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DRAFT:
Assessing the Benefits of Policies Designed to Reduce Acid Deposition: A Decision Analytic Benefit-Cost Framework

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ASSESSING THE BENEFITS OF POLICIES DESIGNED TO REDUCE ACID DEPOSITION: A DECISION ANALYTIC BENEFIT-COST FRAMEWORK

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PREFACE

The purpose of this project was to consider different approaches for conducting benefit-cost studies in the evaluation of policy options for reducing acid deposition. There are several basic steps in the performance of this type of baseline assessment. First, the issues that pose critical questions for the development of the appropriate control strategies must be identified. Second, the data that are available to evaluate the alternative policy options must be assessed, and important data gaps identified. Finally, the different approaches available to perform an integrated benefit-cost assessment should be evaluated. One objective of this project is to consider new methods to perform such assessments.

The design of projects to assess the benefits of strategies to mitigate acid deposition is particularly difficult. The complexity of the affected aquatic and terrestrial systems have made it difficult to identify the effects of acid deposition with any degree of certainty. For example, it is hard to isolate the effects of acid deposition from the numerous other factors that could be adversely affecting a particular tree, fish species, or other environmental attribute. In addition, analyses of acidic precipitation extend across many scientific disciplines and areas of research. This breadth poses problems of integrating information generated by different research disciplines and requires that a benefits assessment be truly interdisciplinary. One of the most difficult integration tasks is between the output of the atmospheric transport models and the research on the effects. For example, long range transport models predict wet and dry sulfate deposition in terms of kilograms per hectare per year (kg/ha·yr), while many researchers of aquatics and terrestrial effects use micro equivalents of hydrogen ions per liter of rain (H^+ μeq./l) as the indicator of deposition in their damage assessments.[1] The conversion from one value to the other is not easy and requires estimates of the seasonally adjusted volumes of rain, the H^+ contributions from other sources (e.g., NO_x emissions and natural sources), as well as an interpretation of whether the indicator (in this case H^+ ion concentration) is actually meant to represent other factors as well. Also, it is not uncommon for scientists to use one specific factor as an indicator of stress which is ac-

[1]For example, the Henrikson Nomograph is a model used for estimating the change in lake pH as deposition changes. The input to the calculation is μ eq of H^+ per liter.

tually an index of a larger number of variables. As a result, policy makers must be cautious when interpreting scientific testimony which is focused only upon one factor. These considerations indicate that while different researchers have been performing excellent work within their own areas, the necessary integration of their work has been very difficult to achieve. Advance planning, however, can help to curb these difficulties through the specification of policy relevant research programs.

An extensive survey of scientific literature on acid deposition and discussions with individuals involved in ongoing research was undertaken to examine the availability of information for benefits studies. In addition to assessing the available information, this interaction with researchers in the different disciplines presented an opportunity to discuss the design of benefits studies with researchers generating the basic data.

Several recommendations have been developed during this project. One recommendation is to start designing an integrated benefits or policy assessment methodology immediately. This would accomplish several objectives. By designing an integrated assessment methodology prior to the completion of many of the scientific studies being performed as part of the National Acid Precipitation Assessment Plan, it would help to assure that all the linkages and information required for policy evaluation are actually being developed, and that they will, in fact, be integratable. Identifying the items required by an evaluation or benefits model, but not currently available is one method of identifying data gaps and assigning research priorities. Developing an integrated assessment model in some detail while much of the scientific research is ongoing will help to assure that the outputs of, say, the atmospheric models will, in fact, be the inputs needed to assess the impacts of acid deposition on aquatic and terrestrial ecosystems as well as in other damage categories.

A second recommendation is to develop an explicit procedure for characterizing the uncertainty in the analysis. Any assessment of strategies to mitigate acid deposition must necessarily deal with many uncertainties. The way in which these uncertainites are handled will be important in addressing several critical policy questions and will, in large part, determine the usefulness of the results. A suggested method for incorporating uncertainty is presented along with an example of its application.

Finally, one of the purposes of benefit-cost studies is to provide a link between the policy makers and the scientists. Attention must be given to the manner in which the information is transmitted to policy makers. The results of benefit-cost studies should provide current information to policy makers on the critical issues as well as incorporating, to whatever extent possible, the current state of the scientific community's opinions in highly uncertain areas.

1.0 PROBLEM STATEMENT

This section will discuss several issues that are central to the debate on what actions, if any, should be taken to reduce acid deposition. In addition, it will cover, in general terms, the available policy options and the information needed to choose among those policies.

1.1 Issues

There are a number of contrasting views held by parties who have studied the acid deposition problem. Several of these are presented below:

One View:

- o Substantial damages to the environment are presently occurring and immediate action is required to prevent potentially irreversible damages.

Opposing View:

- o Adequate time is available to collect and analyze new information.

One View:

- o The currently available information is adequate for the formation of control strategies.

Opposing View:

- o The limited information on the effects of acid deposition on ecosystems, as well as uncertainty regarding the sources of the pollutants makes immediate action undesirable.

These statements indicate that one of the focal points of the debate is the timing of the decision. To put it another way, when is the available information sufficient to warrant a decision to either take action to reduce acid deposition or to conclusively decide that additional controls are unnecessary? Because the complexities inherent in assessing the effects of acid deposition essentially preclude the precise documentation of the environmental damages, a decision, whenever it is made, will be based on uncertain information. The question then becomes, "At what point is the uncertainty so great that decisions to act should be delayed while additional information is gathered and, conversely, when is there enough certainty to act?"

The implications seem clear. A benefits study designed to help resolve these issues must include a mechanism for dimensioning the uncertainty around the estimated effects. Additionally, a study design that can examine the costs and benefits of delaying action to allow for the collection of additional information would be useful.

1.2 Types of Policy Options and Their Information Requirements

Given the current status of acid deposition research, policy makers have three general courses of action. First, they could decide to immediately implement controls to reduce acid deposition. Second, a decision could be made to do nothing at this time, but to engage in research designed to provide better information and reduce the uncertainty. Third, a compromise strategy could be chosen that would take limited action to reduce acid deposition in conjunction with a research program designed to provide additional information.

Given these three general policy options, the analyst must ask what information will best assist the policy maker in choosing among these options? Useful information would include:

- Estimates of the current levels of acid deposition.

- Estimates of how damages are likely to change as acid deposition levels change.

- Estimates of the probability of different occurrences, and the penalties of being wrong.

1.3 The Role of Benefit-Cost Studies

The appropriate role of benefit-cost studies in setting and evaluating environmental policies has often been controversial. To partially side-step this controversy, the term benefit-cost study will be broadly interpreted. In this paper, a benefit-cost study is one that details the different beneficial and detrimental impacts without, necessarily, putting a monetary value on every attribute. Some benefits can be valued in dollars while others can simply be itemized and compared to costs in a subjective manner. The need for this type of benefit-cost analysis would seem unambigious. It is simply an itemization of the consequences of a policy in a manner that can be compared to the costs. No attempt is made to provide a comprehensive discussion of these damage categories or policies. Instead, the focus is on examining the types of scientific information available and how benefits studies can be designed to use this information.

2.0 PROBABILISTIC BENEFIT-COST ANALYSIS

This section presents an argument for the use of probability distributions as an integral part of the calculation of costs and benefits. The application of probabilistic methods to benefit-cost studies of environmental policies is not typically done; however, there have been several exemplary applications (see National Academy of Sciences (1975b) and Morgan et al. (1979)). Conversations with researchers conducting studies on atmospheric transport of pollutants, terrestrial impacts, and aquatic impacts have indicated concern regarding the uncertainty present in any estimates of damages caused by acid deposition. However, no formalized approach for determining the dimensions of this uncertainty is currently being used. Assuming a benefit-cost framework, the explicit incorporation of uncertainty into benefit-cost estimates would have the following advantages:

- It would help decision makers evaluate alternative policies with uncertain implications.
- It would eliminate the use of point estimates which represent a "best" estimate. The use of point estimates often results in misplaced confidence in the accuracy of estimates by policy makers who are not fully versed in the scientific complexities of the problem.
- It would allow for the estimation of the value of gathering additional information.
- It would provide the information necessary to estimate the costs and benefits of delaying action to control acid deposition in order to collect additional information.

2.1 Uncertainty in the Estimates of Damages and Benefits

There has been an ongoing debate regarding the environmental effects of acid deposition and the benefits to be gained by strategies to reduce anthropogenic sources of acid deposition. One of the common themes in this debate is that the complexity of ecosystems, as well as the limited knowledge of those systems, makes any current assessment of damages from acid deposition spurious and effectively precludes the use of these estimates in policy formation. This position has many proponents and is the keystone of the utility industry's position on acid deposition. A report prepared by Battelle Laboratories (1980) concluded that there is a need for better and more reliable information on acid precipitation before environmental decisions can be made on a rational basis.* The Utility Air Regulatory Group (1981), in a communication to the Administrator of the U.S. EPA, Ms. Anne Gorsuch, concluded that ". . . in light of the troubling uncertainties . . . regulatory controls cannot be intelligently evaluated until the critical chemical, ecological and economic questions have been resolved." The Utility Air Regulatory Group goes on to state that "where multibillion dollar costs are involved, there must be a high degree of certainty that significant benefits will result from the imposition of such costs. I think everyone will agree that no such certainty presently exists."**

These statements indicate an extensive concern with the uncertainty surrounding the benefits from acid deposition mitigation strategies. They also imply that a benefits study should explicitly incorporate uncertainty into the methodology if it is to be credible to, at least, many of the interested parties. Much of the debate on the uncertainties of acid deposition damages seems ill focused. The simple existence of uncertainty does not pose a problem. The problem stems from a need to quantify and dimension the uncertainty. As yet, there has been no systematic attempt to dimension the uncertain outcomes.

If the uncertainty associated with the benefits can be dimensioned, then benefits studies can yield useful policy implications. For example, Crocker (1981) provides an estimate of economic damages from acid precipitation of five billion dollars annually. If it were possible to deduce that this estimate had a .5 probability of being correct, but also a .5 probability of there being no damages from acid precipitation, then the decision to implement pollution control measures becomes one of deciding how much society is willing to pay to avoid a .5 probability of a five billion dollar loss. If society is risk neutral, a cost of control of up to $2.5 billion would be acceptable. A more realistic example would be comprised of a number of different benefits outcomes, each associated with a probability of occurrence. If the information is available, a continuous probability distribution of damages from acid deposition can be used. Given information on the appropriate outcomes and their probabilities, a best policy option can be selected. The problem is to derive the probabilities and outcomes.

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* Executive Summary, Battelle Laboratories (1980).

** Utility Air Regulatory Group (1981, p. 21).

The conventional approach used in benefit studies is to discuss the weaknesses and uncertainties in the data, but then to choose best estimates and proceed with the calculations as if they were certain values. When uncertainty is incorporated into the analyses, two approaches are generally used. If the damage functions or monetary values have been derived statistically from historical data, then confidence intervals around the estimated parameters have been used as a measure of the uncertainty. While useful measures of uncertainty, these confidence intervals are based on a number of underlying statistical assumptions that may or may not be true. Furthermore, when damage functions are based on laboratory or controlled field studies, confidence intervals can be difficult, or in some cases, impossible to calculate.

The second approach for handling uncertainty in benefit-cost studies has been to try to establish a lower bound for the estimate of benefits. This is done by selecting the parameters used in the benefits calculations conservatively, i.e., whenever uncertainty is present the researcher tries to err on the low side. By doing this, the researcher hopes to guarantee, with a high probability, that the actual benefit estimates are greater than or equal to the estimated levels. This procedure is useful in establishing the dominance of selected policies. If a conservatively estimated, lower bound of the benefits still exceeds the costs of a control policy, then one can be quite sure that the actual, unknown benefits will exceed costs. However, there is no actual dimensioning of the uncertainty in this approach.

If the range of uncertain outcomes of strategies to control acid deposition is to be dimensioned, it is necesary to base the estimates of the probability distributions on subjective evaluations by experts. Two questions then arise. First, can subjective probability distributions be obtained, and second, how accurate will the probability assessments be?

Addressing the second question first, it would seem that the use of subjective probability distributions will necessarily be an improvement over a decision making framework that uses only a single "best estimate" of damages. In choosing a single best estimate, the researcher or policy maker must be selecting this estimate from some underlying, intuitive distribution. If there is not an underlying distribution, then there is no basis for claiming that any particular estimate is better than any other. By not expressing this intuitive distribution, the researcher is not utilizing all of the information at his disposal. In addition, he may be obscuring information important to the correct interpretation of his results. As a researcher conducts experiments or performs studies, numerous choices and tradeoffs are made in the design and scope of the project. Often, these choices are based on subjective probability assessments of the most likely structure of a causal relationship. Scientific research, as well as environmental decisionmaking, requires that numerous subjective probability assessments be made during the normal course of events. Making these underlying, intuitive probability assessments explicit should only increase the amount and quality of information available to decisionmakers.

Another advantage to the use of explicit probability distribution is the additional qualitative understanding that can be gained through the process of quantifying important decision parameters.* Examples of the use of subjective judgements in a structured model have been evaluated in controlled laboratory studies. Many of these studies have shown substantial benefit from the use of judgement based models when compared with the more common and untutored intuitive decision processes.** These approaches require the estimation of parameters for which data are not available. By having to express estimates in unambiguous quantitative terms, researchers and policymakers are forced to give more thought to parameters potentially important to the decision problem.

There is some concern about whether these subjective probability distributions can be obtained for the important decision parameters. Many researchers and most people in general, are uncomfortable with making probability assessments when little is known about the population. In this case, the population is the set of acid precipitation induced damages. Different methods can be used to develop estimates of these distributions. Two of the best known are the fractile approach for the assessment of a judgemental distribution (H. F. Raiffa, 1970), and probability encoding (C. F. Spetzler and von Holstein, 1975). Scientists are occasionally hesitant to express their subjective probability assessments when they pertain to research either they or their colleagues are

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* Keeney and Raiffa (1976, p. 364) discuss the advantages in qualitative understanding that were gained through the construction of joint probability functions for potential outcomes in an air pollution control decision problem.

**See S. H. McIntyre (1982) for a discussion of the use of these models making marketing decisions.

conducting. The use of techniques that maintain anonymity should help reduce this reluctance. Another concern sometimes expressed by scientists is that this procedure is not rigorously scientific. However, the arguments that support the direct incorporation of uncertainty into the decisionmaking process would hopefully be convincing enough to enlist the cooperation of the researchers in the field. In fact, conversations with individuals currently conducting research on the effects of acid deposition have indicated a lot of interest in these approaches, and an expressed interest in participating in these studies.

In summary, the encoding of information in probability distributions is a promising approach for handling uncertainty in the scientific and economic information on acid deposition damages. This requires subjective judgements be made, but subjective probability assessments are implicit even in the generation of single valued "best estimates." This procedure allows these judgements to be made openly, and also subjects them to review. In addition, explicitly incorporating uncertainty into the analysis brings more information to bear on the problem at hand. Finally, any decision to implement a policy to control acid deposition will be based to a large extent on subjective judgements, (i.e., a subjective evaluation of the odds of being correct and the penalties associated with being wrong). There are two choices, either the policy makers are left on their own in trying to perform this implicit decision calculus, or experts in their respective fields can assist decision makers by providing information on these probabilities.

2.2 Evaluating Whether the Available Information is Adequate for Setting Policies

Assuming that acidic deposition causes environmental change, a major issue in the debate over the merits of policy action to mitigate acidic precipitation concerns the timing of the decision. There are two important questions. First, "when is there enough information available to make a decision to act?" Secondly, "what is the optimal time frame for the implementation of the policy?" Environmental actions taken at different points in time can have different costs and benefits. There are several reasons for this time dependence. There can be benefits associated with delaying a decision in order to perform additional research and develop better data on which to make a more appropriate decision. A second reason is that the stream of costs and benefits will likely vary over time; for example, better pollution control technologies may be available in the future. Postponing a decision to require controls until the less expensive technologies are available would reduce the costs of control, and possibly increase the net benefits of environmental improvements. On the other hand, if immediate control were critical to the preservation of important environmental benefits, the decision not to implement controls could decrease the net benefits. Both of these issues are important to the current debate over the appropriate public policy towards mitigating acid precipitation.

Industry trade associations as well as many state governmental organizations have expressed a concern that there is an unwarranted rush to pass judgement on the sources of acid precipitation and its environmental damages. Their position is based on two factors. First, they expect that the costs of controlling SO_2 and NO_x will be lower in the future, and second, they feel that adequate time is available to collect and analyze new information on acid precipitation in order to make a better public policy decision.* In other words, their position is that there is no immediate, severe threat to the environment and, therefore, the benefits to delaying the decision in order to gather additional information to reduce the uncertainty outweigh the costs of the delay, i.e., any environmental damages that may occur during the delay. Others disagree with this position expressing the opinion that immediate action to protect the environment is required.**

This question on the appropriate timing of the decision on acid precipitation has been a focal point of the debate. Perfect information on the effects and causes of acid precipitation will never exist, but additional information designed to reduce the uncertainty surrounding key decision parameters may be of great value in reaching a "correct" policy decision. In decision analysis, procedures have been developed for assessing the value of increased information. This value can then be compared to the costs of gathering the additional information and the risks to the environment from delaying action. This procedure can also be used to identify the specific areas where additional information will be of most value. Given the debate regarding the appropriate timing of the decision, a systematic examination of the benefits and costs of additional information may be warranted.

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* Edison Electric Institute (1981).

** A recently completed study by the National Academy of Sciences (1981) takes this position.

The basic procedures used to value additional information are well known and can be found in Hirshleifer and Riley (1979), Raiffa (1970), and Schailfer (1969). The ability to use these methods is a direct consequence of using probability distributions to express uncertainty as dicussed in section 2.1. An example illustrating the use of subjective probability distributions to estimate the value of a research program can be found in an analysis conducted by North and Merkhofer for the National Academy of Sciences (See NAS 1975b). They calculated the value of resolving the uncertainty in the human health damages resulting from SO_2 in choosing the correct control strategy for coal fired power plants.

