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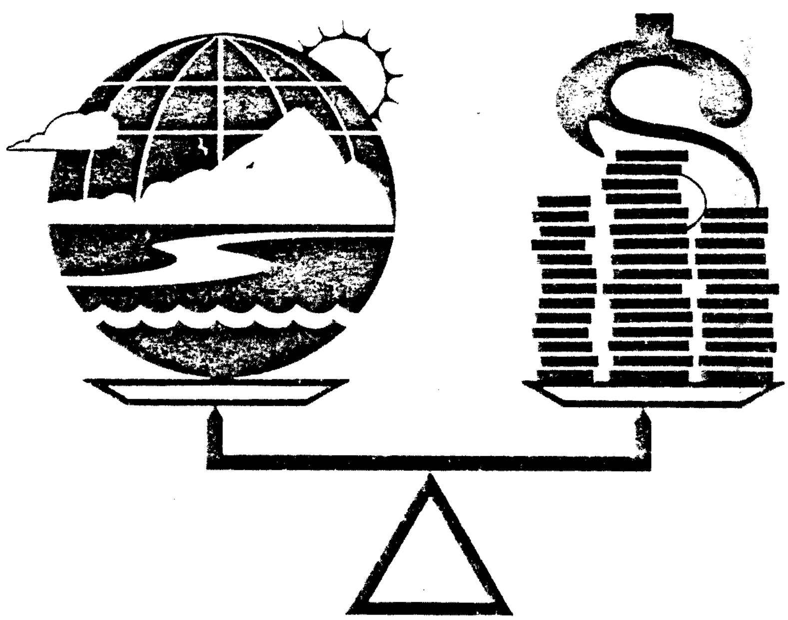
Dimensioning Uncertainty in Estimates of Regional Fish Population Damage Caused by Acidification in Adirondack Ponded Waters



Dimensioning Uncertainty in Estimates of Regional Fish Population Damage Caused by Acidification in Adirondack Ponded Waters

A Final Report Prepared For:

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1.0 INTRODUCTION

This report presents the procedures and results of an exploratory study dimensioning the uncertainty around estimates of regional biotic effects caused by fresh water acidification. This information is meant to augment scientific results by presenting an interpretation of current scientific information concerning acid deposition to policy makers. As such, it must include a measure of the confidence which can be placed in uncertain specific estimates, thereby providing policy analysts with an additional critical perspective.

The premise underlying the method depicted in this report is that an acid deposition policy assessment will be made regardless of the uncertainty or incompleteness of the scientific data. Considerable uncertainty regarding the effects of acid deposition will probably remain even after the research sponsored by National Acid Deposition Task Force is presented in 1989. As a result, policy assessment will be made with uncertain information on the effects of acid deposition, the current rates of acidification, and the reduction of acid deposition that would result from a reduction in precursor emissions. This means that any decision to implement an acid deposition control strategy will contain an implicit evaluation of the probability that a given policy option is the correct choice. Assessment planners have two options:

- either policy makers can be left on their own in evaluating scientific uncertainties, or
- scientists and experts can directly assist decision makers by providing information on these uncertainties.

If the latter option is preferred, the question becomes one of determining how to provide information on the extent of uncertainty in the scientific data so that it is both useful to the decision maker and scientifically accurate.

There is no question that the techniques used in this project will be viewed as controversial by some parties. Still, it is important that the uncertainty in the estimated scientific relationships be dimensioned and this report presents one procedure for accomplishing this. There are, however, other possible techniques. If reviewers and researchers view this approach as inadequate, the authors encourage these individuals to suggest alternatives, particularly since it is important that this dimensioning of uncertainty be performed. This is a "first try", and it is important that alternatives be considered. Still, the conclusions drawn from this project indicate that this approach, or variations of this approach, are able to provide needed information.

It is important that the information provided by this type of analysis be placed in the proper perspective. As with all techniques, there are potential pitfalls in its application. Two particular concerns need to be stated:

1) Policy makers may have an incorrect or inaccurate perception of how "good" experts can be in making these subjective assessments, and thus can be misled by the results; and,

2) That the elicitation of expert subjective judgements does not become a substitute for performing needed effects research.

The information provided by this type of project is meant to augment the more conventional presentation of scientific results. These techniques help to put scientific estimates and conclusions in perspective. The dimensioning of uncertainty is based on current scientific research and knowledge, and is simply another way of presenting this information. It should not be viewed as a substitute for new scientific research.

In this project, considerable care was taken to avoid forcing scientists to make judgments or to portray results at a level of precision beyond what they felt was reasonable. Expert judgments required by this type of study will, by necessity, be somewhat vague. As a result, it may not be appropriate to attempt to obtain precise estimates of the probability distribution for each uncertain outcome. This limitation is explicitly recognized in this study. This project focuses on obtaining estimates of the range of potential effects with only limited expectations regarding the ability of scientists to accurately provide probabilities associated with different outcomes within that range.

The report is organized in the following form. Chapter 2.0 presents some background on the importance of dimensioning the scientific uncertainty in acid deposition research, and the reasoning which led to the selection o[illegible] Chapter 3.0 details the development of the estimation procedure. Chapter [illegible] [illegible]es the performance of the estimation procedure and presents the results of the [illegible]. Chapter 5.0 shows how the collected data can be interpreted and used in an assessment of regional damages to fish populations. Chapter 6.0 presents conclusions drawn from the application of the approach.

2.0 APPROACH BACKGROUND

This chapter presents background information useful for understanding the interpretation of scientific uncertainty used in this project. The first section presents several reasons for dimensioning the uncertainty around scientific estimates for use in policy assessment. The second section discusses the philosophy of the approach, and compares it with techniques used in other studies. The third section discusses how this information could fit into an overall policy assessment model.

2.1 DIMENSIONING SCIENTIFIC UNCERTAINTY FOR POLICY ASSESSMENT

The conventional approach for incorporating scientific uncertainty in policy assessment has been to discuss the weaknesses of the data, but then to select best estimates and proceed with the calculations as if they were certain values. Although scientists carefully explain the limitations of their data and, therefore, the limitations of their results, policy analysts still have to use these results in policy assessment. The policy analysts may simply be unaware of how these factors affect the use of an estimate in a policy assessment framework. By having the scientists dimension the uncertainty due to these limitations, policy analysts will be provided with interpreted results which should, in conjunction with other scientific results and testimony, provide a more comprehensive perspective of the policy alternatives.

When uncertainty is directly incorporated into a policy assessment, two approaches are generally used: statistical derivation of confidence intervals and estimation of a conservative lower bound of effects. If estimates of the effects of acid deposition are derived statistically from historical data, then confidence intervals around the estimated parameters have to be used as a measure of the uncertainty. Confidence intervals, while useful measures of uncertainty, are based on a number of underlying statistical assumptions that may or may not be true. These include assumptions regarding the actual distribution of the residual errors, the functional form of the model, and the inclusion of all important causal variables correlated with variables included in the model. Further, many effects estimates are based on laboratory experiments, or from samples taken in limited geographic areas that then must be applied to larger regions. For these reasons, uncertainty bounds based on statistically derived confidence intervals typically express a lower bound of the uncertainty.

The second approach for handling uncertainty in benefit-cost studies has been to try to establish a lower bound for the estimate of benefits (reductions in damages). 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 that the actual benefit estimates are greater than or equal to the estimated levels. This procedure can be 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. There is, however, no actual dimensioning of uncertainty in this approach.

If the range of uncertain outcomes of strategies to control acid deposition is to be dimensioned, it may be necessary to base the estimates of the uncertainty on subjective evaluations by experts. Even if simulation models or statistical models are used, an alternative dimensioning of the uncertainty can provide useful and, in some cases, necessary information. It may also be necessary to dimension the uncertainty surrounding the application of mechanistic models calibrated for narrow regions in order to obtain regional estimates of the effects. Granting a rationale for the performance of subjective assessments, two questions then arise. First, can subjective evaluations of uncertainty be obtained, and second, how accurate will these assessments be?

Addressing the second question first, the use of subjective probability distributions will be an improvement over a decision making framework that uses only a single "best estimate" of uncertain damages. In choosing a single best estimate of uncertain effects, the researcher or policy maker must be selecting this estimate from some underlying, intuitive probability distribution. If there is not an underlying distribution, 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 fact, he may be obscuring information important to the correct interpretation of his results. As a researcher conducts experiments or performs studies, numerous choices are made in the design and scope of the project. Often, these choices are based on subjective probability assessments concerning the most likely structure of a causal relationship. Scientific research, as well as environmental decision making, requires that numerous subjective probability assessments be made during the normal course of events. Making these underlying, intuitive assessments explicit will only increase the amount and quality of information available to decision makers.

Another advantage in the use of explicit procedures for dimensioning uncertainty 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 benefits from the use of judgement based models when compared with more common and untutored intuitive decision processes.** By having to express the extent of the uncertainty in quantitative terms, researchers and policy-makers are forced to give more thought to the information requirements important to the decision problem. Explicit procedures for dimensioning uncertainty will also assure consistency across different researchers. If procedures for dimensioning uncertainty are not defined, many different and possibly non-comparable methods will likely be used by the different researchers.

Many important policy and assessment questions can be addressed by dimensioning the uncertainty around effects estimates:

1. It will help decision makers evaluate alternative policies with uncertain implications.

2. By using explicit procedures for dimensioning uncertainty, <u>information critical to policy assessment can be subject to formal peer review</u> with respect to both its content and estimation procedures.

3. It will assist in the determination of research priorities by showing the benefits of reducing uncertainty in different effects areas.

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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 the models in making marketing decisions.

4. It will allow, in conjunction with economic analysis, important policy questions to be addressed, particularly:

   - the appropriate timing of control strategies
   - the benefits and costs of delaying the implementation of control strategies in order to collect additional information.

2.2 BACKGROUND TO THE APPROACH USED TO DIMENSION UNCERTAINTY

The approach for dimensioning uncertainty most often used in risk assessment has been to have experts provide point estimates of the probability of occurrence of different events. The precision implied in these point probability estimates simply may not be realistic. In spite of the sophisticated probability encoding techniques that are available (see Lichtenstein et al., in press, and Spetzler and Stael von Holstein, 1975), scientists whose opinions regarding the likelihood of different events, which may be only vaguely formulated, can feel manipulated by a precise probability encoding process. In response to this concern, Suppes (1974) and most recently Feagans and Biller (1981) have used estimates of probability intervals rather than less realistic point estimates of probabilities for different effects estimates.

In developing a method for assessing health risks in the setting of National Ambient Air Quality Standards (NAAQS), Feagans and Biller obtained upper and lower subjective probabilities for each event under consideration. The vagueness or imprecision of the experts' judgement in their approach is reflected in the difference between the upper and lower probabilities. The method selected for use in this study is similar to the approach used by Feagans and Biller in that the imprecision in the experts' ability to express or dimension uncertainty is directly addressed. The focus is on estimating the range of potential effects (i.e., upper and lower bounds to effects) with only a simple weighting scheme to express the likelihood of different outcomes within that range. The Feagans and Biller approach is designed to provide considerably more detailed information. They consider each outcome within the possible range of effects and have the expert estimate upper and lower probabilities for each outcome. Although the elicitation depicted in Chapter 4 of this report has less ambitious information goals, scientific experts were able to provide the requested estimates more reliably and, therefore, view them as more credible. The lack of information on causal mechanisms associated with acidification effects as [illegible]rge variability in ecosystem response to acid deposition warrants conservati[illegible]ons regarding the precision with which experts can associate different eff[illegible]es with probabilities.

