterion was the rate of return, a technique used more by the private sector than the government. The paper is easy to read. We had hoped, based on the title, for more specific guidance on how risk analysis is used by managers. The paper, though reasonable for its time, is now dated and is not particularly recommended.

Review

The Arctic Pilot Project was to have been a marine transportation system conceived to exploit the large gas reserves of Canada's Northern Archipelago. Its total cost was estimated to be $3 billion (1983 Canadian). The treatment of economic and technical risks was a significant part of the overall project management function.

In order for project management to deal effectively with risk a project specific risk analysis methodology was developed. The risk analysis was designed in order to provide backers of the project with information about the likely economic viability of the project. Several independent risk analyses were undertaken for the logistics, facilities, shipping and sea-lift components of the project. It was then necessary to integrate these studies in a fashion that summarizes the risk potential of the entire project.

The rate of return was identified as the index variable to be used to represent risks to the overall project. This indicator was judged to be the best indicator of the project's overall success. The analysis did not include consideration of risk to environmental resources. It's emphasis appears to be on the project's economic performance, and, as a result of which, the project was abandoned.

A fault tree was used to delineate the sources of risk which were combined according to the fault tree structure. Risks were quantified in the form of cumulative probability distributions (cdf) and the analysis relied on simulations using Monte Carlo procedures and sensitivity analysis. Results are presented in terms of the cdf for rate of return.

The analysis relied most heavily on fault tree analysis and "risk centre identification". Risk centres identified were capital costs, operating costs, estimates of escalation rates, market price estimates, and overall project production. Key variables were identified for the risk centres and were the focus of subsequent sensitivity analyses.

The authors suggest their method is a general one. The steps include: 1) establishing a project breakdown structure; 2) identifying risk centres; 3) constructing a fault tree; and 4) calculating probability distributions for all pertinent available input data. The simple act of creating the risk model is valuable for its identification of the project's most sensitive components.

A2: "Problems of Risk Assessment in Water Resources Management." By Richard C. Allison and Roger Durand. The Environmental Professional. Vol. 13. 1991. pp. 326-330.

Applicability

In this paper the authors argue the importance of risk assessment and risk management for water resources. Their view is a big picture one. Though there is little that can be called new or revealing in this article, it does affirm the importance of the risk analysis work the Corps is involved with in the management of the Nation's water and environmental resources.

Review

The need to assess risks to water resources and to manage those risks properly has never been more evident. The authors offer examples of drought, hospital wastes on the shoreline, and other recent headline events as proof of their assertion. Despite the mention of flood and drought, their focus seems clearly fixed on human health issues. With such an urgent need, the time for proper risk assessment is now. Despite important developments in risk assessment, including scholarly and popular attention, better analytical methods, and more effective communication, they conclude water resource analysts ability to assess risks remains remarkably limited.

Allison and Durand offer eight major interrelated problems that constrain our ability to do proper risk analysis. These problems inhibit the resolution of debate with respect to water health and safety. The problems are: 1) failure to distinguish risks to the environment from risks to human health; 2) lack of general agreement on what constitutes an adverse effect on human health; 3) the inability to specify cause-effect relationships for certain health and safety outcomes; 4) lack of a dose-response threshold for many hazardous materials; 5) great variation in the susceptibility of human beings to the effects of exposure even when there is a dose-response threshold; 6) limited understanding of the toxicological consequences of many substances in wide use; 7) inability to obtain valid, reliable, and sufficiently precise measurements of crucial risk variables; and 8) difficulty defining acceptable risk.

The authors offer examples of how these problems limit the debate on water resources for recreational water, drinking water and irrigation water. For example, "At present, there is virtually no reliable and valid epidemiological evidence to support a quantitative, microbiological standard based on fecal coliforms for judging recreational water safety." A risk assessment by the Wastewater Division of the City of Colorado Springs is put forth as a model study.

What can managers do in the face of these seemingly intractable problems? First, abandon any idea that there exists a general-purpose, uniform "off-the-rack" approach to risk assessment that will be good for all occasions. Second, conduct environmental, epidemiologic assessments that are tailored to your own risk situations and to the variables of your own unique setting. Third, concentrate on developing what has been termed "policy for error variance", an option for coping with or adjusting to the uncertain or unpredictable. This is an idea similar in spirit to the adaptive management strategy the Corps has proposed for ecosystem restoration.

Fourth, go to work immediately on fostering improved communications between the “makers” and the “takers” of risk.

A3: "On Quality, Peer Review, and the Achievement of Consensus in Probabilistic Risk Analysis." By G. Apostolakis, B.J. Garrick, and D. Okrent. Nuclear Safety. Vol. 24, No. 6, November-December, 1983. pp. 792-800.

Applicability

This article was selected for review for several reasons. First, it presents some of the thoughts of the Nuclear Regulatory Commission (NRC), and it is important to proceed with some awareness of what other agencies are doing in the area of risk analysis. There are several publications referenced in this article not reviewed elsewhere in this report that would appear to be well worth the time required to become familiar with them. Second, we find the title suggests many issues that will be important to Corps analysts involved in environmental resource risk analysis. The quality of the work is always going to be a concern. We believe that because of the potential controversy attending environmental issues both peer review and achieving consensus are going to be very important issues.

The paper was rather general in tone and as such it serves as a very good introduction to some of the work of the NRC and to the issues raised in the title. In recounting lessons learned it offers Corps planners insight into issues that may have taken months or years to learn from experience. For example, does the Corps want a risk analysis paradigm that all would follow like the NRC favors and EPA has? It does provide some quality assurance but it also could result in finding square pegs in round holes. This issue and others like it deserve careful consideration by analysts seeking to establish reasonable standards for risk analysis in a new area of endeavor. The article is highly recommended to those interested in risk analysis paradigms, guidance and the like.

Review

Several problems face users of Probabilistic Risk Analysis (PRA). First, how do you put the numerous and diverse elements of a PRA together in a way that does not violate any rules of the many disciplines involved in the PRA? Second, how do we assure that independent groups can reproduce significant results? Third, how do we reach consensus with problems that rely so heavily on decision tools developed for use by a single person (for example, subjective probability theory) when groups of people try to use these theories and tools? In this article the authors address several issues that arise in connection with these problems.

With regard to quality assurance, i.e., the quality of the PRA itself, the authors note that PRA is a tool that can be used or abused by project opponents. Furthermore, when data are lacking the PRA can be legitimately questioned by anyone. NRC safety policy has advanced the position that:

> "One way to improve the consistency of PRA results is to provide some assurance that analysts follow equivalent procedures, make similar assumptions, treat phenomena consistently, and utilize a common data base" (p. 794).

The NRC staff favors a highly prescribed PRA format. The *National Reliability Evaluation Program (NREP) Procedures Guide* is a step in this direction. The benchmarks established make quality comparisons easier. The first step toward standardization suggested is to limit the scope of the PRA, considering only the most important things first, gradually expanding the scope of the analysis. This is an approach that could aid the development of a risk analysis strategy by the Corps.

Proceeding cautiously and with open debate and discussion seems to be the unspoken principle for developing PRA guidelines for the NRC. Peer review is considered to be an extremely important part of a PRA. In fact, four levels of review are proposed in the *PRA Procedures Guide*. Study team review of all work by an internal peer review group is first. Methodological mistakes are identified with the most confidence at this level. Review by plant operating personnel would allow people most familiar with the operation of systems (for the Corps these might be resource agency personnel) to review the work for technical errors in modeling the relevant plant and site characteristics (perhaps ecosystems in the Corps studies).

The third level of review is peer review. This is to be done by true peers, people not involved with the study but with capabilities equivalent to those who did the study. This review would concentrate on the methods, information sources, judgments and assumptions. Management review would concentrate on the perspective, scope, and suitability of the analysis.

The consensus problem is to be expected in a PRA, especially when the subject matter is one of controversy. Experts do not have to agree on everything. Many aspects of probability theory and decision theory have been developed for analysts acting alone. When groups have to reach consensus on analyses that rely on highly individualized tools (for example, subjective probability assessments) disagreement is inevitable. Where data exist the interpretation of evidence can vary from expert-to-expert. The authors argue that quality assurance is an important part of the process that could lead to consensus. They see standardization of methods as a way to provide that quality assurance.

A4: "Risk Assessment Principles in Environmental Impact Studies." By M. Carolota Arquiaga, Larry W. Canter, Deborah Imel Nelson. The Environmental Professional. Vol. 14. No. 3. 1992. pp. 204-219.

Applicability

This paper is the conceptual godfather of the articles by Canter and Cairns (1993), found elsewhere in this review (reference A10). It's primary purpose is to establish that EISs were not doing what they were supposed to do with regard to the analysis of human health impacts. This it does well. In its second part, it establishes a need for an environmental health assessment methodology and suggests such a generic methodology.

The article is of some historical interest. It offers very little of immediate value to Corps analysts developing risk analysis methodologies for environmental resources planning. Like many other articles reviewed in this report, it was chosen solely on the strength of its title, which simply could not be overlooked.

Review

This paper comprises two major parts. In the first, it establishes that EISs have not done the human health impact assessments that policy and law require. In the second part, the authors offer a generic assessment methodology.

The introduction begins by pointing out the significance of the National Environmental Policy Act (NEPA) of 1970. The environmental impact assessment (EIA) procedure required by NEPA has now been adopted by more than 75 countries around the world. The authors argue that two topics have received inadequate attention in the EIA process. They are "..the minimal focus that human health impacts typically are given in EISs and the lack of quantitative assessment methods for the prediction and assessment of human health impacts." Interestingly, many authors encountered in this review have argued that human health effects have been emphasized almost to the exclusion of natural ecosystems. These authors argue the exact opposite.

The authors, all from the University of Oklahoma, reviewed 39 EISs prepared in the U.S. between 1980 and 1990. This was not a random sample of EISs. Using a set of review questions, the authors set about a systematic review of these EISs. In their discussion, the authors describe many of the problems they encountered, including such fundamental issues as deciding what is meant by health. The review included four flood/hurricane surge protection projects, one reservoir, one marina, and one river dredging project. The remaining 32 EISs covered a wide variety of construction and disposal projects.

Health impacts were divided into physical, chemical, radiological, and biological. The number of EISs including each of these types of impacts was identified. An EIS could include more than one type. Of 38 EISs with physical health impacts, 19 addressed these impacts, three of them in a quantitative manner. Thirty-three chemical impact EISs saw 20 addressed, three of them quantitatively. Nine of ten radiological health impacts were addressed, none of them quantitatively. Of 13 biological health impacts, three were addressed, none quantitatively. From these results the authors concluded human health impacts have been given inadequate attention in most EISs since 1980. Biological impacts were concluded to have received the least attention.

Arquiaga et al. offer ten reasons illustrating the need for a health impact assessment methodology. They next offer a generic methodology that is based on the ten fundamental activities conducted in a typical EIS. This methodology, summarized in the authors own words follows:

1) Preparation of description of project and need for project (note health-related components);
2) Review and analysis of pertinent institutional (health-related) information;
3) Identification of possible impacts (on human health) from construction and operation of project type and alternatives;
4) Preparation of a description of the affected environment (focus on health characteristics and delivery systems);
5) Prediction of impacts (health related);
6) Assessment (interpretation) of the predicted impacts (based on standards/risk quantification);
7) Identification and evaluation of mitigation measures (to minimize undesirable health impacts);
8) Selection of proposed action from the alternatives being evaluated (include health impacts as a decision factor);
9) Preparation of written documentation of the EIA process (incorporate health focus);
10) Monitoring of environmental impacts during project construction and operation (include health indicators and measures of health hazard).

A5: Ecological Risk Estimation. By Steven M. Bartell, Robert H. Gardner, and Robert V. O'Neill. Boca Raton: Lewis Publishers, 1992. pp. 252. Eight chapters. ISBN 0-87371-163-7.

Applicability

This is a book for biologists skilled in the techniques of ecological risk analysis or for skilled risk analysts seeking a better understanding of ecological risk in aquatic systems. It is not very mathematical but the language is the technical language of ecological risk, ecology and biology. If you are a reader who knows that an increased bioturbation of sediments and increased growth of certain oligochaetes exposed to low concentrations of endrin under laboratory conditions is an example of a hormetic response, this book is for you. Although it is not an easy book for the non-professional to understand, there is a wealth of useful information. For the right reader it is recommended.

Review

Because our ability to forecast the probable effects of novel chemicals on ecological systems has not kept pace with either society's increasing chemical arsenal or its thirst for information about these effects, there is a need for ecological risk analysis. In general terms, ecological risk is an attempt to quantify the potential danger posed by chemicals from a variety of toxicity tests that have been devised. Ecological risk analysis remains in its formative stages primarily because of our lack of data and lack of understanding of the function and complexity of unique ecological systems.

This book presents a methodology that uses the results of laboratory toxicity tests to forecast the likelihood of measuring toxic chemical effects on populations in natural aquatic systems. The objective of ecological risk assessment is "..to use available toxicological and ecological information to estimate the probability that some undesired ecological event will occur." These ecological endpoints can include such events as: local extinction of some species; unacceptable decline in the abundance of some economically important taxa; unacceptable increase in the abundance of some undesired population or species; unacceptable change in a fundamental ecological process; and loss of species habitat.

The authors do a credible job of laying out the attributes of a good risk methodology in a pragmatic fashion. The emphasis is clearly on being able to use data currently being produced, though the authors' speculation on future directions for ecological risk analysis in the concluding chapter is not to be missed. The nature of the toxicological and ecological data used to estimate ecological risk in aquatic systems is described at some length. The discussion is comprehensive but relatively advanced. For example, median lethal concentrations (LC_{50}), effective concentrations (EC_{50}), median effective dose (ED_{50}), and median lethal dose (LD_{50}) are all discussed as benchmarks for estimating ecological effects of toxic chemicals; but none of them are defined adequately for readers not already familiar with the concepts.

Interspersed throughout the book are some valuable nuggets of information. The discussions on legislation and sources of toxicological data are two such examples. Following a discussion of the nature of the data and its inherent uncertainties the authors offer a standard water column model as the aquatic ecosystem model of choice. This model proves interesting because it simulates complex competitive and predator-prey dynamics in the context of a seasonal, multidimensional environment. The hypothesis underlying the development of ecological risk methods is that an ecosystem model, in this case the standard water column, can be used to extrapolate the results of laboratory toxicity data into meaningful predictions of ecological effects in natural aquatic systems. The water column model is useful because sublethal toxic effects can be expressed as changes in the rates of the physiological process equations for population growth. Whatever else its appeal, the model is pragmatic.

The water column model also permits exploration of sublethal toxic effects on predator-prey and competitive interactions among populations in addition to the direct effects on specific populations. Yet another advantage of the model is that it explicitly represents a dynamic physical-chemical environment in which the simulated ecological and toxological interactions occur.

The authors present a model designed to use laboratory toxicity data to modify the aquatic system model to forecast the ecological effects of toxic chemicals in Chapter 4. Estimating exposure is identified as the critical step in any risk analysis. Well-defined concentration-response functions (CRFs) for each of the model populations and each toxic chemical would be the ideal. Such data are not to be expected. Linear approximations to the CRFs are the rule and the interpolation issues are substantial.

The key to the bioassay simulation model is the effects matrix. Population mortality is interpreted as a decrease in biomass. These decreases, related to exposure levels, can be mathematically described by disaggregating the rate of decrease into its physiological constituent processes. The growth parameters are modified by the so-called “E matrix”. Each row element defines the population-specific fractional change in a growth parameter required to simulate the population's expected response to the exposure concentration for that matrix. The effects factors are assigned to a distribution with a mean equal to itself and a coefficient of variation of 100%. One matrix is generated for each exposure concentration used in the risk analysis. This is the key component of the overall risk model.

After presenting the component pieces of an ecological risk model in the early chapters, a risk algorithm bringing all the components together is presented in Chapter 5. The risk algorithm was applied to a variety of organic and inorganic contaminants for several different aquatic systems. One example showing effects of various chemical exposures on phytoplankton, planktivorous fish, and other groups is presented. Sensitivity analyses are conducted using five different scenarios. The results are expressed as probabilities of different endpoints being achieved under different exposure concentrations of chloroparaffins.

In an evaluation of the risk forecasting methodology the authors wrestle with numerous philosophical and pragmatic issues. Perhaps one of the most generally applicable points they make is:

> "Unproductive debate can be avoided by simply recognizing that the model is invalid by definition. The value of the model is determined by its facility for increasing the basic understanding of the science involved, by the model's ability to extend current predictive powers, or, if lucky, both" (p. 164).

The results show that the duration of the simulations used to estimate risk should include several cycles to ensure the effects are not confined to transient system behavior. Attempts to evaluate the accuracy of the toxic effects predictions were, generally, not successful, because of a lack of data and limitations of current methodology.

A6: "Endangered Species and Uncertainty: The Economics of a Safe Minimum Standard". By Richard C. Bishop. American Journal of Agricultural Economics. pp. 10-18, February, 1978.

Applicability

In this paper Bishop presents a clear, concise and articulate argument for giving the benefit of the doubt to preservation alternatives over development alternatives. This article provides a decision criterion that many environmental interests will welcome. Though the article is somewhat dated it still offers a timely contribution to the public policy debate. This article can be easily read by economists and others and is highly recommended.