The value of information can be expressed as the difference between the expected benefits of a decision based on current information, and the expected benefits of a decision based on new information. The usual first step is to calculate an upper bound on the value of additional information, i.e., the value of perfect information. Of course, perfect information can never be obtained, but the calculation of the value of perfect information provides a useful upper bound to the value that can be obtained from any additional information. The computation of this upper bound is easy, given that probability distributions are used to dimension the uncertainty.*

For example, consider the following simple example of how the value of perfect information can be calculated for a case where there are discrete outcomes. Suppose that the damages from acid deposition are estimated to be $10 million. The uncertainty surrounding the calculation of these damages is such that the probability of these damages occurring is estimated at .6, while the probability of there being zero damages is .4. Also, the cost of implementing controls to eliminate the damages from acid deposition are estimated to be $3 million. The problem can be summarized as follows:

- probability = .6 that acid deposition damages are $10 million
- probability = .4 that acid deposition damages are zero
- cost of controlling acid deposition is $3 million

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* See National Academy of Sciences (1975a, p. 185) and National Academy of Sciences (1975b, p. 630).

The expected value from the control of acid depostion is .6 x $10 million or $6 million, while the costs of control are only $3 million. Based only on this information the decision would be to implement the controls. However, there is a significant likelihood, i.e. 40 percent, that this course of action is incorrect resulting in a loss of $3 million dollars. The value of the additional information that would resolve this uncertainty can be calculated. This value is the probability of being wrong multiplied by the penalty of being wrong. In this case, the penalty associated with being wrong is $3 million, dollars and the probability of being wrong is .4; therefore, the value of perfect information is (.4 x $3 million) or $1.2 million. Since perfect information will never be available, this provides an upper bound to the value of additional information for the decisionmaker.

If instead, the problem was characterized by the following parameters:

- probability = .8 that acid deposition damages are $10 million;
- probability = .2 that acid deposition damages are zero;
- cost of controlling acid deposition is $3 million;

The decision maker is now more certain that the correct strategy is to implement controls, and the value of additional information that would eliminate all uncertainty is only (.2 x $3 million) or $.6 million. This is one half the value of information calculated in the preceeding example. Thus, as the certainty of the correct choice increases, the value of additional information decreases.

In examining alternative policies and in deciding whether to collect additional information, it is often very useful to perform these types of calculations. Without them, decision makers may have no idea what values they should be placing on additional information. These rough calculations can serve as benchmarks for the value of additional information. Without such calculations, informal estimates of the value of additional research may be quite inaccurate. In particular, individuals who are not accustomed to or are uncomfortable with making decisions under uncertainty often place too high a value on resolving uncertainty.

Estimates can also be obtained for the value of imperfect information from research that does not eliminate the uncertainty, but instead provides information that can be used to estimate a new, more accurate probability distribution of damages. These procedures are straightforward in theory, but can be complex in practice. To estimate the value of a research experiment designed to provide additional information on the damages from acid precipitation, one would have to develop a subjective probability distribution of the outcomes of the research prior to the research being conducted. An estimate of the value of information from this experiment could be obtained by using Bayes' theorem to adjust the prior probability distribution of damages given the subjectively estimated distribution of research outcomes.* The difference between the benefits of the decision based on the prior probability distribution and the benefits of the decision using the revised probability distribution of damages yields the estimated value of information from this particular research experiment. This type of pre-posterior analysis of the value of information is also advocated by Conrad (1981) to address uncertainties associated with potential irreversible environmental damages.

An important assumption in valuing the additional information that can be obtained from a particular research experiment is the requirement that the researcher be able to generate a subjective distribution of the likelihood of the different outcomes of the experiment prior to the performance of the research. Estimating subjective probabilities can, in general, be an unsettling task and in this specific case it often proves even more difficult. However, researchers often have an intuitive assessment of the likely outcome of experiments and this procedure is designed to use this information. Still, a useable upper bound on the value of information can be easily obtained by calculating the value of perfect information, as shown earlier, given that the estimates of the costs of control and of damages are expressed as probability distributions. The calculation of this upper bound on the value of information will be useful in setting research priorities and can, in fact, help determine if additional research is necessary.

The estimates obtained for the value of additional information should be compared to the costs of obtaining that information. The costs of obtaining the information is comprised of two parts -- the direct costs of the research and the expected value of the environmental damages that could occur during the time period the research is taking place. A

* An example and discussion of valuing imperfect information can be found in chapter 7 of H. Raiffa (1970).

decision to proceed with a research program should weigh the likely benefits of the information generated against these costs.

Useful insights can be gained by an analysis of the benefits and costs of delaying the policy decision on acid precipitation to allow additional research to be conducted. Two pressing problems facing decision makers are the determination of the appropriate timing of the decision and whether the available information, although uncertain, is sufficient for a good policy decision. These questions can be addressed by the use of probability distributions to dimension the uncertainty in the estimates of damages from acid deposition.

3.0 ONE APPROACH TO PROBABILISTIC BENEFIT-COST ANALYSIS

One approach to probabilistic benefit-cost analysis will be presented in this section. There are a number of approaches that can be used, but they all have certain basic elements in common.

One of the primary considerations in the design of this particular approach is the ease with which the information can be presented to decision makers. One problem that can be present in probabilistic analyses is that the complexities of the methodology can make it difficult to communicate the results to policy makers. It is important to present the methods and results in a manner that facilitates understanding and instills confidence in the procedures. During the course of this project, several briefings were presented to non-technical policy makers in an attempt to determine the aspects of the approach that were difficult to communicate. Many, if not most, policy makers are unfamiliar with probabilistic approaches to benefit-cost analysis and, as a result, may not have much confidence in the approach. Thus, it is necessary to design studies whose logic can be as easily understood as possible.

In this chapter, care is taken to make sure that all the calculations are straightforward and easily reproducible. For example, rather than using a computer algorithm to manipulate probability distributions, a piecewise linear cumulative probability distribution is used to allow for straightforward computation.

3.1 Steps in the Analysis

The basic steps that must be performed in the approach are summarized in Table 3-1. The first step is to identify the available policy options, i.e., the potential control strategies and their costs. This simply involves an identification of the different options available to the policy makers. It is often useful to develop estimates of the costs of each policy option prior to performing the benefits estimation. Since the costs of environmental control options can typically be estimated more accurately than the benefits, knowledge of the costs of the different strategies can be useful in reducing the dimensions of the benefits estimation problem. This can allow researchers to take advantage of the asymmetry regarding the relative precision of the cost estimates compared to the relative inaccuracy with which the benefits can be estimated.

TABLE 3-1

A PROBABILISTIC APPROACH

Step 1 - Identify policy options, i.e., potential control strategies and their costs.

Step 2 - Determine the underlying assumptions that are necessary for each policy option to be optimal.

Step 3 - Estimate the probability that the assumptions necessary for each policy option to be optimal are actually the true states of the world.

Step 4 - Make the best (tentative) decision given the current information.

Step 5 - Estimate the value of gathering additional information to reduce uncertainty.

Step 6 - Decision stage: Choose between a terminal policy action or a research plan to gather additional informtion.

The second step is to specify the underlying assumptions that must be true for each of the policy options to be the correct choice. This step is designed to clearly spell out the implications of adopting one policy over another. If a policy is selected for implementation, there are a number of implicit assumptions that accompany its choice as the best policy. For example, one obvious assumption is that the benefits from the policy outweigh the costs. The nature of the underlying assumptions will be made more clear in a following example. The purpose of specifying these underlying assumptions is to make sure that the implications of each policy are well understood and to establish criteria against which the benefits estimates can be compared.

The third step is to estimate the probability that the assumptions necessary for each policy option to be the correct choice are, in fact, actually true. The fourth step uses the information gathered in steps 1 through 3 to make the best decision given the current information. In step 5, the benefits and costs of acquiring additional information to reduce the uncertainty are estimated. The final step in the analysis is to decide whether to implement a control strategy or to delay in order to undertake further research.

3.2 Sample Calculations

An example set of calculations is presented to illustrate the different steps in the analysis.* The numbers selected for this example are chosen for illustration only, but they are not too dissimilar from reported estimates.

The basic data for this example are shown in Table 3-2. There are three policy options being considered. The first strategy is a "do nothing" strategy resulting in no change in emissions; therefore, the current level of anthropogenically caused acid deposition would be unchanged. The second strategy is to implement pollution controls which would reduce anthropogenic sulfur emissions by 20 percent. This is assumed to cost $1 billion and would reduce deposition from current levels of 30 kilograms per hectare per year (kg/ha/yr) to 25 kg/ha/yr. The third strategy is to implement controls that would reduce emissions by 40 percent. This is assumed to cost $3 billion and would reduce deposition from the current levels of 30 kg/ha/yr to 20 kg/ha/yr.

*The basic structure of this example comes from National Academy of Sciences (1975b) Chapter 13.

TABLE 3-2

Basic Data for the Sample Calculations

CONSIDER THREE POLICY OPTIONS:

Strategy 1 - No change in emissions.

Strategy 2 - Implement pollution control which would reduce emissions by 20%.

Strategy 3 - Implement pollution controls which would reduce emissions by 40%.

DATA

Strategy	Control Costs	Reduction in Emissions	Total Sulfate Deposition	Change in Sulfate Deposition
1	0	0	30 kg/ha/yr	0 kg/ha/yr
2	$1 billion	20%	25 kg/ha/yr	5 kg/ha/yr
3	$3 billion	40%	20 kg/ha/yr	10 kg/ha/yr

It is important to recognize that these numbers are chosen to facilitate a comparison of different strategies and for ease of calculation. However, the numbers selected fall into a reasonable range of actual estimates. For example, the costs of achieving a 45 percent reduction in total sulfur emissions in the eastern 31 state region were estimated by the Office of Technology Assessment (OTA, 1981) to cost between $3.3 and $4.1 billion dollars. The OTA analysis assumed that all the emissions reductions would be met by controlling electric utilities. They also estimated a least cost strategy of achieving the 45 percent reduction at $3.1 billion. Thus an estimate of $3 billion for an emissions reduction of 40 percent does not seem inappropriate. The OTA also estimated the costs of achieving a 36 percent reduction in emissions to fall between $1.7 and $2.6 billion. The cost estimate of $1 billion for a 20 percent reduction in emissions would seem to be a reasonable figure.

Translating reduced anthropogenic sulfur emissions into reductions in actual sulfate deposition is very difficult. In this example, it is assumed that a 20 percent reduction in emissions results in a 16.6 percent reduction in sulfate deposition, and a 40 percent reduction in emissions reduces deposition by 33 percent. The difference between the percent change in emissions and the change in deposition could be due to some fraction of sulfur emissions resulting from natural sources or nonlinearities in the atmospheric chemistry. The current transfer matrices for the atmospheric models being constructed as part of the phase III U.S. - Canadian Transboundary Project use linear chemistry. This implies a proportional reduction in anthopogenic emissions and deposition. After allowing for some fraction of deposition accruing from natural sources, the reductions in deposition resulting from the changes in emissions assumed in this example are, at least, plausible.

The final assumed parameter is the current level of acid deposition, i.e., 30 kg/ha/yr. This figure is an approximate estimate of the average annual acid deposition occurring in the Eastern U.S. region. Some areas have higher deposition rates while others are considerably lower. This value was obtained by examining maps in the Interim Transboundary Report (1981) and assuming roughly equal levels of wet and dry deposition.

The selection of the different policy options to be considered and their costs completes step 1 of the 6 steps presented in Table 3-1. The second step is to specify the assumptions that are necessary for each policy option to be the best choice. These are outlined below:

- Strategy 1 is the correct choice when the following are true:
  - total benefits from strategy 2 are less than $1 billion, i.e., the benefits of the other strategies do not exceed their costs; and,
  - the social cost of sulfur deposition is less than $200 million per kg/ha/yr (see Figure 3-1).
- Strategy 2 is the correct choice when:
  - total benefits of a 20 percent reduction in emission exceeds $1 billion (i.e., the benefits exceed costs); and,
  - the social cost of sulfur deposition is between $200 million and $400 million per kg/ha/yr. (see Figure 3-1).
- Strategy 3 is the correct choice when:
  - benefits of a 40 percent reduction in emissions exceed $3 billion (i.e., the benefits exceed costs; and,
  - the social cost of sulfur deposition is greater than $400 million per unit (kg/ha/yr) (see Figure 3-1).

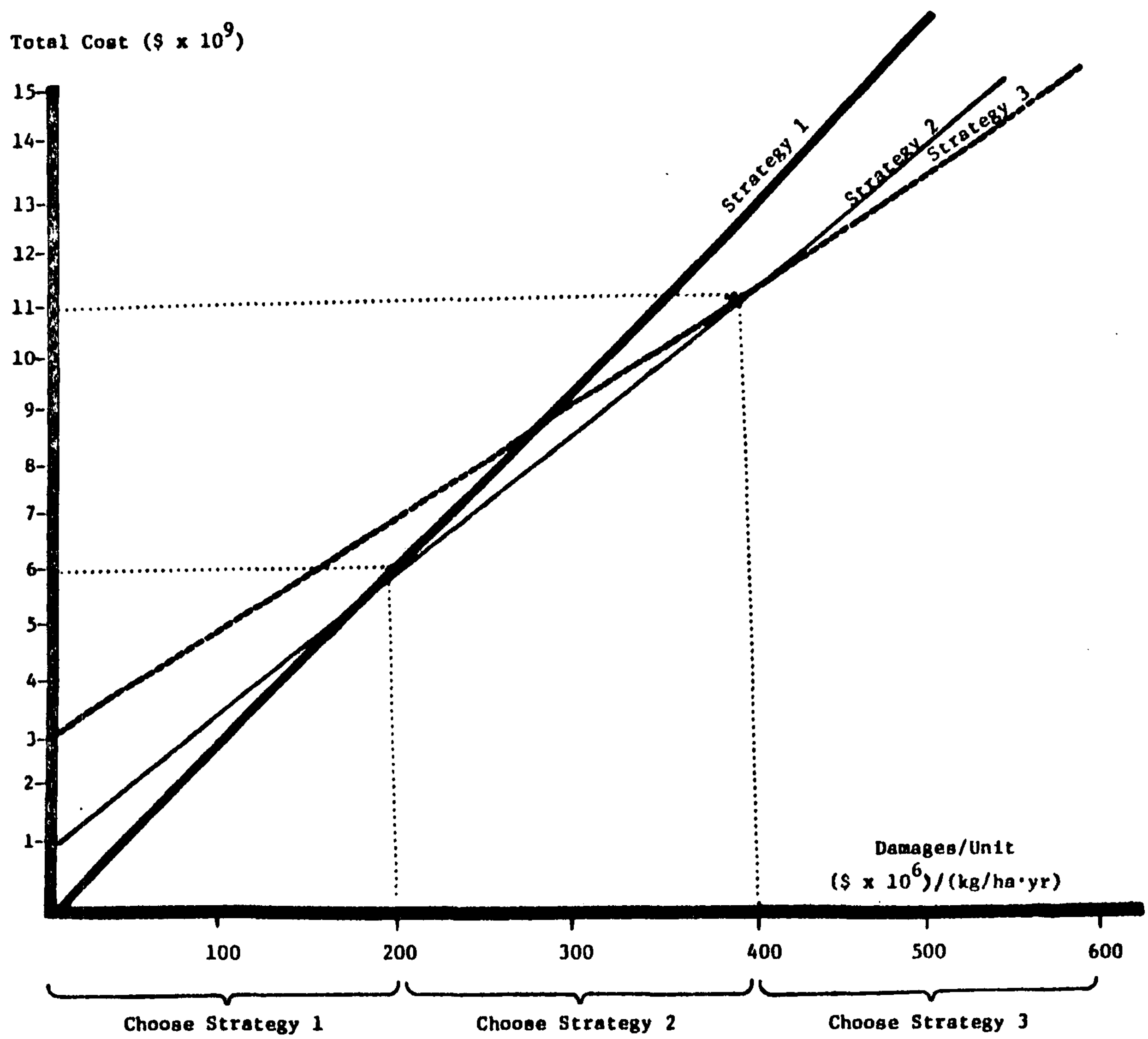
These assumptions indicate that any decision to implement a specific control strategy incorporates a judgement regarding the social cost of the current level of emissions. By specifying the social costs per unit necessary to make each control strategy the correct choice, this judgement is made explicit. This allows for an assessment of the probability that each of these underlying assumptions is actually the true state of the world. In the case of acid precipitation, the selections between H^+ ion concentration and biologic effects are principally what are responsible for one assumption, rather than another being correct.

These assumptions can be depicted graphically.* Figure 3-1 shows the control strategy that minimizes total costs for different values of social cost per unit (kg/ha/yr) of deposition. The total costs measured on the vertical axis are defined as the costs of pollution control plus the social costs from the remaining, uncontrolled emissions. If the social costs of deposition are less than $200 million per unit, then strategy 1 would be the correct choice. If social costs per unit fall between $200 and $400 million per unit, then strategy 2 would be the correct choice. If social costs are greater than $400 million per

*This graphical depiction was used by North and Merkhofer in National Academy of Sciences (1975b).

FIGURE 3-1

Policy Crossover Points



Damages per Unit of Acid Deposition
($ x 10^6)/(kg/ha·yr)

unit, then strategy 3, the tightest control strategy, would minimize total costs. The calculations made to construct Figure 3-1 are shown in Tables 3-3, 3-4, and 3-5.

These categories correspond to the selection criteria used by economists, i.e., the comparison of marginal benefits and marginal costs leading to maximization of net benefits. Given the information on the costs of the two strategies and using linear segments to characterize the discrete investments, the total cost curve is shown in Figure 3-2a. The corresponding marginal costs are shown in Figure 3-2b. The criterion for strategy 2 to be the correct choice is that marginal benefits exceed marginal costs.

Figures 3-1 and 3-2 depict the underlying assumptions that must be true for each of the policy options to be the correct choice. These criteria can select the best policy among the three under consideration; however, there may be policies not under consideration that might be superior. Still, through the use of an iterative process where different sets of policies are examined in successive analyses, an optimal solution can be approached.

The example used in this section reduces to the problem of estimating the probabilities that damages per unit fall into three categories:

- the probability that damages per unit of deposition fall within the interval between zero and $200 million;
- the probability that damages per unit of deposition are between $200 million and $400 million;
- the probability that damages per unit of deposition are greater than $400 million.

While still a very difficult problem, estimating the probability that damages fall within a selected range is often a more tractable task than estimating the probability that damages are equal to a specific value.

Organizing the information in this manner has several advantages. First, the selection of a number of discrete policy options to be evaluated more closely resembles the process decision makers actually undertake. It is unusual for decision makers to view the control parameters as continuous variables with a goal of selecting the level that maximizes net benefits. Instead, a limited agenda of policy options is devised and the alternative policies evaluated.