The objective of this process is to obtain information concerning the uncertainty of effects estimates, and not to implement a procedure that requires a level of precision that can not be met. Wallsten et al. (1983) cite publications which show that U.S. Army intelligence analysts do not use explicit quantitative probability estimates in their analyses because they believe numeric estimates fail to convey the vagueness inherent in their opinions. The method taken in this study falls in between the precise estimation of a probability distribution and the refusal to incorporate any numeric probability estimates.*

2.3 A POLICY ASSESSMENT APPROACH

The framework used to dimension uncertainty in this project was developed from the data requirements of several economic studies as well as other general policy assessment approaches (see Violette and Peterson, 1982). There are a number of common characteristics to the assessment approaches that were considered. One such characteristic is that rather than focusing on optimizing, i.e., picking the best approach from among all possible approaches, the policy approaches considered utilize a satisfying criteria. Instead of selecting the best policy from all potential policy options, the approach focuses on selecting the best policy from a limited set of options. For example, a preselected set of policy options could encompass:

Policy 1 - a no change strategy, i.e., no new controls.
Policy 2 - a 20 percent decrease in precursor emissions.
Policy 3 - a 40 percent decrease in precursor emissions.

These three policy options are quite distinct. The information needed to pick the best policy from among these three is very different than the information required to deter-

*As was pointed out by Wallsten et al. (1983), the use of non-numeric phrases to describe uncertainty may cause problems because the phrases are understood differently by different people.

mine whether a 20 percent or 25 percent reduction in emissions is the better choice. Choosing between policies this similar will be a difficult task, given current information concerning the effects of acid deposition. Only limited resolution between different policy options may be achievable due to uncertainty in effects estimates.

If the costs of the three policy options presented above are $0, $1 and $3 billion annually, then:

- o Policy 1 will be the best choice of the three if benefits from adopting Strategy 2 are less than $1 billion and the benefits of Policy 3 are less than $3 billion, i.e., the costs of each of the control strategies are larger than the benefits.

- o Policy 2 will be the best choice if the net benefits of a 20 percent reduction in emission (benefits - costs) are positive and greater than the net benefits of Policy 3.

- o Policy 3 will be the best choice if the net benefits of a 40 percent reduction in emissions are positive and greater than the net benefits of Policy 2.

Violette and Peterson (1982) show how these selection criteria can be framed as the probability that the benefits of reductions in emission fall into given intervals. Although Violette and Peterson (1982) formulated the intervals in terms of average damages in dollars per unit of acid deposition to facilitate comparisons across different emissions reductions policies, the basic concept involves estimating the probability that the benefits of a 20 percent reduction in emissions exceed its costs (i.e., the probability that benefits are greater than or equal to $1 billion) and the probability that the benefits of a 40 percent reduction in emissions exceeds $3 billion. Estimating the probability that benefits of a given control strategy are greater than or equal to a given cost of control is a much simpler task than estimating the marginal damage curve (as economists conventionally prescribe), or even estimating the probability that benefits equal a given number, i.e., obtaining a point estimate. The assessment problem may also be construed as being analagous to purchasing insurance against unwanted and uncertain future damages. In this case, different acid deposition control strategies can be viewed as purchasing insurance in order to prevent the occurrence of environmental damages. The decision maker would be asked to determine the extent of the premium which he would be wi'. _ to purchase in order to avoid different acid deposition-caused effects and their associated probabilities.

The framework presented above greatly reduces the information requirements of the assessment. The dimensioning of the uncertainty may be somewhat vague and imprecise, as the level of resolution is simply that necessary to select between distinctly different policy options. It recognizes that imprecise or uncertain effects estimates will not be sufficient to differentiate between slightly differing policy alternatives. One result of this type of assessment is to eliminate clearly inappropriate policy options while specifying a set of "satisfactory" alternatives.

Even if the types of uncertainty bounds placed on effects estimates are not incorporated within a policy assessment procedure of this type, they will still be valuable in accurately portraying current scientific information to policy makers. For example, the procedure employed in this project integrates many scientific complexities in a format which presents regional damages to fish populations resulting from fresh water acidification. A principal benefit of this approach is the clear display of scientific information not previously available to the decision maker. The results of this project are meant to provide broadly defined and integrated perspectives to non-scientists dependent upon scientific information for the performance of their responsibilities in policy assessment.

3.0 DEVELOPMENT AND STRUCTURE OF THE DAMAGE FUNCTION ESTIMATION PROCEDURE

This chapter outlines and discusses the design of a process for presenting scientific information on fresh water acidification in a manner useful for policy assessment. To be useful in policy evaluation, the scientific estimates should be regional in scope and the uncertainty in the estimates should be dimensioned. The elicitation process developed in this project meets these two criteria. The development of the elicitation is an important part of this approach. If the elicitation were not carefully designed, it could misrepresent current scientific information. In order for scientific and policy researchers to have confidence in the results of the elicitation, this chapter details the logic used in the design of the elicitation. The discussion is divided into four segments reflecting the temporal and logical development of that process. Section 3.1 specifies the purpose of the estimates and the scope of their application. The remaining sections outline the work performed in order to accomplish these objectives. Section 3.2 reviews the development of the initial elicitation framework. This initial elicitation structure served as the starting point for developing a structure that would be credible to the scientific community and still meet the needs of policy assessment. Section 3.3 shows how this initial structure evolved as a result of presentations and pre-tests of the procedure. Section 3.4 presents the final form of the elicitation structure.

3.1 SCOPE AND PURPOSE OF THE ESTIMATES

As noted in Chapter 1, the purpose of this project was to assess a particular approach for evaluating regional damages to aquatic biota caused by acid deposition.* Chapter 2 presented the background and justification for this approach in policy assessment. This section addresses the use of this approach for quantifying the uncertainty in estimates of regional damages to aquatic ecosystems. Broadly speaking, the purpose of the process was to determine the response of selected aquatic populations, i.e., fish and more

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* Because functional relationships between atmospheric acid loading and lake acidification have not yet been adequately quantified in North American waters, the goal of the project was to obtain predictions of the biotic consequences of regional changes in levels of fresh water acidification.

specifically, gamefish to increased hydrogen-ion concentrations in fresh water ecosystems. The project could have, however, focused upon other aquatic populations (such as macroinvertebrates), or on chemical and biologic processes (such as oligotrophication), or lastly, upon changes in the structure of aquatic communities.*

The number of fish species that could be analyzed was limited. Game fish species were the focus of this application due to their more obvious social and economic value to society.** Although some non-game species are known to be quite sensitive to the effects of acidification, it is difficult to estimate economic damages resulting from their decline or extinction. It is important, however, to realize that assessments of the impacts of acid deposition should not be limited to only those effects that can be easily quantified in economic terms.***

The aim of this project was to estimate the relationship between changes in fresh water pH and loss of fish populations on a regional basis. The independent variable is the current pH of ponded waters, not the precipitation pH. The broader question of how acid deposition affects fish requires the development of additional information showing the linkage between deposition and changes in lake water chemistry. The latter relationship could be provided if two additional pieces of information were available: (1) the ionic constituents of dry and wet deposition; and (2) the fate of those atmospheric ions described in terms of their interaction with the edaphic environment and subsequent

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* While the biologic effects of acidification caused by acid deposition have been widely observed and reported at virtually all trophic levels in Scandinavia, Canada, and the United States, the effects upon fish have been the most carefully investigated and documented in the literature. In addition, the decline of fish populations in both Scandinavia and North America has been a focal point of public and political concern.

** Damage estimates were, however, performed on three non-game species during the project. In two cases, because the scientist believed he knew substantially more about a particular non-game species than candidate game species. In the other, a non-game species was considered because of its status as an "indicator" of a system's response to acidification. For additional detail, see Sections 3.2 and 3.3.

*** Additional work is being undertaken to investigate the best way to incorporate ecosystems effects that cannot be easily quantified in economic terms. A description of the effects should allow decision makers to incorporate the non-economic effects within the assessment. The authors of this report do not advocate an assessment based only on effects that can be economically quantified.

transport to the aquatic ecosystem.* Such an analysis would have the general structure outlined below.

Step 1 - Estimate the probability that changes in emissions of precursors will result in changes in acidic deposition.

Step 2 - Estimate the probability that changes in deposition will cause changes in aquatic chemistry.

Step 3 - Estimate the probability that changes in given water quality parameters will cause effects in given fish populations.

While the performance of the analysis outlined above would provide policy-makers with considerably more information than provided by the performance of Step 3 alone, the present analysis was considered appropriate given the scope and objective of this project.

There are a number of regions in the United States which contain fish populations inhabiting dilute lakes and streams exposed to acid deposition inputs (Haines, 1981; Pfeiffer and Festa, 1980; Schofield, 1976, 1982; Baker, 1982; Arnold, 1980). These regions possess generally low acid neutralizing capacity and have drainage systems situated in areas of crystalline or metamorphic bedrock with shallow soils of low buffering capacity (Omernik, 1982).** While numerous areas in the United States possess poorly buffered surface waters, inventories of water quality and fish population status are incomplete for all of these areas. The most extensive available inventory data and the only published literature relating fish population decline to pH within the United States covers the Adirondack Region of New York State. Consequently, this region was selected to evaluate the use of this probabilistic approach as a tool for evaluating the regional effects or impacts of acid deposition. The Adirondack Region is also useful in that a

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* Atmospheric precipitation is water in equilibrium with atmospheric gases which contains dissolved and suspended matter taken up by the water droplets during passage through the atmosphere. As the water contacts the soils and bedrock of a region, it interacts with the mineral constituents physically and chemically, leaching out the more soluble fractions. This water flows into rivers and lakes, creating changes in the concentrations of the ions in the surface water. These changes cause biotic responses being examined in this report.

** Acid neutralizing capacity (ANC) is the equivalent sum of all bases which can be titrated with a strong acid. The base neutralizing capacity (BNC), is the sum of all acids which can be titrated with a strong base. Total ANC and BNC can be considered as the composite of individual acid/base systems (Driscoll and Bisogni, 1982; Henriksen, 1981).

number of previous damage assessments have been prepared [illegible] Pfeiffer and Festa, 1980; Menz and Mullen, 1982). Comparison of the current assessment with the conclusions and procedures of its predecessors should allow for a more complete review of the current technique.

A large data set covering the Adirondack Region is maintained by the New York State Bureau of Fisheries. The fish listing developed by the state contains information on approximately 3,500 waters with over 35,000 records. However, the Department of Environmental Conservation (DEC) has current data for only 937 of the approximately 3,500 surface waters contained within the file. Information contained within the file is derived from three main sources: a survey of water quality and fish populations in Adirondack surface waters conducted from the 1920s to the present; a survey of 214 of the 219 Adirondack lakes above 610 meters conducted in 1975 (Schofield, 1976); and the results of a sampling program established in 1975 by the DEC to determine the "scope of water quality impacts associated with acid ion deposition" (Pfeiffer and Festa, 1980). Since 1975, the DEC has sampled 937 Adirondack ponds and lakes, or 34 percent of the total number of lakes and ponds within the Adirondack Ecological Zone.* More comprehensive water chemistry investigations have been conducted upon single Adirondack lakes, or in some cases, small watersheds. The Integrated Lake-Watershed Acidification Study (ILWAS) studied lake acidification processes for three lake watersheds in the Adirondack Park Region of New York (Chen, 1980). In addition, detailed chemical analyses have been conducted by Dr. Charles Driscoll and co-workers for a small number of lakes (Driscoll, 1980; 1982a; 1982b). The DEC has closely monitored six lakes in Hamilton and Herkimer counties since 1978 (Pfeiffer and Festa, 1980). While stream water chemistry has not received the same emphasis as ponded water chemistry, recent studies conducted by the New York DEC (Colquhoun, 1981, 1982) have indicated that Adirondack streams are affected by pH and alkalinity depressions.