Review

The author's objective may be summarized by the following quote from the opening of the article:

> "Suppose that a hydroelectric dam has been proposed which would flood the last remaining habitat of an endangered species. Suppose further that there is no alternative method of preventing extinction of this species except to maintain its habitat in an unflooded condition. The goal of this paper is to explore the conceptual issues which are central to the development of an economic framework for confronting public decisions of this type" (p. 10).

This well-written paper performs two major tasks. First, it advances an argument for how extinction irreversibly narrows the reservoir of potential future resources, creating the possibility of large, though uncertain, future social losses. Second, it offers the "safe minimum standard" (SMS) policy option that would maintain sufficient population and habitat to assure the survival of the species.

The problem of irreversibility and uncertainty is that "characteristics" of the natural environment become natural resources over time, through changes in human tastes and preferences, income, population, technology, social institutions, and public policies. The long run implications of allowing the reservoir of species to be reduced are uncertain. We don't know if or when unanticipated events will cause natural phenomena to become valuable natural resources. Oil was not a resource until technology had advanced to the point where the energy stored in it could be harnessed in productive ways. Potential extinction is an important public policy issue, more now than when this article was first written. We have little basis for judging which life-forms we can lose without future social and economic consequences.

One solution to this problem of irreversibility and the uncertainty of future losses would be to adopt the safe minimum standard. The SMS arises from the minimax principle of game theory, i.e., society should choose the strategy that minimizes maximum possible losses. Suppose society has two choices: 1) E, for extinction, which means building the dam; and, 2) SMS, not building the dam and leaving the valley unflooded, protecting the habitat. Further suppose there are two states that can occur. In state 1 there are no large future losses if the species become extinct. In state 2 the species would be worth a great deal to society, perhaps as a cure for cancer or a new energy source. The table below presents the matrix of losses associated with this situation:

Strategy	State 1	State 2	Maximum Loss
E	0	y	y
SMS	x	x-y	x

The value of the species in state 2 is y; in state 1 it has no value. The present value of net benefits from the dam is designated x. If we do not build the dam and state 1 prevails we lose benefits of x. If state 2 prevails we lose the benefits x less the gains y from having protected the species.

In this case, E should be chosen if x>y, SMS should be chosen if y>x; and, if x=y we are at a point of indifference. The authors point out that: 1) this criterion is extremely conservative; 2) the payoff matrix is not known with certainty; and, 3) distribution effects of the gains and losses are ignored. They modify the minimax criterion by suggesting that we should adopt the SMS strategy unless the social costs of doing so are unacceptably large. How high must costs be before they are unacceptably large is not pragmatically addressed. The authors suggest it is up to society to decide.

The authors then go on to discuss then recent work by Resources for the Future (RFF). This includes one of the earliest and best discussions of problems one might encounter in estimating net development benefits, B_d, and net preservation benefits, B_p. The basic problem is that there are divergences between what the authors see as net measurable preservation benefits, B'_p, and B_p. The reasons for the potential divergence include the existence of: 1) option value; 2) existence value; 3) ambiguity in property rights; and, 4) technological change.

Because of the existence of these uncertainties RFF concluded that public choices between development and preservation must proceed in three steps. First, B_d must be carefully examined. If they are negative, development is not justified regardless of environmental impacts. Second, we must evaluate B'_p and compare them to B_d. If $B'_p > B_d$, development is not justified. Third, even when $B'_p < B_d$, the existence of option values, existence values, ambiguous property rights , and technological change means that $B_p > B_d$ is possible. Give the benefit of the doubt to preservation, say the authors.

A7: <u>Risk Assessment in Conservation Biology</u>**. By M.A. Burgman, S. Ferson, and H.R. Ackakaya. London: Chapman & Hall, 1993. pp. ix, 314. Seven chapters, four appendices. ISBN 0 412 35030 0.**

Applicability

This book appears to be particularly applicable to biologists interested in applying risk analysis to conservation biology. The writing style is eminently clear and the organization is exceptional. Critical concepts and terminology are clearly defined. Population models are developed in a logical and easy-to-follow manner. Though the mathematics will be difficult for practitioners and analysts who have not used these skills regularly, they should present no problem to anyone who has worked with mathematical models at a graduate level. Finding the data for the models, however, will be a major constraint on the use of these models.

This book could prove a treasure trove of concepts, ideas, and models for Corps analysts and managers seeking ways to formulate the objectives of environmental resource studies. Furthermore, it will be an invaluable aid to those who will assess the environmental management alternatives. The authors provide algorithms for many of the risk models. The references are excellent. Selective reading of this book is recommended for anyone who wants to learn some of the language of conservation biology and extinction. The book is highly recommended for demographers, biologists, and other biological scientists.

Review

> "Apart from a relative handful of wildlife managers based in government institutions around the world, most ecologists have had little to do with the management of the populations they study and less to do with decision-making and policy formulation within the bureaucracies that administer wildlife management. For this reason, much ecological research has little direct relevance to many of the immediate and pressing problems facing wildlife managers" (p. 272).

With these words the authors capture the essence of what may prove to be an obstacle to the Corps' environmental resource planning efforts, at least as related to conservation biology. According to the authors, there is a paucity of readily usable models for assessing and managing the risks to selected populations and species. Nonetheless, this book does a superb job of describing the state-of-the-art in risk assessment for population survival.

This is a book about how to build stochastic models for risk assessments of population decline. The models presented in the book address several common questions in conservation biology, for example, “How will the population change in the future?”; “What is the risk the population will become extinct?”; “How should a stocking program be managed?”; and “Where should re-introductions be planned to optimize results?”.

The book begins by presenting the change in population size as a random walk. If you have never understood what a random walk is, have no fear. A strength of this book is its clarity.

> "Consider yourself walking parallel to a boundary fence. At every third step you take a pace sideways, either toward or away from the fence. You decide which direction to take after flipping a coin. If it is heads you move towards the fence and if it is tails you move away"(p. 7).

Using this analogy to the random walk the authors effectively introduce the basic terminology of the book. Quasi extinction risk is the is the chance that a population will fall below a small population threshold that may be unacceptable for conservation, management, economic, or aesthetic purposes. The authors suggest the best approach to risk assessment is to quantify the probability of extinction within a given time period. The sources of uncertainty that contribute to change in population abundance can be classified as phenotypic (variation between individuals within the same population), demographic (variation in the average chances of survivorship and reproduction), environmental (unpredictable change in the environment over time), and spatial (variation in environmental conditions between spatially separated patches of habitat).

Unstructured or single-dimensional models are models that treat the entire population as monolithic. They ignore age differences, life history stages, and different spatial patterns. The first models discussed are linear models of this type. A birth-and-death model for white rhinos is developed and made successively more complex from a stochastic perspective. The first stochastic model introduces demographic variance. Subsequent models address population ceilings, removals, and environmental variance. A particularly helpful feature of this book is that algorithms are presented for many of the models presented in the text. It is therefore easy to follow the logic of the risk calculations taking place in the model.

Quasi extinction curves are introduced and are shown to be an effective means of summarizing the models results. The curves plot probability of various threshold population sizes over a fixed number of years. One of the sample model runs reveals that over a 50 year period there is about a 40% chance the population will become extinct.

In Chapter Three a nonlinear model is introduced. Density dependence is one of the primary features added to the model in this chapter. The models address the situation where high population densities cause a decline in population growth as well as the Allee effect where population density falls below some critical level and population growth declines. The use of side bars in this chapter and throughout the book provide vivid and actual examples of the effects being modeled.

Several recent unstructured models are introduced in the chapter. The authors, in their review of these models, stress that the choice of the best model must be based on autoecological information concerning intra species interactions, and not just on the statistical fit of a model to observations of past population size. It is important to have an understanding of the population dynamics and life history of a species. Sensitivity analysis is introduced in this chapter as a tool that is recommended throughout the remainder of the book. Testing the sensitivity of model results to different values of critical parameters plays a prominent role in the risk assessments presented.

The next three chapters present structured population models. These matrix models are designed to capture the internal structure of a population, using matrices to capture the abundances for each of the components of the population. Though these models yield substantially more detailed forecasts they require considerably more data to parameterize.

Chapter Four presents age- and stage-structured population dynamics models that have been used or suggested by biologists. Age-structured models account for the differences that are important among individuals related to age. For example, differences in survival, mortality, longevity, maternity rate, age distribution and abundances, dispersal, and other demographic uncertainties have all been addressed by one model or another in the literature.

Stage structure models are suggested when the chances of reproducing, surviving, dispersing or dying depend on physiological development and an organism's status independent of its age. The mathematics of these models will be difficult for many analysts. The Usher matrix is presented as a special case of the generalized Leftovitch matrix for stage-structured populations. These matrices are described. Like the Leslie matrix model developed for age-structured populations, the authors show how environmental variation effects may be modeled.

In Chapter Five spatial structure and metapopulations dynamics are modeled. Previous models assumed that all individuals, no matter where they occur within the spatial range of a population, experience the same changes in environment and have the same chances of surviving and reproducing. Few biologists will feel entirely comfortable with such models. Apart from spatial variations in soil characteristics, hydrology, and topography, more extreme events like fires, drought and floods will have non-uniform effects on populations.

These models offer the most promise for application to habitat models now used by the Corps. However, it must be noted that these are not habitat models, they are dynamic population models. It just so happens that they address some of the habitat issues that are confronted in habitat evaluation models. Spatial structure and metapopulation dynamics are important for viability analysis and extinction risk assessment for four main reasons according to the authors. First, conservation biology is concerned with the protection of species. Second, habitat loss is probably the major cause of species extinctions. Third, the existence of multiple populations introduces new susceptibilities like movement or isolation of populations. Fourth, the combination of nature reserves that gives a species the highest chance of survival can only be assessed by analysis of a metapopulation.

The two most important aspects of metapopulation dynamics to consider are the correlation between environmentally-induced fluctuations in the vital rates of different populations, and the rate of dispersal of individuals between populations. These factors are frequently modeled as a function of the geographic distance between populations. Occupancy models are presented to simplify the problem. Generalizations of the simple occupancy models are used to model the factors cited above. A new model presenting the dynamics of local populations as well as environmental correlations and dispersal is presented. An example shows how to determine the best design of nature reserves.

The consequences of the loss of genetic diversity are presented in Chapter Six. Adaption to change, inbreeding depression, and outbreeding depression are addressed in models developed to handle genetic variation. It's found that loss of genetic variability may affect the ability of a species to adapt to environmental change and it may reduce population average survivorship and fecundities. The average rate of loss of alleles is modeled as a function of population size.

> "All but the simplest models in this book defy parameterization because of a lack of data. This underlines the complexity of superficially simple questions such as 'What increase in risk results from this management alternative?' or 'Is it better to spend money on the rehabilitation of a corridor, or on the extermination of a feral predator?' It also underlines the scarcity of data essential to answer some of the most fundamental questions facing conservation biologists" (p. 269).

The authors suggest that the exercise of building a model rationalizes a problem and quantifies ideas. These results alone are worthwhile, regardless of the quality of the model results.

Some of the more vexing uncertainties of conservation biology are not addressed in this book. For example, it is frequently assumed that some small population threshold can be identified as critical to the survival of a population. This threshold is treated as given throughout the text and experience shows this is one of the fundamental uncertainties that continues to vex analysts. In addition, many statistics can be applied to conservation biology problems. The authors offer advice that would be well heeded by Corps planners. When designing strategies to conserve or manage biological species, one must choose which to use for decision-making. A strategy that maximizes average population growth will not necessarily maximize the time to extinction. The objectives of the plan are critical to the design of the analysis and the management strategies.

A8: "Ecological Function and Resilience: Neglected Criteria for Environmental Impact Assessment and Ecological Risk Analysis." By John Cairns, Jr. and B.R. Niederlehner. The Environmental Professional. Vol. 15. No. 1. 1993. pp. 116-124.

Applicability

This is an excellent article that should be useful to any environmental resources planner. It is an extremely well-written, balanced article that exhibits a clarity of argument rarely seen. Additionally, the authors provide excellent citations to other relevant works in the field. The references alone are worth the trouble of obtaining this article. We learned more about ecological risk analysis from this article than any other. This paper will be of particular interest to Corps personnel who will have to develop risk analysis methodologies and guidance. The title's reference to resilience makes it clear that this is an important article for anyone concerned with ecological restoration. It provides a framework for thinking about how one might go about identifying and quantifying risks to such projects. The same framework would be very useful for traditional Corps projects as well. This is an important article for Corps planners, one of the very best encountered in this review.

In essence, the authors argue that using indicator species, a structural endpoint approach to assessment, may not be the best way to approach assessment. They argue effectively for the use of functional endpoints and resiliency assessments to aid the decision-making process.

Review

Water purification, oxygen production, carbon storage, climate regulation, and production of food, wood, and medicinal drugs are but a few of the functions of ecosystems that human society depends upon. Resilience refers to an ecosystem's ability for a specific functional parameter to return to some approximation of its predisturbance condition. Judging the acceptability of risk requires knowing whether a damaged ecosystem can recover to an approximation of its predisturbance function and structure. In this paper the authors review the current state of knowledge of ecosystem function and resilience and evaluate the incorporation of functional end points and measures of ecosystem resilience into environmental impact assessment.

The substance of the paper begins with a critique of the use of indicator species as a measure of environmental health. Censuses of indicator species are not particularly well thought of by the authors. The problems with the use of indicator species include the following:

1) The system is based on a solid knowledge of the responses of organisms to stresses. There are many species for which there are no indicators.
2) The responses of organisms to impact is not uniform across stress type. The use of indicator species for one stress does not accommodate other categories of stresses or the cumulative effects of all the stresses that may be present.
3) Environmental protection must assure organisms are robust and healthy not just present.
4) The approach is reactive; it records, rather than prevents, damage.

The authors find that functional end points are directly relevant to management goals for environmental protection. They are also species neutral, i.e., microorganisms are as important as macroorganisms. Functional measures integrate the effects of stress on all community members and focus on properties that are essential to the sustainability of the ecosystem. Functional end points may be generalized from one ecosystem and stress type to another. The article offers two informative tables identifying functional end points generically and for selected systems.

In general, Cairns and Niederlehner find methods for determining ecosystem function less developed than methods for determining ecosystem structure. Exceptions include sewage and forest productivity. Ample evidence exists to establish there is functional change in stressed whole ecosystems. They discuss the use of regional reference habitats as baseline measures that would facilitate the use of an index of biotic integrity (IBI) or other such indices. Their discussion of sensitivity analysis of functional assessments provides a well-balanced review of the literature.

Of particular interest to Corps analysts will be the discussion of resilience. Not only is it important to predict the magnitude of structural and functional effects of projects but it is also important to predict the probable duration of these effects. If changes are short-lived and small to a redundant component of a system on a local scale, the consequence may well be acceptable. Changes that are irreversible or reversible only over a long period of time that compromise unique resources may be judged unacceptable. An understanding of an ecosystem's ability to recover its original structure and function or some reasonable facsimile is an important part of the decision process concerning the risks of projects.

Central to environmental resources planning is the ability to make predictions about environmental outcomes resulting from alternative courses of action. The authors argue that the soundness of these predictions depends on the availability of good dose-response models. After the risk assessment, the acceptability of the risk is determined based on: 1) the magnitude, time span, and spatial extent of direct physical, chemical, and biological changes to the environment; 2) the environmental end points responding to these changes; 3) the magnitude of environmental response; 4) the reversibility of impairment; 5) the uniqueness of the resources at risk; and 6) who benefits and by how much versus who loses and by how much.

The article ends with a discussion of some common problems of risk assessments. These include multivariate stresses and responses, unavoidable uncertainties, and public perception of risks. On balance this is as well-written and thorough going a discussion as you are likely to see on the subject.

A9: "Benefits and Risk of Using Predators and Parasites for Controlling Pests." By L. E. Caltagirone and C.B. Huffaker. Ecological Bulletin. No. 31, 1980. pp. 103-109.

Applicability

This article is a good introduction to the concept of biological control of populations. It provides just enough detail to give the novice reader a feel for the technique. The discussion of risk remains at a rather general, almost superficial level. This article is recommended for managers and other non-biologist readers. The experienced biologist may find it elementary.

Review

Biological control is defined here to mean the regulation of populations by natural enemies, i.e., predators, parasites, and pathogens. Using biological controls to regulate systems of populations requires an awareness of the fact that prey and predator, parasite and host populations are reciprocally-density dependent. These control systems can be self-sustaining.

Biological control has often been characterized by a broader definition than offered here. The use of sterile adults, plant resistance, pheremones and other chemicals of biological origin are sometimes considered biological control in other contexts. The fear that using a natural enemy to eliminate a pest, with the natural enemy then becoming a greater pest than the one it was recruited to control, is a common fear that leads to the question, "What are the risk aspects of biological control?"

Predators and parasites are used to control pest populations in two general situations. First, when a species colonizes a new area its population may reach high levels because of a lack of natural enemies in the new location. In this case, enemies have to be recruited from native areas. Second, there could be a change in the environment that changes the population density of the prey or parasite enabling the pest population to grow.