TABLE 3-3

Total Costs if Strategy 1

-- No Reductions in Emissions --

is Chosen

If Social Costs, i.e., damages per unit of deposition, are: ($ x 10^6 per kg/ha/yr)	Then Total Costs are: ($ x 10^6) per year	=	Total Social Costs ($/unit x Loading*)	+	Costs of Control ($ x 10^6)
100	3,000	=	(100 x 30)	+	0
200	6,000	=	(200 x 30)	+	0
300	9,000	=	(300 x 30)	+	0
400	12,000	=	(400 x 30)	+	0
500	15,000	=	(500 x 30)	+	0
600	18,000	=	(600 x 30)	+	0

*The loading is the deposition level (i.e., units/year) that remains after the strategy has been implemented.

TABLE 3-4

Total Costs if Strategy 2

— A 20 Percent Reduction in Emissions --

is Chosen

If Social Costs, i.e., damages per unit of deposition, are:	Then Total Costs are:				
($ x 10^6 per kg/ha/yr)	($ x 10^6) per year	=	Total Social Costs ($/unit x Loading*)	+	Costs of Control ($ x 10^6)
100	3,500	=	(100 x 25)	+	1,000
200	6,000	=	(200 x 25)	+	1,000
300	8,500	=	(300 x 25)	+	1,000
400	11,000	=	(400 x 25)	+	1,000
500	13,500	=	(500 x 25)	+	1,000
600	16,000	=	(600 x 25)	+	1,000

*The loading is the deposition level (i.e., units/year) that remains after the strategy has been implemented.

TABLE 3-5

Total Costs if Strategy 3

— A 40 Percent Reduction in Emissions —

is Chosen

If Social Costs, i.e., damages per unit of deposition, are:	Then Total Costs are:				
($ x 10^6 per kg/ha/yr)	($ x 10^6) per year	=	Total Social Costs ($/unit x Loading*)	+	Costs of Control ($ x 10^6)
100	5,000	=	(100 x 20)	+	3,000
200	7,000	=	(200 x 20)	+	3,000
300	9,000	=	(300 x 20)	+	3,000
400	11,000	=	(400 x 20)	+	3,000
500	13,000	=	(500 x 20)	+	3,000
600	15,000	=	(600 x 20)	+	3,000

*The loading is the deposition level that remains after the strategy has been implemented.

FIGURE 3-2

Total and Marginal Costs of Emissions Control

FIGURE 3-2a
Total Cost Curve
($ x 10^9)

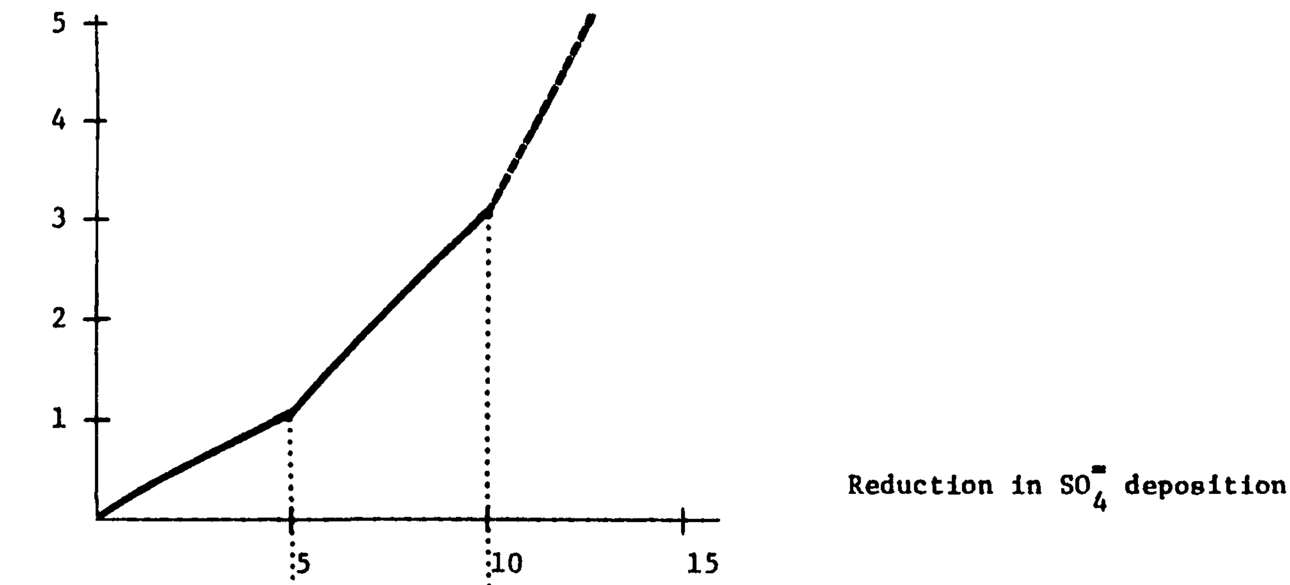
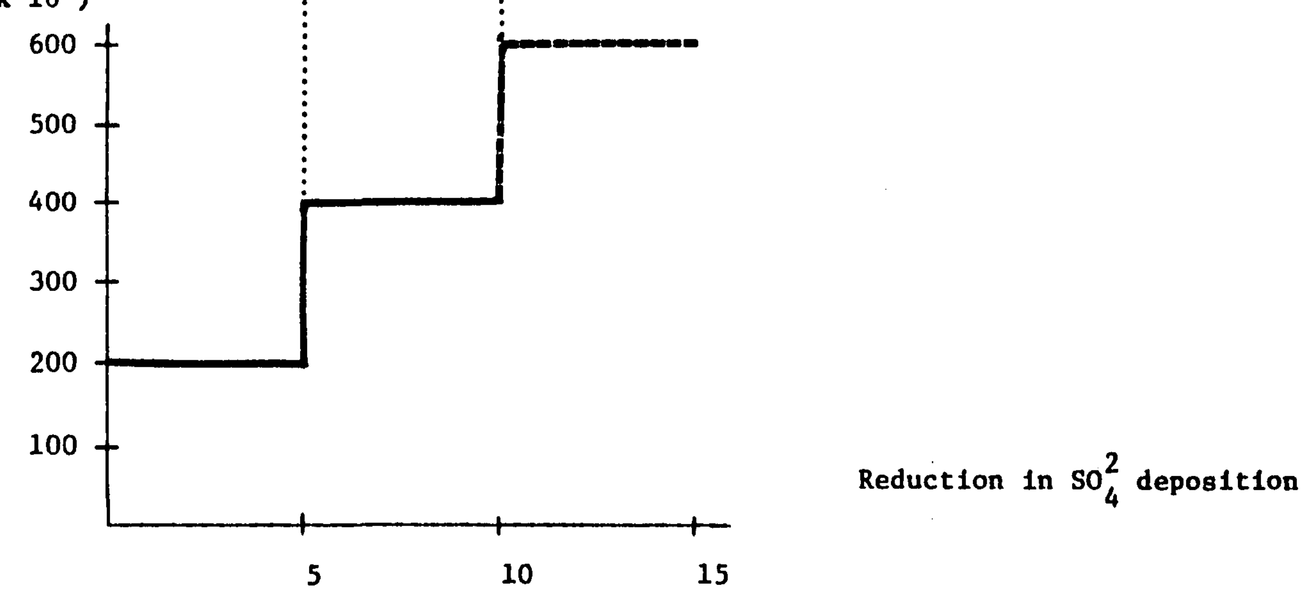


FIGURE 3-2b
Marginal Costs
($ x 10^6)



A second advantage is that the explicit presentation of the underlying assumptions that must be true for each of the policy options to be the correct choice is a useful way of organizing information, and it helps to inform decision makers of the implications of choosing one policy over another.

To complete the example calculations, assume that the cumulative probability distribution shown in Figure 3-3 represents the results of a probability elicitation. This cumulative probability distribution was selected to depict a substantial amount of uncertainty regarding the appropriate policy choice. The cumulative probability distribution shows the probabilities of each strategy being the correct choice. From Figure 3-3 the probabilities are:

- probability (0 ≤ damages/unit < $200 million) = .35 for strategy 1 to be correct
- probability ($200 million ≤ damage/unit < $400 million) = .40 for strategy 2 to be correct
- probability ($400 milion ≤ damages/unit) = .25 for strategy 3

This probability distribution was selected to give each option a reasonable probability of being the correct choice and to reflect the considerable range of uncertainty currently found in the debate on damages from acid deposition. The .35 probability that strategy 1, a no control strategy, is correct is very close to the probability of strategy 2 being the correct choice. In addition, the .25 probability that the high control option is the correct choice is also significant. As a result, these probabilities reflect considerable uncertainty about the correct policy decision.

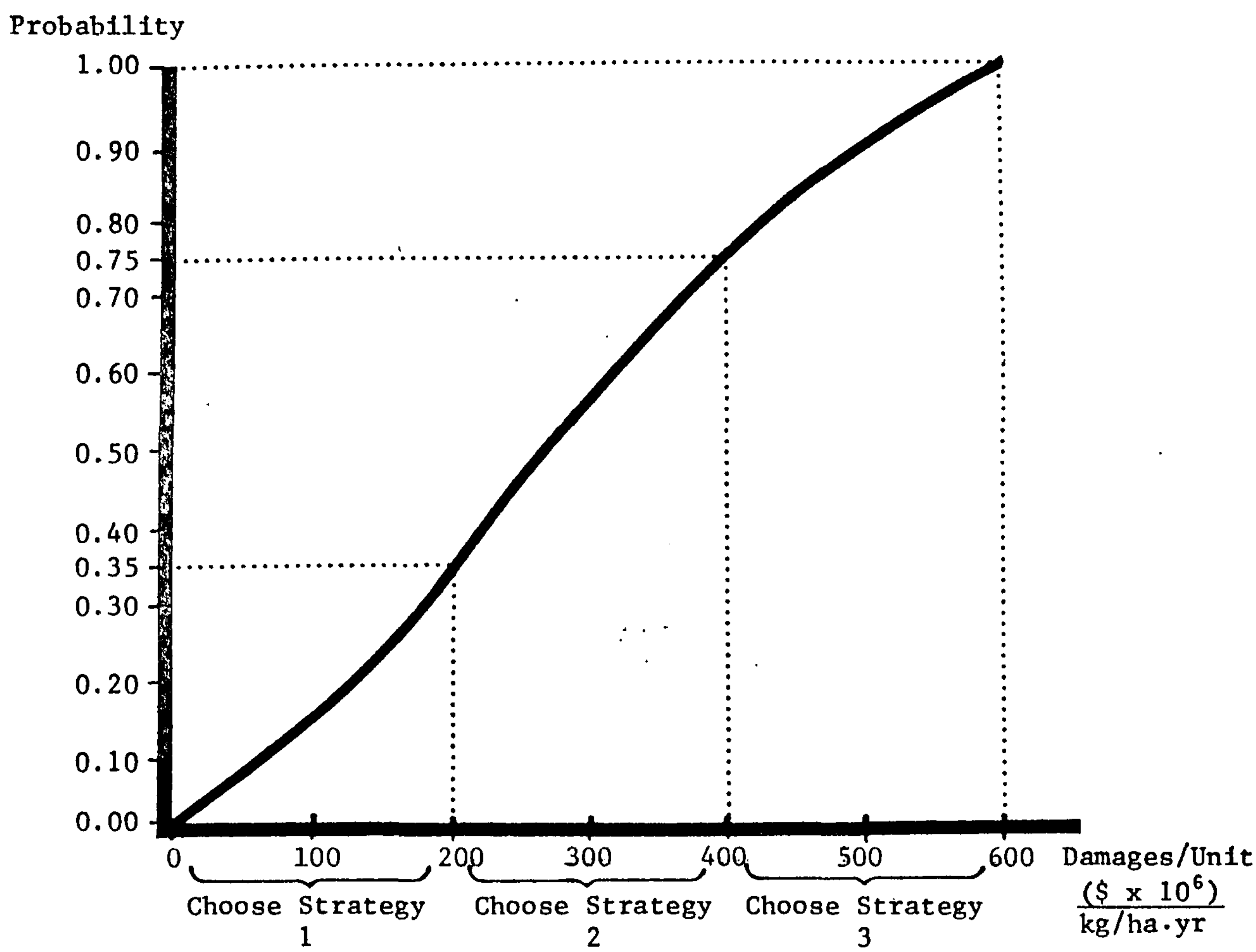
Given this information, the decision maker would choose strategy 2, the most likely correct strategy. However, given these probabilities there is a significant likelihood that either strategy 1 or strategy 3 could be the appropriate strategy.

3.2.1 The Value of Additional Information

The use of probabilities allows the decision maker to calculate an upper limit to the value of information — the value of perfect information. The value of perfect information is calculated by multiplying the probability of being wrong times the penalty of

FIGURE 3-3

Cumulative Probability
Distribution for the Damages
of Acid Deposition



being wrong. To determine the penalty of being wrong, a loss function is constructed. The loss function shows the penalty of choosing strategy 2, when strategy 1 or strategy 3 is actually the correct choice. The loss function can be calculated from Figure 3-1. It is the difference between the net benefits of selected strategy (i.e., strategy 2), and the strategy that would have been correct if the social cost of a unit deposition falls outside the range that makes strategy 2 the correct choice.

The loss function for this example is depicted in Table 3-6. If strategy 2 is chosen under the assumption that damages per unit of deposition are between \$200 and \$400 and actual damages per unit turn out to be zero, then \$1 billion is spent on emissions control with no beneficial effects at all. In this case, the penalty of choosing strategy 2 is \$1 billion. If strategy 2 is chosen and damages per unit are actually \$100 million, then the penalty is \$500 million. There is some benefit that results from the emissions controls; however, the benefits are not sufficient to justify the costs of implementing control strategy 2.

The loss function in Table 3-6 provides the penalties of being wrong. Now the probabilities of being wrong must be estimated before the value of additional information can be calculated. To simplify the calculations, the cumulative probability distribution in Figure 3-3 is approximated by three linear segments over the intervals: $0 \leq$ damages/unit $<$ \$200 million; \$200 million $\leq$ damages/unit $<$ \$400; and \$400 $\leq$ damages/unit. The use of a piecewise linear cumulative function assumes equal probabilities for each outcome (i.e., damages per unit). Recall that the probabilities of each strategy being the correct choice are:

- probability of strategy 1 being correct = .35
- probability of strategy 2 being correct = .40
- probability of strategy 3 being correct = .25

The probability of choosing strategy 2 but having strategy 1 being correct is simply .35, the likelihood of strategy 1 being correct. Similarly, the probability of choosing strategy 2 when strategy 3 is actually correct is .25.

Since the values of the loss function for outcomes of damages per unit between \$0 and \$200 million as well as between \$400 million and \$600 million are equally likely, the

TABLE 3-6

Loss Function if Strategy 2 is Chosen

But is Incorrect

If Actual Damages ($ x 10^6) Per Unit Are:	Then the Penalty ($ x 10^6) Is:
$ 0	$ 1,000
50	750
100	500
150	250
200 to 400	0
450	250
500	500
550	750
600	1,000

value of perfect information can be calculated by using only the midpoints of the loss function segments for strategies 1 and 3.* The value of perfect information is then:

(.35 x $500 million) + (.25 x $500 million) = $300 million

This implies that, given the policy evaluation example detailed above, a decision maker would be willing to pay $300 million per year to completely resolve the uncertainty. Thus, for the relatively large amount of uncertainty depicted in the cumulative probability distribution of Figure 3-3, the $300 million upper bound on the value of information provides a benchmark value that can be compared to the costs of gathering additional information. Another factor that affects the value of information in addition to the probabilities is the range of damages considered plausible. In this example, the range of damages is from $0 to $18 billion per year. The actual damages are assumed to fall within this range with certainty. If this range is changed, the value of additional information would also be changed. Still, a range of damages of $0 to $18 billion per year is quite broad.

If the probabilities of each policy option being the correct choice change, then the value associated with additional information will change. Two examples are:

A. Suppose information not previously available yields the following revised probabilities:

- probability (0 ≤ damages/unit < $200 million) = .25
- probability ($200 million ≤ damages/unit < $400 million) = .60
- probability ($400 million ≤ damages/unit) = .15

Then, the value of perfect information is:

(.25 x $500 million) + (.15 x $500 million) = $200 million

B. Suppose the revised probabilities are:

- probability (0 ≤ damages/unit < $200 million) = .15

---

*Since all outcomes for each segment of the loss function are equal likely, multiplying the midpoint of each segment times the cumulative probability of having the outcome occur in that segment gives the same answer as multiplying the marginal probabilities times each potential outcome.

- probability ($200 million $\leq$ damages/unit $<$ $400 million = .80
- probability ($400 million $\leq$ damages/unit) = .05

Then, the value of perfect information is (.15 x $500 million) + (.05 x $500 million) = $100 million

These figures can also be used to develop rough estimates of the value of imperfect information. The value of a research program that would revise our original probabilities of (.35, .40, .25) to the probabilities (.25, .60, .15) used in example A can be calculated as the difference between the value of perfect information given the two sets of probabilities. The value of perfect information given probabilities of (.35, .40, .25) is $300 million per year and $200 million per year for probabilities of (.25, .60, .15). Thus, the value of research expected to decrease the uncertainty by revising the probabilities from (.35, .40, .25) to (.25, .60, .15) is $100 million. Similarly, the value of research expected to revise the probabilities from (.35, .40, .25) to (.15, .80, .05) is $200 million per year. If the outcome of the research is uncertain and, say, the revised probabilities are equally likely to turn out to be (.25, .60, .15) or (.15, .60, .05); then, the estimated value of the research program yielding this imperfect information would be (.5 x $200 million) + (.5 x $100 million) or $150 million.

The simple example in this section not only shows the types of insights that can be generated by this approach, but through the use of plausible numbers provide some idea of the value of additional information which can be obtained. Through this process, decision makers who may have no idea of what values should be placed on additional research can obtain a rough estimate of what the value of additional research may be.

3.2.2 The Timing of the Decision

The large values for additional information calculated in the preceding section indicate that performing additional research may be beneficial, but it is important to recognize that they say nothing about which policy should be implemented while the research is being undertaken. For example, it cannot be concluded on the basis of a high value of additional information, that a good strategy is to delay the implementation of controls until more information is collected. To address this question the analysis needs to be extended an additional step.