Data on fish populations within the Adirondacks are generally limited to presence-absence data contained within the DEC fish listing. Standing crop data was, however, collected for three brook trout ponds using interview techniques by DEC staff in 1973. The DEC interviewed fishermen to estimate angling pressure per acre for each lake and the number of fish caught. From this, the DEC estimated the standing crop of these

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* Thirty-five additional Adirondack lakes and ponds were surveyed and test netted by the DEC in 1982.

three brook trout ponds, expressed as yield per acre in 1972 as: Black, 1.18 pounds/acre; Shaver, 1.81 pounds/acre; and Whey 0.28 pounds/acre. However, considering that there are some 2,759 lakes in the Adirondack Ecological Zone (3506 in the broader DEC fish listing), such limited standing crop information is scarcely useful for the prediction of fish populations in the region, or for the estimation of the effects of acidification upon those fish communities.*

Areas other than the Adirondacks have also been surveyed for data on water chemistry and fish populations, yet the majority of the data remains unpublished, unreleased, or incompletely analyzed by the investigators. When these data become available, a regional assessment similar to the one performed in this report could be conducted. Investigators at the Brookhaven National Laboratory are currently conducting an assessment of acidic precipitation effects on surface and groundwaters for the entire United States. The major objectives of the research are: (1) quantification of the sensitivity of freshwaters within the United States to acidification; (2) determination of the extent to which they have been impacted; and (3) investigation of the impact of acidification on groundwaters using current and historical data. The researchers are collating existing data on water quality from STORET and 157 other sources. Data are entered into the Acidification Chemistry Information Database (ACID). By September 1982, the ACID database contained approximately 1.7×10^6 data values obtained on 5.7×10^5 dates from 4.15×10^4 water quality stations in the eastern United States. Data are restricted to stations which report that 60 percent of their alkalinity measurements are equal to or less than 500 µeq/l, or those with pH measurements of 7.5 or less (Hendrey, 1983). In addition to BNL's work, surveys have recently been conducted by the Fish and Wildlife Service in New England (Haines, 1982, unpublished) and in the Mid-Atlantic states (Arnold, 1980). The U.S. EPA Environmental Research Lab in Duluth has characterized water chemistry in northern Minnesota, Wisconsin, and Michigan and is using what current information exists on fish populations and a number of other parameters to evaluate the characteristics and resource value of each of a number of different watershed lake types.

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* In 1980, Pfeifer estimated that there were approximately 2,877 individual lakes and ponds within the Adirondack Ecological Zone. This number was revised in the 1981 Acidity Status Summary.

Major scientific uncertainties concerning the effects of hydrogen ion concentration upon fish populations might usefully be divided into two domains. First, as noted above, there is currently very little comprehensive inventory data covering water quality and fish population status. Second, there is substantial uncertainty regarding fish population responses to lake and stream water acidification.*

3.2 DEVELOPMENT OF THE PROCESS

The process can be divided into four segments: (1) the development of the initial elicitation structure; (2) the pretest and evaluation of the initial structure, followed by revisions to the elicitation; (3) the implementation of the final elicitation structure; and (4) the analysis of the results. This section reviews the development of the elicitation framework. The initial step in developing the elicitation was to review the available scientific research literature covering the effects of pH depression upon aquatic organisms; this is discussed in Section 3.2.1. The initial elicitation structure, discussed in Section 3.2.2, was quite detailed in order to reflect the complexity of the direct and indirect effects of pH shifts upon fish populations. Discussions with cooperating scientists allowed important simplifications in the elicitation format to be made. Section 3.3 summarizes this procedural development, while emphasizing key issues relevant to the assessment of fish population change as a function of change in pH. The final elicitation structure is discussed in Section 3.4.

In order to develop and implement the analysis, the investigators used a highly interactive approach. Section 3.2, and to a lesser extent, Section 3.3 attempt to convey the evolution and development of the analysis over time.

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* Damage estimates relating pH values to fish population declines are extremely uncertain. Lake morphometry, primary production, plus calcium and dissolved organic carbon concentrations, to list but a few factors, appear to all have profound influences upon the toxicity of a given lake or pond pH value to a fish population, and as these and other parameters vary widely, plotting regional fish population response to pH values is very problematic. In addition, recent work by Driscoll and co-workers has shown significant temporal and spatial variability of pH values and other water chemistry parameters within a small Adirondack lake (unpublished data). Given this degree of chemical variability and, for example, apparent brook trout avoidance of low pH waters in favor of waters with a higher pH, lakes with measured critical or lethal pH values could possibly sustain fish populations.

3.2.1 Literature Review

The first step in developing the elicitation was the compilation of an extensive file covering the effects of low pH on aquatic organisms at different trophic levels. This review of the broader aquatic effects literature had several purposes: (1) achieving an appreciation of the primary scientific hypotheses concerning the effects of depressed pH upon organisms in dilute acidified waters; (2) listing the critical scientific uncertainties both from the perspective of hypothesis confirmation and policy assessment; and (3), developing a working vocabulary, to enable the authors to participate in discussions with members of the scientific community. The accomplishment of (3) enabled the interdisciplinary translation of one analytic idiom, aquatic ecology and biology, into that of another, policy assessment. Such interdisciplinary understanding was found to be helpful in the development of the elicitation logic and in the specification of its variables.

More specifically, the objectives of the literature review were to:

1. Identify the effects of pH depression and associated metal toxicity upon aquatic organisms.

2. Identify the mechanisms by which pH depression and metal toxicity are thought to affect aquatic organisms.

3. Identify the majority of aquatic organisms and all fish species on which "acid deposition" research has been conducted.

4. Identify the critical uncertainties of the effects of pH depression and metal toxicity upon individual species and aquatic communities.

5. Determine if fish populations could be expected to decline as a result of some greater sensitivity of essential or preferred prey organisms to declining pH values; i.e., determine if indirect effects are important for the calculation of fish population mortality.

A cross-referenced indexing system was utilized for the literature reviewed. Each paper was categorized by species, subject, and metal where appropriate (See Table 3-1). Based upon the literature review, a list was compiled of a number of important fish for which

Table 3-1

Subjects By Which the Aquatic Literature Was Classified

Algae	Physiological Damage
Bioassay	Phytoplankton
Community	pH Stress - Acidification
Development	Reproduction
Invertebrates	Resistance
Lentic	Respiration
Lotic	Survival
Macrophytes	Zooplankton
Metal Toxicity	

data existed upon the effects of acidic conditions and associated m. . . .) (Table 3-2). Each fish species was characterized as being either a lentic, lotic or lentic-lotic inhabitant. Within each category, further subdivisions were based upon the predominant feeding habits of adults. Three food habit categories were recognized: (1) planktivores; (2) insectivores; and (3) piscivores. Although simplistic, this approach was useful in sorting and evaluating the literature concerning possible food chain and trophic community affects upon fish populations.

Five life stages were recognized for each species: (1) egg; (2) sac-fry; (3) fry; (4) juvenile; and (5) adult. This division allowed the investigators to record the effects of low pH and toxic metal concentrations upon different reproductive life stages of the fish species in question. Both field observations and laboratory experiments have suggested to researchers that the reproductive life stages are particularly sensitive to low pH. Furthermore, tolerance to low pH and elevated toxic metal concentrations varies significantly among the early reproductive or development stages of different species (Baker, 1981; 1982).

Information derived from the literature was recorded as it pertained to the different life stages of the species in question. Specifically, data were sought on chronic and acute lethal levels of pH for each life stage, metal toxicity levels, and physiological and population responses to each (see Table 3-3 for an example).

3.2.2 The Initial Elicitation Structure

The collection of the extensive set of data outlined in Section 3.2.1 was motivated by the complexity of the biological effects and the specific elicitation procedure developed. The framework of the initial elicitation structure resulted principally from interplay between the investigator's interpretation of the scientific literature and the form of analysis imposed by subjective assessment.

The structure of the elicitation was designed to incorporate a number of scientific complexities resulting in a subjective damage function expressing fish population decline. The decline was initially expressed as a percentage reduction in the fish population of a given stream or lake habitat. Mortality was expressed as a function of the independent

Table 3-2

Fish Species for Which Literature Contains Information on Effects of Acid Stress and/or Metal Toxicity[1]

Salmo clarki	Cutthroat trout
Salmo gairdneri	Rainbow trout
Salmo salar	Atlantic salmon
Salmo trutta	Brown Trout
Salvelinus fontinalis	Brook trout
Carassius auratus	Goldfish
Cyprinus carpio	Common carp
Phoxinus phoxinus	Minnow
Pimephales promelas	Fathead minnow
Catostomus commersoni	White sucker
Esox lucius	Northern pike
Ictalurus nebulosus	Brown ballhead
Ictalurus punctatus	Channel catfish
Cyprinodon nevadensis	Desert pupfish
Lebistes reticulatus	Common guppy
Lepomis macrochirus	Bluegill
Perca fluviatilus	Perch
Rutilus rutilus	Roach
Brachydanio rerio	Zebra fish
Jordanella floridae	Flag fish

[1] Species with only anecdotal information available were not included.

Table 3-3

Example of Data Compilation

Salvelinus fontinalis (Brook Trout)

lentic-lotic, insectivore.

EGG

pH STRESS	METAL TOXICITY
(74)[1] 24.6% mortality at pH 4.65	(54) Cd: no affect 0.06-6.4μg/l
(94) pH 4.5 mortality threshold	(69) Cu: 17.5 g/l no effect
(153) pH less than 6.5 caused significant decrease in egg hatchability and growth, pH 4.45 100% mortality	

SAC-FRY

pH STRESS	METAL TOXICITY
(74)[1] Acclimation to sub-lethally low pH increases survival of fry in low pH, poor survival in pH 4.00-4.65.	(69) 17.4-32.4 μg/l greatly affected growth and survival.
(94) Survival of fry at pH 4.5.	(54) Cd: No effect 0.06-6.4μg/l.
(153) Alevin mortality 100% at pH 5.00 in 3 month study.	

FRY

pH STRESS	METAL TOXICITY
(82) Damage occurs at pH 5.2 and lower	(54) Cd: no effect on survival 0.06-6.4 μg/l but discussed growth
	(69) Cu: same as sac-fry

[1] Access number for literature file.

Table 3-3

Example of Data Compilation

(Continued)

Salvelinus fontinalis (Brook Trout)

lentic-lotic, insectivore.

pH STRESS	METAL TOXICITY
JUVENILE	
(77) O_2 transport capacity of blood decreases at low pH; caused by Na loss because Na balance requires energy, therefore Na efflux at low pH	(54) Cd: no effect 0.06-6.4 μg/l but reduced growth
(87) low pH causes O_2 uptake to be inhibited, thus net Na loss	(69) Cu: 17.4-32.5μg/l severely affected growth and survival
(153) 100% mortality at pH 4.45, mortality 25% at pH 6.56 or lower	
ADULT	
(153)[1] Survive at pH 4.5, recommended pH maintained at 6.5 or greater.	(69) Cu: 17.4-3.4μg/l no effect
(168) Decreased survival at pH 4.2 over time. More tolerant to low pH in winter than summer, O_2 demand less in winter.	(54) Cd: 3.4 mg/l strongly affected spawning males. 6.4μg/l killed.