When considering the safety of biological controls one must distinguish between safety for humans and safety for other organisms in the environment. Paper nest wasps are effective predators of soft bodied insects but they present a risk of sting to humans.

The other possible risks are derived from the impacts of predators and parasites on the environment. When species are transferred from one world region to another we must be concerned that the predator or parasite will eradicate a species or subsequently turn into a pest itself. Though the authors find that few taxa deviate from their special feeding habits, they recommend quarantine.

The authors are unabashed proponents of biological control. "The use of predators and parasites for pest control, when it is the result of a well thought out, carefully executed program is, in our opinion, risk-free. It would appear that when simply undoing the biological control is not an option, quarantining the predator/parasite first is, in the authors' assessment, sufficient to remove the major risks of biological control."

A10: "Pragmatic Suggestions for Incorporating Risk Assessment Principles in EIA Studies." By Larry W. Canter. The Environmental Professional. Vol. 15. No. 1. 1993. pp. 125-138.

Applicability

This article will be of particular interest to environmental resource planners specifically and water resource planners generally. It is chock full of interesting and useful lists and descriptions (e.g., three figures and five tables).

The author starts from the CEQ and NEPA requirements to include a risk assessment (RA) in an environmental impact assessment (EIA). Referring primarily to the EPA risk assessment paradigm he describes a number of risk assessment procedures. There are some genuinely useful ideas in these procedures. The rapid risk assessment described in Figure 2, for example, is an idea that can be readily adapted by Corps planners for a variety of applications.

Review

Policies were enunciated in the 1970s that first required risk assessments. These risk assessments came of age during the 1980s and continue to evolve in the breadth and sophistication of their application. Canter uses the EPA model for human health effects: hazard identification, dose-response assessment, exposure assessment and risk characterization. The introduction provides an overview of the evolution of the worst case scenario to a reasonably foreseeable case and it briefly considers international applications of this type of analysis. He concludes that it is timely to develop specific protocols and guidance that will ensure the incorporation of risk assessment principles in the EIA. The potential benefits of including risk assessment principles include: 1) encouragement of integrated thinking by the interdisciplinary EIA team; 2) the opportunity to focus attention on risk reduction activities such as waste minimization, pollution prevention, and mitigating measures; and 3) the inclusion of emphases on emergency response measures in the event of accidents and associated environmental perturbations.

Canter's brief overview of the risk assessment process provides one of the best succinct summaries of the EPA risk assessment paradigm. The four steps are discussed in just enough detail to clearly define them without bogging down in detail. There is just enough discussion of the difficulties encountered at each step to leave the reader with a general feeling of understanding for the paradigm. Along the way the author presents some very useful and interesting summaries of other works in this area. Examples of practical suggestions for incorporating risk assessment in EIA studies are included in the discussion.

A seven-stage quantitative risk assessment method is summarized, as is a methodology integrating human health and environmental impacts. The EPA's on-line database, Integrated Risk Information System (IRIS), describing risk information for over 370 chemicals, is described. The author includes some discussion of the literature that provide approaches for dealing with exposure assessments, total human exposure (THE), total exposure assessment methodology (TEAM), rapid risk assessment, and the use of expert panels and focus groups. An eleven-step method for dealing with uncertainty is particularly useful and worthy of consideration should the Corps ever develop guidelines for dealing with this issue.

Canter presents five EIS examples used to address health risks. They are of interest because of the different approaches used in each. One employs a probabilistic approach. Other approaches include a qualitative-quantitative approach (like the rapid risk approach mentioned earlier), qualitative descriptions, and a relative risk approach. The range of topics covered by existing risk assessments in EIAs is impressive. From drinking water to cannabis eradication to an impressive vegetation management study by the U.S. Forest Service that would appear to warrant close study by Corp personnel, there is a great range of work that has already been done that should not be overlooked.

The author concludes with some recommendations. Two steps are needed to enhance the incorporation of risk assessment into EISs. First, he advocates one or more technical and policy related conferences on the relationships between risk assessment and EIA. The target audiences are agency personnel, contractors, and private industry. Second, he advocates training courses for EIA practitioners. The most appropriate action he sees, however, is for CEQ regulations to be modified to include risk-related requirements that address risk/hazard assessments and the inclusion of contingency plans.

There is much of interest in this paper. Because of its wide range of topics there is relatively little detail. As a sampler and an entree to the range of topics and the literature it is an excellent reference for Corps planners.

A11: "A Risk Analysis Methodology for Assessing Natural Resource Degradation." By R. Cincotta and F. Pérez-Trejo. Land Degradation and Rehabilitation. Vol. 2, No. 3, July-September 1990. pp. 191-199.

Applicability

In this paper the authors define an unacceptable outcome and present a simple methodology for quantifying the risk of that unacceptable outcome as the number of times that outcome is observed over a large number of iterations. The method is applied to a natural resource context but is perfectly general. The unacceptable outcome could be the number of times a benefit-cost ratio falls below one or it could be the number of times a species disappears from a project area in a fifty-year planning horizon. It's an uncomplicated, well-known and neat idea that may find applications in many situations environmental resource planners face.

The contribution of this article is one of nuance. By specifying thresholds of unacceptability, simulation results can be used to focus on how often the threshold is crossed. This is just a different way of looking at the results of a simulation. Frequently we look at the expected value and distribution of an uncertain value. In this case we simply want the probability that a critical value is equaled or exceeded.

Review

This paper claims it "..addresses the need for evaluative research of resource strategies," a goal it does not meet. However, it provides a useful example of risk analysis focusing on the notion of acceptance limits.

To achieve sustainable production in natural resources systems we must maintain the critical components of ecosystems within acceptable limits. What's "acceptable" is a subjective judgment of the resource's condition. The authors assert that societal notions of acceptability and unacceptability can be reduced to quantifiable limits that some groups strongly prefer not to cross. An acceptance limit is defined as a function that separates a domain of acceptable status from a domain of unacceptable status. Problems may have several acceptance limits working at once. For example, a population level may be defined in terms of minimum viable populations for survival, low population levels that evoke poor hunting or observation experiences, or large population levels that result in intolerable damages to crops. Three levels of acceptance limits are identified: family level of resource users, production system level, and ecosystem level.

The elements of the basic risk analysis methodology suggested by the authors are as follows:

1) Choose a strategy to be applied to a resource or resource use.
2) Determine a critical state variable that can be used to indicate an unacceptable outcome for the strategy under investigation.
3) Determine an acceptability limit for the critical variable.
4) Identify suitable decision rules for the strategy.
5) Simulate the function of the system.

6) Determine the risk that the strategy under consideration will fail during the planning period.
7) Evaluate other parameters of risk and failure.

Each iteration of the simulation model is a planning period. The risk of failure is defined as the number of planning periods in the simulation in which acceptable limits are exceeded, divided by the total number of iterations. Analysts are admonished to avoid adding complexity to the model that will make it difficult to communicate the risks to decision-makers.

A hypothetical example is presented. In it a farmer must sell 500 kg of product each year to get the cash required for survival needs. Any extra is added to storage. He needs a minimum of 1,000 kg in storage for his family's needs. Fifteen percent of storage is lost to rot. The strategy under consideration is one of crop variety and cropping method, I(t), that yields a per hectare output as a linear function of rainfall (which averages 250 mm per year with a standard deviation of 100 mm). A second strategy, A(t), recommended by the government, has a non-linear relationship to rainfall. A(t) is better during favorable rainfalls but worse during low rainfalls. The model is further complicated by other constraints on the government strategy.

Using a 30-year planning period and random rainfall patterns, simulations for the two strategies, I(t) and A(t), are run. Unacceptable outcomes are those that fail to produce enough food. The parameters reported are: risk probability (number of planning periods that had one or more failures divided by the total number of planning periods (a planning period is a single iteration of the simulation model)); failure rate (average number of unacceptable states per planning period with one or more failures); range of failures (maximum number of failures per planning period minus minimum number per planning period); and the median value of a failure (median production level in kg for a failed production level). The analysis showed the I(t) strategy to be the better of the two.

The authors conclude that risk analysis is important as a learning tool. The exercise of identifying critical variables and acceptance limits raises vital issues of which analysts must be aware. This too is a point well-taken by Corps analysts embarking on environmental resource risk analysis.

A12: "Impact of Discharges as a Basis for Control Measures". By R.A. Conway. Water Science and Technology. Vol. 14, pp. 95-109, 1982.

Applicability

The title and list of key words for this article sounded promising. The article turned out to be focused narrowly on water quality and it was somewhat dated for the purposes of this review. It contains terminology that would now be considered incorrect in usage, though in fairness to the author these were terms that undoubtedly were struggling for an identity in 1982. It is of limited utility today.

Review

The purpose of this article was to make a case for additional studies to assess the impact of discharges upon the aquatic environment in order to allow water quality managers to tailor the control measures used to the impacts observed. Observing advances in the environmental risk assessment field at the time the article was written, the author proposes that the risk assessment methodologies might be adapted for use by water quality managers. The author cites several studies that seem to argue that at times there is little environmental benefit achieved by the large expenditures on capital and energy for water treatment.

Conway identifies the stochastic-statistical approach, the model ecosystem, the deterministic approach, and the baseline approach as the four approaches to environmental risk analysis. Though this classification might be challenged today, he chose to use the deterministic approach to examining the fate and effects of chemicals in the environment. The deterministic approach might today be considered a form of sensitivity analysis that relies on identification and parametric variation of key variables in the model.

A hazard assessment model showing the relationship between chemical fate and effects is presented. Candidate tests for screening ecological impacts of new effluents are identified for chemical fate and ecological effects. Data required for modeling environmental input (entry), transport (mobility), and transformation (persistence) are used to estimate an effective environmental concentration of the effluent or chemical agent. The resulting concentration is compared to known toxicity information to determine the significance of impacts. Selected mechanisms affecting the fate of chemicals for the input, transport, and transformation functions are listed. In Table 4, key environmental properties of physical, chemical and biological transport are identified.

The article identifies key components of a deterministic approach model and proceeds to the point of listing factors and variables to consider. The article stops short of offering any analysis and is of limited utility today.

A13: "What is Ecological Economics?" By Robert Costanza. Ecological Economics. Vol. 1. No. 1. February 1989. pp. 1-7.

Applicability

The following article launched a new journal, *Ecological Economics*. It was selected not so much because of its direct relevance to risk and uncertainty analysis in environmental resource planning contexts, but because we did not know what ecological economics was. It seemed to be a new area of concentration that could be of interest to analysts working in both the ecological and economic fields. This would include many Corps analysts. The article is a simple introduction to the concentration and the journal, a journal that looks like it will be well worth monitoring by environmental planners and risk analysts.

Review

"*Ecological Economics* is a new field formed at the intersection of two older ones" (p. 5). It addresses the relationships between ecosystems and economic systems in the broadest sense. It includes neoclassical environmental economics and ecological impact studies as subsets, but it is formed to encourage new ways of thinking about the linkages between ecological and economic systems. It implies a holistic view of the problem of studying and managing our world.

The author notes that the most insidious form of ignorance is misplaced certainty. Current economic paradigms rely heavily on the assumption of continuing growth. An economy's health is often measured by a stable and high rate of growth of its gross domestic product (GDP). Costanza differentiates between two world views that differ in strikingly important ways. First, there is the technological optimist. According to this paradigm, energy and resource limits to growth will be overcome by new technology. The technological pessimist, on the other hand, assumes technology will not be able to circumvent fundamental energy and resource constraints and that economic growth must eventually stop.

Ecologists have frequently been among the latter group, largely because in natural systems resource constraints always limit growth. Economists tend to fall into the prior group. Costanza argues that there are vast differences in the specific public policies we should pursue, depending on whether the optimists or pessimists are right. Optimists argue that unless we believe the optimistic future is possible and behave accordingly, it won't come to be. Pessimists believe that such pursuit of growth will bring the inevitable decline on more quickly. To sustain our system we should begin to conserve resources now. These are two fundamentally opposing views of the future. Each is compelling in the simplicity of its argument, each with profound implications for life on earth.

The conflicts in these two world views can be seen in the work of the Corps. It's more complicated than an NED versus EQ debate, but every Corps analyst has seen intractable situations in which local interest and resource agencies have been unable to communicate effectively. We suspect that is often because of the fundamental differences Costanza describes in this article.

Costanza appears to side with the pessimists as he concludes too little attention is being paid to policies based on technologically pessimistic assumptions. Pursuing these policies or having them be one of the alternatives should be part of our policy dialog. The true energy and environmental state of the world may be the greatest uncertainty we face in environmental resource planning, a point we are well-advised to never forget. Issues of sustainability are issues about limits. Issues about limits are issues about uncertainty. If we are uncertain about limits, the prudent course is to assume they exist. Or, we might add, we should develop alternatives that assume they exist.

A14: "Prospect Risk Analysis Applied to Ground-Water Reservoir Evaluation". By George H. Davis. Ground Water. Vol. 20, No. 6, pp. 657-662, November-December 1982.

Applicability

One of the advantages of the earlier risk literature is that it frequently meets the needs of analysts just being introduced to the topic or just beginning to apply it to new fields. As risk analysis is extended into new areas it will have to start modestly. This easy-to-read paper provides a simple example of how risk analysis can be applied to the quantification of uncertain resources. It provides helpful lists of questions, steps in estimating quantities of uncertain water resources and an easy-to-follow example presenting the results in a convenient cumulative distribution function. It relies on a simulation using the Monte Carlo process. Some of the language used by the author is stilted and is no longer in general use by risk analysts, if it ever was. It is recommended for readers relatively new to risk analysis.

Review

This paper applies probabilistic methods to the problem of estimating the storage capacity and hence initial yields of ground-water reservoirs. The process used in the past, for lack of better methods, has been to use all the available data in basin-wide estimates without differentiating the varying certainty we have in our data.

Developing water resources is a risky undertaking. According to the author, the primary questions to answer in a risk analysis of this type are identified as: 1) How large is the resource? 2) Where is it located? 3) In what size deposits does it occur? 4) How certain are we of our opinions? 5) How long will the resource last under various operating alternatives?

The method of analysis is divided into two parts. The first is estimating volume factors, including area, aquifer thickness, and storativity. The second part is estimating the risk factors that apply to these critical variables. This technique is a generally applied and useful one. Identifying critical variables and quantifying the uncertainty attending these variables would be a useful first step for environmental resource risk analysts as well.

The procedure used in this particular study can be summarized by the following seven steps. First, assemble all available hydrogeologic data on the ground-water reservoir. Second, summarize the information. Third, quantify the data to the extent feasible. Fourth, convene a panel of hydrogeologic experts who individually review the data. Fifth, each expert provides a subjective estimate of storage capacity. Sixth, results are reviewed by the group of experts. Seventh, the subjective estimates of the experts are used in a Monte Carlo simulation to derive probabilistic estimates of the reservoir under consideration.

This technique of using subjective probability assessments to quantify uncertainties in a qualitative manner is likely to be an important tool to environmental resource planners. The description of the technique and presentation of the results are now relatively routine. Distinctions between "risked" and "unrisked" values are not mainstream distinctions, but this is a minor distraction. The author recaps the value of this article best in his own words in his summary. The method presented by Davis offers advantages over the former determinate method because it:

1) Incorporates uncertainty into the resource estimate.
2) Displays the possible range of estimates, and accommodates widely-differing views.
3) Breaks the assessment procedure into component parts that can be critically examined.
4) Provides ease of revision through updating of components.
5) Provides a systematic approach to a topic that has not been handled in a systematic way in the past.

A15: "Risk Computation for Environmental Restoration Activities." By J. G. Droppo, Jr., J.W. Buck, D.L. Strenge and B.L. Hoopes. Journal of Hazardous Materials. Vol. 35. 1993. pp. 341-352.

Applicability

Environmental restoration has become one of the Corps of Engineers' priority missions. This article presents one example, site cleanup, of what environmental restoration means to the Department of Energy. The DOE's emphasis on site cleanup gives them a more narrow focus than the Corps' restoration program will have.

This paper is of interest to Corps analysts for a number of reasons. First, it is useful for any insight it provides on the issue of risk analysis for restoration. Second, it has obvious implications for any future Superfund activities of the Corps. Third, it provides an introduction to the notion of using a risk screening tool for preliminary decisions about relative risks. Any one of these contributions makes the article worth reading. To have all three together makes it a very useful article for any analysts seeking better understanding of risk analysis for environmental restoration. Preliminary interest in possibly developing a single risk analysis model for selected environmental resource planning activities would be well served by examining DOE's experience with a single model approach described in this paper.

Review

Environmental restoration activities covered by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) must address environmental and public health risks. The remedial process begins with problem identification and leads to final site cleanup. At each stage of this site cleanup process risk evaluations are required. In the early stages uncertainty is greatest, data are weakest, and risk computation requirements are less demanding than they become as the process progresses.

A number of computer models are used to estimate risks related to environmental restoration of sites contaminated with hazardous wastes. The authors, from Battelle Pacific Northwest Laboratory, describe the Multimedia Environmental Pollutant Assessment System (MEPAS), one such model used during the early stages of analysis to screen the order of magnitude of risks. MEPAS enables the user to establish risk-based priorities from among a large number of potential problems.