The correct policy option to implement while research is being conducted is the policy that minimizes the expected discounted total costs of both pre- and post-research periods. This is simply the selection of the combination control strategy and research plan that maximizes net benefits. To illustrate this, the three policy options examined in the preceding section will be considered in combination with three research plans.

The three research plans to be considered are:

A: To conduct no research.

B: To conduct a ten year research program that at its conclusion will yield perfect information, i.e., the correct control strategy will be known. The cost of this research program is assumed to be \$15 million per year for a total of \$150 million.

C: To conduct a stepped up five year research plan that will yield perfect information at its conclusion. Due to the tighter time constraints and resulting inefficiencies, this research plan is budgeted at \$200 million, i.e., \$40 million per year.

The policy makers now have nine options:

- Choose strategy 1 - no control with:
  - 1a, no additional research
  - 1b, the ten year research plan
  - 1c, the five year research plan.
- Choose strategy 2 - a 20% reduction in emissions with:
  - 2a, no additional research
  - 2b, the ten year research plan
  - 2c, the five year research plan.
- Choose strategy 3 - a 40% reduction in emissions with:
  - 3a, no additional research
  - 3b, the ten year research plan
  - 3c, the five year research plan.

Recall from the previous section that the probability of damages/unit of acid deposition being between zero and \$200 million per unit is .35 (the low damage case). The probability that damages per unit are between \$200 million and \$400 million is .40 (the medium damage case) and the probability that damages are greater than \$400 million is .25 (the high damage case). Again, using a piecewise linear curve to approximate the continuous cumulative probability distribution of Figure 3-3, only the midpoint values of these three cases and the associated probabilities are needed to calculate the expected values for each case.

The next step is to show how the streams of total costs will vary over time. Total costs now include the money spent on research in addition to the costs of pollution control and the social cost of the remaining, uncontrolled emissions, i.e., the damage resulting from the acid deposition remaining after the controls have been implemented.

Since each of the nine policy options have three potential outcomes, there are twenty-seven cases to be evaluated. For each case, the benefits and costs for each year must be calculated. Tables 3-7a through 3-7c show how the benefits and costs vary over time for the choice of strategy 1 — no control — in conjunction with a five year research plan. Table 3-7a shows the stream of benefits and costs if the five year research plan shows that the damages from acid deposition are low, i.e., between 0 and $200 million per unit. Since no controls have been implemented, no change in strategy is called for at the end of the five year research plan. A discount rate of five percent and a planning horizon of thirty years are used to calculate the net present value of each stream.*

Table 3-7b shows the stream of benefits and costs for strategy 1 with a five year research plan and an outcome of the research indicating moderate damages from acid deposition (i.e., between $200 and $400 million per unit). Now a change in strategy is called for at the conclusion of the five year research plan. It is now known with certainty that strategy 2 — a 20% reduction in emissions -- is the best policy. In year 6, this strategy is implemented incurring control costs of $1 billion per year and yielding benefits of $1.5 billion per year.

Table 3-7c shows the stream of benefits and costs for strategy 1 with a five year research plan and an outcome of the research indicating high damages from acid deposition (i.e., greater than $400 million per unit). Again, a change in strategy is called for at the conclusion of the five year research plan. Strategy 3 — a 40% reduction in emissions —

*The selection of discount rate and planning horizon can be the subject of some controversy. The recent Office of Management and Budget (OMB) guidelines for benefit-cost analysis call for a discount rate of 10%. However, the peculiar nature of environmental benefits probably calls for the use of a lower discount rate. The results are less sensitive to the length of the planning horizon, provided it is sufficiently long.

TABLE 3-7a
Flow of Costs and Benefits for Strategy 1
with a Five Year Research Plan
— Outcome: Low Damages from Acid Deposition —

Year	(A) Total Environmental Damages Without Any Control* ($ x 10^9)	(B) Remaining Damages After the Chosen Strategy Has Been Implemented ($ x 10^9)	(C) Benefits (A - B) ($ x 10^9)	(D) Control Costs ($ x 10^9)	(E) Research Costs ($ x 10^9)	(F) Total Costs (B + D + E) ($ x 10^9)	(G) Net Benefits (C - D - E) ($ x 10^9)
1	3	3	0	0	.04	3.04	- .04
2	3	3	0	0	.04	3.04	- .04
3	3	3	0	0	.04	3.04	- .04
4	3	3	0	0	.04	3.04	- .04
5	3	3	0	0	.04	3.04	- .04
6	3	3	0	0	0	3	0
7	3	3	0	0	0	3	0
8	3	3	0	0	0	3	0
9	3	3	0	0	0	3	0
10	3	3	0	0	0	3	0
11	3	3	0	0	0	3	0
12	3	3	0	0	0	3	0
13	3	3	0	0	0	3	0
14	3	3	0	0	0	3	0
15	3	3	0	0	0	3	0
16	3	3	0	0	0	3	0
17	3	3	0	0	0	3	0
18	3	3	0	0	0	3	0
19	3	3	0	0	0	3	0
20	3	3	0	0	0	3	0
21	3	3	0	0	0	3	0
22	3	3	0	0	0	3	0
23	3	3	0	0	0	3	0
24	3	3	0	0	0	3	0
25	3	3	0	0	0	3	0
26	3	3	0	0	0	3	0
27	3	3	0	0	0	3	0
28	3	3	0	0	0	3	0
29	3	3	0	0	0	3	0
30	3	3	0	0	0	3	0
NPV at Year 1	46.1	46.1	0	0	.173	46.27	- .173

*Assumes current deposition levels of 30 kg/ha/yr.

TABLE 3-7b
Flow of Costs and Benefits for Strategy 1
with a Five Year Research Plan
— Outcome: Moderate Damages from Acid Deposition —

Year	(A) Total Environmental Damages Without Any Control* ($ x 10⁹)	(B) Remaining Damages After the Chosen Strategy Has Been Implemented ($ x 10⁹)	(C) Benefits (A - B) ($ x 10⁹)	(D) Control Costs ($ x 10⁹)	(E) Research Costs ($ x 10⁹)	(F) Total Costs (B + D + E) ($ x 10⁹)	(G) Net Benefits (C - D - E) ($ x 10⁹)
1	9	9	0	0	.04	9.04	- .04
2	9	9	0	0	.04	9.04	- .04
3	9	9	0	0	.04	9.04	- .04
4	9	9	0	0	.04	9.04	- .04
5	9	9	0	0	.04	9.04	- .04
6	9	7.5	1.5	1	0	8.5	.5
7	9	7.5	1.5	1	0	8.5	.5
8	9	7.5	1.5	1	0	8.5	.5
9	9	7.5	1.5	1	0	8.5	.5
10	9	7.5	1.5	1	0	8.5	.5
11	9	7.5	1.5	1	0	8.5	.5
12	9	7.5	1.5	1	0	8.5	.5
13	9	7.5	1.5	1	0	8.5	.5
14	9	7.5	1.5	1	0	8.5	.5
15	9	7.5	1.5	1	0	8.5	.5
16	9	7.5	1.5	1	0	8.5	.5
17	9	7.5	1.5	1	0	8.5	.5
18	9	7.5	1.5	1	0	8.5	.5
19	9	7.5	1.5	1	0	8.5	.5
20	9	7.5	1.5	1	0	8.5	.5
21	9	7.5	1.5	1	0	8.5	.5
22	9	7.5	1.5	1	0	8.5	.5
23	9	7.5	1.5	1	0	8.5	.5
24	9	7.5	1.5	1	0	8.5	.5
25	9	7.5	1.5	1	0	8.5	.5
26	9	7.5	1.5	1	0	8.5	.5
27	9	7.5	1.5	1	0	8.5	.5
28	9	7.5	1.5	1	0	8.5	.5
29	9	7.5	1.5	1	0	8.5	.5
30	9	7.5e	1.5	1	0	8.5	.5
NPV at Year 1	138.4	121.8	16.56	11.0	.173	133	5.4

*Assumes current deposition levels of 30 kg/ha/yr.

TABLE 3-7c
Flow of Costs and Benefits for Strategy 1
with a Five Year Research Plan
— Outcome: High Damages from Acid Deposition —

Year	(A) Total Environmental Damages Without Any Control* ($ x 10^9)	(B) Remaining Damages After the Chosen Strategy Has Been Implemented ($ x 10^9)	(C) Benefits (A - B) ($ x 10^9)	(D) Control Costs ($ x 10^9)	(E) Research Costs ($ x 10^9)	(F) Total Costs (B + D + E) ($ x 10^9)	(G) Net Benefits (C - D - E) ($ x 10^9)
1	15	15	0	0	.04	15.04	- .04
2	15	15	0	0	.04	15.04	- .04
3	15	15	0	0	.04	15.04	- .04
4	15	15	0	0	.04	15.04	- .04
5	15	15	0	0	.04	15.04	- .04
6	15	10	5	3	0	13.0	2
7	15	10	5	3	0	13.0	2
8	15	10	5	3	0	13.0	2
9	15	10	5	3	0	13.0	2
10	15	10	5	3	0	13.0	2
11	15	10	5	3	0	13.0	2
12	15	10	5	3	0	13.0	2
13	15	10	5	3	0	13.0	2
14	15	10	5	3	0	13.0	2
15	15	10	5	3	0	13.0	2
16	15	10	5	3	0	13.0	2
17	15	10	5	3	0	13.0	2
18	15	10	5	3	0	13.0	2
19	15	10	5	3	0	13.0	2
20	15	10	5	3	0	13.0	2
21	15	10	5	3	0	13.0	2
22	15	10	5	3	0	13.0	2
23	15	10	5	3	0	13.0	2
24	15	10	5	3	0	13.0	2
25	15	10	5	3	0	13.0	2
26	15	10	5	3	0	13.0	2
27	15	10	5	3	0	13.0	2
28	15	10	5	3	0	13.0	2
29	15	10	5	3	0	13.0	2
30	15	10	5	3	0	13.0	2
NPV at Year 1	230.6	175.4	55.2	33.1	.173	208.7	21.9

*Assumes current deposition levels of 30 kg/ha/yr.

is now the proven best choice. In year 6, this strategy is implemented incurring control costs of $3 billion per year and benefits of $5 billion per year.

Tables 3-8a through 3-8c show the stream of benefits and costs of choosing strategy 2 with a five year research plan for the three different outcomes. The other twenty-one cases can be calculated similarly. It is apparent from these tables that the out of pocket research costs play a relatively insignificant role in evaluating the appropriate timing of the decision. They are dominated by the potential environmental damages that may occur while the research is being done.

The results of the analysis are shown in Tables 3-9 and 3-10. Table 3-9 shows the expected total cost for each strategy and research option. Total cost is comprised of three items: the environmental damages from the uncontrolled deposition, the costs of pollution control and the costs of research. The best policy is then the strategy and research plan that minimizes expected total cost. The policy with the lowest expected total cost is strategy 2 -- a 20 percent reduction in emissions -- in conjunction with a five year research program to determine the actual extent of damages. The second best policy is to implement strategy 2 with a 10 year research program. The two worst strategies are strategy 1 with no research to verify its appropriateness and strategy 3 also with no research. Thus, research is valuable, but it does not necessarily mean that the optimal action is to delay controls until better information is available.

It is interesting that implementing strategy 2 with no research to verify its appropriateness is still a better option than strategy 1 with a 10 year research program. This strategy would delay implementing controls until after a 10 year research program is completed. Strategy 3 with no research is preferred to strategy 1 with research in spite of the large values for additional information calculated in the preceding section.

Table 3-10 illustrates the same results, but it is probably clearer since it is presented in terms of net benefits. The best option, strategy 2 with a five year research plan, has expected net benefits of $9.3 billion per year. This is $1.7 billion higher than the best delaying strategy, i.e., taking no action until the completion of a five year research program. In this example, the risks of overcontrolling, i.e., implementing what turn out to be overly stringent controls during the research period, are outweighed by the risks of undercontrolling for acid deposition.

TABLE 3-8a
Flow of Costs and Benefits for Strategy 2
with a Five Year Research Plan
— Outcome: Low Damages from Acid Deposition —

Year	(A) Total Environmental Damages Without Any Control* ($ x 10^9)	(B) Remaining Damages After the Chosen Strategy Has Been Implemented ($ x 10^9)	(C) Benefits (A - B) ($ x 10^9)	(D) Control Costs ($ x 10^9)	(E) Research Costs ($ x 10^9)	(F) Total Costs (B + D + E) ($ x 10^9)	(G) Net Benefits (C - D - E) ($ x 10^9)
1	3	2.5	.5	1	.04	3.54	- .54
2	3	2.5	.5	1	.04	3.54	- .54
3	3	2.5	.5	1	.04	3.54	- .54
4	3	2.5	.5	1	.04	3.54	- .54
5	3	2.5	.5	1	.04	3.54	- .54
6	3	3	0	0	0	3	0
7	3	3	0	0	0	3	0
8	3	3	0	0	0	3	0
9	3	3	0	0	0	3	0
10	3	3	0	0	0	3	0
11	3	3	0	0	0	3	0
12	3	3	0	0	0	3	0
13	3	3	0	0	0	3	0
14	3	3	0	0	0	3	0
15	3	3	0	0	0	3	0
16	3	3	0	0	0	3	0
17	3	3	0	0	0	3	0
18	3	3	0	0	0	3	0
19	3	3	0	0	0	3	0
20	3	3	0	0	0	3	0
21	3	3	0	0	0	3	0
22	3	3	0	0	0	3	0
23	3	3	0	0	0	3	0
24	3	3	0	0	0	3	0
25	3	3	0	0	0	3	0
26	3	3	0	0	0	3	0
27	3	3	0	0	0	3	0
28	3	3	0	0	0	3	0
29	3	3	0	0	0	3	0
30	3	3	0	0	0	3	0
NPV at Year 1	46.1	44.0	2.15	4.33	.173	48.57	- 2.3

*Assumes current deposition levels of 30 kg/ha/yr.

TABLE 3-8b
Flow of Costs and Benefits for Strategy 1
with a Five Year Research Plan
— Outcome: Moderate Damages from Acid Deposition —

Year	(A) Total Environmental Damages Without Any Control* ($ x 10^9)	(B) Remaining Damages After the Chosen Strategy Has Been Implemented ($ x 10^9)	(C) Benefits (A - B) ($ x 10^9)	(D) Control Costs ($ x 10^9)	(E) Research Costs ($ x 10^9)	(F) Total Costs (B + D + E) ($ x 10^9)	(G) Net Benefits (C - D - E) ($ x 10^9)
1	9	7.5	1.5	1.0	.04	8.54	.46
2	9	7.5	1.5	1.0	.04	8.54	.46
3	9	7.5	1.5	1.0	.04	8.54	.46
4	9	7.5	1.5	1.0	.04	8.54	.46
5	9	7.5	1.5	1.0	.04	8.54	.46
6	9	7.5	1.5	1.0	0	8.54	.46
7	9	7.5	1.5	1.0	0	8.54	.46
8	9	7.5	1.5	1.0	0	8.54	.46
9	9	7.5	1.5	1.0	0	8.54	.46
10	9	7.5	1.5	1.0	0	8.54	.46
11	9	7.5	1.5	1.0	0	8.54	.46
12	9	7.5	1.5	1.0	0	8.54	.46
13	9	7.5	1.5	1.0	0	8.54	.46
14	9	7.5	1.5	1.0	0	8.54	.46
15	9	7.5	1.5	1.0	0	8.54	.46
16	9	7.5	1.5	1.0	0	8.54	.46
17	9	7.5	1.5	1.0	0	8.54	.46
18	9	7.5	1.5	1.0	0	8.54	.46
19	9	7.5	1.5	1.0	0	8.54	.46
20	9	7.5	1.5	1.0	0	8.54	.46
21	9	7.5	1.5	1.0	0	8.54	.46
22	9	7.5	1.5	1.0	0	8.54	.46
23	9	7.5	1.5	1.0	0	8.54	.46
24	9	7.5	1.5	1.0	0	8.54	.46
25	9	7.5	1.5	1.0	0	8.54	.46
26	9	7.5	1.5	1.0	0	8.54	.46
27	9	7.5	1.5	1.0	0	8.54	.46
28	9	7.5	1.5	1.0	0	8.54	.46
29	9	7.5	1.5	1.0	0	8.54	.46
30	9	7.5	1.5	1.0	0	8.54	.46
NPV at Year 1	138.4	115.3	23.1	15.4	.173	130.8	+ 7.51

*Assumes current deposition levels of 30 kg/ha/yr.

TABLE 3-8c
Flow of Costs and Benefits for Strategy 1
with a Five Year Research Plan
— Outcome: High Damages from Acid Deposition —

Year	(A) Total Environmental Damages Without Any Control* ($ x 10^9)	(B) Remaining Damages After the Chosen Strategy Has Been Implemented ($ x 10^9)	(C) Benefits (A - B) ($ x 10^9)	(D) Control Costs ($ x 10^9)	(E) Research Costs ($ x 10^9)	(F) Total Costs (B + D + E) ($ x 10^9)	(G) Net Benefits (C - D - E) ($ x 10^9)
1	15	12.5	2.5	1	.04	13.54	1.5
2	15	12.5	2.5	1	.04	13.54	1.5
3	15	12.5	2.5	1	.04	13.54	1.5
4	15	12.5	2.5	1	.04	13.54	1.5
5	15	12.5	2.5	1	.04	13.54	1.5
6	15	10	5.0	3	0	13.0	2.0
7	15	10	5.0	3	0	13.0	2.0
8	15	10	5.0	3	0	13.0	2.0
9	15	10	5.0	3	0	13.0	2.0
10	15	10	5.0	3	0	13.0	2.0
11	15	10	5.0	3	0	13.0	2.0
12	15	10	5.0	3	0	13.0	2.0
13	15	10	5.0	3	0	13.0	2.0
14	15	10	5.0	3	0	13.0	2.0
15	15	10	5.0	3	0	13.0	2.0
16	15	10	5.0	3	0	13.0	2.0
17	15	10	5.0	3	0	13.0	2.0
18	15	10	5.0	3	0	13.0	2.0
19	15	10	5.0	3	0	13.0	2.0
20	15	10	5.0	3	0	13.0	2.0
21	15	10	5.0	3	0	13.0	2.0
22	15	10	5.0	3	0	13.0	2.0
23	15	10	5.0	3	0	13.0	2.0
24	15	10	5.0	3	0	13.0	2.0
25	15	10	5.0	3	0	13.0	2.0
26	15	10	5.0	3	0	13.0	2.0
27	15	10	5.0	3	0	13.0	2.0
28	15	10	5.0	3	0	13.0	2.0
29	15	10	5.0	3	0	13.0	2.0
30	15	10	5.0	3	0	13.0	2.0
NPV at Year 1	230.6	165.5	66.0	37.5	.173	202.2	28.4

*Assumes current deposition levels of 30 kg/ha/yr.