[1]Access number for literature file.

variable, pH.* The initial structure proceeded from simple to more complex scenarios (see Figure 3-1). Initially, the participating scientist would estimate damage based upon a simple laboratory experiment. Because considerable research on the effects of pH depression on fish has been performed in bioassay experiments, and because these experiments allow for the variation of one variable while holding others strictly constant, the process of estimating dose-response (pH-mortality) relationships was simplified (Wood, C.M. and D.G. McDonald, 1981; Spry et al., 1981). From this simple scenario, the scientist would participate in successive elicitations, with each new elicitation adding more complexity. The last step in this process is an elicitation designed to estimate the effects of pH decline on selected fish populations in natural habitats.

The gradient of complexity in the initial elicitation structure evolved from a previous study conducted by ERC. In that work, scientists appeared to have greater success in providing damage estimates for carefully specified situations in which one variable of an experimental situation was changed, while the remainder were left constant. When faced with more uncertain estimates of damages to receptors, e.g., a natural habitat or region, participants expressed the belief that they knew too little to be able to provide any damage estimate. Elicitation Steps 1, 2, and 3 in Figure 3-1 were included to serve as preparatory steps so that participants would be able to complete Step 4 of the initial elicitation structure.**

In order to apply the initial elicitation framework, the fisheries habitat of the Adirondacks was divided into three parts: the lentic, the lotic, and the lentic-lotic. For each of these habitats, three different trophic-niches were stipulated, to be filled by those fish which could be considered either piscivores, insectivores, or planktivores. For each trophic-niche, at least one species of fish was to be the subject of an elicitation. Therefore, a minimum of three species of fish - each representative of a different ecological

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* Adverse effects of acidification on fish may be a function of both pH levels and elevated metal concentrations in surface waters. In the Adirondack mountain region, aluminum, manganese, and zinc have exhibited increased concentrations at depressed pH levels (Schofield, 1976). Aluminum has received the most attention as being potentially toxic to fish populations, and research indicates that damage estimates based only on pH levels may be in error (Baker 1982).

** Reluctance to express subjective judgements about uncertain environmental effects is probably due to a number of factors, including: (1) unfamiliarity with the concept and its application; (2) a belief that subjective judgements are not scientific and (3) the improper specification of the variables in the relation being estimated.

Figure 3-1

Overview of the Initial Elicitation Structure

<u>First Step Elicitation</u>

Estimates of mortality for different reproductive life stages of a fish species in a controlled flow-through apparatus.

<u>Second Step Elicitation</u>

Estimates of mortality for a species "population" comprised of different reproductive life stages in a controlled flow-through apparatus.

<u>Third Step Elicitation</u>

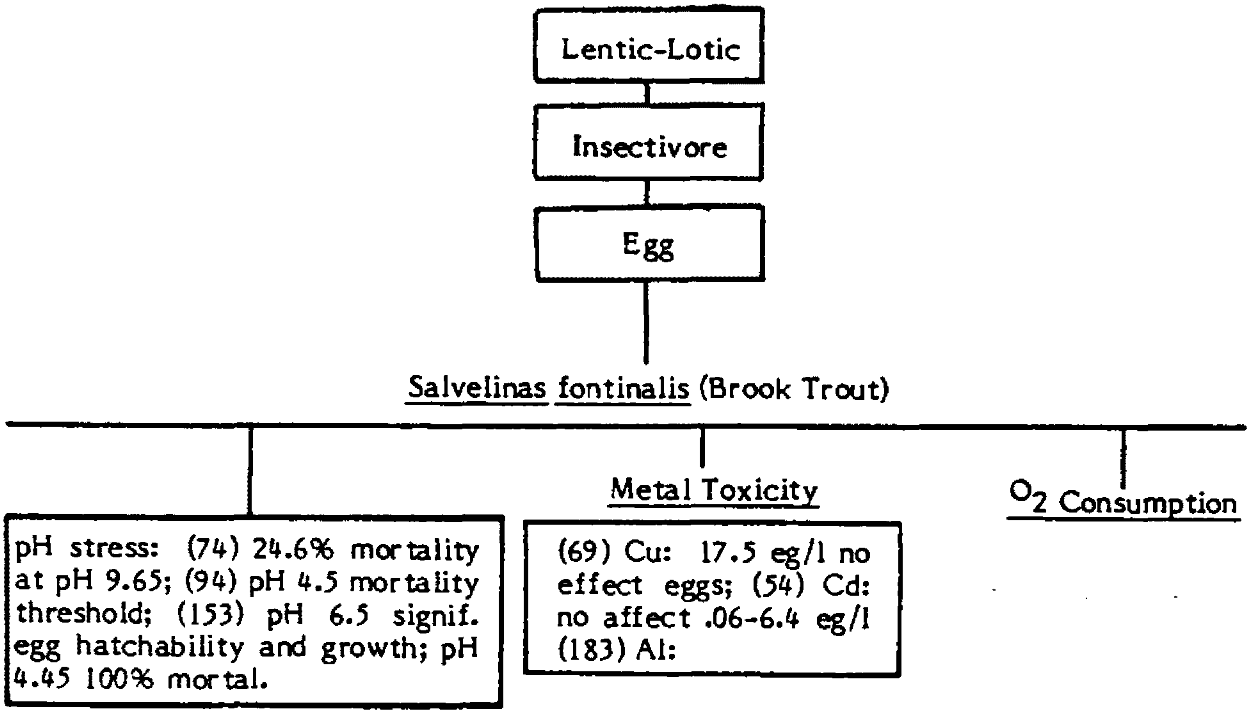
Estimates of mortality for a single species population in three "representative" lentic-lotic habitats.

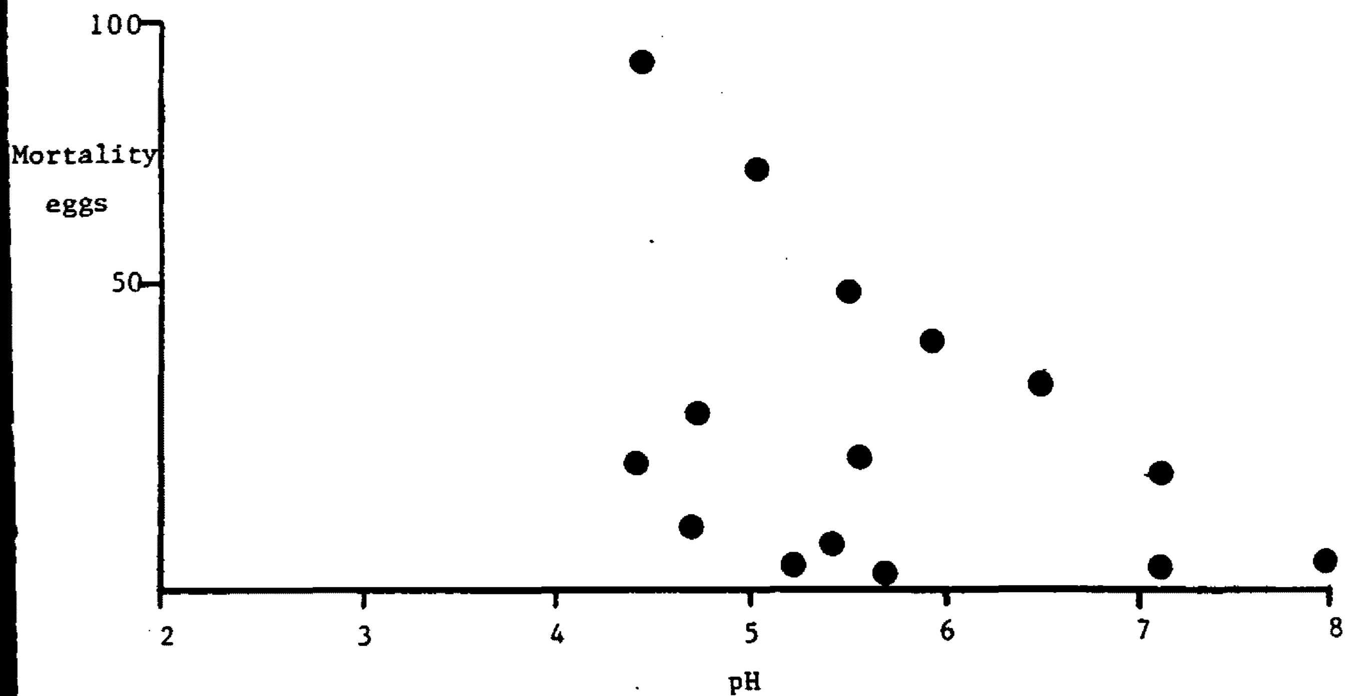
<u>Fourth Step Elicitation</u>

Estimates of mortality for a single species population, incorporating interspecific interaction and possible changes in trophic relationships occurring in three "representative" natural habitats.

Figure 3-2

Egg Mortality of Brook Trout Reported in the Literature*,**





* Numbers in parenthesis refer to data file listings.

** Graph represents % mortality of eggs as a function of pH. Points are taken from the literature.

niche - were to be investigated for each habitat type. Because a number of game fish would occupy similar positions within <u>this</u> framework, for example, brook trout and rainbow trout, the actual number of elicitations would have been greater than three. Inquiry into non-game species was considered appropriate in order to better represent possible interspecific effects and food chain disruptions.*

The investigators did not completely specify the fish species to be considered in the analysis. It was decided that the final determination of the fish species to be analyzed should be a product of the interview process between the investigators and the participating scientist. Because fisheries scientists or ecologists are generally more familiar with certain fish species, it was assumed that results of the elicitation would be more reliable if participating scientists were able to specify those particular fish species for which they had the greatest confidence in their predictions. As a consequence of this indeterminancy, the data obtained from the literature review was organized in parallel to the logic of the elicitation procedure whenever it was available (see Figure 3-2). Every reproductive stage of the fish species under consideration was evaluated in terms of percent survival relative to a set of water quality parameters.

The literature review revealed that certain metals are present in increased concentrations in acidic waters, namely zinc, manganese, and aluminum (Schofield, 1976). Presumably these elevated concentrations are a result of the increased solubility of these metals at lower pH values. Of these metals, only aluminum has been found to be toxic to fish at concentrations currently measured in acidified waters (Baker 1981; Baker and Schofield 1982; Muniz and Leivestad, 1980). On the other hand, calcium has been shown to decrease the membrane permeability of fish undergoing acid stress, and consequently decrease the rate of sodium loss. A number of investigators have observed correlations between decreased calcium content and fish mortality as well as correlation between increased calcium concentration and fish survival (Spry, 1981). As a result, it was felt necessary to specify the concentrations of aluminum and calcium in the water for each pH level. The relationships between aluminum, calcium and pH were taken from regressions computed by Schofield (1976) of Cornell University. These relationships were based upon water chemistry samples taken from 214 lakes above 610 meters in elevation (see Figures 3-3 and 3-4).

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*Indirect effects and interspecific relations were explicitly structured into the logic of the analysis in the fourth, and last step of the process (Figure 3-1).