The model uses readily available information on contaminant characteristics, release rates, and other factors, as model inputs. Standard computational techniques are used to model transport pathways and exposure pathways. Outputs are identified in terms of human health impacts. The unique contribution of MEPAS is that it has integrated components of many separate models into a single system. It is used to identify problems that merit additional resources for further study. Version 3.0, developed for the personal computer, is described briefly in the paper. MEPAS has been applied to both multiple site and site-specific studies.

An example of a risk-based ranking of wastes for a single site is provided in the paper. MEPAS was used to establish the relative importance of radioactive and nonradioactive constituents potentially stored in underground single-shell tanks at DOE's Hanford Site in Washington. The potential human health impacts that result from groundwater transport of different chemical constituents were analyzed. The sensitivity of the hazard ranking to recharge and transport rates was also investigated. The results show many orders of magnitude in differences in risk-based rankings of constituents. MEPAS has apparently proved to be a valuable scoping tool. From a list of about 70 constituents, five radionuclides, headed by carbon-14, and eight noncarcinogenic chemicals, headed by cyanide ion, were identified as most threatening.

The notion of a single integrated model that facilitates initial risk screening of problems/management measures is an idea that would likely appeal to Corps analysts. Whether such a model is feasible or even desirable is a long way from being determined. An important first step in considering the development of such a tool would be to find out more about the MEPAS model and how well it has served the DOE decision-making process.

A16: "Application of Environmental Risk Analysis to Goundwater Protection". By M.O. Ettala. Water Science Technology. Vol. 20, No. 3, pp. 87-93, 1988.

Applicability

This paper presents a technique for dealing with risks in a subjective or qualitative manner that may be very useful to environmental resource planners who are struggling with how to begin to apply risk analysis in this new arena. It offers lists of questions and information sources that might be helpful, in a suggestive fashion, to planners trying to get started with environmental resource risk analysis. There is really little of substantive use in the paper, and is woefully short on the details of the risk analysis and the techniques the paper purports to be examining.

This is an easy-to-read paper for anyone interested in exploring simple, beginner methods for estimating risks in a new subject area. For this purpose it is recommended. Those seeking help in groundwater risk analysis will be disappointed.

Review

Industrial hazards are divided into risks to property, persons, know-how and operations. One kind of operations risk is environmental impairment liability. The increase in such risks has given rise to the need for prevention of environmental hazards. The aim of this paper was to present a method of analysis that will make it possible to identify and assess the risks to groundwater involved in industrial operations and to present measures for controlling them. In addition, the author examined the applicability of fault trees, action error, hazard and operability study (HAZOP), and management oversight and risk tree (MORT).

Four risk analyses were conducted over the period 1985-87 in the chemical, forest and foodstuff industries. A risk model consisting of the following stages was used: 1) identification of risks; 2) assessment of magnitude of risks; and, 3) corrective measures proposed. The studies revealed that the causes and consequences of risk may be so complex that a working group is required to address the risk analysis.

The author suggests the working group should consist of four to eight experts. The working group should be an interdisciplinary team that comprises experts in risk analysis, the relevant industrial processes, personnel responsible for matters relating to environmental protection, and management.

Lengthy lists of information sources and interview questions that may be relevant for groundwater protection are included in the article. Ettala found that it was not easy to quantify the consequences of environmental risks in money terms and devised a risk scale. The consequences ranged from 1 = negligible to 5 = very serious. The probabilities of these consequences were classified from 1 = very improbable to 5 = very probable.

The results of the analysis are presented in a qualitative form. For example, one source of risk or cause of damage was identified as "continuous overflow from production lines". The consequences of this hazard are "corrosion of floors, floor drains and sewers, pollution of groundwater". These consequences were ranked a four, with five a maximum damage. The likelihood of this hazard is a five, very probable. Potential measures to control the risks include "elimination of overflow, more careful selection of materials, training". The presentation of these and other results in Table 1 of the paper present a subjective/qualitative approach to risk analysis that may be useful to environmental resource planners while awaiting development of more analytical techniques.

A17: "Valuing Environmental Resources Under Alternative Management Regimes." By A. Myrick Freeman, III. Ecological Economics. Vol. 3. No. 3. September, 1991. pp. 247-256.

Applicability

Much of our understanding and knowledge of the world we live in is uncertain or risky. Increasingly more of this uncertainty is turning up in books and articles about risk and uncertainty analysis. There is still a great deal of the essential uncertainty that is embedded in all that we do. Uncertainty is so prevalent that it is often accepted without particular notice. This article is an excellent example of how uncertainty is routinely analyzed without any explicit recognition of the fact that we are dealing with fundamental uncertainties.

This is an economics paper that deals with two separate management alternatives for the blue crab fishery. One is perfect regulation (i.e., efficient in an economic sense), while the other is open access fishery. The analysis makes extensive use of assumptions in its modeling and presents an explicit sensitivity analysis. At no time, however, do risk or uncertainty appear as explicit themes in this paper. We have observed during the course of this literature review that this is a common occurrence. Hence, the inquisitive analysts should never overlook a promising title simply because the words risk or uncertainty appear nowhere in the title or the list of key words. There is a great deal of interest to risk analysts going on out there and ideas can be found in seemingly unlikely places from time-to-time.

A handy idea here is that environmental resources produced or protected by a project may not have an observable market value. However, if the resource is an input to the production of something that does have an observable market value, the value can be estimated from that other market. Freeman uses changes in the value of blue crabs to estimate the value of changes in the amount of wetlands. It's a well known technique for economists.

Review

Freeman uses the data from a 1987 Ellis and Fisher article (EF) to calculate the economic value of different resource management alternatives. EF describe the theoretic welfare economics basis for estimating the value of environmental resources that are inputs in the production of marketable commodities such as fish. Specifically, they looked at the value of wetlands as an input in the production of the Gulf Coast blue fin crab fishery. Economic value in this article is described as the sum of producer and consumer surpluses and changes in these surpluses associated with different amounts of wetland acreage.

Freeman looks at two different management regimes for the fishery. Because the EF paper equated price and marginal cost, Freeman concludes this is consistent with a perfectly competitive market structure (open access fishery), or that the resource is a common property resource with optimal regulation of effort and catch. Theory suggests that in the long-run under perfect competition there will be no producer surplus. The value of the resource is expected to vary under the two regimes. This paper shows the value of the resource could be lower under optimal management than open access, a result that some find counter intuitive.

The model basically allows the author to generate supply and demand curves and estimate areas under them. To do this, an iso-elastic demand function and a Cobb-Douglas production function are assumed. The academic's ability to assume functional forms gets the author over a hurdle that Corps analysts cannot often leap. While the theory and methods are often of most interest in the journals, in the planner's world the magnitudes of numbers, the data they came from, and the techniques used are subjected to more rigorous review.

The analysis starts from an assumed base of 25,000 acres of wetland and looks at changes in the value of the crab resource to measure the value of wetlands for increases to 100,000, 300,000, and 500,000 acres of wetlands. The analysis is a nice example of sensitivity analysis or what the spreadsheets now call a data table. The values of wetlands are estimated for three different amounts of wetlands, at four different demand elasticities, for two management regimes (regulation and open access).

The results show that different management regimes are optimal depending on demand elasticities. This article can be very helpful to Corps analysts in showing a way to approach the problem of valuing something that does not appear in the market. Wetlands are valued by observing their effects on the crab market. The value of wetlands is shown to change with the manner in which the fishery is managed. The good news is that these are ideas that can be applied to many situations. The bad news is that the results were contingent upon the author's assumptions about apparently unobserved demand and production functions. Results were very sensitive to elasticity of demand which was also unknown. With more data this technique shows considerable promise.

A18: "Public Policy and Environmental Risk: Political Theory, Human Agency, and the Imprisoned Rider." By John Martin Gillroy. Environmental Ethics. Vol. 14. Fall 1992. pp. 217-237.

Applicability

This is a difficult article for those, like this reviewer, unfamiliar with the literature on human and moral agency. In fairness to the author, we may not have fully appreciated his finest points. However, the author, a political scientist, suggests that using economic welfare analysis as the basis for resolving environmental risk situations is inadequate. The author finds that the economist's rational choice model fails to account for human agency.

There are many within and without the Corps who would agree that an economic analysis of risky situations is by itself inadequate. Few economists would argue with this point. In this point the author has much company. Where many will part company with the author is over his impression that risk-benefit analysis is the only criteria that matters. That is surely not the planning context created by the Principles and Guidelines used by the Corps. The author seems to miss the obvious point that economics offers but one approach to assess and evaluate risky situations.

The author's assault on the economic paradigm for risk analysis is weakened by the fact that he makes several errors in interpreting economic theory. The critique of economics is well-intentioned but something less than effectively executed. This article will be of interest to those who enjoy a more philosophic approach to the problem of environmental risk. Once again, the emphasis is on the human health dimension of environmental risk.

Review

Gillroy begins with an overview of risk and the economic point of view. He finds that the economic criteria lack the proper moral grounds to serve as guideposts to the analysis of policy options. The economist's assumptions "..do not adequately address the strategic and moral reality of environmental risk dilemmas, and therefore prescribe policy that does not address what is fundamentally at stake in these decisions." Leaving the details of his arguments to those motivated to read the article, we found the review was based on a superficial and incomplete understanding of the economics paradigm generally and its application to risky situations specifically.

Defining environmental quality as a public good, Gillroy begins to build his argument for a different set of guideposts. On the way to developing his notion of an "imprisoned rider" he translates the well known prisoners' dilemma to the polluter's dilemma. This problem has been used to show that when individuals are allowed to act in their own self-interest their strategic decisions will lead society to a sub-optimal outcome. If individuals could somehow be required to or coerced into cooperating, everyone would end up better off. In the case of pollution, Gillroy shows that self interest in the use of a public good will lead to more pollution than would result if we cooperated. These results are well known in the literature.

Gillroy's contribution is that he develops the idea of a critical mass of people who must be required to go along with the collective standard for environmental quality. Even in this development Gillroy seems to be oblivious to the fact that his arguments will hold for only a very narrow, and generally uninteresting, set of circumstances.

The author provides a compelling argument for government intervention in the protection of environmental quality. Government must regulate to prevent a catastrophe from bringing about collective and irreversible harm. He warns that free-riding on the provision of environmental quality can lead to such a catastrophe because it doesn't take many defectors to do serious environmental damage if they are emitting particularly noxious pollutants.

Building on his polluters' dilemma, Gillroy argues that there is a significant asymmetry of power in the strategic game over environmental quality. The players in a simple two actor game can be seen as a group of individuals who have no power to pollute and, therefore impose no risks on themselves or the other actor; and, the other player who is a polluter. The polluter has an obvious incentive to pollute in order to hold down costs. Thus, one group has risks imposed upon them with no apparent gain. When there is no regulation in such a situation, the optimal strategy will be for the polluter to pollute, an even less desirable outcome than when we compare two polluting players.

This exploitation of unorganized individuals can proceed without their direct knowledge. It leads to the worst payoff for the citizens and the best for the polluter. Gillroy calls the individual in this situation an imprisoned rider. He can only be freed through some coercive force that will define and protect public interest. This means risks must be distributed and managed fairly.

Gillroy rejects what he describes as the economist's reliance on preference theory as the basis for allocating risks. He substitutes agency of the individual as the standard for policy making. His definition of agency did not provide an apparent conflict with economic theory. In fact, it provided no distinction from that theory that this reviewer could ascertain. That is undoubtedly the reviewer's shortcoming. Agency is a concept that gets at the individual's vital and intrinsic values that transcend mere preferences. There follows a somewhat protracted argument about the policy imperatives of human agency.

> "The imposition of an environmental risk is an act of disrespect on the part of one actor who increases his or her personal welfare at the expense of others' vital capacity and intrinsic value. The essential component of environmental risk is its potential to harm the most basic capacities of the individual" (p. 233).

The author draws a distinction between risks that can be chosen and those that are imposed. The former are a product of human agency, the latter are the lot of the imprisoned rider. It is, he concludes, the role of government to eschew the use of subjective welfare calculations and free the imprisoned rider through ex ante regulation of environmental risks. This conclusion will find many supporters.

A19: "Risk Analysis, Fuzzy Logic and River Basin Management." By P.W. Jowitt. <u>Water Science and Technology: A Journal of the International Association on Water Pollution Research</u>. Vol. 16, No. 5-7, 1984. pp. 579-585

Applicability

This article was chosen to be included in this review because of its title. Its central theme is that the robustness of the model is more important than its sophistication. That seems a very worthy idea for environmental resource planners to bear in mind. We don't need large complex models as much as we need models that are capable of providing useful results. This article is of rather limited applicability.

Review

Water pollution control measures are designed to reduce the mean level of some pollutant over time. Considering the effects of a temporary operational failure resulting in a solids overflow, Jowitt poses several dilemmas. He notes that most pollution incidents are not well-defined. Typically, both the river and the treatment plant behave in a "noisy" fashion. The relationship between upstream and downstream conditions is highly corrupted by random disturbances and is unlikely to be predictable in detail except over fairly short time periods. As a result, the assessment of system performance and the exercise of control seems to rest less on analytical understanding of the system than on a behavioral one.

Jowitt argues that a fuzzy assessment of treatment plant dynamics and river behavior are more important means of control. Fuzzy logic seeks to harness the treatment plant manager's experience and expertise via operational control actions simulated by statements such as: "If discharge level is 'high', increase sludge waste rate by a 'small' amount". Such fuzzy statements are preferred to the more analytical results that come from noise-corrupted differential equations. The author argues the robustness of fuzzy logic is to be preferred to the sophistication of differential equation models.

Precise but inaccurate models can be a problem because unknown variations (noise) are difficult to embed in the differential equation models. "Fuzzification" of the estimation algorithm is required. In the author's opinion, using expert system and fuzzy logic theory to develop an operating philosophy that is an extension of common sense is to be preferred over uncertain analytical systems.

A20: <u>Wetland Creation and Restoration: The Status of the Science</u>. Edited by Jon A. Kusler and Mary E. Kentula. Washington, D.C.: Island Press, 1990. pp. xxv, 595. Twenty-eight articles with an executive summary. ISBN 1-55963-044-2 paperback.

Applicability

This book does not explicitly address risk and uncertainty issues that arise in the creation and restoration of wetlands. It addresses so many of these issues implicitly, however, that it proves an invaluable source of insight into the nature of much of the uncertainty attending wetland creation and restoration. It is an essential element of any library on wetlands for its lists of literature cited after each article alone. Fortunately, most of the articles are well-written and illustrated and full of valuable, hard-to-find information as well.

This collection of articles by authors selected for their expertise in particular areas of wetlands science or their active involvement in actual wetland creation or restoration meets several needs at once. It provides a preliminary evaluation of the status of the science of wetland creation and restoration in the U.S. As such it is a valuable introduction to all parties interested in this topic. It provides considerable detailed technical discussion of interest to the scientific community, balanced with a considerable emphasis on the management issues. The discussions throughout the articles constantly and consistently highlight the relevant uncertainties encountered in wetland creation and restoration. It does not include any systematic discussion of habitat models. It is highly recommended.

Review

Less than half of the 215 million acres of wetlands estimated to be present in the 48 coterminous states at the time of the European settlement remain. Each year an estimated 450,000 acres of wetlands, an area 12 times the size of the District of Columbia, are destroyed. Questions about how well restored or created wetlands compensate for destruction of existing, naturally functioning wetlands assume increasing significance as the United States moves toward a policy of no net loss of wetlands. This important book addresses the state of scientific knowledge of and about wetland creation and restoration in two volumes. It will help planners, analysts and managers eliminate the uncertainty about what it is we are uncertain about. This book is most useful for its ability to point out what we don't know.

The first volume comprises a series of regional reviews. Each of the 16 regional reviews summarizes wetland creation and restoration experiences in broadly defined wetland regions (e.g., coastal plain wetlands in Florida, forested wetland vegetation in the southeast). The reviews summarize the available information and describe what has and has not been learned. These discussions are invaluable aids to the careful reader who is trying to learn what the major types and causes of uncertainty about wetland creation and restoration are.

The second volume comprises a series of 12 theme papers covering a wide range of topics of general application to wetland creation and restoration. These include such broad themes as planning (goals, objectives, and so on) and management techniques, as well as specific themes such as wetland zonation, vegetation change, and moist-soil impoundments for nonpersistent emergents.

Conclusions from these articles are offered in a profoundly insightful and effective executive study. With regard to the adequacy of our scientific understanding and the success of creation and restoration projects in meeting project goals, following are some conclusions gleaned from the articles.

1) Practical experience and the available science base on restoration and creation are limited and vary with region and wetland type.
2) Most wetland restoration and creation projects do not have goals specified. This complicates efforts to evaluate the success of the project. Partial or total revegetation is rarely the specific goal of a project but it is often the easiest to measure.
3) Monitoring of wetland and creation projects has been uncommon. There has been little short-term monitoring and less long-term monitoring.

These findings have significant implications for the Corps' proposed adaptive management technique. It would appear that such techniques will be blazing trails in virgin territory. Those blazing such trails will be buoyed by this text’s plethora of practical advice. This includes check lists, diagrams, and suggestions such as "It is not enough to design a project and turn it over to traditional construction personnel."