Table 3-9

Total Costs for the Alternative Strategies and Research Plans
($\$ \times 10^9$)

	Research Outcomes for the Level of Acidic Deposition Damages				
	Low	Medium	High	Expected NPV	Rank
Strategy 1 - no control with:					
No research	46.1	138.4	230.6	129.1	(8)
10 year research plan	46.2	134.7	215.4	123.9	(6)
5 year research plan	46.3	133.0	208.7	121.6	(3)
Strategy 2 - 20% emissions reduction with:					
No research	53.8	130.7	207.6	123.0	(5)
10 year research plan	50.1	130.9	203.8	120.8	(2)
5 year research plan	48.5	130.8	202.2	119.8	(1)
Strategy 3 - 40% emissions reduction with:					
No research	76.9	138.4	199.8	132.2	(9)
10 year research plan	61.7	134.6	199.9	125.4	(7)
5 year research plan	55.0	133.0	200.0	122.4	(4)

Table 3-10

Net Benefits for the Alternative Strategies and Research Plans

($\$ \times 10^9$)

	Research Outcomes for the Level of Acidic Deposition Damages				
	Low	Medium	High	Expected NPV	Rank
Strategy 1 - no control with:					
No research	0	0	0	0	(8)
10 year research plan	-.12	3.71	15.2	5.2	(6)
5 year research plan	-.17	5.4	21.9	7.6	(3)
Strategy 2 - 20% emissions reduction with:					
No research	-7.7	7.7	23.1	6.2	(5)
10 year research plan	-3.97	7.6	26.8	8.3	(2)
5 year research plan	-2.34	7.5	28.4	9.28	(1)
Strategy 3 - 40% emissions reduction with:					
No research	-30.7	-.1	30.8	-3.1	(9)
10 year research plan	-15.6	3.7	30.6	3.7	(7)
5 year research plan	-8.7	5.3	30.6	6.76	(4)

3.2.2.1 Irreversible Capital Investment in Pollution Control Equipment

One argument in favor of delaying decisions to implement environmental controls while additional research is undertaken is based on the irreversible, fixed capital investment that is required by many control strategies. If the control strategies are capital intensive, implementing a control strategy only to rescind it five years later may impose high costs. The previous example assumed perfectly flexible resources, i.e., if the research demonstrated that damages from acid deposition were low and the currently required level of control too stringent; then, the resources used to control pollution could be freely transferred to other productive uses. This assumption of perfectly flexible capital is not likely to be the case.

The capital investment in pollution control equipment may not be readily transferable to other uses. However, the variable costs (e.g., labor and raw materials) are no longer incurred if the equipment is not used. This effect can be captured in the analytical framework presented in the previous section. Flue gas scrubbers for the control of sulfur emissions are one of the most capital intensive pollution control technologies. Depending on the removal levels, about one-third to one-half of the calculated annualized cost of scrubbers is due to the capital cost component.* Other pollution control strategies, such as burning lower sulfur coal, may have a considerably lower proportion of their costs comprised of fixed capital costs.

To account for this capital inflexibility, it was assumed that 40% of the costs of pollution control (i.e., the capital cost portion) continued even if the standards are relaxed and the control no longer needed. The annualized control costs used as the basis for the cost of control estimates used 15 years as the equipment life in the calculation.** Thus, if the outcome of the research program indicated that the current standards were too stringent and pollution controls were not needed, the capital costs are assumed to continue for the full fifteen year period, i.e., until the capital costs are fully paid off.

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*For example, see: A Review of the Literature Relevant to the Assessment of the Impacts of Acid Deposition Mitigation, prepared by Energy and Resource Consultants, Inc.; and Pechan, E. Reducing Sulfur Oxide Emissions from the Electric Utility Industry, both prepared for the Long Range Transport of Air Pollutants Assessment, Office of Technology Assessment, October 1981.

**See Pechan (1981).

This is felt to liberally represent the potential costs from implementing a pollution control program prior to conducting additional research and then having the research indicate that the controls were not necessary. This procedure assumes that there is no other use for the equipment, i.e., the equipment has a zero salvage value. This is an extreme assumption. Some of the equipment will undoubtedly have value in other uses.

Although this approach accurately represents the opportunity costs of the investment to society, it overstates the costs incurred by industry. If the pollution control equipment were no longer needed, private companies would write off the equipment as a tax loss. Thus, private companies would have this loss mitigated by reduced taxes and would only have to absorb roughly 54 percent of the cost of the capital equipment. Although this tax reduction reduces the impact on private companies, the social costs are unaffected. The reduced tax revenue to government would have to be made up from another source. As a result, these tax factors were not considered in this analysis.

Tables 3-11 and 3-12 show the calculations after incorporating the assumption of fixed capital investment. The entries with asterisks are the only entries whose values differ from the previous results shown in tables 3-9 and 3-10. The only outcomes affected by this additional assumption are outcomes for scenarios where pollution controls are implemented prior to completing research and then the having the research show the control levels to be too stringent. As a result, only six outcomes are affected.

The incorporation of a fixed capital investment assumption has little impact on the results. In general, the same conclusions hold. The two best strategies remain the implementation of control strategy 2—moderate controls--with either a five-year or ten-year research plan. The third best strategy is to delay the implementation of pollution controls until an accelerated five-year research program is completed. The two worst strategies remain the implementation of strategy 3--tight controls-- and strategy 1--no control— without conducting any research. Again, it is interesting that the implementation of control strategy 2—moderate control— without conducting any research is superior to taking no action, i.e., strategy 1 until a ten-year research program is completed.

Table 3-11

Total Costs for the Alternative Strategies and Research Plans
Assuming Irreversible Capital Investment in Pollution Control Equipment
($\$ \times 10^9$)

	Research Outcomes for the Level of Acidic Deposition Damages				
	Low	Medium	High	Expected NPV	Rank
Strategy 1 - no controls with:					
No research	46.1	138.4	230.6	129.1	(8)
10 year research plan	46.2	134.7	215.4	123.9	(5)
5 year research plan	46.3	133.0	208.7	121.6	(3)
Strategy 2 - 20% emissions reduction with:					
No research	53.8	130.7	207.6	123.0	(4)
10 year research plan	51.47*	130.9	203.8	121.3*	(2)
5 year research plan	50.2*	130.8	202.2	120.5*	(1)
Strategy 3 - 40% emmissions reduction with:					
No research	76.9	138.4	199.8	132.2	(9)
10 year research plan	65.7*	137.3*	199.9	127.9*	(7)
5 year research plan	60.7*	136.4*	200.0	125.6*	(6)*

* Values changed due to the fixed capital investment assumption.

Table 3-12

Net Benefits for the Alternative Strategies and Research Plans
Assuming Irreversible Capital Investment in Pollution Control Equipment
($ x 10^9)

	Research Outcomes for the Level of Acidic Deposition Damages				
	Low	Medium	High	Expected NPV	Rank
Strategy 1 - no controls with:					
No research	0	0	0	0	(8)
10 year research plan	-.12	3.7	15.2	5.2	(5)*
5 year research plan	-.17	5.4	21.9	7.6	(3)
Strategy 2 - 20% emmissions reduction with:					
No research	-7.7	7.7	23.1	6.26	(4)*
10 year research plan	-5.31*	7.6	26.8	7.9*	(2)
5 year research plan	-4.03*	7.5	28.4	8.7*	(1)
Strategy 3 - 40% emmissions reduction with:					
No research	-30.7	-.1	30.8	-3.1	(9)
10 year research plan	-18.8*	.98*	30.6	1.5*	(7)
5 year research plan	-16.1*	-.6*	30.6	1.8*	(6)*

* Outcomes with values changed due to the fixed Capital Investment assumption.

3.2.2.2 Sensitivity of the Analysis to Different Probability Estimates

The preceding section presented an example that showed how one can evaluate alternative options relating to the timing of a decision to control acid deposition. In particular, the example examines a decision on whether to delay taking action while additional research is conducted. Most of the parameters used in the example have some basis in prior research. However, some of the parameters are purely speculative and are chosen to facilitate the example. Still, it is hoped that these speculative parameters fall within a plausible range. A critical set of speculative parameters are the probabilities used in the analysis. These probabilities represent the likelihood that damages from acid deposition are large enough to justify different control strategies and were depicted in Figures 3-1 and 3-3. No reliable estimates of the probability that damages fall within these ranges were available for this analysis. Instead, the probabilities were chosen to represent considerable uncertainty regarding the actual damages resulting from acid deposition. This section will examine how the appropriate policy changes as the probabilities of different levels of environmental damage from acid deposition changes.

Although this example is based on numbers that are at present speculative, the calculations can help develop insights on the appropriateness of alternative strategies for controlling acid deposition. In particular, this approach can serve to depict the circumstances under which different control alternatives would be most appropriate. This section, through sensitivity analysis, will present a broader discussion of the conditions under which each of the different alternatives would be the most appropriate course of action.

The preceding section ranked the control strategies according to their desirability given the following probabilities:

- Probability of Outcome A -- low damages:
  (O $\leq$ damages/unit $<$ \$200 million) = .35
- Probability of Outcome B -- medium damages:
  (\$200 million $\leq$ damages/unit $<$ \$400 million) = .40
- Probability of Outcome C -- high damages:
  (\$400 million $\leq$ damages/unit = .25

With these probabilities, costs of control and reductions in deposition used in this example, the best strategy was strategy 2 -- a 20% reduction in emissions in conjunction with an accelerated five-year research plan. The second best option was to implement strategy 2 with a ten-year research program. The options of waiting to implement controls until completion of either a five-year or ten-year research program were ranked third and fifth respectively. It is possible to calculate the set of the estimated probabilities that would change these results. In particular, it would be of interest to determine what set of probabilities would result in strategy 1--no control-- being the correct choice.

Strategy 1--no control--with a five-year research plan would be preferred to the previously preferred strategy 2--20% reduction in emissions-- with a five-year research plan under the following circumstances:

1.) If the probability of Outcome C--high damages = .25 and;
   - probability of Outcome A--low damages $\geq$ .54
   - probability of Outcome B--medium damages $\leq$ .21

2.) If the probability of Outcome C--high damages = .20 and;
   - probability of Outcome A--low damages $\geq$ .50
   - probability of Outcome B--medium damages $\leq$ .30

3.) If the probability of Outcome C--high damages = .10 and;
   - probability of Outcome A--low damages $\geq$ .43
   - probability of Outcome B--medium damages $\leq$ .47

The probabilities required to make strategy 1 with a five-year research plan preferable to strategy 2 with a five-year research plan are very dependent upon the likelihood of high damages occurring. If there is a reasonable likelihood (i.e., $\geq$ .25) that damages from acid deposition are in the high range, then the probability of damages being in the low range must be roughly twice as high as the probability of moderate damages.

Strategy 1 with a ten-year research program is preferred to strategy 2 with a five-year research plan under the following circumstances:

1.) If the probability of Outcome C--high damages = .25; then, there is no combination of probabilities that result in strategy 1 with a ten-year research plan being preferred to strategy 2 with a five-year plan.

2.) If the probability of Outcome C--high damages = .20 and;
   - probability of Outcome A--low damages $\geq$ .74
   - probability of Outcome B--medium damages $\leq$ .06

3.) If the probability of Outcome C--high damage = .10 and;
   - probability of Outcome A--low damages $\geq$ .62
   - probability of Outcome B--medium damages $\leq$ .28

Strategy 1 with a ten-year research plan will be preferred to strategy 1 with a five-year research plan under the following circumstances:

1.) If the probability of Outcome C—high damages $\geq$ .0075, then strategy 1 with a five-year research plan is always preferred

2.) If the probability of Outcome C—high damages = .005 and;
- probability of Outcome A—low damages $\geq$ .935
- probability of Outcome B-medium damages $\leq$ .060

3.) If the probability of Outcome C--high damages = .001
- probability of Outcome A—low damages $\geq$ .839
- probability of Outcome B—medium damages $\leq$ .160

These calculations show that for strategy 1 with a ten-year research program to be preferred to strategy 2 with a five-year research program, the probability of the actual damages of acid deposition falling in the low range must be quite high, i.e., greater than 60%. For strategy 1 with a ten-year research plan to be preferred to strategy 1 with a five-year research plan, the probability of damages from acid deposition falling in the low range must be 84% or higher. If the probability of damages falling into the high range is greater than 1%, then strategy 1 with a five-year research plan will always be preferred to strategy 1 with a ten-year research plan.

This form of "WHAT IF" scenario analysis can present problems with the appropriate interpretation of the results, but it is useful for providing reference points for the decision parameters where none may otherwise exist.

3.3 Discussion

This section has demonstrated, through the use of an example, a possible approach for addressing what are felt to be some of the critical acid deposition policy issues: determining the dimensions of uncertain parameters, estimating the value of additional information, and evaluating the appropriate timing of the decision.

The estimates of control costs and the relationship between changes in emissions and changes in deposition are comparable to other estimates found in the literature. However, there are currently no reliable estimates of the probability that damages fall into any of the ranges considered in this analysis. Instead, the probabilities chosen for this example were selected to represent a situation where there is considerable uncertainty. The example is intended to provide estimates that may, to a limited extent, generate insights into plausible policy options for reducing acid deposition. However, the primary purpose is to demonstrate the usefulness of probabilistic damage estimates by presenting examples of the method and types of analysis that can be performed. The problem now is to estimate the probabilities of the natural occurrence of various levels of damage from acid deposition.

There were several simplifying assumptions used in the example that deserve discussion. First, the uncertainty that is present in the relationship between changes in emissions and changes in deposition was not considered. This is a major source of uncertainty. Its omission in this assessment allows for the use of a two dimensional graph (Figure 3-1) to depict the implicit assumptions necessary for each policy option to be the correct choice. An assessment that would incorporate the uncertainty in atmospheric transport as well as in the damages per unit of deposition could use a three dimensional version of Figure 3-3. Another approach would be to use a scenario analysis with each scenario representing a different relationship between emissions and deposition. The probabilities that the emissions to deposition factor falls within these specific ranges would then be estimated. These improvements are straightforward, but some effort is required to develop the necessary probabilistic estimates of the emissions to deposition relationships.

A second simplifying assumption was the use of piecewise linear approximations to the cumulative probability distribution depicted in Figure 3-3. Since the probabilities used in the example are speculative, this assumption makes little difference and it greatly simplifies the calculations. A third assumption is that expected values alone are the proper measure of benefits and costs. Risk aversion of any extent would necessitate a more complex analysis.

Some of the advantages of this type of probabilistic approach include the allowances for the explicit incorporation of uncertainty into the estimates and the specification of the assumptions regarding the level of damages from deposition that are required for each policy option to be the correct choice.

These analyses showed that, given the data used in this example and the uncertainty expressed by the probabilities, the value of obtaining perfect information that would eliminate any uncertainty in the decision was estimated at $300 million per year. This value serves as an upper bound to the value of information. The value of imperfect information that would not eliminate all the uncertainty but would revise the probabilities such that the policy maker's level of certainty regarding the correct choice is increased by 50 percent (i.e., increasing the probability of being correct from .4 to .6) was valued at $100 million dollars per year.

Although large values for additional information were calculated, this only indicates that research on the issue could prove valuable. It says nothing about the appropriate timing of the decision to implement a control strategy. For example, a large calculated value for additional information does not necessarily imply that the correct policy choice is to delay until additional research is performed. To assess this, three research plans with different time frames and costs were considered in conjunction with the three policy options. The outcomes of the hypothesized research plans were very favorable in that it was assumed that each research plan would yield perfect information, i.e., each plan would reveal with certainty which strategy is the correct choice. Thus, in the examples used, the policy maker faced a choice of delaying the implementation of controls until the completion of either a five year research program at a cost of 200 million dollars, or a 10 year research program at a cost of $150 million. Even with the assumption that each research plan would yield perfect information at its conclusion, it was not the optimal strategy to delay the implementation of controls. The best choice over a wide range of assumptions was to implement strategy 2 -- a 20 percent reduction in emissions -- in conjunction with the five year research plan. This option remained the best choice even when the probabilities of each strategy being correct were changed from .35 for strategy 1, .40 for strategy 2, and .25 for strategy 3 to equal probabilities for each (i.e., .33, .33, .33); and even to a set of probabilities where strategy 1 was most likely to be correct (i.e., .40, .35, .25).

Thus, this set of data, although speculative, indicates that even in the presence of a large amount of uncertainty and a research plan guaranteed to yield perfect information, the best policy option was not to delay implementing controls. Instead, the best policy in this example, was the implementation of a moderate level of control accompanied by a research plan designed to determine, as quickly as possible, whether the correct choice has been made and if the emissions reductions should be increased or relaxed. These results were relatively insensitive to small changes in the key parameters.

There are two additional scenarios that could have important policy implications but that were not addressed in this example. The first is the possibility of irreversible environmental damages and the second is the possibility of a higher upper bound on the magnitude of environmental damages. The consideration of either of these effects would make it even more desirable to implement strategy 2 (moderate control) or strategy 3 (tight control) while research is being undertaken.

What is now needed is research to provide better estimates of these parameters, particularly the probability that damages fall into different levels. The next chapter will address the sources of uncertainties in the damage estimates and methods for estimating probabilistic damage functions.

4.0 PROBABILISTIC DAMAGE FUNCTIONS AND ESTIMATES

The applicability of the approach outlined in Chapter 3.0 is dependent upon the ability to estimate a probability distribution of damages due to acid deposition. The probability distribution used in Chapter 3.0 is for aggregate damages from acid deposition. This aggregate probability distribution would be constructed using a bottom-up approach. This chapter discusses how the probability distribution for aggregate damages from acid deposition would be generated.

4.1 Elicitation of Probabilistic Damage Functions

The approach that would be used to develop the probability distribution for damages from acid deposition is characterized as a bottom-up approach. Damages from acid deposition would be divided into many separate categories and probabilistic damage functions would be estimated for each category. These probability distributions would be combined to generate an aggregate damage function. This approach would require the cooperation of scientists conducting research on damages due to acid deposition.