Figure 3-3

Relationship between aluminum concentrations and pH in Adirondack lakes more than 610 meters elevation, June 24-27, 1975

(log Y = 3.99-0.34X, r = -0.675)

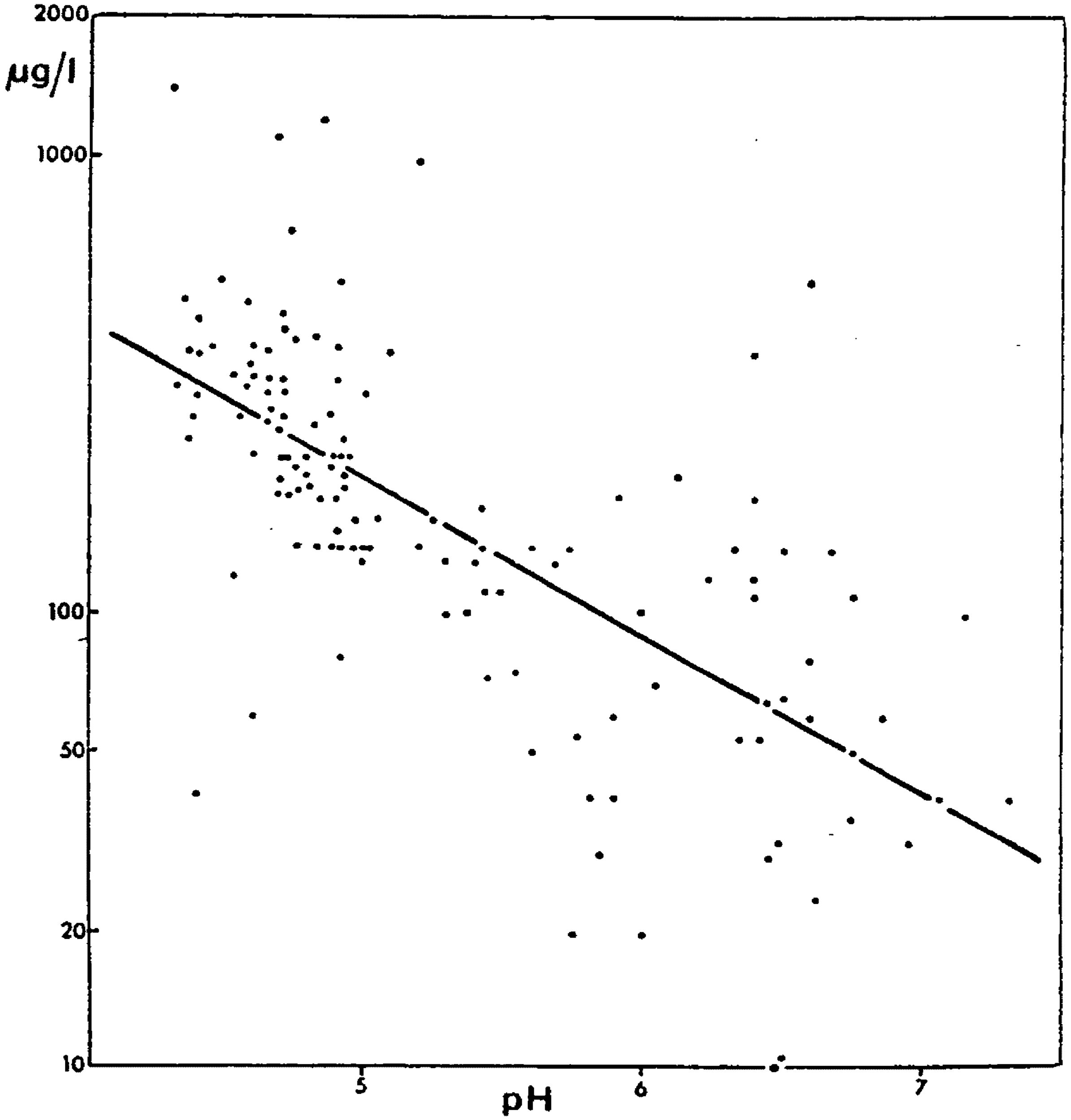
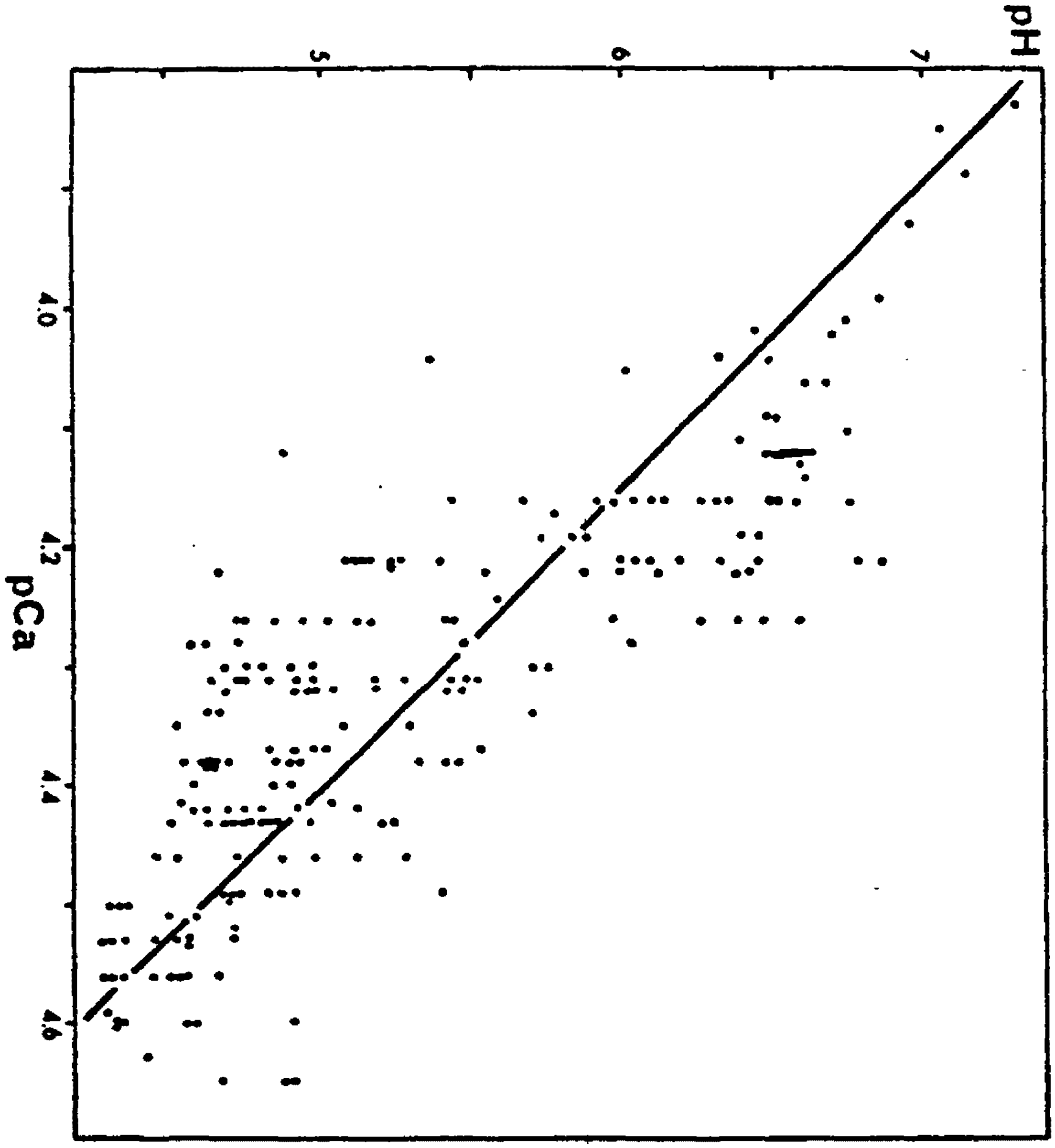


Figure 3-4

The relationship between pH and pCa for Adirondack lakes more than 610 meters elevation (Y = 22.23-3.91X, r = 0.826)



The second elicitation in the initial framework consisted in the aggregation of life stage effects (see Figure 3-1). A single species population consisting of all reproductive life stages was, by hypothesis, contained within a single flow through vessel. Assuming values for the elapsed maturation time of each reproductive stage then enabled estimates of class survivorship at different pH levels. This process was to be iterated through a complete reproductive cycle for each fish population. The time allotted for maturation of each reproductive stage is shown in Table 3-4.

The second step was designed to capture the effects of declining pH values and associated metal toxicities on the population structure of a given fish species. As previously noted, one of the primary mechanisms proposed to explain the loss of fish populations is the recruitment failure of a new year class. Field observations have been reported which indicate that acid stressed fish populations often have missing year classes. Step 2 would enable estimates of population structure given a range of pH values. Step 1, while considered analytically necessary for the performance of this judgement is obviously not sufficient. If Step 1 were - in the opinion of the participating scientist - superfluous, he could then directly perform the elicitation at Step 2.

The third elicitation was designed to obtain estimates of population reduction in three lakes, and considered only direct effects on a single species. The lakes initially considered were Woods, Panther, and Sagamore. Each of these lakes is located within the Adirondack Park Region of New York State and receives similar acidic inputs. Of the three lakes, Woods is considered acidic (typical outlet pH between 4 and 5), Panther is considered neutral (typical outlet pH near 7), and Sagamore possesses an outlet pH which usually varies between that of Woods and Panther. The Woods, Sagamore and Panther Lake Watersheds have been exhaustively characterized as the result of the Integrated Lake-Watershed Acidification Study funded by the Electric Power Research Institute. The characterization utilized for the initial elicitation was based upon information published by Chen et al. (1981).

Three lakes characterized by Dr. Charles Driscoll (1980) were also considered. These were Big Moose Lake, North Lake and Little Moose Lake. Big Moose Lake and North Lake are both acidic lakes with pH levels below 5, while Little Moose Lake is characterized as being neutral with pH values above 7. Dr. Joan Baker has also conducted recent field studies examining fish populations at Big Moose, North, and Little Moose Lakes (Baker, 1981). The conjunction of the chemical and biological surveys suggested that

Table 3-4

Maturation and Exposure Times Allotted for Different Reproductive Stages in the Initial Elicitation

Eggs	2 Weeks
Sac Fry	3-4 Weeks
Fry	8-10 Weeks
Juvenile	56-60 Weeks

these lakes might provide better examples for the aquatic scientists during the elicitation process. No final decision was made at this stage of the project, as the selection of "representative" lakes was felt to require the assistance of the scientists selected to conduct the pretest and evaluation of the elicitation framework.

This third elicitation included considerations of natural habitat sensitivity. The uncertainty in estimates of the relationship between fish mortality and pH included, influences of lake morphometry, such as uneven mixing, temperature stratification, different inlet, groundwater upwelling, and outlet chemistries, pulse events, and lake turnover time.

The step 4 elicitation was designed to elicit fish population decline within each of the three lakes incorporating both direct and indirect effects; e.g., interspecific competition, replacement, and changes in the structure of the food chain.

The careful specification of watershed geology, soil type, and lake morphometry in Steps 3 and 4 was considered necessary in order to: (1) present standard sets of data to the scientists participating within the elicitation; (2) partially reflect the range or variability of chemical, biological, and geological parameters of Adirondack watersheds; (3) provide some basis for a regional extrapolation of damages to fish populations; and (4) determine the significance of the variability between "bioassy results" and "lake estimations" for the assessment of regional effects. Because a number of the scientists were more familiar with Adirondack water chemistry and fish populations than the remainder of the participants, a careful specification of the particular lakes under consideration was required. Identical data sets were required for the elicitation in order to prevent possible errors or bias in the aggregation of the cumulative damage functions prior to the computation of regional effects. The lakes were to be selected so that they would be considered representative of a class of Adirondack lakes sharing similar water quality parameters. The investigators originally intended to extrapolate from these three "representative" lakes to obtain estimates of the effects of changing pH records on fish populations for the Adirondack Mountain Region. However, this initial elicitation structure was revised extensively prior to its application. The final elicitation structure made this extrapolation unnecessary.