With regard to the success of restoration and creation projects, the articles offer the following points, among many others.

1) Restoration or creation of a wetland that "totally duplicates" a naturally-occurring wetland is impossible. However, some systems may be approximated and individual wetland functions may be restored or created. This does not mean, however, that it will have habitat or other values equaling those of a natural wetland.
2) Partial project failures are common. Total failures are common for some wetlands, like sea grass and certain forested wetland areas. Although the causes differ, common problems are identified throughout the articles.
3) Success varies with the type of wetland and target functions including the requirements of target species. There appears to be more success with revegetation of coastal, estuarine, and freshwater marshes than most other types. There are very few studies concerning the use of restored or created wetlands by particular animal species.
4) The ability to restore or create particular wetland functions varies by function. That ability depends on the amount of available scientific knowledge (fundamental uncertainty issues); the ease and cost of creating or restoring certain wetland characteristics (topography and infiltration capacity, for example); and, the probabilities that structural characteristics will give rise to specific functions (risk and uncertainty issues). These themes can be found throughout the articles.

5) Long-term success may be quite different from short-term success. The major threat appears to be hydrologic fluctuations. Other threats include pollution, erosion, off-road traffic, and grazing.
6) Long-term success depends upon the ability to assess, recreate, and manipulate hydrology. The extent to which hydrology can be determined and established is an important determinant of success. The authors find the greatest probability for success are, in order: I) estuarine marshes; ii) coastal marshes; iii) freshwater marshes; iv) isolated marshes supplied by surface water; v) forested wetland; and, vi) isolated freshwater wetlands.
7) Success often depends upon the long-term ability to manage, protect, and manipulate wetlands and adjacent buffer areas. These are considerable insights for the Corps' adaptive management approach to environmental restoration planning. Many articles make the point that original design specifications may prove insufficient to achieve project goals and midcourse corrections are often critical to long-term success.
8) Success depends upon expertise in project design and upon careful project supervision. In this new area there appears to be no substitute for experience.
9) "Cook book" approaches for wetland restoration or creation will likely be only partially successful. The basic problem appears to be that scientific uncertainty is too great to enable us to provide rigid guidance. However, guidance suggesting ranges of conditions conducive to success are both desirable and possible.

Many of the authors list specific research needs in their papers. These provide valuable identification of major and significant sources of uncertainty. With regard to filling these gaps in scientific knowledge the papers lead to the following conclusions.

1) Systematic monitoring of restoration or creation projects is needed. This will require careful baseline studies and monitoring selected features of the new/restored systems at periodic intervals.
2) Demonstration projects offer the greatest promise for "control" and are needed.
3) More traditional scientific research is needed on a wide variety of topics.
4) Continued synthesis of existing scientific knowledge is needed. Too much of what exists is fragmented by time, geography, and money.

The collection of papers offers considerable discussion of these points throughout the book. In the executive summary fourteen recommendations for wetland managers are offered. These recommendations, culled from the papers, are clear and practical. The most valuable contribution of this collection of papers is the major step they take in identifying the major sources of uncertainty in creating and restoring wetlands, managing them, and assessing their success. This book is a must for anyone involved in wetlands restoration and creation.

A21: "Application of Event Tree Risk Analysis to Fisheries Management." By Ernst Linder, G.P. Patil, and Douglas S. Vaughan. In Ecological Modeling. Vol. 36, 1987. pp. 15-28.

Applicability

This article was selected because of its fishery application. Fisheries will be important resources in Corps planning and this article provides an example of what is being done to apply risk analysis to fisheries. The authors make extensive use of event trees. The article is of uneven quality. Though the substance is sound, the article has many spelling and grammatical errors, rather unheard of in the professional literature. We're not sure what to make of this but it's not a sign of strength.

The article provides a good example of how continuous distributions can be discretized to keep event trees manageable. The article does not follow the EPA human health paradigm for quantifying environmental risks and that alone makes this article worth a look for anyone dealing with risk analysis of fisheries.

Review

In this article risk analysis is defined as the evaluation of the probability of end events, such as maximum sustainable yield, in terms of sequences of earlier events, such as stock-recruitment. In fisheries science and management, the biological/ecological variability and uncertainty are very large compared to the uncertainties encountered in the physical and engineering sciences. Estimating fishery populations and harvest levels are difficult tasks. In this article the authors use decision/event trees to structure the risk analysis. Two examples are offered: the Georges Bank haddock fishery; and the Gulf of Mexico menhaden fishery.

In Georges Bank increased fishing effort and reduced stock size led to a dramatic decrease in the fishery. By 1980 scientists concluded the catch must be halved to restore the fishery to pre-1960 levels. The catch was not restricted so the survival of the fishery becomes an important question. The authors propose the use of risk analysis to evaluate alternative management strategies. Virtual population analysis (VPA) was used to estimate the size of year classes after the fact. Stock-recruitment models based on VPA values are used to construct a probability event tree that assesses the probability of recovery of the fishery. Recovery is defined as two strong-year classes during the three-year period from two to four years after the current year.

Survival depends on mortality as well. Mortality and annual spawning stock depend on fishing effort. The authors evaluated two choices for fishing mortality: F_{max}, the fishing effort that results in maximum yield per recruit; and, 2) $F_{0.1}$, the fishing effort that maintains stock sizes above the lowest quintile of previously observed stock sizes.

Traditional event tree analysis presents a specific point estimate with a separate probability for each event. The authors divided the probability density function into three interval estimates: upper ($\geq 1\sigma$), middle (-1σ to $+1\sigma$), and lower ($\leq -1\sigma$). In fact, the authors did not go beyond $\pm 2\sigma$, covering about 95% of the potential observations. The distribution was normalized to probabilities of 0.1, 0.8, and 0.1. The intervals keep the event tree to a manageable size. The probability of two high recruitment years out of three when fishing effort is F_{max} was 0.549. For $F_{0.1}$ the probability was 0.876. A similar analysis is offered for the Gulf menhaden.

A22: "Risk Analysis for Conservation Biologists." By Lynn A. Maguire. Conservation Biology. Vol. 5, No. 1, March 1991. pp. 123-125.

Applicability

This brief article provides a handy introduction to a dilemma faced by many conservation biologists. Trained as scientists they are loathe to take a strong stand on an issue until sufficient data are available to support that stand. Unfortunately, waiting can limit the range of options. Risk analysis is suggested as a solution to this dilemma.

In environmental resource planning Corps analysts are frequently dealing with agencies and other stakeholders who act before/without sufficient data for scientific certainty. Their actions are often founded in legislative or regulatory standards. One might infer from this article that risk analysis could improve this coordination process portion of the decision process.

This is an easy and quick read with several interesting ideas for those new to the issue of risk analysis in the environmental resource arena. Of all the areas of risk analysis reviewed as part of the preparation of this report, risk analysis for conservation biologists appears to be the subfield most closely aligned with the needs of environmental resource analysts. This article is recommended for those seeking a general orientation to some of the issues and general approaches to risk analysis.

Review

The article begins with the definition, "Conservation biology has been described as a crisis discipline, where limited information is applied in an uncertain environment to make urgent decisions with sometimes irrevocable consequences" (p.123). Substitute environmental mitigation, ecosystem restoration, or environmental resource planning for conservation biology, and you have a functional definition with which many analysts would readily agree.

The crux of the article is that scientific training frequently prevents biologists from speaking out on issues before all the evidence is available. Reluctance to initiate captive breeding for the California condor and the black-footed ferret reached the point where continued inaction would have resulted in a disaster. By delaying implementation to the last moment the prospects for success of these programs were nearly lost.

How can conservation biologists balance their commitment to scientific excellence and their responsibilities for solving environmental problems? Risk analysis, the author suggests, may be the answer. Considering the uncertainties inherent in a decision problem in a systematic way clarifies choices. What's the range of things that could be said about a management decision? What mistakes could be made in what is said? What are the consequences of being right or wrong in terms of management actions taken or not taken, changes in the status of environmental and social consequences, professional status, and impacts on funding or employment? The author asks how do we regulate air pollution to protect forests when we don't know the effects of air pollution on forests? An interesting question with many parallels indeed.

The author presents a simple decision tree that artfully demonstrates how the uncertainty in structure of the decision problem can be illustrated. She considers consequences to the forests, budgets, and the scientist's status. The advantages of this approach are: 1) it is personalized; 2) it brings our actions more in line with our beliefs; 3) it helps us avoid unnecessarily conservative positions; and 4) it helps us distinguish between the sphere of the analyst and the decision maker.

A23: "Risk Analysis of Multiple Environmental Factors: Radiation, Zinc, Cadmium, and Calcium." By Junko Matsubara, Kuiaki Ishioka, Yoshisada Shibata, and Kazuaki Katoh. Environmental Research. No. 40, 1986. pp. 525-530.

Applicability

One of the most vexing problems of any risk analysis is how to account for the complex interactions and interdependencies of multiple factors. Most risk analyses still treat factors as largely independent of one another. This article, though developed for the health risk analysis field, does offer a cogent example of how one might approach the problem of interdependencies among factors. Though the authors allude to the combination of variables in interaction terms they, unfortunately, side-step the opportunity to do so in this article. This article is recommended to readers interested in how one might combine the effects of several variables in an analysis. The technique used, a multiple logistic model, typically requires a graduate level exposure to econometric or statistical analysis.

Review

Environmental problems are the net result of many influences. Adult diseases are associated with multiple risk factors that have been difficult to evaluate. The authors suggest, "..it is better to take several risk factors into account simultaneously for considering environmental problems, though the traditional scientific approach is to focus on a single risk factor."

This paper reports the results of a laboratory experiment in which 360 mice were exposed to four risk factors at once. The risk factors were gamma radiation in intestinal doses; zinc through drinking water; cadmium by spot injection; and a calcium-deprived diet. The mortality rates were noted and the experiment was repeated with another group of 360 mice.

The mortality rate of a mouse within 30 days was modeled using a multiple logistic model as follows:

$$\theta = \{1 + \exp(- \beta_0 - \beta_1 x_1 - \beta_2 x_2 - \beta_3 x_3 - \beta_4 x_4)^{-1}\}$$

θ takes the value 0 if the mouse lives and 1 if it dies. The x variables indicate the extent of exposure to the four factors considered. The results showed crude mortality rates of 5.83% for the first group of mice and 5.23% for the second group. Radiation was found to contribute most to lethality and zinc tended to reduce the lethality of the gamma radiation. Interaction terms in the form $x_i x_j$ could be added to the model but this was not done. When such terms are added, interpretation of partial derivatives can be difficult. However, this was an important if unexploited advantage of this model.

The authors conclude the article with the following point: "Therefore we assume that multiple risk analysis using a multiple logistic model works for effective sum-up of the data from a multivariate experimental system and provides tentative estimates for risk prediction" (p. 530).

A24: "The Marginal Cost of Species Preservation: The Northern Spotted Owl". By Claire A. Montgomery, Gardner M. Brown, Jr., and Darius M. Adams. Journal of Environmental Economics and Management. Vol. 26, pp. 111-128, 1994.

Applicability

This article is the conceptual offspring of several ideas presented in other works reviewed in this annotated bibliography. This article provides an excellent example of how interdisciplinary analysis brings together many of the concepts separately developed in the literature. Bishop's (1978) economics article (reference A6) and Burgman's (1993) biology book (reference A7), reviewed elsewhere in this report, provide diverse perspectives on complex issues. Montgomery et al. integrate the perspectives of both disciplines in an effective manner that provides an excellent model for Corps planners. This is not a multidisciplinary approach to the problem. It is an interdisciplinary approach that truly integrates the perspectives of the two disciplines.

This paper presents a marginal cost of survival curve that could provide an extremely valuable model for the Corps to consider for its decision process. The article will be difficult for non-economists and for those who do not have some calculus background. It is nonetheless well worth the effort for these people as well as economists and others with some mathematical background. It provides an example of a model that may well be one of the more promising ideas on the horizon for environmental resource planners.

Review

The authors begin by posing the question, "Which species should we attempt to save and what means should we employ?" To answer the first question we must understand the genetic and economic uniqueness of the species and its contribution to biodiversity. How might this species contribute to the survival of other species? What is its ecosystem function? Answering the second question requires us to estimate the relative merits and costs of alternative preservation methods.

In the U.S., the evaluations are currently made implicitly, rather than explicitly, by the U.S. Department of Interior Fish and Wildlife Service (FWS) within the legal constraints of the Endangered Species Act. The authors argue that the analysis of economic trade-offs inherent in these issues is the intellectual turf of economists. The question most often asked of economists in planning contexts where a species has been identified as a valuable component of diversity (or, perhaps, as an indicator species) is, "What is the cost to ensure its survival?" This, the authors say, is the wrong question. The right question is not how much will it cost to ensure survival but, what is the probability that the species will survive.

So framing the question, the authors argue that certainty of survival is not a realistic approach to the issues raised above. The probability of survival is the appropriate way to approach the measurement of project outputs with regard to targeted species.

Models of species population dynamics and relevant markets were linked to derive a marginal cost curve for species survival using the northern spotted owl. The current controversy attending the northern spotted owl is summarized effectively before the net economic trade-offs surrounding the owl issue are quantified through the development of a supply curve.

The basic model used is:

$$S(C) = \text{Prob}\ [Y(T_0) \geq Y_{min}|C]$$

where C is the capacity of protected owl habitat, measured in owl pairs, that protected habitat is capable of supporting if fully occupied; Y(T) is population at time T; T_0 is a chosen time horizon; and Y_{min} is a chosen threshold population size. Most spotted owl biologists agree that timber harvest and protection of habitat for nesting owl pairs are mutually exclusive or at least highly conflicting. Hence, objectives of social benefit estimation require that specific tracts of land be allocated to one use or the other.

Potential welfare losses in wood products markets (softwood lumber, plywood, and stumpage) were estimated using the Timber Assessment Market Model. These losses in billions of 1990 dollars were estimated for various reductions in annual public timber harvests. In addition, the probability of the owl population exceeding the minimum safe standard (see Bishop 1978, reference A6) at the end of 150 years as a function of habitat capacity was estimated. The annual reduction in public timber harvest in board feet for each additional pair of protected owl pairs was also estimated as a function (i.e., the marginal physical cost curve).

Using the marginal physical cost curve as the common linkage, a marginal cost curve for owl survival is estimated. This curve shows the cost in billions of 1990 dollars of increasing the probability of owl survival by one percentage point. Results are presented for selected conservation strategies. The Interagency Scientific Committee (ISC) proposal would result in a $33 billion welfare loss in return for a 91% chance the owls would still survive after 150 years. Increasing the chance of survival from 90% to 91% means an additional cost of $1.4 billion.

The technique is promising because it supports the type of marginal cost analysis currently favored for environmental resource planning. It allows a different kind of trade-off from the current cost per habitat unit. Unfortunately, the models used in this paper do not obviate the need for controversial studies. The most controversial portion of the subject study "..appears to be the biological relationship between habitat capacity and the probability of owl survival." Thus, the habitat models will continue to occupy a position on the critical path toward improving the risk and uncertainty analysis for environmental resources planning. The authors astutely point out that it is likely to be politically difficult to enact a policy that imposes a heavy toll on one region for the general benefit of all.

A25: "Fuzzy Multigroup Conflict Resolution for Environmental Management." By G. Munda, P. Nijkamp, and P. Rietveld. In <u>The Economics of Project Appraisal and the Environment</u> edited by John Weiss. Aldershot, England: Edward Elgar Publishing Limited, 1994. pp. 161-183. ISBN 1 85278 678 7.

Applicability

This article was selected in order to demonstrate how extensions of fuzzy set theory are being used to address issues of uncertainty. It suffers from a lack of detail that the authors justify by referring the reader to their other articles. This will frustrate the reader unfamiliar with the literature on fuzzy set theory and coalition formation. Nonetheless, the article does provide the reader entree into these two new fields of theory. Thankfully, a case study is provided that does suggest how these techniques can be used to evaluate environmental projects using multi-criteria techniques. The reader won't be able to read this article and turn around and apply the techniques, but he will know there is a technique out there that could well suit his purposes in many situations. This could be enough to send the reader on a search for the additional referenced articles or someone experienced in these techniques. The article is recommended for making the reader familiar with the existence of these techniques.

Review

Evaluation models are used to judge the feasibility and desirability of alternative courses of action. They can be monetary or non-monetary but the necessity of analyzing conflicts among policy objectives in the case of environmental issues have led to a need for more appropriate tools. The authors suggest multiple-criteria evaluation techniques provide such tools. Qualitative multi-criteria methods for environmental management using a mix of quantitative and qualitative information, also called mixed information problems, are discussed, but the emphasis is on "..a discrete multi-criteria method whose impact (or evaluation) matrix may include either crisp, stochastic or fuzzy evaluations of the performance of an alternative a_n with respect to a criterion g_m."

The main steps of this method include: 1) definition of a fuzzy region of satisfactory alternatives; 2) comparison of fuzzy sets; 3) pairwise comparison of alternatives; and 4) evaluation of alternatives. Unfortunately, the article does not include nearly enough detail to appreciate the steps. Additional details are provided in other articles written by Munda. Fortunately, however, a very nicely developed example is presented later in the article. The reader may not appreciate the mathematical rigor of the approach but it's applicability is very evident.