During the course of the project, a number of probabilistic damage functions for different species of trees and fish were developed. The principal reason for developing these damage distributions was to provide a basis for discussion of the estimation methodology with scientists currently conducting research on damages. This was undertaken to determine the usefulness of the approach in representing the uncertainty in the estimation of damages from acid deposition. In general, this procedure received support from the scientists, and, as a result, a formal elicitation of probabilistic damage functions seems feasible and should yield valuable information.

A probability elicitation exercise is a session in which an interviewer queries an expert to develop a consistent estimate of the frequency distribution of an uncertain quantity. The procedures for eliciting judgmental probability estimates have received substantial study yet there is no one accepted method for generating these probability distributions. A number of probability encoding techniques for use in policy analysis have been reviewed in Morgan et al. (1979).

Regardless of the particular elicitation technique, certain basic principles apply:

1. The person interviewed should have specific knowledge of the aspect of the environmental effect being assessed.

2. There should be an explicit understanding between the elicitor and the respondent as to what is being assessed. For example, specifying that a discussion is about the impact of acid rain is not sufficient. The elicitation should be specific regarding the parameters felt to induce the effect (e.g., H^+ ion concentration or toxic metals), the time frame under consideration, the species of plant or fish, and the dimensions of the impact (e.g., reduction in biomass or population of fish). The appropriate specification of the dimensions of the damage is an important task.

3. Some respondents may be uncomfortable thinking in terms of frequency distributions. They may tend to offer a single estimate and not deviate. Their willingness to consider variations about the single estimate may be enhanced by postulating higher or lower impacts and asking them what circumstances could result in these different impacts. This broadens the discussion to more than their 'best guess' scenario.

4. The elicitor should not begin by asking for a best guess. This will focus the discussion on a single value and limit consideration of the extremes. Instead, the elicitor should first attempt to define the range of potential impacts.

5. The elicitor should explore the extreme values suggested by the respondent by postulating scenarios that would extend the limits or by having the respondent do this. The ultimate limits achieved in this fashion are more realistic bounds than the ones that will be suggested initially as they are more nearly free of the central tendency bias.

6. Graphical tools to illustrate the concepts of probability may be useful in helping the respondent make tradeoffs between ranges of outcomes.

7. Care must be taken to assure that the opinions of the respondent are unbiased. The possibility of bias should be investigated in a discussion at the beginning of the interview.

During the course of the project, probabilistic damage functions were estimated for five species of trees and eight species of fish. These damage functions were elicited from only one or two scientists and should only be interpreted as examples of the procedure. The purpose of the solicitation was to discuss the process with scientists and to ascertain whether they felt it could yield useful results. Figure 4-1 shows the outcome of one elicitation for the estimated effect of changes in pH on the population of rainbow trout.

The damage function measures the change in population of rainbow trout as the pH of a lake declines. The range of possible impacts is shown by the dotted lines and the dashed line shows the most likely estimate. The damage function shows that at a pH of 7.0, there is no effect from pH on the population of fish and that this is known with certainty. As the pH declines to 6.5, there is the possibility of an impact on the rainbow trout population. The impacts range from no effect (i.e., a zero change in population) to a 10% decline in fish population, with the most likely impact being a 3% decline in fish population. This slight impact would be due to only the most susceptible fish being affected. As the pH declines to 5.0, the range of possible impacts increases and the expected, or most likely, impact also increases. With further declines in pH, the range of possible impacts tends to narrow since at an extremely low pH, there is a high degree of certainty that the fish population will experience significant population decreases. Then, at a pH of 4.0, it is determined that rainbow trout cannot survive. There is a 100 percent decline in population and this effect is known with certainty.

This probabilistic damage function was constructed in the following manner. The first step was to construct a table such as that shown in Table 4-1. The elicitor begins by asking the expert if there is any possibility of a pH of 7.0 resulting in a reduction in the rainbow trout fish population. After some discussion of the possibilities, the expert concludes that there really is no chance of a pH of 7 having an adverse impact on the fish population. As a result, zeros are entered in the low, midpoint, and high columns of the

FIGURE 4-1

Estimated Damage Function for Rainbow Trout (*Salmo gairdneri*)

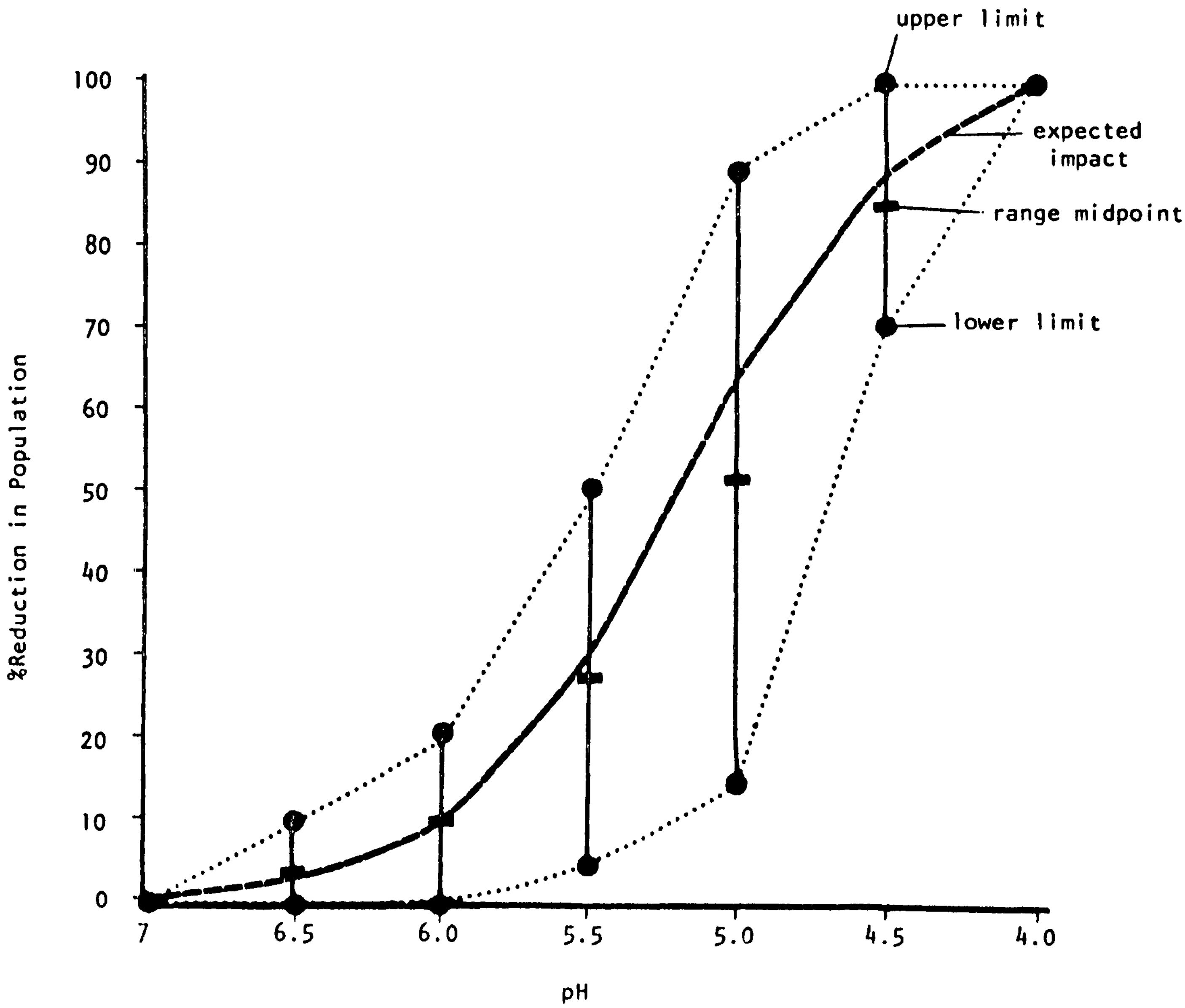

TABLE 4-1

Elicitation Table

Species of Fish: Rainbow Trout

	Range of Impacts				
pH Level	Low	(Weight)	Midpoint	(Weight)	High
7.0					
6.5					
6.0					
5.5					
5.0					
4.5					
4.0					

table. The next set of queries concerns the possibility of adverse impacts occurring at a pH of 6.5 At this pH level, the expert is uncertain as to whether adverse impacts may occur. After some discussion of the scenarios and assumptions that could result in there being no impact or there being some adverse impact on the fish population, the expert concludes that the possible impacts range from zero on the low end to 10% on the high end. As a result, a 0 is entered in the low column and 10% is entered in the high column (See Table 4-1a). These lower and upper bounds were chosen to represent roughly a 95 percent confidence interval. Thus, the lower and upper bounds entered in the table do not determine the absolute limits to the range of possible damages but, instead, serve to define effective limits such that there is only a small probability that damages fall outside the range. In this case, the assumed 95 percent confidence interval implies that there is a 2.5 percent chance that the damages will be below the lower bound and an equivalent probability that damages will be above the upper bound.

Once the range of impacts for a given pH is specified in the above manner, the experts were queried regarding the probabilities of the different outcomes within this range. It was quite difficult to elicit responses regarding the most likely damage outcome within the estimated range. Typically, the experts were either unwilling to give an estimate of where the most likely value would fall or felt that they did not have the information necessary to develop an estimate of the most likely impact. In such circumstances, the usual procedure was to enter the midpoint in the table and then ask the expert a question similar to: "If you were a betting man, would you bet that the actual adverse impact of a pH of 6.5 would fall above or below the midpoint?" Often, when questioned in this way, the experts would express a strong conviction regarding where they would place a bet, even when they previously were not able to provide estimates of where the most likely impact would fall. Once the expert decided whether the adverse impacts on the fish population were likely to be above or below the midpoint of the range, an "X" is placed either above or below the midpoint to express this weighting of the probabilities. In Table 4-1b, the "X" placed between the low value of zero and the midpoint impact of 5% indicates that the expert felt that the most likely outcome for the impact on fish population from a pH of 6.5 is between 0% and 5% rather than between 5% and 10%. The elicitation procedure is continued until estimates for all the pH levels were developed (see Table 4-1b). When an "X" was placed in the interval, it was assumed that it was one third more likely that the actual adverse impact would fall in the interval weighted by the "X". Figure 4-1, previously presented, is a graphical depiction of the completed elicitation table (Table 4-1b).

TABLE 4-1a

Elicitation Table

Species of Fish: Rainbow Trout

	Range of Impacts				
pH Level	Low	(Weight)	Midpoint	(Weight)	High
7.0	0		0		0
6.5	0				10%
6.0					
5.5					
5.0					
4.5					
4.0					

TABLE 4-1b

Elicitation Table

Species of Fish: Rainbow Trout

	Range of Impacts				
pH Level	Low	(Weight)	Midpoint	(Weight)	High
7.0	0		0		0
6.5	0	"X"	5 %		10 %
6.0	0		10 %		20 %
5.5	5 %		27.5 %	"X"	50 %
5.0	15 %		52.5 %	"X"	90 %
4.5	70 %		85 %	"X"	100 %
4.0	100 %		100 %		100 %

4.2 Discussion of the Elicitation Procedure

The elicitation procedure described above is admittedly crude, but it is adequate to serve as a starting point for discussion of the viability of the general approach. In addition, if damage functions for many species of fish and vegetation, as well as materials damage and human health effects are to be estimated, increased sophistication in the estimation of each individual damage relationship may not be warranted. An adequate representation of the uncertainty surrounding estimates of aggregate damages from acid deposition may not require a procedure any more sophisticated than that presented in the preceding section.

There are several problems in the design of an elicitation process that require careful thought. One important problem is the appropriate specification of the dimensions of the damage function. The preceding example used pH as the independent variable (or causative agent) and percent reduction in fish population as the dependent variable, however, there are other options. For example, changes in the biomass of the fish population could have been used as a measure of the damage instead of the reduction in numbers of fish. In addition, pH is not the only index of water quality that can be used to dimension the impact of acid deposition on fish populations. There are other important factors, such as concentrations of toxic metals -- aluminum and mercury concentrations are of particular concern. Often, low pH levels and high concentrations of toxic metals are closely correlated since rainfall with a low pH tends to leach toxic metals from the soil. Another problem is the specific measure of pH used, i.e., peak measurements or average pH. The pH of a lake is not constant and much of the scientific literature indicates that considerable damage results from episodic events. The spring snow melt or particularly heavy rains can cause short-term, but severe, depressions in pH. These episodes often occur in the spring and can be very damaging to fish reproduction. In some cases, they can be so severe as to cause the elimination of a fish species from a lake with otherwise high pH levels. Considerations of this type can be folded into the elicitation of the probabilistic damage function presented earlier by incorporating different scenarios into the range of possible outcomes.

The incorporation of these additional factors into the damage function complicates the interpretation of relationship. For example, a damage function expressed in terms of pH and percent reduction in fish population may, in fact, be representing a wider range of variables and a more complex relationship. Also, this makes estimation of the range of outcomes and probabilities even more difficult for the experts.

The preceding discussion indicates that the process used to generate subjective probabilities can be simply stated but, in actual applications, a number of complications invariably arise. In spite of these problems, the approach has many advantages. These include:

- Environmental policy decisions, as well as most other regulatory decisions, will always be subject to uncertainty. A dimensioning of this uncertainty by technical experts will provide additional information that has not been available to policy makers in the past. Since any decision requires, at least, an implicit assessment of the uncertainty, the alternative is to require the often less-knowledgeable policy makers to form their own opinion of the probabilities without assistance from the scientific community.

The following advantages are taken from Morgan et al. (1979):

- The approach may contribute to "better" decisions. Since there is considerable evidence that people are poor statistical processors, a formal analytical technique may help to avoid some of the pitfalls of a "seat of the pants" approach.

- Results are obtained in a quantitative form which can be easily incorporated into subsequent analyses.

- Results explicitly incorporate a statement of the uncertainty associated with the knowledge. . . something which has been all too frequently ignored in more of the previous regulatory decision-making.

- Results can be obtained at a fairly low cost.

The use of subjective expert judgments has substantial benefits but the use of this approach is not without pitfalls. In their review of the use of subjective probability estimates, Morgan et al. (1979) cite the following concerns:

- People may have an incorrect or incomplete perception of how "good" a job expert can do at making subjective quantitative assessments, and thus may be misled by the results.

- People who obtain such assessments from experts may not adequately use current understanding of the problems in this field to obtain the best possible results.

- Use of quantitative subjective judgements in regulatory decision-making without a proper understanding of their limitations could lead to subsequent litigation and legal decisions which might significantly limit a regulator's ability to employ such techniques in the future.

- Because they are relatively cheap, produce quantitative "technical looking" results, and because in some fields (e.g., toxic substances) regulators are faced with overwhelming data needs, there is a real danger that the elicitation of expert subjective judgements may begin to become a substitute for doing needed research.

After consideration of the advantages and disadvantages, Morgan et al. (1979) conclude by saying: "To our mind, these potential problems do not outweigh the substantial benefits that can result from using subjective expert probabilistic judgement in policy analysis." The arguments and analysis presented in this report support this conclusion, but they also reinforce the importance of careful application of decision analysis techniques and an understanding of the limitations of the approaches.

4.3 A Sample Application: Damages to Forests from Acid Depositions

An example of how the elicitation process outlined in Section 4.1 can be used to develop probabilistic estimates of damages is presented in this section. The steps that must be performed to develop probabilistic damage estimates are presented in Table 4-2. An elicitation for five species of trees was conducted. The results from this elicitation are subject to several important limitations. The primary limitation is that only two individuals were used in the elicitation. As a result, the full range of views and research outcomes may not be represented. It is important that not too much significance be placed on these early elicitations. An elicitation encompassing a larger number of experts and the inclusion of a broader range of tree species and scenarios in the elicitation process could result in different estimates of the range and probabilities of damages. The purpose of this section is to serve as an example of the method.

TABLE 4-2

Damages to Forests from Acid Deposition:
Steps in the Analysis

Step 1. Estimate Probabilistic Damage Functions.

1.1 Obtain the subjective judgements required to fill in the elicitation table (i.e., Table 4-1).

1.2 Translate the elicitation table into probabilistic damage functions.

Step 2. Develop Baseline Estimates of Damages.

2.1 Obtain estimates of the current levels of acid deposition that tree species are exposed to.

2.2 Calculate the level of damages that are occurring at current deposition levels using the estimated damage functions.

Step 3. Estimate how the forest damages will change under the different policy options being considered.

3.1 Develop estimates of how the exposure of each tree species to acid deposition will change.

3.2 Use the probabilistic damage functions to estimate the new level of forest damages that will result under each policy option.

3.3 Subtract the levels of damages occurring after implementation of the policy from the baseline level of damages to calculate the estimated improvement or benefit

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Probabilistic damage functions were developed for five species of trees -- two softwood species (spruce and balsam fir) and three hardwood species (yellow birch, maple and beech). Table 4-3 shows the outcome of the elicitation of the effects of acid deposition on red spruce. Table 4-3 shows the range of damages to the red spruce population that could be expected to occur, given an exposure to an annual average rain pH.*

Table 4-3 is interpreted in the same manner as the previous elicitation example presented in Table 4-1. The "X" entered in the "weight" columns on Table 4-3 are used to indicate that portion of the range of damages the experts felt included the most likely damage outcome. The elicitation table is used to develop a probability distribution of damages for each pH exposure level.

Figure 4-2 shows the cumulative probability distribution of damages to red spruce associated with a rainfall pH of 4.5 This was constructed from Table 4-3 using the following assumptions:

- o The range of damages, i.e., a 15% to 80% reduction in population due to a rainfall pH of 4.5, represents a 95% confidence interval. That is, there is a 2.5% probability that the actual reduction in population may be below 15% and the probability that damages exceed 80% is also 2.5%

- o Actual damages are one third more likely to fall on the side of the midpoint deemed most likely, i.e., the side marked with the "X".

The cumulative probability distribution indicates the following probabilities for the reduction in red spruce biomass due to exposure to rainfall with a pH of 4.5:

Prob. ($0 \leq$ % population reduction $<$ 15%) = .025
Prob. (15% $\leq$ % population reduction $<$ 47.5%) = .57
Prob. (47.5% $\leq$ % population reduction $<$ 97.5%) = .38
Prob. (97.5% $\leq$ % population reduction $<$ 100%) = .025

---

* In order for the pH to have an adverse effect on red spruce, presented in Table 4-3, the reduction in pH would have to last for several years.