3.3 EVOLUTION OF THE ELICITATION STRUCTURE

The initial four step elicitation structure presented in the preceding section served as the starting point for developing a structure which would be credible to the scientific community and still allow for the estimation of regional effects. The initial elicitation structure is complex relative to the final elicitation structure. The principal reason for the complexity of the initial structure was the investigators' desire for the assessment to directly capture as many differences in fish population response to different water chemistry variables as possible. After scientific review, it became apparent that while the initial structure, or something like it, would more explicitly address mechanisms of fish mortality than would a more simplified approach, that the current inventory data and time available for the performance of the project would not warrant the application of these more complex formulations. In addition, the detailed specification of the variables in the initial elicitation made subjective estimates of the effects very difficult to perform with any degree of confidence. Selecting the appropriate degree of resolution for the framework proved, in itself, a difficult interdisciplinary problem. This is significant for two reasons. First, it suggests that the selection of the variables for "regional" assessments of acid deposition effects should be a function of two considerations: the current state of scientific knowledge and the precision of other complimentary analyses. Second, it suggests the continued importance of scientific contributions to the development and application of assessment "models".

The initial elicitation was developed by the project investigators with only minimal discussion with outside scientists. The next steps consisted in: the presentation of the initial structure for comments; a pretest of the elicitation in order to identify problems; and revisions prior to its actual implementation. Comments were solicited from three audiences — researchers studying the effects of depressed pH on fish populations, aquatic chemists familiar with the Adirondack region, and decision theory researchers familiar with techniques for eliciting expert judgements.

Before conducting an elicitation, a number of questions needed to be addressed. First, did the structure of the elicitation reasonably represent the estimation problem?

Second, were the independent and dependent variables selected for the elicitation appropriate?* Third, could scientists reasonably take into consideration the large number of factors that influence the response of fish populations to low pH and acidification? Lastly, what information could be compiled that would help the scientists estimate the range of uncertainty around estimates of the effects of pH on fish populations?

The first presentation of the initial elicitation structure was to the Duluth EPA Laboratory.** The purpose of the meeting was to present the initial elicitation framework to a scientific audience for a preliminary review. Several recommendations were made for improving the clarity of the presentation.*** A second presentation of the elicitation structure was scheduled at Carnegie-Mellon University with a researcher**** familiar with techniques for eliciting expert judgements. The purpose of this meeting was to exchange ideas regarding the best method for eliciting the lower and upper bounds for the effects of pH on fish populations. Potential biases in the manner in which individuals estimate subjective parameters were considered, as were biases that could result from the way in which questions were asked or from the presentation of information during the elicitation.

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* An important issue which needed to be considered during this pretest period was whether the selected dependent and independent variables were appropriate. In the initial elicitation framework the independent, or causal, variables were a given summer, surface pH measurement, assumed to be taken in the epilimnion, and related concentrations of total aluminum and calcium for typical Adirondack waters. The dependent variable was to be a percent reduction in a species fish population. Scientists were to consider differences in characteristics of Adirondack lakes in estimating the range of possible effects for a given pH, including size of the lake, possible existence of refuges within the lake; genetic variability in the susceptability of fish to pH depressions, and the likelihood that a lake with a given summer surface pH record would experience severe spring pH depressions.

** Dr. Orie Loucks, Dr. Gary Glass, and Dr. George Rapp of the EPA Duluth Laboratory were generous with their time and made many helpful suggestions.

*** The Duluth scientists questioned the general scope of the approach and how the scientific participants were selected. In order to address these and similar questions, the project investigators prepared a memorandum for distribution to the selected elicitation participants outlining the following points: the need for the extension of scientific results to broader regions; the nature of the uncertainty implicit in such an extension; and the mechanism proposed by ERC to dimension this uncertainty. It was decided to include a summary volume of a previous report which suggested application of this technique in order to dimension the uncertainty surrounding effects estimates, and a progress report outlining work performed on the project.

**** Dr. Max Henrion of Carnegie-Mellon University was particularly helpful.

The next set of meetings were with effects scientists for preliminary tests of the structure of the elicitation.* As a result of these discussions, substantial changes were made in the elicitation. Many additional uncertainties were identified that affect regional estimates of the effects of pH on fish populations. While the investigators initially developed parameters which they felt necessary to a regional assessment (3.2.2), scientific participants often suggested important qualifications in the approach because of either: (1) lack of inventory data; or (2) lack of scientific understanding of a mechanism or effect. Figure 3-5 presents a revised intermediate elicitation structure. The revised structure represents a clear simplification of the investigators' original schema. While the output of both the initial and the intermediate elicitations remained the same, i.e., the percentage reduction of a fish population within a small set of exemplary lakes, the intermediate elicitation structure aggregates the elicitation of damages to the different reproductive life stages (eggs, sac fry, and fry) into one elicitation. Damages to both juveniles and adults were to be estimated in Step 2. Step 3 of the intermediate elicitation structure provided the same output as Step 4 of the initial elicitation structure (See Figures 3-1 and 3-5). The elicitation of the damage functions was to be performed over three different Adirondack lakes, Sagamore, Woods, and Panther. Dr. Baker advised against the use of Big Moose, Little Moose, and North Lake, which were also being considered, because they were less likely to be representative of a broad range of Adirondack lakes.**

The prediction of impacts upon fish populations in natural habitats as functions of pH would thus encompass such considerations as: (1) the temporal and spatial variation in

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* The assistance from Dr. Joan Baker of North Carolina State University and Dr. Carl Schofield of Cornell University is gratefully acknowledged. Dr. Baker worked with the project investigators for several days, asking helpful questions and offering suggestions for improvement.

** The sampling sites at Big Moose, Little Moose, and North Lake are all located at moderately high elevations (approximately 550 m). All three lakes are larger than 150 ha. While both Big Moose and North Lakes are "acid" (pH is less than 5), Little Moose is a neutral lake (pH is greater than 7). The geologic makeup surrounding all three lakes is similar, with the area being underlain by siliceous bedrock (Driscoll, 1980).

Figure 3-5

Intermediate Elicitation Structure[1]

1. Elicitation over damages to reproductive life stages (eggs, sac fry, fry)

2. Elicitation over damages to juveniles and adults

3. Elicitation over damages occurring in representative habitats.

[1] One and Two are bioassay flow-through experiments. Three is based on set of exemplary lakes.

the lake water chemistry in relation to the occurrence of sensitive fish life history stages; (2) correlations between occurrence of the particular fish species and water quality within the Adirondacks; and (3) the results of laboratory bioassays and the determination of the survival of fish eggs and larvae as functions of pH. As with the initial elicitation structure, the results of Steps 1 and 2 were not considered to be outputs for the regional assessment, but rather preparatory guides for the performance of the final, Step 3, elicitation.

In addition to the above changes, the expression of aluminum levels as a function of pH for use in the elicitation was changed (from that shown in Figure 3-3) to that shown in Figure 3-6. Figure 3-6 is adapted from Driscoll (1980) and represents the concentration of inorganic monomeric aluminum as a function of pH. Work by Baker (1980) and Baker and Schofield (1981) indicates that the species of aluminum present in dilute waters influences the toxicity of those waters to fish species.

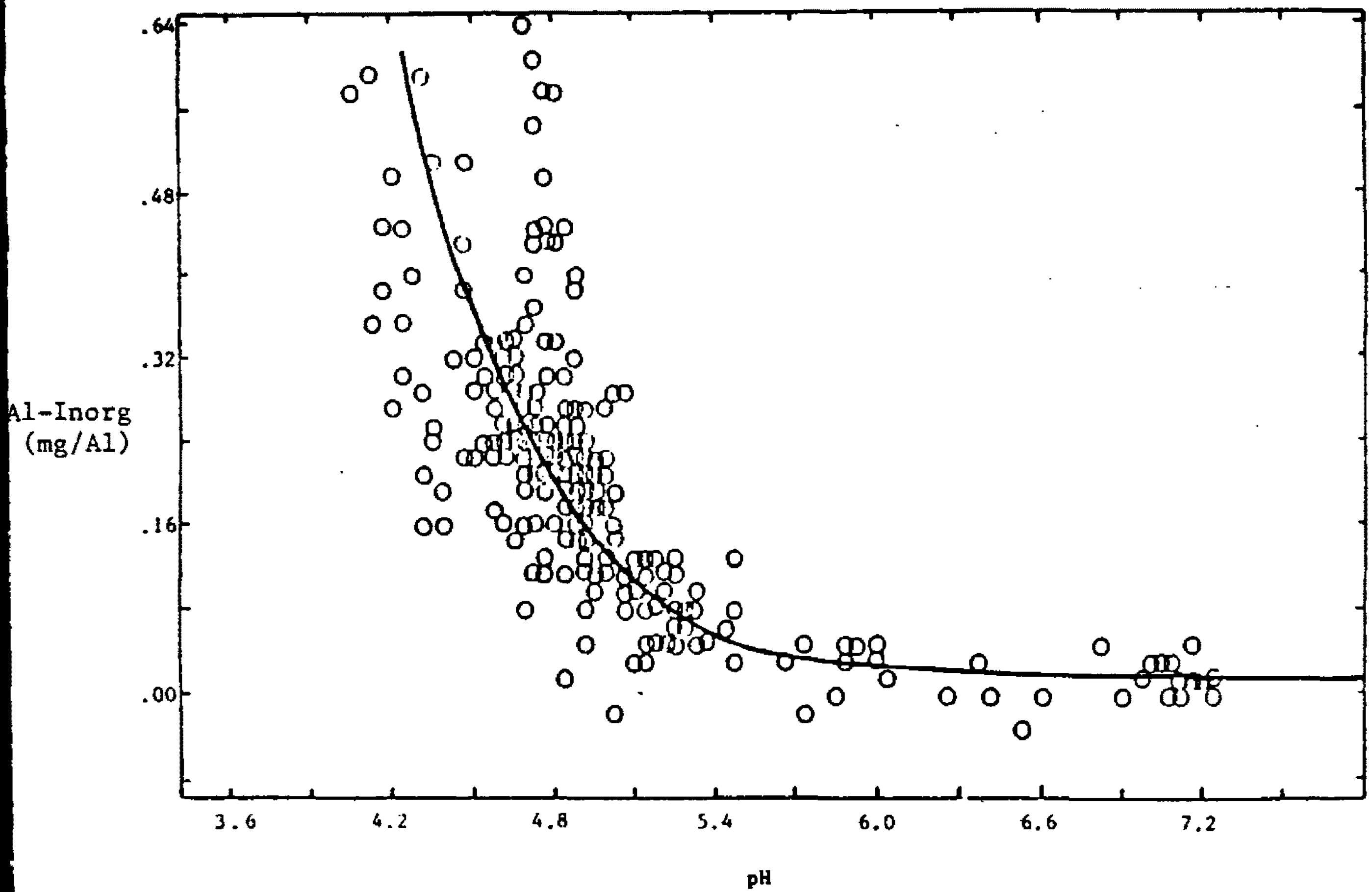
The final portion of the meetings consisted of a pretest of the elicitation interview process. Initially, it was hoped that the interview and technique would be sufficiently polished to allow for the performance of the intermediate elicitation. However, because of a number of difficulties, the interview was not able to be completed.* The principal obstacle was the data output from Step 3 of the elicitation. The output in the initial elicitation structure was expressed as the percentage reduction of a given fish population within a lake. Because the data base maintained on fish in lakes by the New York DEC contains only presence-absence data for fish populations within the Adirondacks, the use of the elicited damage functions expressing change as percentage reductions of the fish populations within representative lakes was problematic. To make the elicitation of the damage function expressed in Step 3 of the intermediate elicitation structure appropriate, biomass or population statistics would need to be developed for the Adirondack Region. The Morpho-Edaphic Index was considered as a possible mechanism for the prediction of fish biomass with the DEC data set. It was decided, however, that while

* The unexpected difficulties that were encountered illustrate the importance of pretest applications of elicitations. Many important insights were obtained from an actual dry run of the elicitation which were not apparent during the discussions of the procedure.