After introducing the steps of their method the authors provide a concise overview of coalition formation theory. The aim of this theory is to predict a set of coalitions that are likely to be formed in favor of or opposition to alternatives in a given political situation. The overview, though sparse, provides an introduction to several applied game-theoretic principles including size theory, policy theory, and its two variants, minimal range theory and policy distance theory. The discussion of the model and coalition formation theory are likely to frustrate readers not familiar with fuzzy set theory and game theoretics. If they prevail to the illustration of the method, their effort will be rewarded.

The case study considers a marl winning process in the Netherlands. Marl winning is part of the concrete production process. Marl winning destroys many of the original ecosystem values. Thirteen evaluation criteria are developed for economic, social and environmental values. Seven alternative actions are developed and an evaluation matrix for a fuzzy land use problem is presented. The alternatives are ranked for criteria like national production of marl, tourist attractiveness, and diversity and scarcity of eco- and bio-components using a fuzzy linguistic scale. In other words, because there is a dearth of quantitative data, each alternative is ranked for each criteria as either bad, moderate, good or excellent.

In addition to this evaluation matrix six interest groups are identified. Fuzzy evaluations of alternatives according to each interest group are provided using terms like bad, fairly bad, moderate, fairly good, good, and very good. The fuzzy multi-criteria procedure proposed for each pairwise comparison proceeds as follows. Three statements for each pairwise comparison are considered: a_1 is better than a_2; a_1 and a_2 are indifferent; and a_1 is worse than a_2. A degree of truth is expressed for each statement by the evaluator. That is, they indicate that the statement is either true, $\tau = 1$, or the statement is false, $\tau = 0$.

On the basis of these pairwise comparisons (it is not explained how group judgments are arrived at) between alternatives, the alternatives are ranked in sets. For example, in this example $(a_4, a_5, a_6, a_7)>(a_1, a_2, a_3)$, where the a_i are the alternatives. Using a semantic distance function a similarity matrix is developed that shows how similar the various interest groups are to one another in their views. The degree of similarity is subsequently used to predict coalitions that can be expected to form at various similarity thresholds.

The article provides an interesting example that will suggest many analogous situations for Corps planners. The fuzzy set approach illustrated here provides the reader with an introduction to the types of things that can be done to address the uncertainty that will inevitably arise in environmental projects.

A26: "The Values of a Habitat." By Kelly Parker. Environmental Ethics. Vol. 12. No. 4. Winter 1990. pp. 353-368.

Applicability

This paper has a "don't miss" title. Environmental resource planning is currently very much habitat-oriented. The value of habitat is one of the fundamental uncertainties of the planning process. Unfortunately, for the analyst seeking pragmatic advice, this philosophical piece provides none of that. The author develops a notion of pragmatic environmental thinking in a paper that has nothing to offer the risk analyst, but a great deal to offer those who want to contemplate the true value of habitat. Generally, we find it a good think piece that has little pragmatic value to planners in this form. The author says if we can get people on different sides of an issue to see that we all must experience both the adequacy and significance of a habitat, then we have the common ground we need to work out some solutions. We're not convinced this framework has the appeal to overcome the emotional arguments of a spotted owl conflict, but you may think differently.

Review

Technology has changed the balance between humans and their environment. Parker argues that we need a framework for determining the principal value of an environment. An important first step in developing that framework is to determine what it is that makes a place important. The author claims an anthropometric perspective to environmental thinking and begins the paper by examining two other anthropometric theories: environmental preservation and judicious development. A major distinction between the two theories is who has the burden of proof. The preservationist places this burden on those who would infringe on natural systems. The developer places the burden on those who would protect a resource from use. Proof is a fundamental exercise in reducing uncertainty. Hence, in spirit this article does relate to the issues of risk and uncertainty.

Parker reviews three arguments used by preservationists against developers. After offering his own preservationist views he concludes that "..we must find some common ground on which we can discuss the reasons each of us has for putting forth such considerations." The considerations he refers to are our views for preservation or development.

The author believes pragmatic environmental thinking provides that common ground. "The point of pragmatic environmental thinking is to work within the human experience of the world, but to expand the scope and meaning of that experience beyond the usual level of dull inattentiveness which fosters environmental exploitation and destruction." The author contends there is a real connection between the human world and the environment and argues that we are not really distinguishable from whatever environment we find ourselves in.

Section 1002 is a 1.5 million-acre stretch of tundra that will either become part of the Arctic National Wildlife Refuge or it will be opened to oil companies for exploratory drilling; a classic preservationist/developer clash. Parker argues that few of us have any experience with a wilderness area like Section 1002 as a habitat.

To get people to value an area like this as a habitat we must discover some basis in other aspects of our common experience. He then draws an analogy between urban and natural ecologies.

An urban habit must be adequate for life, but it also must be a significant habitat for life. Adequacy refers to meeting our basic needs for health, safety and nutrition. Significance means it must nourish our spirits as well. The Earth must also be biologically adequate and spiritually significant. The common ground for the developer and preservationist is our common human way of experiencing an environment. "The key to finding common ground is to sensitize the motorboaters to the affective and biological role of woods in their experience of the world, and likewise to sensitize the environmentalists to the roles of the pleasure boat industry in their experience of the world." Parker presents his framework as one that can overcome impasses like Section 1002 and others. Considerations of adequacy and significance can, he maintains, help us resolve conflicting positions on a common ground. Any idea that offers help in resolving complex conflicts is worthy of additional consideration.

A27: "Characterization and Evaluation of Uncertainty in Probabilistic Risk Analysis". By G.W. Parry and P.W. Winter. Nuclear Safety, Vol. 22, No. 1, January-February 1981. pp. 28-42.

Applicability

This article was selected on the strength of its title, which promises some insight in the handling of uncertainty in risk analysis. It delivers that, but not in the most useful form for the typical reader of this review. One must really know the risk analysis and probability literature to appreciate this article. It is important, however, in that it presents some of the thinking about uncertainty issues that was taking place in the nuclear safety industry over a decade ago. Reading this article's description of probability requires time and work. It's a difficult discussion for most analysts, but it is as easy a discussion of some of the basic issues in subjective probability that will be found in the scientific literature. This article is not recommended to the novice in risk analysis.

Review

Probabilistic risk analysis for three major studies in the nuclear field serve as the starting point for this article. Results of these risk analyses were plotted as a frequency of occurrence of an accident sequence versus the accident's particular consequence. These figures display a level curve along which the expected value of the risk is constant. During the three studies, however, significant uncertainties were encountered in both the frequencies and the consequences of events.

One of the major problems encountered in the risk assessment of nuclear plants is that many of the event sequences of interest are, by design, rare. It is impossible to build a data base that could be used to make inferences within a reasonable time frame. The principle technique applied in these instances was the combined event and fault-tree decomposition of accident sequences into more basic events. Frequently, data were available for these more frequent events so the frequency of the rare events could be built from them.

The sources of uncertainty found in these studies has been categorized as model and data uncertainty. The discussion that ensues on these points is not nearly as informative as that offered by Morgan 1992, described elsewhere in this report (reference G13). The authors do indicate some important limitations of fault-trees, however. First, it is often not possible to be sure that all events leading to the "top" of the tree have been identified. Thus, completeness is a major problem. Some of the other problems identified in the article, such as multistate logic and external events, have long since been handled by the fault-tree tools. Thus, the article suffers from its age. One of the major problems identified is the fact that the probabilities of events are uncertain.

The article hits its stride in the discussion of the subjective theory of probability. Though difficult for those unfamiliar with the probability literature, it is a valuable contribution to the risk analysis literature if for no other reason than the many classical references offered by the authors. Anyone who wants an introduction to the classical and seminal works in probability theory could do much worse than to start with this article.

The authors favor a Bayesian approach to probabilistic risk analysis. The experience of the nuclear industry with a lack of data has lead the authors to believe that the correct framework for assessing coherent probabilities is Bayesian. Degree of belief, coherence and exchangeability of events are identified as the most important features of subjectivist probability theory. Each is discussed briefly and is carefully footnoted.

After offering the briefest of overviews on Bayes theory (Baird 1989, reviewed elsewhere in this report (reference G1), does a much nicer job in his book), the authors address the two Bayesian schools of thought on the choice of a prior: subjective and objective. Given the evidence that exists, should two different people have the same prior (objective), or is it permissible for them to have different priors (subjective)? There follows a nicely developed, but short, discussion of the principle of stable estimation, the principle of indifference, invariance theory, principle of maximum entropy, the method of Box and Tiao, and the method of Novick. These represent issues confronted and approaches to resolving these issues in formulating “ignorance” priors. These topics will generally be a bit esoteric for the needs of most Corps analysts.

The discussion of the quantification of uncertainty that follows is difficult. Most readers would be better served by consulting the Baird 1989 text (reference G1). Advanced probability students will be able to appreciate the discussion of Bayesian confidence intervals and tolerance. The authors found a major shortcoming in the fact that there are apparently no methods capable of handling both tolerance and confidence. Therefore, physical and statistical uncertainty are often combined in single makeshift measures.

The authors conclude that a Bayesian framework is best for rare events when data are lacking and expert opinion is a major source of information. These sound like the circumstances Corps planners will often face.

A28: "First Things First: Needed - A Genetics Risk Analysis Science." By Jeremy Rifkin. The Environmental Forum. Volume 3, Number 10. February, 1985. pp. 39-41.

Applicability

What would be the harm in using some new plant genetically engineered to mature quickly to provide cover for some little critter? We don't know. That is precisely the author's point in this article. The argument raised may be a bit esoteric at first glance, but it is likely that at some point a Corps District may be faced with the need to address this issue. When it comes up, Rifkin has raised a few points that may help analysts begin to think about this fascinating issue.

Review

"Biologists are able to recombine genetic material from unrelated species, and in so doing create modified and novel forms of life that have never previously existed in nature." This is a direct quote from Rifkin's article, one of many that gives the reader reason to pause and reflect. Rifkin says biotechnology is about to replace the pyrotechnology, that has had us heating, melting, forging, shaping, welding, and cooking inert materials into new shapes and forms to transform life on earth. Dismayed that government seems to hone in on questions of how to proceed and how to regulate bio-engineered products rather than whether to do it, the author suggests that we need a risk assessment methodology to judge the potential risk of these products. In the absence of such a methodology he believes we should reject the introduction of any genetically engineered products into the environment.

Though this article is woefully short for addressing such weighty issues, Rifkin does a good job of raising some disturbing questions. First, he points out that genetically engineered products are different from the petrochemical products he uses for comparison in important ways. Because they are alive they are much more unpredictable. It's far more difficult to assess all the potential impacts a product might have on the environment. These products have the ability to reproduce, grow and migrate. Once released they are virtually impossible to recall. As a result, the potential long-term risks to the environment are unknown and great. Rifkin suggests that if only a small number of these products are harmful the sheer volume of new bioengineered products virtually ensures that some will become problems.

A second set of problems is that genetic technology as applied to agriculture and animal husbandry is designed to increase the speed of maturation and gross productivity of plants and animals beyond the limits imposed by natural systems. Genetically engineered products can place additional burdens on natural systems. For example, increased photosynthesis will also require greater use of soil nutrients, thus threatening further depletion and erosion of our endangered soil base. Arguing in this fashion, Rifkin presents living resources "..as finite and depletable as fossil fuels."

The third set of problems stem from the author's observation that transferring genetic traits from one species into the permanent hereditary code of another species poses grave long-term environmental dangers and raises fundamental moral questions. The reader will wish Rifkin had said more on this point, surely to be heatedly debated in the decades to come.

For all the above reasons, the author finds attempts at genetic engineering of microbes, plants and animals tantamount to playing "ecological roulette". He asks a question any analyst faced with the use of bioengineered products would be wise to ask. "Are we wise enough and smart enough to begin the process of redesigning the blueprints of living systems without destroying the very foundations of the earth's environment?"

A29: "COMPARE: An Integrated Tool for Hazard Assessment and Risk Analysis." By G. Rinaldi, S. Stanghellini, and P. Vestrucci. Environmental Software. Vol. 7 No. 4. 1993. pp. 203-215.

Applicability

COMPARE is a highly specialized tool developed for use in a narrow range of applications. Though this software package is of little direct use or interest to Corps analysts, it is interesting because it illustrates that integrated risk analysis tools have been developed and used. MEPAS is another software tool described in one of the articles reviewed in this annotated bibliography (see Droppo 1993, reference A15).

COMPARE, MEPAS and similar tools could be of interest to modelers and Corps analysts who have contractors develop risk analysis software for them. This software, developed by Italian scientists, is available from: G. Rinaldi, NIER, Via S. Stefano, 16 40125 Bologna Italy. Telephone: 39-51-239728, fax: 39-51-227824.

Review

COMPuter Aided Risk Evaluation (COMPARE) is a prototype integrated tool for developing hazard assessment and risk evaluation using various modeling techniques, scenario simulations and spatial analysis. It is a geographical information system (GIS) that integrates data preparation and input modules, modeling modules, spatial analysis modules, and data display modules. COMPARE helps analysts address industrial hazard concerns in an interdisciplinary and interactive way.

The package evaluates the consequences and risks of possible accidents in an industrial area through simulations. The user interface, data structure, and system architecture are described with flow-charts and text, but of necessity remain very much a black box in this paper. The innovation of COMPARE is the real integration of different tools and techniques. This is made possible by a computer aided design (CAD) system as a base to build a GIS, based on a suitable "C-like" language able to deal with graphic objects.

COMPARE is used for industrial accident analysis. It would seem that with some adaptation a model like this could be used to analyze oil spills or other accident-like events. To use the package the analyst must first digitize the plant/factory and geographical maps. The program provides predefined tanks, reactors, furnaces, heat exchangers, pipelines and towers. New components can also be defined. The geographical map includes three territorial entities: vulnerability centers (schools and inhabited areas, for example); resources for emergency management (e.g., hospitals, fire stations); and main routes. Data are entered for each entity (distance from plant and population, for example).

Next the analyst must locate source points on the plant map. These indicate probability of accidents, substances involved, flow rate, temperature, and so on. The analyst's most important task is the identification of possible events that might occur at the plant. Various scenarios associated with the selected source points can be simulated by running consequence models chosen from the set stored in the system model base. The output of the evaluation is a contour map of the consequences; for example, radiation for fire, overpressure for explosion, and concentration for toxic gas dispersion.

The model base allows the simulation of different accident scenarios including: dispersion of neutral gas; dispersion of heavy gas; unconfined vapors cloud explosion; jet fire; fire ball; and pool fire. The risk evaluation estimates the expected number of deaths using values estimated from a probit model. COMPARE has been used for the development of documentation for a chemical plant that stores and handles flammable and toxic substances.

A30: "Risk Sharing in the Design of Environmental Policy." By Kathleen Segerson. American Agricultural Economics Association. Vol. 68. December 1986. pp. 1261-1265.

Applicability

Who should bear responsibility for damages when a polluter is in compliance with all regulations but still causes damages? Is it the polluter because he has caused the damage? Or, is it the victim, because the polluter was in compliance with society's regulations? The question is specific but not narrow.

This article is more academic than most articles in this review in that its focus is the development of theoretical optimal choices under varying circumstances. The parallel to environmental investments might be how should responsibility for stochastic negative outcomes, analogous to pollution events, be determined when the party responsible for the outcome, the polluter, was in compliance with existing regulations. In other words, whose fault is it if we did everything we were supposed to have done but something still went wrong? More importantly, what mix of regulation and judicial system resolution should be used to achieve an optimal solution to problems like these? This article answers that question for a rather specific set of circumstances. It answers it from an economic perspective assuming the expected utility of the polluter and victim are the values to be optimized. It will be of very limited applicability to most environmental resource investment problems.

Review

The article begins by considering two policy options for dealing with stochastic, rather than continual, pollution events. One is through the ex ante constraints of the regulatory process. The other is through the ex post constraints of the judicial system. Which policy is best? Segerson concludes that depending on whether polluters and victims are risk averse or risk neutral, different policies may be desirable. The allocation of risk is only one factor to be considered. Another important factor is the incentive effect. The government's ability to induce polluters to take actions to reduce their probability or magnitude of a pollution problem depends on the extent to which pollution events are observable or unobservable. Regulatory models generally are based on the assumption that actions by the polluter to reduce the probability or magnitude of pollution are observable. Incentive scheme models are based on the assumption that these actions are not observable.

Thus, Segerson establishes the framework for examining three distinct situations. In the first, there are no incentive problems. The level of allowable observable and unobservable pollution actions can be imposed on the polluter. The problem reduces to a simple maximization of the expected utilities of the polluter and victim subject to the constraint of a minimum level of utility for the polluter. This is a simple risk sharing problem. The first order conditions show that if victims are risk averse and polluters are risk neutral, polluters should be subject to full ex post damages. If the opposite is true and victims are risk neutral and polluters are risk averse, then there should be no ex post liability. If both parties are risk averse, a partial ex post liability scheme is optimal.

In the second application of the model the firm must be induced to take socially efficient actions. In the first model these actions could be imposed. The results show that if polluters are risk averse and their actions affect the probabilities of alternative states of nature, then a partial liability scheme, somewhere between full ex post and full ex ante liability, is efficient.