Figure 4-2

Cumulative Probability Distribution for Damage to Red Spruce Exposed to Rainfall with an Annual Average pH of 4.5

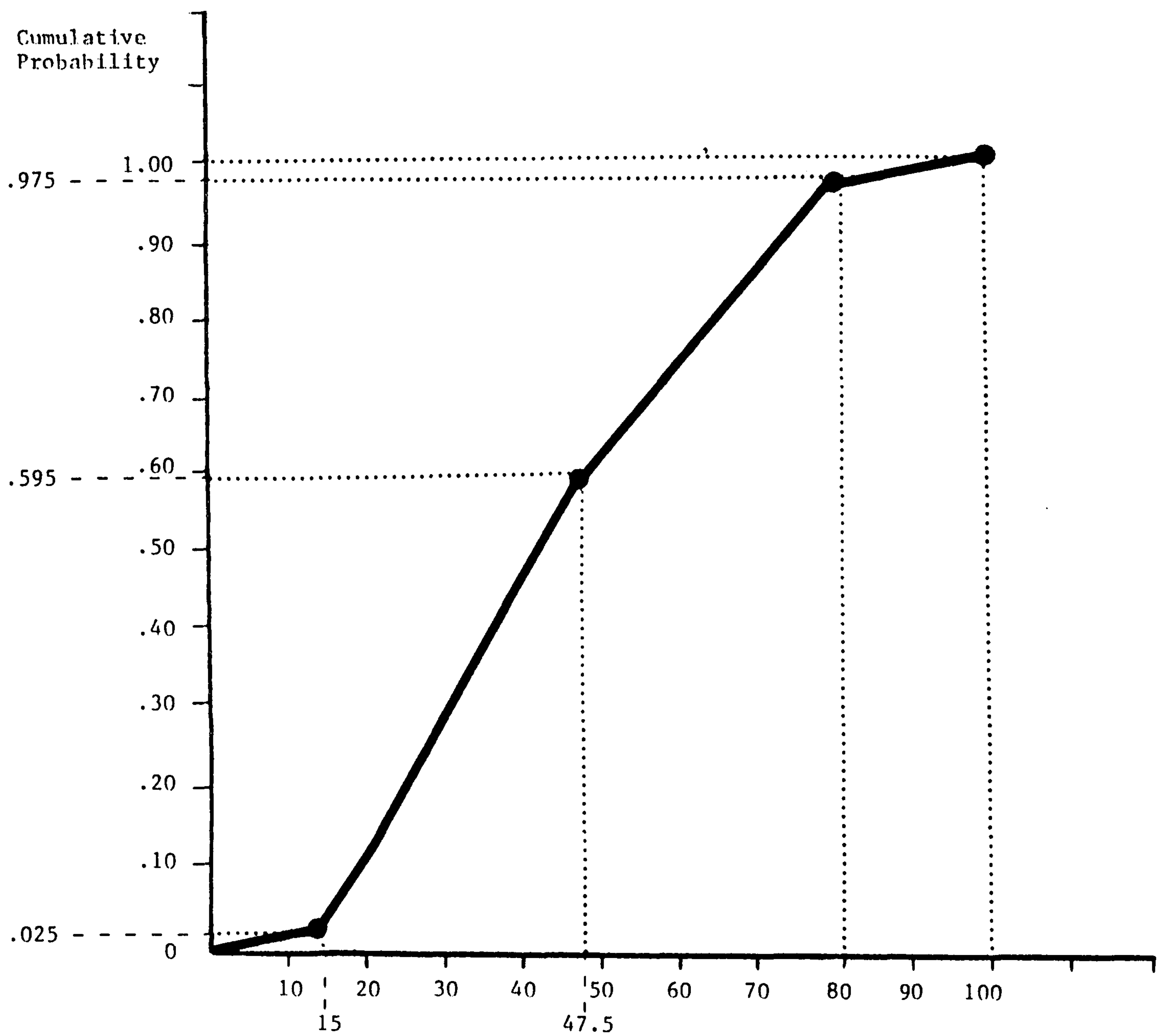

TABLE 4-3

Percent Decline in Biomass for Red Spruce Due to Acid Rain

Indicator Variable Rain pH	Lower Bound of Damage	(Weight)	Midpoint	(Weight)	Upper Bound of Damage
5.5	0		0		0
5.	0		0		0
4.5	15	X*	47.5		80
4.	30	X	60		90
3.5	60	X	80		100
3.	60		80	X	100

*The "X" indicates which side of the midpoint the expert felt actual damages were most likely to occur.

Figure 4-3 shows the marginal probability distribution corresponding to the cumulative distribution shown in Figure 4-2.

The elicitation table shown in Table 4-2 is used to generate a probability distribution of damages for trees exposed to rainfall of a given pH. The next step in constructing the probability distribution for baseline (i.e., current) damages from acid rain is to determine the rain pH red spruce trees are currently exposed to. This was done by overlapping maps of forest populations with maps showing average rain pH. Only the New England region and the states of New York and Pennsylvania were considered in this analysis. Table 4-4 shows the estimates of the population of the five tree species exposed to different levels of rain pH.

This exposure information can be combined with the estimates of damages at the different pH exposure levels to generate an estimate of current damages from acid rain. This is done separately for each pH range using the midpoint of the pH range to generate the probability distribution of damages for each pH level. The aggregate distribution of damages for all five species of trees is calculated in three steps:

(1) The distribution of damages for each species for each pH exposure category are calculated.

(2) The distribution of total damages for each species of tree is calculated by combining the distributions across the pH categories for the same tree species.

(3) The distribution of total damages for all species of trees is calculated by combining the distributions for each species.

The frequency distributions were combined using a Monte-Carlo simulation. A critical assumption in this calculation is that the damage functions are independent. That is, that the damage done to one species at a given pH is not influenced by the damage done to another species at the same pH. Uniform biases in the damage function estimates or biological factors such as the damage to one species being offset by reduced competition

Figure 4-3

Marginal Probability Distribution for Damages to Red Spruce Exposed to Rainfall with an Annual Average of pH of 4.5

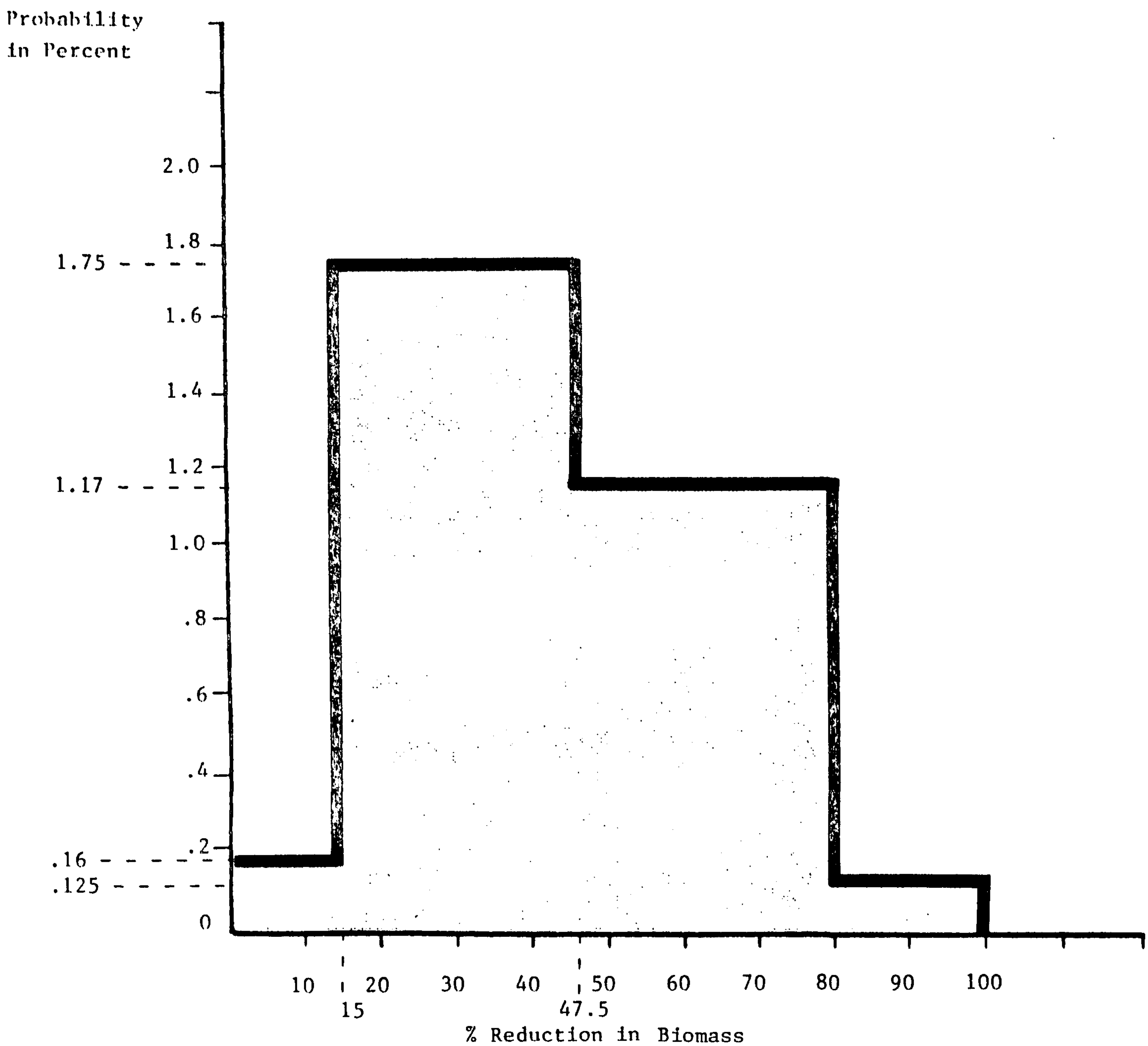

TABLE 4-4

Net Volume of Growing Stock on Commercial Timberland
in New England, New York and Pennsylvania
(million cubic feet)

Current Rain pH Levels (Exposures)	Tree Species				
	Spruce	Balsam Fir	Yellow Birch	Maple	Beech
pH 4.5-4.4	1959	1959	246	852	221
pH 4.4-4.3	5035	5035	1398	6965	1114
pH 4.4-4.2	266	266	409	5466	1053
pH 4.2	neg.	neg.	195	3510	712

Sources:

1. Timber materials from: An Analysis of the Timber Situation in the United States 1952-2030, United States Department of Agriculture, Forest Service.
2. pH levels from maps in Memorandum of Intent on Transboundary Air Pollution, Phase 2, Interim Report, Working Group 2, July 1981.

from other damaged species could invalidate the assumption of independence.* This would widen the distribution of combined damages in the case of estimation bias, or narrow it in the case of offsetting biological factors.

In surveying the biological literature, it has become clear that damages may not be independent. The extent of the interdependence is not clear at this time as more research is needed. It would certainly be possible to include elicited views on issues such as species replacement in the decision analytic framework.

The estimates of the baseline damages from acid deposition are presented for softwoods (spruce and balsam fir) and hardwoods (yellow birch, maple and beech). A value of $1.60 per cubic foot was used for the stumpage price for softwoods and $.60 per cubic foot was used as the stumpage price for hardwood.**

The cumulative probability distribution for damages to both hardwoods and softwoods is presented in Figure 4-4. The estimated range of damages from acid deposition at current deposition levels range from 520 million to 1,480 million. The estimated median damage level is $1,280 million. Given this cumulative probability distribution, the probabilities for damages from current levels of acid rain falling in selected ranges is:

- Prob ($0 \leq$ Damages $<$ \$696 million) = .10
- Prob (\$696 million $\leq$ Damages $<$ 1,279 million) = .40
- Prob (\$1,279 million $\leq$ Damages $<$ 1,404 million) = .40
- Prob (\$1,404 million $\leq$ Damages) = .10

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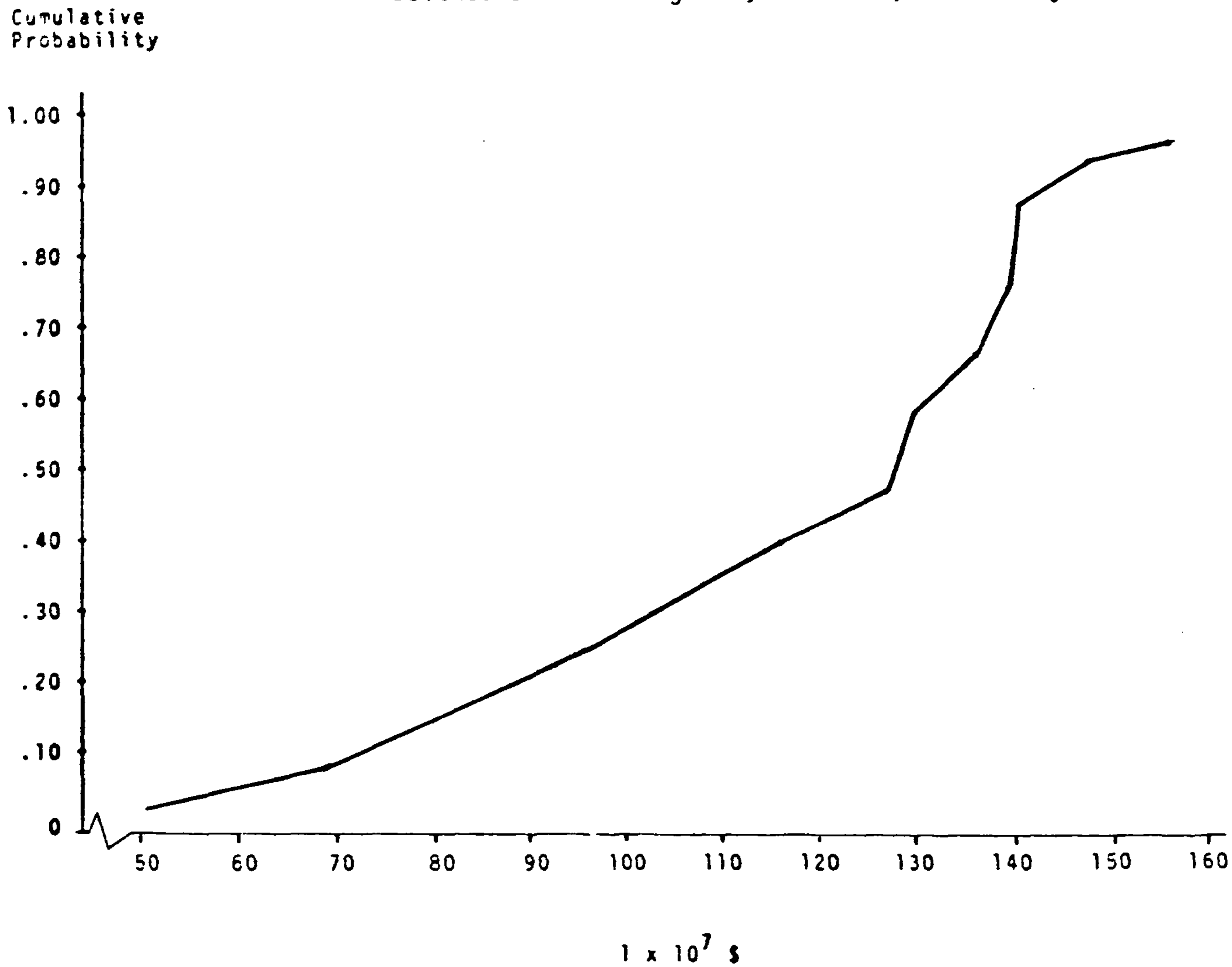
*This can occur when two species of trees in the forest have varying sensitivities to acid rain. Even though both species may be adversely affected by acid rain, as the population of the more sensitive species is reduced due to acid rain, the reduced competition between the species could offset the negative effects of acid rain and result in an increase in the population of the more resistant species.

**These estimates are from Lerner, W., Ed., Statistical Abstract of the United States, U.S.G.P.O., Washington, D.C., 1979.

FIGURE 4-4

Baseline Distribution of Damages to Both Hardwoods and Softwoods in New England, New York, and Pennsylvania



This particular elicitation showed relatively high probabilities of there being substantial damage to forest from acid precipitation. In particular, the median damage estimate for the area comprised of New York State, Pennsylvania and the New England Region was calculated to be $1.28 billion. The probability that damages fall between $1.28 billion and $1.41 billion is estimated at 40%, and the probability the damages are less than .7 billion is 10 percent. There are several possible reasons for these high damage estimates. First, the area under consideration has the most severe acid deposition and the vast majority of damages to forests can be expected to occur in this region. Other possible reasons for these high damage estimates stem from potential biases in the elicitation and application of the damage functions. Only two experts were used in the elicitation and it is possible that the full range of research results on damages are not adequately represented. Another possible bias, and potentially the most serious is that if a specific species of tree is shown to have a growth reduction due to acid precipitation no other commercially valuable trees are assumed to replace it. For example, if acid deposition reduces the stock of red spruce, the stock of balsam fir trees (a more resistant species) may increase due to reduced competition among the species. The commercial value of the replacement trees is not considered. This would tend to overestimate the damages due to acid deposition.

The next step in the analysis is evaluating how damages will change as anthropogenic emissions change. This poses a difficult problem. It is not as clear how the pH of the rain will change as emissions change. Naturally occurring rain is commonly cited as having a pH of 5.6, although this can vary widely at different locations. In this analysis, the assumption is made that the naturally occurring pH of rain is 5.6. If the pH of the rain is less than 5.6, then this reduced pH is due entirely to anthropogenic sources. The H^+ ion concentration that results in a pH of 5.6 is 2.51 micro-equivalents per liter; if the observed pH of the rain is 4.4 the H^+ ion concentration is 39.8 micro-equivalents per liter. The difference between the two, i.e., 37.3 micro-equivalents per liter, is assumed to be the contribution from anthropogenic sources.