Figure 3-6

Inorganic Monomeric Aluminum as a Function of Sample pH

From Driscoll, 1980



the MEI is useful as a predictor of fish biomass over a broad range of water chemistries, the index would not be accurate for the dilute lakes within the Adirondack region. In addition, even if the MEI could be used successfully to predict biomass, it is unable to distinguish between the fish species that might or might not be present within the lake. While this might not be much of a problem for primarily mono-culture fish habitats, for example, brook trout ponds, the difficulties associated with its application to other lake types and habitats precluded its application.

During these meetings no decision was made concerning the treatment of these questions. However, because they were considered to be potentially very important, a number of possible elicitation structures were discussed that would satisfactorily meet the criteria of policy-relevance (i.e., dimension uncertainty and furnish regional effects estimates) and scientific credibility, while also avoiding the problems posed by the use of representative lakes and the need for the generation of biomass or population data.

3.4 THE FINAL ELICITATION STRUCTURE

The final form of the elicitation structure represents a considerable simplification of both the intermediate and initial elicitation structures. It estimated the percentage of Adirondack lakes which could possibly, but no longer can, sustain populations of a particular fish species at a given summer pH measurement taken in the epilimnion. Thus, the dependent variable was changed from a measure of the reduction in fish biomass or population to a measure of the reduction in a fish species habitat. This change responds to considerations mentioned earlier, and reflects the general absence of inventory data expressing biomass or number of fish per unit of measurement.

Because a substantial gamefish stocking program exists in the Adirondacks, separate elicitations were felt to be necessary for stocked and non-stocked gamefish populations. This adjustment was necessary because of different sensitivities of the reproductive and adult life stages to pH depressions. Scientists were asked to estimate the percentage of Adirondack lakes which could possibly, but no longer can sustain both: (1) self-sustaining populations of a particular game fish; and (2) properly stocked populations of juvenile and adult game fish. For non-game species, for example, white sucker, the sensitivity of only unstocked populations was evaluated.

The obvious structural difference between the final elicitation structure and its predecessors consists of the elimination of bioassay estimations of population mortality. These were eliminated for two reasons. First, time required for the elicitation interview would be significantly reduced. Second, the elicitation over the different life stages of the fish species did not, in the opinion of several scientists, significantly contribute to the third and most important elicitation result.*

An advantage inherent in the final elicitation structure is that the scientists directly extended the estimation of regional effects over the Adirondack mountain region. The method proposed in the initial and intermediate elicitation structures required the extrapolation of the elicitation results for three "representative" lakes to the entire Adirondack region. While this procedure reduces uncertainty in the estimation of fish damages for the "representative" lakes, the extrapolation to the Adirondack Region would be done without the explicit dimensioning of the uncertainty by the scientists.

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* The relative uncertainty of response in these hypothetical bioassay experiments was quite small when compared to the uncertainty of other aspects of the regional estimation of effects.

4.0 IMPLEMENTATION AND RESULTS

This chapter reviews the implementation of the final elicitation structure and the resulting damage relationships obtained through interviews with participating scientists. Section 4.1 discusses the work done in preparation for the elicitations including the selection of the participating scientists. Section 4.2 discusses the actual performance of elicitation. Section 4.3 summarizes the results of the elicitations.

4.1 PREPARATION FOR THE ELICITATION

4.1.1 Selection of Participating Scientists

The selection of scientists for participation in the elicitation was an important part of the project. The first step was to compile a list of authors from the peer review literature and government reports consulted by ERC during the literature review. Weighting in selection was assigned on the basis of: (1) the number of recent publications; and (2) the amount of work performed in the Adirondack mountain region. On the basis of this initial review, a list of scientists was compiled. A number of Canadian scientists were included within the list of possible participants in order to provide a comparison between Canadian and American research communities.

The second step consisted in the contacting of possible participants and determining their willingness to participate in the study. During these initial phone conversations, the length of the proposed interview (approximately four hours), the research area, and the information requirements of the project were outlined. On the basis of these discussions, the number of potential candidates was narrowed down. On the other hand, a number of additional candidates were proposed by those scientists initially contacted. Table 4.1 contains a list of the scientists who finally participated in the study and the dates of their interviews with ERC.

These elicitation interviews were complemented by discussions with Walter Kretser of the New York State Bureau of Fisheries and Charles Driscoll of Syracuse University. The purpose of the discussion with Mr. Kretser was to review the records maintained within the Adirondack Waters Data Management System. As a result of conversations with Mr. Kretser, the investigators obtained the complete data file for the 3506 ponded waters within the Adirondack area. The discussions with Dr. Driscoll addressed; first, the general review of the project's scope and methodology; and second, a review of the water chemistry parameters being proposed for use in the study.

4.1.2 Preparatory Orientation and Review Material

Prior to the interview process, all the scientific participants received orientation packets in the mail. The mailing took place approximately two weeks prior to the elicitation. The purpose of this mailing was to introduce the approach and the project goals in more detail to the elicitation participants. The package included three separate documents:

(1) A description of the meeting agenda and a brief explanation of the rationale behind this type of approach.

(2) A project progress memo which reviewed the status of the work performed on the project and outlined the remainder of work to be accomplished.

(3) A summary of a previous report providing background information on the approach.*

4.1.3 Compilation of Background Data for Use in the Elicitation

A notebook of data was compiled as a reference for the scientists to use during the elicitation. This data included a table adapted from Baker and Schofield (1981) listing the mean concentrations of selected ions for Adirondack lakes and streams sampled during

* "Assessing the Benefits of Policies Designed to Reduce Acid Deposition: A Decision-Analytic Benefit-Cost Framework," (Violette and Peterson, 1982).

Table 4.1

Interview Participants

Name	Institution	Date of Interview
Carl Schofield	Department of Natural Resources Cornell University Ithaca, New York	11/5/82
Martin Pfeiffer	Bureau of Fisheries, DEC Route 86 Ray Brook, New York	11/8/82
Douglas Spry	Department of Biology Mimaster University Hamilton, Ontario	11/10/82
Gordon Craig	Ministry of Environment Rexdale, Ontario	11/12/82
Gail Beggs	Ministry of Natural Resources Toronto, Ontario	11/15/82
Jim MacLean	Ministry of Natural Resources Toronto, Ontario	11/15/82
Joan Baker	North Carolina State University Acid Deposition Program	11/17/82

1977-1978 (see Table 4- While this information was of only limited value for the participants with extensive understanding and knowledge of Adirondack waters, it provided a useful indicator of the constituents likely to be present in dilute Adirondack waters for the Canadian participants. Relationships between pH and pCa and between pH and inorganic monomeric aluminum were also included.

The relationship between pH and inorganic monomeric aluminum was also represented in a table (see Table 4-3). The only other data shown to all participants was the Environmental Protection Agency's Critical Assessment Document Table 4-24 (Baker, 1982 Draft).* The data was provided in order to supplement the scientists' judgment and to provide a convenient and uniform reference source for all participants. In some cases, however, participants supplemented this data by consulting their own sources during the course of either the pre-elicitation interview or the elicitation itself.

4.2 PERFORMANCE OF THE ELICITATION

The meeting with elicitation participants can be divided into four segments:

(1) an introductory briefing and interview

(2) discussion of the parameters to be estimated and variables considered

(3) the performance of the damage function elicitation

(4) a review and assessment of the elicitation procedure and its results.

While each of the meetings followed the basic structure outlined above, there were differences between the interviews. These differences are attributable more to the different information requirements of the scientific participants than any variability of methodological design or implementation on the part of the investigators. This section

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* A number of participants were shown data representing the temporal and spatial variability of water chemistry within Dart Lake in the Adirondacks (unpublished data provided by Charles Driscoll).

Table 4-2

Mean concentrations (mg/l)(± standard error) of selected ions in softened, dechlorinated water utilized in all laboratory experiments and in Adirondack lakes and streams sampled during 1977-1978

Ion	Adirondack waters	
Ca	2.0	±0.6
Mg	0.4	±0.1
Na	0.7	±0.3
K	0.4	±0.1
free F	0.025	±0.060
SO_4	6.2	±0.9

Table adapted from Baker and Schofield, 1981.

Table 4-3

Approximate Inorganic Aluminum Concentration for Adirondack Ponded Waters*

(mg/l)

pH	Al
7.2	neg.**
6.9	neg.
6.6	neg.
6.3	neg.
6.0	.02
5.7	.04
5.4	.06
5.1	.11
4.8	.21
4.7	.24
4.5	.38
4.4	.44
4.2	.6
3.9	neg.**
3.6	neg.**

Note: At lower elevation, organic complexation could reduce the availability of inorganic aluminum at or below pH 4.4.

* Used as background data for elicitation.

** Negligible levels of inorganic aluminum concentrations.

will address the three segments of the interview listed above while indicating the range in variability of the interview format and process.

4.2.1 Introductory Briefing

The first step in every interview consisted in the review of a briefing package prepared by ERC staff in order to further acquaint participants with the project, its methodological justification, and data requirements. The principal point made during this segment of the interview was that any decision to implement an environmental policy must be based upon a probability assessment of the odds of benefits (monetary or non-monetary) from the policy exceeding the costs of its implementation. The purpose of the project was stated to be the construction and implementation of a framework which would allow scientists to participate in the direct extension of the results of recent scientific research into damage estimates useful for policy analysis. Secondly, it was stressed that this was an evaluation of this approach for dimensioning and incorporating scientific uncertainty in estimates of the regional effects of acid deposition.

Some time was spent explaining what the investigators believed were the principal advantages to the approach being utilized in the analysis. The advantages expected are:

- First, that scientific information is less likely to be misinterpreted when the uncertainty is directly and explicitly incorporated into the analysis;

- Second, it was stressed that the subjective probability estimates which express the damage to environmental receptors in this approach are not point estimates, but express the damages as a range. For example, rather than estimating that 20% of the lakes with a given summer pH value would no longer support a self-sustaining brook trout population, the approach estimates with a high confidence interval that, say, between 5% and 60% of the lakes with a given summer pH value would no longer support a self-sustaining brook trout population;

- Third, it was pointed out that because the scientist would be directly responsible for the subjective extension of research results, that the extension would better represent scientific opinion concerning the effects than if it were performed by policy-makers or economists;

- Fourth, because the probability judgements are expressed quantitatively and are explicitly represented they are amenable to scientific review and criticism; and

- Finally, the results of the elicitation can be readily and inexpensively revised in the light of additional research results and conclusions.