In the third model, observable actions are subject to regulation and unobservable actions are subject to incentives. In this joint use of regulation and liability the author finds that if the polluter's unobserved actions affect states of nature, some positive level of ex post liability is optimal. If, in addition, polluters are risk averse, a system of regulation and partial ex post liability is preferred.

The principal finding is that a policy that couples regulation of observable actions with a system of partial liability seems to be a preferable way to balance the need for risk sharing and incentives. This article will not be easy for most readers to follow. The arguments are rather straightforward for economics graduates students but they skip far too many steps for the non-economist to follow. The other significant limitation is finding relevance for the conclusions in the environmental investment field.

A31: "Environmental Risk Analysis: An Overview." By M.P. Singh and Curtis C. Travis. Risk Analysis: An Official Publication of the Society for Risk Analysis. Vol. 11. No. 3. September 1991. pp. 377-379.

Applicability

This is a paper for and about India, responding in part to the need to manage environmental risks made obvious by the Bhopal incident. This article was reviewed in an effort to avoid overlooking international initiatives in the area of environmental risk analysis. Indian risk assessments, as described in this paper, are somewhat behind assessments in the U.S. However, they have learned from our experience. For the most part this article is like an early 1980s rehash of the state-of-the-art of risk analysis. There is little of real use in this article. It does, however, provide examples of cultural adaptations of U.S. analytical techniques.

Review

The Government of India's Ministry of Environment and Forests sponsored a workshop on risk assessment techniques and management in October 1987. The need to control emissions of hazardous air pollutants, plan for the prevention of accidental releases of hazard substances into the environment, and to develop appropriate emergency responses was recognized by all present. Recommendations from that workshop would, presumably, guide the development of the nation's environmental risk analysis program.

A comprehensive program for assessment of risk due to hazardous air pollutants was identified as a primary need. Though prevention was recognized as the best means for protecting human health and the environment, emergency response plans would be needed. Local emergency planning committees would conduct site-specific hazard analyses to develop emergency plans. Technical guidance for identifying and analyzing hazards must be provided. Risk liability insurance was identified as an avenue deserving future investigation as part of emergency planning. The emergency preparedness initiatives included the same elements you would expect to find in a write-up of an American plan. This raises the question in our minds whether something with such psychological/sociological roots can be transplanted so readily from Western to Eastern cultures without substantial retooling. This concern was not reflected in the paper, however.

Land-use planning was another major topic of discussion. The major thrust was to keep population centers away from potentially hazardous facilities. A three-tiered buffer zone has been suggested for India. The inner zone is the area of greatest risk. It should remain an unpopulated green belt. The middle zone has moderate risks but population should still be prohibited. The outer zone has low risks but sensitive development such as hospitals, schools, and the like will need case-by-case consideration.

The workshop participants requested a database information system be developed. It would include toxicological data needed to develop ambient standards as well as a list of symptoms, antidotes, and methods of treatment for exposure to hazardous materials. Environmental data and an inventory of hazardous materials would also be included in the database. Finally, training and public awareness were recognized as significant needs for the country.

A32: "Ecology and Design: An Introduction." By Ian R. Smith. Journal of Environmental Management. Vol. 26. No. 2. March 1988. pp. 103-109.

Applicability

The author in this piece argues that applying design principles to ecological problems is one approach to studying these problems. One of the more important issues the Corps will face in its transition to adaptive management for restoration of environmental resources is understanding how ecological systems and environmental investment projects function and how they fail. This article offers an alternative for treating applied ecology as a problem in design. Unfortunately, this good idea is not as well developed as many readers might like. Nonetheless it provides a focused idea that others may be able to develop further.

Review

Although the science of ecology is developing we do not yet have a methodology for tackling applied problems systematically. In this paper Smith explores the possibility of approaching problems in applied ecology as design problems. He considers and rejects some definitions of design in favor of his own. Smith defines design as "..the deliberate creation of an object and/or procedure in order to fulfill some specified function." The author then adopts the seven interacting design criteria of Papanek as the basis for his article. These criteria are: 1) function (is it clear what the design is expected to do?); 2) use (does it work?); 3) need (is it necessary?); 4) telesis (is it appropriate to the society and conditions in which it has to function?); 5) association (is it psychologically acceptable, i.e., are we comfortable with it?); 6) aesthetics (is it visually exciting, a source of delight?); and 7) method (how is it to be made?).

Smith concentrates on the function and use criteria of ecological design. Telesis, association and aesthetics are normally within the purview of the landscape architect. Need frequently is determined by benefit-cost analysis. Method, he argues, merits a separate discussion at another time and place.

Just what is it that is being designed? The unit of design can be defined as any number of things, so the starting point for any analysis should be a clear understanding of what the unit under consideration is. It could be a few acres of woodland or the whole of the British Isles.

The function of an ecological unit must be explicitly described. Smith indicates there may be many functions, including technical, perceptual, conservation and ecological. Technical functions like water supply, recreation, agriculture and the like are the easiest to identify. Ecological functions are frequently defined as preservation, maintenance and display of species and habitats. Smith points out that the function of ecological projects are not often identified, perhaps in the belief that a clear statement of function provides opponents with easy ammunition. Once a function is established as unacceptable few other arguments will carry any weight.

"Use" gets at the question, does it work or, more appropriately, what is the probability it will not work? Once the function has been established it is then possible to identify the modes of failure, that is, the ways in which the project fails to function. Smith uses a simple load/factor of safety analysis approach to the issue of failure with reliability, recovery rate, and vulnerability as the measures of system performance. He offers an example from the literature (Holling 1973) to illustrate dynamic system performance in a simple way. When the state of the system of interest falls beneath a failure threshold, a problem exists. The amount of time the system state remains below this threshold determines the system's resilience. The problem Smith acknowledges is determining what measure of a system state could be used to determine the failure threshold for an ecological system.

Local extinction of a species, changes in energy, conversion efficiency, and alterations of community structure and species diversity are offered as examples of possible thresholds. Smith never really pulls his argument together effectively. We think it might be: if you can define an ecological unit/system in explicit terms, identify its functions, and the uses to which it is put, it is then possible to identify modes of failure. Smith does say that "..it will never be possible to make decisions solely on the basis of the implications of the mathematical analysis of ecosystem behavior." Combining common sense and experience to understand the possible modes of failure and the requirements to avoid such failures is the true value of the attempt to apply design principles to applied ecological problems.

A33: "Risk Analysis for the Concho Water Snake." By Michael E. Soulé. Endangered Species Update. Vol. 6. No. 10. August 1989. pp. 19-25.

Applicability

This is the kind of article we had hoped to find hundreds of when this literature review was being planned. It is well-written and accessible to all. It deals directly and pragmatically with a well-defined problem and uses techniques that are easy to follow. It provides a clear model for environmental resource planners to model.

That is the good news. The bad news is that it is the only article with all these qualities that we found. It is highly recommended, however, as an example of how analysts can approach recovery planning where they have to make many decisions without adequate information. It relies on subjective risk assessments and the use of decision trees, two useful tools for the Corps' risk assessment of environmental investments. Estimating the probabilities of extinctions of species, at least in the vicinity of a project, offers a great deal of promise as an assessment measure for environmental resource planning. This article provides an exceptional introduction to the use of this concept.

Though we are not particularly impressed with the subjective assessment done for this article, the article itself is an excellent example of how one might effectively describe an analysis in writing. There is much in this article worth using and emulating.

Review

Nerodia harteri paucimaculata, the concho water snake, lives in a small area of central Texas. Reliable estimates of its population size are lacking. Their young feed in rocky shallows or riffles. Its other habitat requirements include basking sites, hibernacula, and pools for adult feeding. In a deft manner the author, in three short paragraphs, makes you feel like you know this snake.

The motivation for this article was the construction of Stacy dam at the confluence of the Colorado and Concho Rivers, a site that includes much prime habitat for as much as one-fourth to one-half the species. The management goal is "..to maintain the viability of the species in the vicinity of its current geographic range." In this analysis the risk of extinction was assessed over the next 25 years. Such clear objectives provide a good example for Corps planners.

The specific objectives of this study were to: 1) identify potential threats, now and in the future, to the snake; 2) identify and clarify the various management interventions available for the snake; 3) estimate the probabilities that each of these threats will occur and that the management measures will be effective; 4) estimate the probability of extinction of the snake, given various combinations of events and management measures; and, 5) analyze the sensitivity of the various estimates to changes in their values. The analysis is intended to provide the best available information about the relative risks of different management measures.

Soulé provides a clear and well explained example of how such objectives can be pursued through decision analysis that relies on subjective probability assessments and decision trees. The analysis showed that the "no dam" alternative was best for the preservation of the snake. Even this alternative carried an 11% chance of extinction over the next 25 years, however. This alternative was followed from best to worst by the following: 1) artificial river (29% chance of extinction) and flushing and scouring (also 29%); 3) artificial riffles (30% chance); 4) reservoir substrata (38.5%); 5) translocation and reintroduction (39%); and, 6) no intervention (40% chance of species extinction).

In a sensitivity analysis the author attempts not to find more accurate estimates of these probabilities but to determine what values are more critical to the analysis. The author's conclusions are, like the rest of his work, clear and effective ways to deal with the inherent uncertainties of recovery work. "The consensus of the experts appears to be that none of the interventions independently reduces the probability of extinction by more than 10 to 15 percent below the 40 percent "no intervention" figure... It is conceivable that the interventions examined herein, given that they all succeed, would reduce the extinction vulnerability of the snake to a level below what it is today. The probability of such a decrease in jeopardy cannot be ascertained given all of the uncertainty surrounding the situation at present... it is quite likely that the estimates of the probability of extinction would be substantially higher if the temporal window were 50 or 100 years."

A34: "Ecological Risk Assessment: Its Role in Risk Management." By David James Stout and Robin A. Streeter. The Environmental Professional. Vol. 14, 1992. pp. 197-203.

Applicability

As is evident from several other reviews in this report, ecological risk assessment is an evolving field of endeavor. Initial efforts to conduct ecological risk assessments have arisen from the need for site remediation. Initial efforts have focused on imitating and attempting to adapt the environmental risk assessment paradigm of the EPA.

This article provides a succinct, albeit brief, summary of the EPA's ecological risk assessment efforts. This area of analysis is going to be important to the Corps for any potential Superfund (CERCLA) work, for dredging/sediment disposal, and any other restoration work involving toxic wastes. It is useful for Corps analysts involved in environmental resource risk analysis to become aware of the environmental and ecological risk assessments methods currently in use by other agencies. This article provides a nice introductory summary of EPA's efforts in ecological risk assessment.

Review

Risk assessment is critical to decision-making concerning site remediation and has been for years. While the focus in the early years was on human health, there is now a need for a reasonable and consistent approach to evaluating ecological risk. With this as their starting point, the authors provide a brief but effective summary of EPA's risk assessment methodology.

Developing conclusions about ecological risks has been frustrated by the following: 1) limitations in available ecological data; 2) paucity of ecotoxicity benchmarks; 3) uncertainty about ecosystem response to chemical perturbation; and 4) lack of Superfund policy defining significant ecological risk. Noting that numerous methods for conducting ecological risk assessments have been proposed and reviewed, the authors present a case study of an ecological risk assessment for the characterization of sediments in the Great Lakes. The ecological risk assessment process consisted of four interrelated steps: 1) identify hazards through the selection of chemicals of concern and characterize baseline ecology and potential receptors; 2) evaluate potential exposure; 3) assess chemical- and media-specific ecotoxicity; and, 4) characterize potential risks. Each of these steps is briefly described.

The case study offers a simple equation for sediment concentration that is used as a screening level criteria. Sediment concentrations derived using the EPA approach were compared to sediment levels of chemicals of concern to develop a hazard ratio. Ratios less than unity indicate no likely adverse effects to biota. The preliminary conclusions in the case study were: 1) acute toxicity to aquatic life inhabiting the lake most likely is not a concern based on either measured or predicted exposure concentrations; 2) mercury probably represents the primary chemical of concern; and, 3) biomagnification potential exists for both mercury compounds and chlorinated benzenes.

Stout and Streeter identify several issues to be addressed in the development of an ecological risk assessment program. These include the need to establish risk management objectives and goals if we are to protect "...environmental receptors beyond humans".

A35: Ecological Risk Assessment. By Glenn W. Suter II, Lawrence W. Barnthouse, Steven M. Bartell, Theodore Mill, Donald Mackay, and Sally Paterson. Boca Raton: Lewis Publishers, 1993. pp. xvii, 538. Four parts and thirteen chapters. ISBN 0-87371-875-5.

Applicability

Lewis Publishers seems to have carved a niche for itself as the publisher of some of the most up-to-date and complete texts on ecological and environmental risk assessment. In this book edited by Suter, also the principle author, advanced students in environmental sciences and practicing environmental scientists will find a good introduction to risk analysis as it is practiced by the EPA in the area of human health effects. The book assumes a basic knowledge of ecology, toxicology, chemistry, mathematics and statistics. It assumes no knowledge of risk analysis. It is an excellent book but it does at times require a rather diverse vocabulary in the natural sciences. It is recommended to anyone interested in a fuller understanding of the field that has come to be known as ecological risk assessment.

Review

The book consists of four parts. The first part (three chapters) is devoted to an introduction to ecological risk assessment. The second part (three chapters) addresses exposure assessments for predictive risk assessments. Part Three (also three chapters) focuses on effects assessment. The last part discusses unconventional ecological risk assessment (four chapters). A handy glossary is also included.

Chapter 1 defines ecological risk assessment as the estimation of risks posed by chemicals. Environmental risk assessment is described as a far more encompassing field of endeavor. Chapter 2 defines a number of concepts essential to ecological risk assessment. "The purpose of ecological risk assessment is to contribute to the protection and management of the environment through scientifically credible evaluation of the ecological effects of human activities" p. (21). Endpoints, essential to any assessment, are defined at length. In brief, an endpoint is a formal expression of the environmental value to be protected. Assessment methods, including physical, statistical, and mechanistic models, are discussed. The requisite discussion of probability and risk and uncertainty can also be found, but they are treated more thoroughly in other publications covered in this review.

The basic ecological risk assessment paradigm is presented in Chapter Three. It is based on the human health risk assessment paradigm, and, though there are many similarities, there are substantial differences as well. Step one is to define the hazard. This requires defining endpoints, describing the environment, and obtaining source items. Step two is the exposure assessment (the dose-response assessment in the human health paradigm). Step three is the effects assessment. Step four is the risk characterization. The authors add risk management as an explicit fifth step that is often assumed to be part of the fourth step in other discussions of the paradigm.

In Part Two the chapters are devoted to a discussion of methods for estimating the exposure of organisms to chemical pollutants. Chapter Four on environmental chemistry deals with estimating the physical/chemical properties of pollutants to determine their behavior in the environment. Billions of tons of natural and synthetic organic chemicals move through the air, water and soil environments each year. Environmental chemistry attempts to describe and quantify environmental processes and the rates and products of movement and transformation. This chapter focuses on environmental reactions to organic compounds by presenting some of the underlying principles of environmental modeling.

Chemical fate and transport models are discussed in Chapter Five. These models take data concerning chemical discharge rates and concentrations together with information about the state of the environment and estimate the amounts and concentrations of chemicals present in each medium. It also estimates rates at which the chemicals will degrade and be transported from place-to-place. This analysis provides an estimate of how long the chemical will reside in the environment.

The quantitative description of the system is frequently referred to as a "mass balance" model. The mass balance model example is carried through much of the chapter that ends with a description of other environmental models of chemical fate (fugacity models, GEOTOX, Environmental Partitioning Models, and others).

Chapter Six addresses exposure, defined as contact with a chemical or physical agent. First, the chapter considers the relevance of the concentrations in media (fluids, solids, multiple media) predicted by the fate models to the environment as experienced by organisms. Second, it considers how the behavior of organisms results in the uptake of pollutants. Third, using toxicokinetic models, it discusses how a concentration of a substance in a medium can be converted into an exposure level.

Part Three, Effects Assessments, discusses methods for estimating the ecological effects that result from exposure to pollutant chemicals. In Chapter Seven organism-level effects are covered. Tests for effects and models for effects are each addressed in turn. The sensitivity of endpoints to differences in species, test conditions, exposure duration and other variables is also discussed. Numerous examples are presented. The chapter also considers models of chemical mixtures. Probit models are used for estimation in some cases. Results are presented in the form of isobolograms. Finally, the risks to individual organisms is estimated or "characterized", in the vernacular of the ecological risk assessment.

Chapter Eight focuses on population-level effects. Endpoints for populations tend toward total population density or biomass, age or size distribution, or yield available to harvest. Population analysis receives an abbreviated discussion after which examples of specific risks of chemicals to specific species are presented. Linking toxicity data to population models using the models of this chapter requires the development of exposure-response functions that deal with uncertainty of varying types.

The last chapter of this section presents ecosystem-level effects assessments. Frequently the endpoints will have ecosystem properties. At least four types of effects can occur at the ecosystem-level that do not occur at the organism or population level. First, effects on a population's ability to interact with populations of other species may occur. Second, indirect effects on a population due to effects on the populations with which it interacts can occur. Third, there can be structural changes in the properties of an ecosystem. Fourth, there can be changes in the functional properties of an ecosystem. Numerous tests and models for ecosystem effects are discussed.