Three additional scenarios are evaluated to determine the effect of different policy options on the damages from acid deposition. The scenarios are:

- a 15 percent increase in H^+ from anthropogenic sources
- a 25 percent decrease in H^+ from anthropogenic sources

- a 50 percent decrease in H^+ from anthropogenic sources

By considering only changes in the H^+ ion concentration of the rain, it was possible to calculate the new pH levels the forests would be exposed to. The new exposures for the different species of trees for each of the three scenarios are shown in Tables 4-5 to 4-7. For example, using Table 4-4 as the baseline and examining the first row, Table 4-5 shows that a 15 percent increase in H^+ ions from anthropogenic sources would decrease the pH of the rain from 4.5 to 4.44. Similarly, if the pH of the current rainfall is 4.5, then a 25 percent reduction in H^+ ions from anthropogenic sources would increase the pH to 4.61. A 50 percent reduction in H^+ ions from anthropogenic sources would further increase the pH to 4.77. These results are used to generate tree species exposure estimates for each scenario (see Tables 4-5, 4-6, and 4-7).

The cumulative probability distributions for damages from acid rain for each of the three scenarios are shown in Table 4-8 and in Figures 4-5, 4-6 and 4-7. A 15 percent increase in anthropogenic induced H^+ ions increased the estimated median value of damages from \$1,279 million to \$1,378 million. A 25 percent reduction in H^+ ions reduced the estimated median value of damages from \$1,279 million to \$1,079 million. Therefore, the benefits of achieving a 25 percent reduction in H^+ ions from anthropogenic sources would have an estimated median benefit, in terms of reduced forest damages, of \$200 million. The range of benefits from a 25 percent reduction is from \$96 million to \$220 million. A 50 percent reduction in H^+ ions reduced the estimated median value of damages from \$1,279 million to \$780 million. The estimated median benefits from a 50 percent reduction in H^+ ions are \$499 million. The range of benefits from a 50 percent reduction is from \$216 million to \$573 million.

Given the cumulative probability distributions shown in Table 4-8 and Figures 4-5, 4-6 and 4-7, it is possible to calculate the probability that benefits from a strategy to reduce H^+ ion concentrations in rainfall are equal to or exceed a certain value for each scenario. For example, if the costs of achieving a 25 percent reduction in H^+ ions from anthropogenic sources were estimated at \$150 million, the probability of benefits, in terms of reduced forest damages, exceeding \$150 million is approximately 70 percent. This is found by subtracting the total damages distribution in Table 4-8 with a 25 percent reduction in anthropogenic emissions from the baseline distribution of damages.

TABLE 4-5

Net Volume of Growing Stock on Commercial Timberland
in New England, New York and Pennsylvania:
Exposures to Rainfall pH given a 15% Increase in Anthropogenic H^+
(million cubic feet)

15% Increase in Anthropogenic H^+ pH Levels (Exposures)	Tree Species				
	Spruce	Balsam Fir	Yellow Birch	Maple	Beech
pH 4.44-4.34	1959	1959	246	852	221
pH 4.34-4.24	5035	5035	1398	6965	1114
pH 4.24-4.14	266	266	409	5466	1053
pH 4.14	neg.	neg.	195	3510	712

Sources:

1. Timber materials from: An Analysis of the Timber Situation in the United States 1952-2030, United States Department of Agriculture, Forest Service.
2. pH levels from maps in Memorandum of Intent on Transboundary Air Pollution, Phase 2, Interim Report, Working Group 2, July 1981.

TABLE 4-6

Net Volume of Growing Stock on Commercial Timberland
in New England, New York and Pennsylvania:
Exposures to Rainfall pH given a 25% Reduction in Anthropogenic H^+
(million cubic feet)

25% Reduction in Anthropogenic H^+ pH Levels (Exposures)	Tree Species				
	Spruce	Balsam Fir	Yellow Birch	Maple	Beech
pH 4.61-4.51	1959	1959	246	852	221
pH 4.51-4.42	5035	5035	1398	6965	1114
pH 4.42-4.32	266	266	409	5466	1053
pH 4.32	neg.	neg.	195	3510	712

Sources:

1. Timber materials from: An Analysis of the Timber Situation in the United States 1952-2030, United States Department of Agriculture, Forest Service.
2. pH levels from maps in Memorandum of Intent on Transboundary Air Pollution, Phase 2, Interim Report, Working Group 2, July 1981.

TABLE 4-7

Net Volume of Growing Stock on Commercial Timberland
in New England, New York and Pennsylvania:
Exposures to Rainfall pH given a 50% Reduction in Anthropogenic H^+
(million cubic feet)

50% Reduction in Anthropogenic H^+ pH Levels (Exposures)	Tree Species				
	Spruce	Balsam Fir	Yellow Birch	Maple	Beech
pH 4.77-4.67	1959	1959	246	852	221
pH 4.67-4.58	5035	5035	1398	6965	1114
pH 4.58-4.48	266	266	409	5466	1053
pH 4.48	neg.	neg.	195	3510	712

Sources:

1. Timber materials from: An Analysis of the Timber Situation in the United States 1952-2030, United States Department of Agriculture, Forest Service.
2. pH levels from maps in Memorandum of Intent on Transboundary Air Pollution, Phase 2, Interim Report, Working Group 2, July 1981.

TABLE 4-8

Cumulative Probability Distributions of
Forest Damages for the Four Scenarios

Cumulative Probability	Baseline Current Damages $\$ \times 10^7$)	15% Increase in Anthropogenic H^+ ions from ($\$ \times 10^7$)	25% Decrease in Anthropogenic H^+ ions ($\$ \times 10^7$)	50% Decrease in Anthropogenic H^+ ions ($\$ \times 10^7$)
.025	51.9	57.2	42.2	30.2
.10	69.6	76.2	58.3	42.7
.20	83.9	91.0	70.4	51.3
.30	98.3	106.3	82.6	60.1
.40	113.2	122.2	95.4	69.1
.50	127.9	137.7	107.9	77.9
.60	129.9	139.7	109.7	79.1
.70	136.4	145.9	116.2	84.3
.80	138.4	147.9	118.0	85.4
.90	140.4	149.8	119.8	86.6
.975	148.8	158.1	126.6	91.3

FIGURE 4-5

Distribution of Damages to Both Hardwoods and Softwoods in New England, New York, and Pennsylvania with a 15% Increase in the Concentration of Anthropogenic Hydrogen Ions

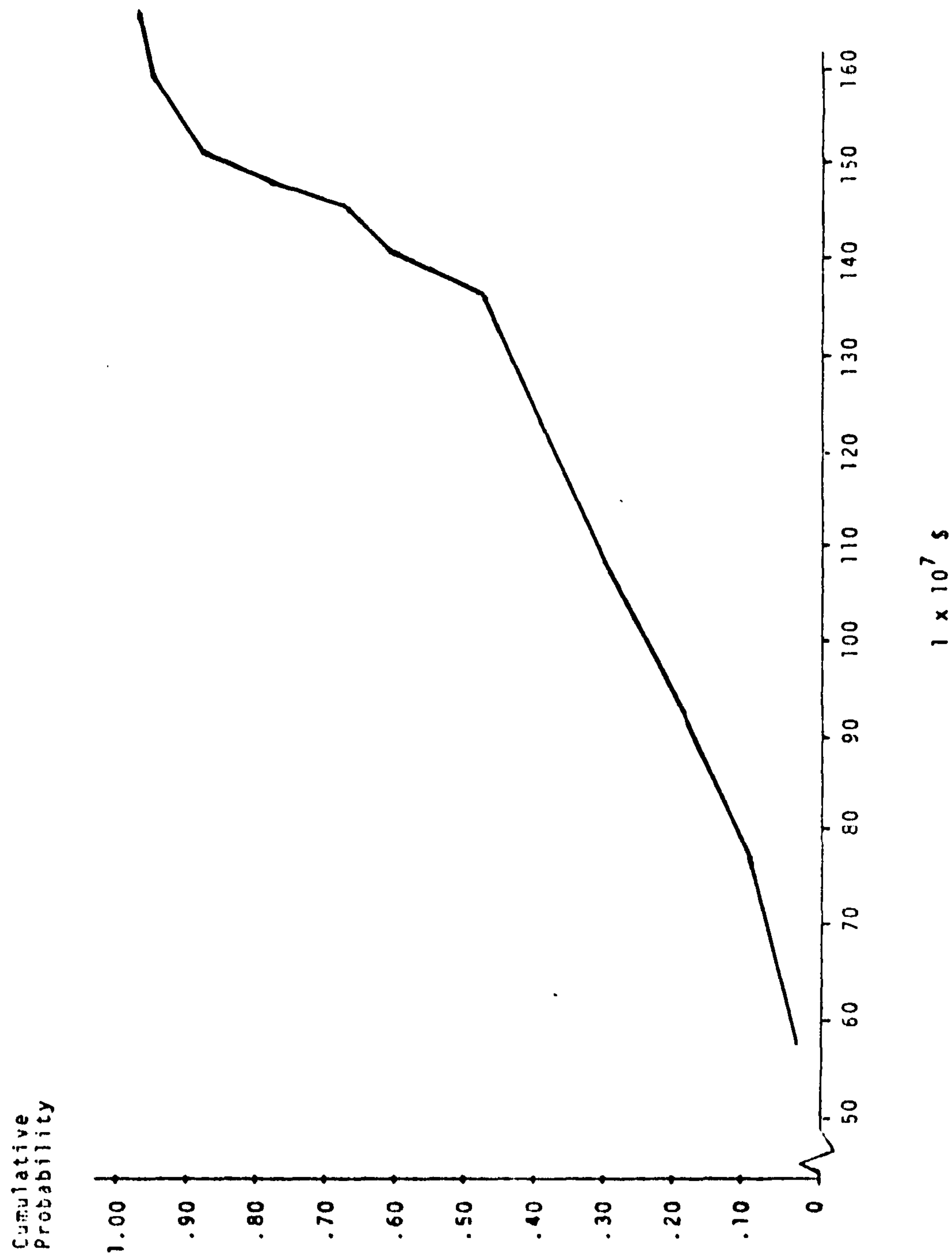


FIGURE 4-6

Distribution of Damages to Both Hardwoods and Softwoods in New England, New York, and Pennsylvania with a 25% Reduction in the Concentration of Anthropogenic Hydrogen Ions

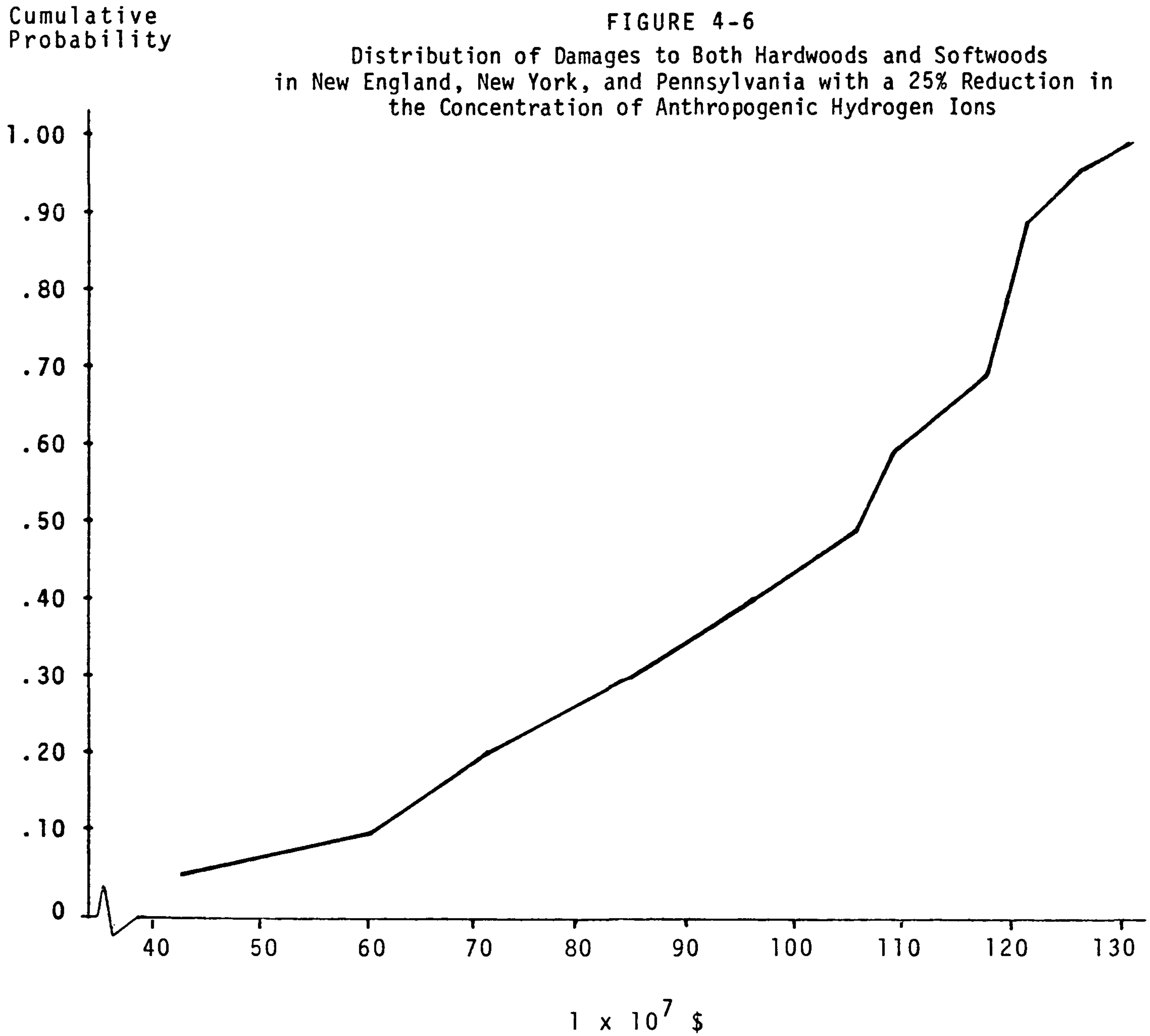
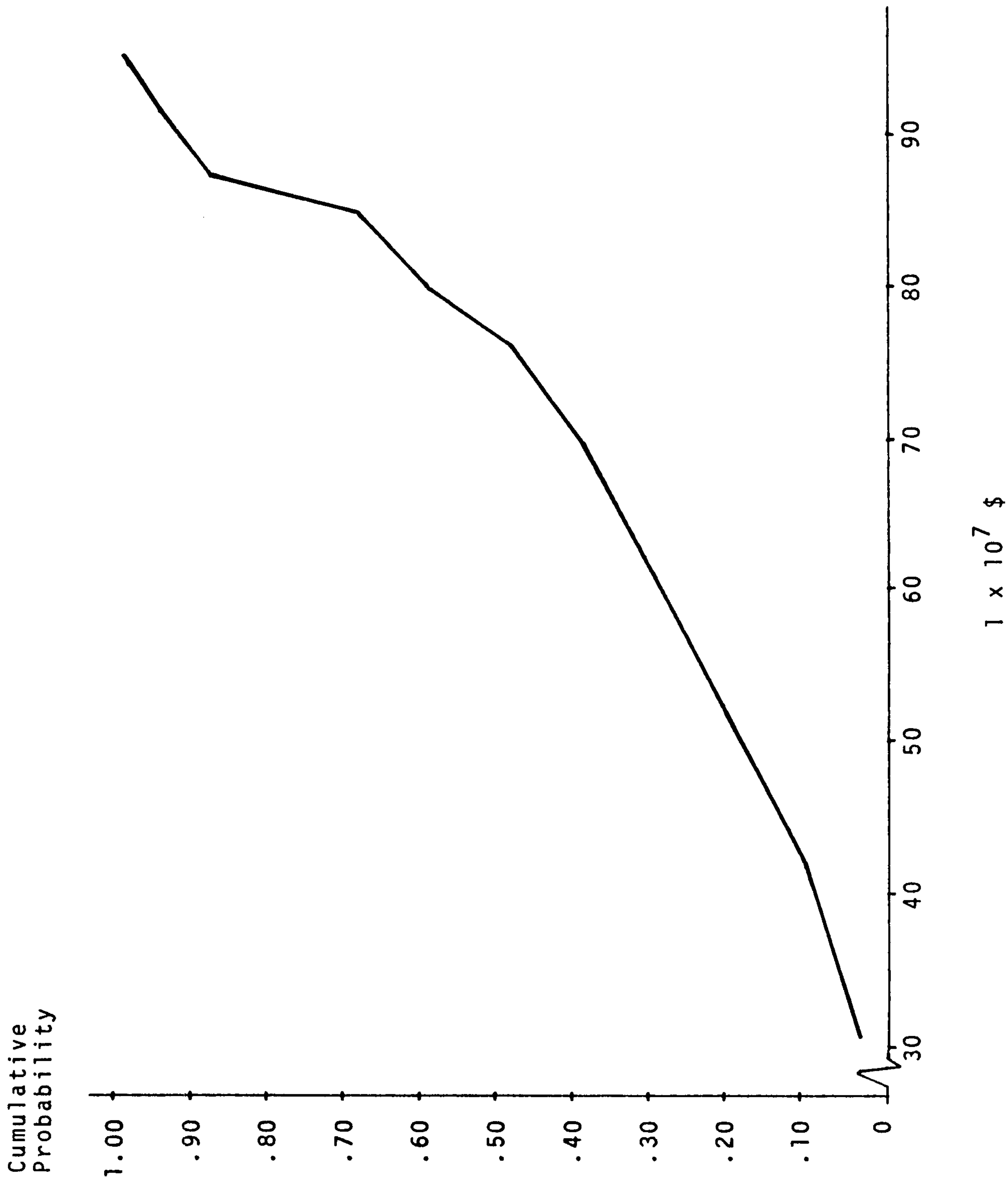


FIGURE 4-7

Distribution of Damages to Both Hardwoods and Softwoods in New England, New York, and Pennsylvania with a 50% Reduction in the Concentration of Anthropogenic Hydrogen Ions



4.4 Summary

This section demonstrated how the probabilistic damage functions can be derived and how they can be used to generate estimates of damages. It remains to be seen how sensitive policy decisions are to the distributions and hence, the degree of resolution needed for dependable decision making. ERC has not pushed the limits on elicitation in this study, but there is every indication that despite the substantial uncertainty about damages, the basic understanding is there to proceed with a decision analytic formulation of acid deposition policy decisions.

Probabilistic damage functions for a number of fish species were also estimated but the lack of information on fish populations as well as a lack of information on the number of lakes at different pH levels prevented the presentation of a similar example for aquatic damages.

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