In the last part of the book, unconventional ecological risk assessments are discussed. Risks that do not fit the paradigm of the earlier text are presented here. Chapter Ten on Retrospective Risk Assessment may be of interest to Corps analysts. While predictive risk assessment was the focus of the early text, this chapter acknowledges that assessment of pollution effects that began in the past and may have ongoing consequences (such as waste sites) are becoming increasingly important. Such retrospective assessments are more diverse than the predictive models addressed up to this point in the book. While predictive models have a proposed source, the impetus for retrospective models can be a source, observed effects, or evidence of exposure. Each type of impetus is discussed in turn. Examples are provided for acid deposition and fisheries, ecological effects of a waste site, and effects of granular carbofuran on birds.

Regional risk assessments are presented in Chapter Eleven. These assessment address larger scale effects of multiple actions (e.g., Exxon Valdez, Chernobyl). In Chapter Twelve the authors argue that much of environmental science has been devoted to monitoring the environment for purposes of surveillance rather than to support risk assessments. Surveillance monitoring serves the purposes of: assessing regulatory compliance; as a means of system control; assessing environmental quality; and detecting the unexpected. Surveillance describes things as they happen rather than predicting or explaining why they happened, as predictive or retrospective risk analysis would demand. However, the authors argue there is no reason why surveillance can't serve risk assessments as well.

Suter begins the chapter on exotic organisms with an admonition from Lewis Carroll to beware the Jabberwock, Jubjub bird, and Bandersnatch. This chapter addresses the introduction of exotic organisms to new areas. A predictive risk methodology based on the same paradigm is offered in this chapter that extends the ideas presented in the Caltagirone (1980) article reviewed elsewhere in this report (reference A9). The current author finds the risk somewhat more imposing. Five typical endpoints for such actions are identified.

A36: "The Complementarity Between Environmental and Economic Risk: An Empirical Analysis." By Paul H. Templet and Stephen Farber. Ecological Economics. Vol. 9. No. 2. February 1994. pp. 153-165.

Applicability

This was another article with a very promising title that didn't deliver what we had hoped for. The supposed conflict between economics and the environment is the focus for this paper. It makes some very good points, but it does not deal with risk in a very explicit way. The risk is more implicit. Though we're not sure the authors would describe it this way, their implicit risk argument goes as follows. Economic development, i.e., jobs, bring risks, i.e., pollution. If we lower the risk of economic ruin, i.e, increase jobs, we increase the risk of environmental ruin. Lower the risk of environmental ruin, i.e., pollution, and we could increase the risk of economic ruin.

The authors deserve points for their creativity. They are attempting to integrate economic and environmental metrics in a way that might help decision makers think about these risks. It's a first attempt in the new field of ecological economics. As such it is welcome; but it is also less than compelling.

Review

The authors begin from a commonly assumed premise. They state, "The traditional view is that enhancements to environmental conditions are costly to economic development. In other words, environmental and economic risks are inversely related." From this position they present a position they consider more realistic: "...the loss of an ecosystem base, or increased environmental risk and reduced economic carrying capacity of the ecosystem, reduces the long-term economic welfare secured from the ecosystem." In other words, economics and ecology are not contraposing forces, they are complementary.

This study examines the long-term complementarity of this relationship by examining the ratio of toxic chemical emissions to jobs (E/J) to see if relative risks, as reflected by this ratio, are consistently related to traditional welfare measures such as income and employment across the U.S. The authors posit that economic and environmental development are the result of a combination of comparative advantages in economic and environmental resources as well as public policies.

Using data from EPA's Toxic Release Inventory (TRI) and the Statistical Abstract of the U.S., the author's estimated the E/J for various SIC code manufacturing sectors. This ratio is represented by the authors as a measure of environmental risk. The E/J reflects total TRI emissions per manufacturing sector job. The ratios ranged from a low for apparel of 2 to a high for chemicals of 3,237. In addition, ratios were calculated for all fifty states. The variations within and across industries and states are discussed. Simple correlations of the E/J to economic variables were calculated. The E/J and per capita income are negatively related, while the E/J is positively related to unemployment and poverty. The authors provide numerous other correlations using different measures of environmental risk including ratios of hazardous wastes to jobs, total Btu use to jobs, and the Green Index.

The analysis seems somewhat superficial at times. The authors do not present a convincing case that E/J or any of the other measures is a meaningful metric of environmental risk, a term they fail to adequately define. It is almost as if the authors found statewide data, developed an index and then began to look for things to correlate it with. The major weakness of this paper is that it lacks a theoretical framework. The reader never gets a good feel for why the authors are correlating these variables. Why these variables? What does it mean? They fail to explain the significance of any of their relationships, perhaps, we fear, because there is none. They seem to implicitly define economic risk as poor economic conditions and they conclude there is evidence that environmental risk and economic risk are complementary. What is missing from this article is that there is no cause and effect theory, nor cause and effect analysis. In fairness to the authors, they acknowledge this near the end of the article.

The paper describes potential policy uses of the E/J ratio. These include: reemphasizing jobs, institutional structures for improving the E/J, development transition, and using the E/J as an environmental scorecard. There was a one year trial use of the E/J as an environmental scorecard in Louisiana in 1990. The scorecard was a ranking system that applied environmental and economic criteria to a company's tax exemption status. In an innovative but amazingly complex and arbitrary fashion, companies requesting tax exemptions were rated using some of the techniques described in this paper. The program was abandoned after one year.

Though we have been somewhat critical of some aspects of this paper it makes an important and significant contribution to the environmental risk analysis literature that should be of interest to Corps personnel. It tried something different, something new. This is not another risk-benefit analysis. It is not a benefit-cost ratio. It was an attempt to develop new metrics that reflect not just economics and not just environmental values. It serves as an example of innovative thinking as we investigate uncharted territory in environmental resource risk analysis.

LITERATURE SOURCES TO MONITOR

INTRODUCTION

The risk and uncertainty literature is relatively recent. The amount of risk material written about environmental planning in general and environmental restoration in particular is, unfortunately, minuscule. Over time, risk analysis is being used in more and more specific applications. Gradually, it will be applied to environmental issues that transcend the human health focus the environmental risk analysis literature has had to this point in time. For example, at this writing, IWR Report 96-R-8, *An Introduction to Risk and Uncertainty in the Evaluation of Environmental Investments*, contains an example of a risk-based analysis of a habitat suitability index model. The Corps' continuing interest in improving decisions through risk analysis alone insures that there will be more applications of risk analysis to environmental studies.

Another significant recent development has been USEPA's publication of *Draft Proposal Guidelines for Ecological Risk Assessment*, EPA/630/R-95/002 October 1995, External Review Draft. A review of this document has not been provided here because EPA has requested that the report be neither quoted, cited, or distributed at this point. Nonetheless, the report is expected to lead to a final set of guidelines at some point in the future. The ecological risk assessment framework offers considerable promise to the extension of risk analysis into the field of environmental planning and bears monitoring.

Although the existing literature is rather limited, the future literature can be expected to blossom. During the preparation of this report a number of literature sources that could be worth monitoring in the future, in order to remain aware of new developments in the literature, have been found. They are described below under the appropriate heading.

JOURNALS AND PROFESSIONAL PUBLICATIONS

Despite the availability and ease of use of online search facilities, we would like to plug an old tried and true method, library browsing. Sometimes the latest literature does not turn up on the online searches until after a considerable time lag. New journals may take quite awhile to appear among the periodicals reviewed by the online services. Other publications may be overlooked because they are not formal publications available for purchase. The online searches failed to identify quite a few of the 52 items selected for review for these and possibly other reasons.

Analysts interested in the literature should from time-to-time visit a major research university and spend an afternoon browsing the periodicals on display. Check the lists of periodicals on microfiche, but be sure to wander among the journals and magazines themselves. It takes just seconds to browse through the titles to see what kind of work the periodical offers. Nothing gives you a flavor for the magazine like flipping through it and observing the subject matter, the difficulty of the writing, the nature of the advertisers, and the backgrounds of the authors.

Following is a list of some periodicals that we think will likely provide valuable information in the future. Many of them may be too expensive for individual Corps Districts to purchase by subscription, and others might be used too infrequently to justify the expense. However, periodic monitoring of these titles would likely be worthwhile for future planning studies and research efforts.

Following are 28 periodicals that would be useful to monitor for future developments in risk analysis related to the environment. The five periodicals that proved most useful in this review have been marked with an asterisk (*).

Challenge
Conservation Biology
Ecodecision Environment and Policy Management
Ecological Bulletins
*Ecological Economics**
Ecological Modeling
Endangered Species Update
Environment and Planning
Environmental Economics
Environmental Ethics
The Environmental Forum
*The Environmental Professional**
Environmental Research
Environmental and Resource Economics
Environmental Science and Technology
*Environmental Software**
Global Environmental Change
Journal of Agricultural and Resource Economics
Journal of Environmental Economics and Management
*Journal of Environmental Management**
Journal of Risk and Uncertainty
Marine Resource Economics
Natural Resources Journal
Project Appraisal
Risk
*Risk Analysis**
Science of the Total Environment
Water Resources Bulletin
Water Resources Research
Water Science and Technology

ONLINE SEARCHES

There is nothing like sitting down to a computer, typing in a few key words, and generating a nice long list of references. When it works it's a wonderful thing. It frequently doesn't work, however, for a variety of reasons. Consider some of the online library searches like CARL. These services allow the user to access the card files of selected libraries from all over the country. The libraries you can search depend on the libraries that participate in that particular service. Frequently there will be a service connecting most of the college and university libraries in a state.

These services generally list only book titles, not journal articles. The subject matter treated in books can be from several months to a few years behind the material covered in periodicals. Many colleges and universities make it a policy not to stock books that are required for course work. They disappear too frequently. Excluding course texts can deprive the searcher of access to some of the latest and best titles. At a minimum, these books are often best suited to readers seeking to learn techniques.

Another common limitation of these services is that it is often impossible to print the search results to a file that can be downloaded. Often printing out long lists of citations is the only way to get a complete list of results.

Finding the proper keywords can be more art than science. Searching a term like "risk" yielded thousands of references in our early search. It was impossible to review each of these citations and it would have been wasteful to print them all. The problem you have to overcome is that a writer or reader of the book had to guess what the keywords for that book were. You, in turn, must guess what keywords they used to catalogue their work. That is easier said than done. It will be necessary for the language of risk analysis to become more standardized for these problems to be avoided in the future.

In addition to library services there are commercial services one can use. Several sell their entire set of citations on CD-ROM. These typically start at about $1,200 and go up. Other services allow users to subscribe. In this case the user obtains an account and can use the service whenever they desire. Libraries are common clients of such subscription services. Still other services will conduct searches for the users on a case-by-case basis. Users can often access these services at college/university libraries.

Expense is an obvious consideration. Purchase of citation databases can be prohibitively expensive. However, they may be reasonable expenditures for an organization like the Corps if they can be purchased and maintained at a central location available to all. Another constraint is creativity, a word we use to mean the ability to get what is of interest to you in the database out of the database. This is the keyword problem again. It has been our experience that there is no substitute for a patient, knowledgeable and creative librarian familiar with the use of the particular online database for getting useful information out of the system.

A third kind of online service is that offered by government agencies. EPA has several of these. They are not usually very user friendly and can take quite a bit of time to learn to use. A fourth potential source of information, not used in this research, could be news groups on the Internet.

Following are a few of the specialty online services that should be considered by analysts. Library online services are not explicitly mentioned because they are ubiquitous.

The following services are offered for general information. Relatively few of them were used during this literature review.

Geographic Information Systems Bulletin Board (GISNET)

GISNET is an online PC-based bulletin board system from EPA's National GIS Program.

GISNET 3405R
401 M Street, SW
Washington, D.C. 20460
Phone: 703-557-3011
Fax: 703-557-3186

Office of Air Quality Planning and Standards Technology Transfer Network Bulletin Board System (OAQPS TTN)

The OAQPS TTN is a network of electronic bulletin boards that provides information and technology exchange in different areas of air pollution control ranging from emission test methods to regulatory air quality models.

Office of Air Quality Planning and Standards
Technology Transfer Network
Bulletin Board System
Research Triangle Park, NC 27711
Phone: 919-541-5384

Clean-Up Information Bulletin Board System (CLU-IN)

The CLU-IN Bulletin Board offers a number of services including online messages and bulletins; computer files, programs, and databases; and Special Interest Group areas.

U.S. EPA
Technology Innovation Office, IS-110W
401 M Street, SW
Washington, DC 20460
Phone: 301-589-8368 or 703-308-8827
Fax: 301-589-8487

Office of Research and Development Electronic Bulletin Board System (ORD BBS)

The ORD BBS is an online, text-searchable database of every ORD publication produced since 1976, including over 17,000 citations.

U.S. EPA
Center for Environmental Research Information
26 West Martin Luther King Drive
Cincinnati, OH 45268
Phone: 513-569-7272
Fax: 513-569-7700

Information Systems Inventory (ISI)

ISI at EPA is an automated catalog of roughly 500 of the Agency's manual and electronic data systems, ranging from scientific models to administrative systems to environmental databases.

ISI Administrator
OIRM/IMSD
3403
U.S. EPA
401 M Street, SW
Washington, DC 20460
Phone: 202-260-1077

Environmental Bibliography

Environmental Bibliography provides access to the contents of periodicals dealing with the environment from 1973 to the present. It corresponds to the Environmental Periodicals Bibliography with over 500 journal titles.

Environmental Studies Institute
International Academy at Santa Barbara
800 Garden Street, Suite D
Santa Barbara, CA 93103
Phone: 805-965-5010
Fax: 805-965-6071

Enviroline

Enviroline covers the world's environmental related information from 1971. It corresponds to the printed Environment Abstracts.

Environment Abstracts
Congressional Information Service, Inc.
4520 East-West Highway, Suite 800
Bethesda, MD 20814-3389
Phone: 800-638-8380
Fax: 301-657-3203

Others

There are a number of additional abstracts, databases, and indices that may warrant monitoring for future developments in the literature. These include but are not limited to the following:

Current Law Index
Environment Abstracts
Environmental Periodicals Bibliography
Health and Safety Abstracts
Index to Legal Periodicals
Journal of Economic Literature
Legaltrac
Legal Resources Index
PAIS Print and Computer Indices
Pollution Abstracts
Risk Abstracts
UnCover Company
WESTLAW

INTERNET RESOURCES

It is with some trepidation that we offer some suggestions for monitoring developments in this field through the Internet. There is no question about the value or volume of resources to be found on the Internet. It is a gold mine. The trepidation stems from the fact that this information is likely to be obsolete and will surely be incomplete almost as soon as it is published. The most important message of this section is therefore that any interested environmental planner or risk analyst should regularly monitor the resources of the Internet for developments in this field.

A recent search for risk-related news groups failed to identify any at this time. RISKANAL is a particularly interesting mailing list for risk analysts. The e-mail address for administration of this list is "listserv@listserv.pnl.gov". The list is maintained by the Pacific Northwest National Laboratory of the Battelle Corporation in Richland, Washington. RISKANAL is a non-moderated list devoted to risk analysis discussions initiated by subscribers. At this writing there are about 600 subscribers and the volume of mail averages about 3-6 pieces per day.

Web sites on the World Wide Web (WWW) are currently the richest source of risk analysis information. A recent search of the WWW using the words "risk analysis" and the Web Crawler search engine returned approximately 1000 documents. Suffice it to say there are a great number of potentially interesting home pages on the WWW. Be forewarned, the quality of information on these sites is variable. Some sites are solicitations for business, some are rarely or poorly maintained and updated (e.g., they disappear or change address without warning), and others seem always to be under construction. Fortunately, however, there are many excellent sites with a wealth of information. Following are a few examples of some potentially useful web sites:

Risk Home Page: http://www.fplc.edu/tfield/profRisk.html

This is an excellent place to begin. The Risk Home Page deals primarily with health, safety, and the environment. It includes an excellent annotated index of articles from the journal *Risk* and many other interesting features. Other examples of risk-related web sites follow, and the contents vary from site-to-site.
Decision/ Risk Analysis: http://www.lumina.com/DA/

Probabilistic Risk and Hazard Analysis (TSA-11): http://www.ta52.lanl.gov/tsa11.html

FERC Risk and Environment: http://www.ornl.gov/ORNLReview/rev26-34/text/hydmain.html/

Environmental Risk Assessment Projects: http://fjwsys.lanl.gov/%7Bjks/TSA/BJK.html

In addition to these risk-related sites it can be beneficial to monitor government agency sites. One need only use the agency name with a WWW search engine to identify sites of particular interest. The IWR home page address is:

HTTP://WWW.WRC-NDC.USACE.ARMY.MIL/IWR/INDEX.HTM

PUBLISHERS

During this literature review we became aware of a publisher that seems to be developing a specialty in risk analysis relating to environmental issues. It would appear to be worth monitoring the offerings of this publisher.

Lewis Publishers
2000 Corporate Blvd., N.W.
Boca Raton, FL 33431

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