At this point, the consensus judgement was: (1) an objective expression (i.e., statistically based estimate) of regional fish damages caused by acid deposition is not currently possible; and (2) regional estimates are required in order to assess policy alternatives with respect to the mitigation of acid deposition.

The length of discussion concerning the theoretical and general aspects of the discussion noted above varied significantly between the interviews. It was the investigators' intention to cover as fully as possible, given time constraints, the queries and responses of the participants. In one case, for example, the discussion centered - for some time - on the need to perform any regional quantitative assessments of the damage occurring as a result of acid deposition and its effects. It was stressed that while there have been a number of attempts to incorporate scientific information and opinion within a policy framework in the acid deposition debate, that none of those attempts have been viewed as wholely satisfactory - either in terms of its explicit treatment of the scientific issues or in its use of economic and decision analytic theory.*

The final step of the introductory briefing consisted of a very brief review of subjective probability assessment and its previous applications within environmental policy decisions.

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* One important benefit of this project was the communication between scientists and individuals involved with the overall integration and assessment of the information for policy analysis. The interdisciplinary discussions that resulted were very informative.

4.2.2 Variable Specification

This part of the interview was a review of the independent and dependent variables used in the analysis. The discussion concerned the scope of the elicitation and had several purposes:

(1) to ensure that the participant understood what the variables represented;

(2) to outline the data compiled by the project investigators for use by participants in the elicitation (discussed in Section 4.1.3);

(3) to determine if any important source of variability or uncertainty had been omitted by the investigators;

(4) to agree upon the fish species for which estimates would be developed.

As noted in Section 4.3, the elicitation was to determine the percent of Adirondack Lakes which could possibly, but no longer can, sustain a given fish population at a specified summer surface pH measurement. The independent variable was pH. However, recognizing the potential importance of inorganic monomeric aluminum and calcium in determining fish response to low pH values, regressions relating calcium and and inorganic monomeric aluminum to pH in Adirondack waters were used to incorporate these factors within the analysis. No other potentially toxic or mitigative metals were explicitly considered. No elicitations were performed without incorporating the effects of monomeric inorganic aluminum and calcium upon the dependent variable.*

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* Metals which consistently exhibit increased concentrations as functions of depressed pH are aluminum, manganese, and zinc. However, neither manganese nor zinc have been found to be toxic to fish at concentrations found in acidic surface waters. Aluminum, however, has been found to be toxic to fish at concentrations as low as .1 to .2 mg/l, a level within the range of concentrations measured in surface waters. Free aluminum ion or aluminum hydroxide forms have been shown to be more toxic than organic aluminum complexes. The solubility of inorganic aluminum in acidic Adirondack surface waters is apparently regulated by some form of aluminum trihydroxide solid (Driscoll, 1980; Baker, 1981).

The estimation of the percentage of Adirondack Lakes which would be incapable of supporting fish populations at a given summer pH value is an, admittedly, complex and difficult task. Fish mortality — even at the same pH — can be expected to vary depending upon a number of factors described by the morphometric and biogeologic characteristics of the lakes. Bog, seepage, and eutrophic lakes can all be expected to have different capabilities to support a fish population given the same pH measurement. In addition, the presence or absence of ground water upwellings, episodic or pulse pH depressions, uneven water mixing (the temporal and spatial variability of chemical species within the lake), acid neutralizing or acidifying inlets, and the biologic production of alkalinity are reported to be related to fish mortality within the literature. Genetic variability as well as the possibility of avoidance behavior and acclimatization by fish populations to depressed pH levels introduce additional uncertainities. During the specification of the elicitation variables, the investigator attempted to determine whether or not the scientist believed that these and other potentially important factors could be successfully incorporated within the analysis.

The species of fish to be considered in the elicitation were determined by the scientists. Not surprisingly, different scientists were most familiar with the response of different species of fish to variations in pH. Participants were encouraged by ERC to estimate damages to important game fish species within the Adirondack region of New York State; however, little benefit was seen in having a scientist participate in an elicitation for a fish species with which he had little familiarity. Three participants elected to perform elicitations over damages to non-game species. In one case, in order to perform an elicitation for a particularly sensitive species; in the other two, the participants felt better able to perform the elicitation over non-game species because of their greater familiarity with the non-game rather than game species. The fish species for which elicitations were performed are shown in Table 4.4. Elicitations over damages to stocked populations of brook trout and lake trout were also performed.

Table 4-4

Fish Species Covered in the Elicitation

Game Species
Salmonidae
Brook Trout (*Salvelinus fontinalis*)
Lake Trout (*Salvelinus namaycush*)
Centrarchidae
Small Mouth Bass (*Micropterus dolomieui*)
Non-Game Species
Catosmidae
White Sucker (*Catostomus commersoni*)
Cyprinidae
Fat Head Minnow (*Pimephales promelas*)
Common Shiner (*Notropis cornutus*)

4.2.3 The Implemention of the Final Elicitation Structure

This section reviews the procedure followed during the actual estimation of damages by the scientific participants.* The eliciting of the ranges of potential effects at each pH level followed an established procedure. Compared with the variability of the other components of the interview, its performance followed a standardized format.

The initial step was to introduce a table similar to that shown in Table 4.5.** The ERC investigator began by asking the participant if there were any possibility of a summer pH measurement of 6.9 or above resulting in a reduction in the number of lakes which could support a fish population, in this example a non-stocked population of brook trout. After some discussion of the question, the expert concluded that there was, in his opinion, no chance of a set of Adirondack lakes with a summer pH of 6.9 or greater losing fish habitat. As a result, zeros were entered in the low, midpoint, and high columns of the table (See Table 4-5a). If the participant preferred, the next set of queries concerned the possibility of impacts occurring at a pH of 6.8. In this example, the expert was relatively uncertain as to whether adverse impacts could be expected to occur over the range of the approximately 3500 lakes being considered. A question typically asked by the investigator was, "if there were 1000 Adirondack lakes reflecting the full range of habitat types, morphometries, and biogeochemisteries which are possible, or that you are familiar with, and these 1000 lakes had a pH of 6.8, would you expect any number of these -- however small the number -- to no longer be able to support a self-sustaining (in this case) brook trout population due to the pH?" After some discussion, perhaps about the variability of pH measurements, the fluctuation of water chemistry in the Adirondack regions, and his own considerable uncertainty, the scientist indicated that there he would expect some impact. At this point no values were recorded on the table. Instead, the investigator attempted to have the participant estimate a range within which he was highly confident that the actual impacts would fall. Attempting to initially establish the boundaries of this range, the investigator would ask, for example, "what would be the least number of lakes affected at this pH; in other words, can you give me a percentage value which would ensure that there would be no lesser degree of impact? At a pH of 6.8, in the present case, the scientist responded with 0 percent as the lower

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* The data set resulting from the elicitations is contained within Section 4.3.

** The form represented in Table 4-5 was used in all but two of the elicitations.

Table 4-5

Elicitation Table

Species: Salvelinus fontinalis (brook trout)

Range of Impacts

Constituents					
	Low		midpoint		High
pH 6.9	( )	( )	( )	( )	( )
	Low				High
pH 6.8	( )	( )	( )	( )	( )
	Low				High
pH 6.7	( )	( )	( )	( )	( )
	Low				High
pH 6.6	( )	( )	( )	( )	( )
	Low				High
pH 6.5	( )	( )	( )	( )	( )
	Low				High
pH 6.4	( )	( )	( )	( )	( )
	Low				High
pH 6.3	( )	( )	( )	( )	( )
	Low				High
pH 6.2	( )	( )	( )	( )	( )

Expert:

Date:

Notes: Self sustaining population

bound to the range. As a result, 0 percent was entered in the low column. On the other hand, to establish the high end of the range, the investigator would ask the participant to consider the greatest possible impacts to the set of Adirondack lakes which both possess summer pH measurements of 6.8 and self-sustaining brook trout populations. After some discussion, the participant indicated that the high end of the range should be 15 percent. As a result, a 15 percent was entered in the high column (see Table 4-5a). These lower and upper bounds were chosen to represent 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 had been specified in the above manner, the participants were questioned regarding where within this range the actual outcome was most likely to fall. It was quite difficult to elicit responses regarding the most likely damage outcomes within the estimated range. A procedure was developed which was acceptable to the scientists and still provided some information on where the most likely outcome would fall. The procedure followed was to enter the mid-point of the range in the table; for example, if the range were 0 percent to 15 percent the mid-point would be 7.5 percent. Upon entering the value for the mid-point, the participant was asked to indicate whether the percentage of lakes no longer able to sustain fish populations would be likely to lie above or below the mid-point. In our example, at pH value of 6.8, the participant indicated that the range between 0 percent and 7.5 percent was more likely to contain the true value than the range between 7.5 percent and 15 percent. Once the participant decided whether the impacts were likely to be above or below the midpoint of the range, an "X" was placed either above or below the mid-point in order to express this weighting of the probabilities (see Table 4-5b).

The elicitation continued until estimates for all the pH levels were developed. In many cases the participant felt that the incremental change of .1 pH was not sufficient to change the estimates listed above. In the current example, the participant, didn't change

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* See Section 5.1 for a discussion of the statistical interpretation of the range expressed by the scientific experts.

Table 4-5a

Elicitation Table

Species: Salvelinus fontinalis (Brook Trout)

Range of Impacts					
Constituents					
Low	___	Midpoint	___	High	
pH 6.9	(0)	( )	(0)	( )	(0)
Low	___	___	___	High	
pH 6.8	(0)	(X)	(7.5)	( )	(15)
Low	___	___	___	High	
pH 6.7	( )	( )	( )	( )	( )
Low	___	___	___	High	
pH 6.6	( )	( )	( )	( )	( )
Low	___	___	___	High	
pH 6.5	( )	( )	( )	( )	( )
Low	___	___	___	High	
pH 6.4	( )	( )	( )	( )	( )
Low	___	___	___	High	
pH 6.3	( )	( )	( )	( )	( )
Low	___	___	___	High	
pH 6.2	( )	( )	( )	( )	( )

Expert:

Date:

Notes: Self Sustaining Population

Table 4-5b

Condensed Elicitation Table

Species: Salvelinus fontinalis (Brook Trout)

Range of Impacts

Constituents	Low		midpoint		High
pH 6.9	(0)	( )	( )	( )	(0)
pH 6.8	(0)	(X)	(7.5)	( )	(15)
pH 5.5	(10)	(X)	(20)	( )	(30)
pH 5.2	(10)	( )	(35)	(X)	(60)
pH 5.0	(30)	(X)	(55)	( )	(80)
pH 4.8	(40)	(X)	(65)	( )	(90)
pH 4.6	(40)	( )	(65)	(X)	(90)
pH 4.4	(60)	( )	(75)	(X)	(90)
pH 4.3	(90)	( )	(95)	(X)	(100)
pH 4.0	(100)	( )	(X)	( )	(100)

the range of the damage function until the pH had reached 5.5. At that pH, the concentration of inorganic monomeric aluminum was estimated to be approximately .05 mg/l, and the pCa was approximately 4.3. At these values, the lower bound of effects was estimated to be 10 percent and the upper bound 30 percent (see Table 4-5b).

In some cases, the participants were so uncertain that they were unable to weight either the "high" or "low" interval. In such a case, no weighting was placed on either side of the midpoint.

Not all of the elicitations began at the highest pH values, 6.9 and above, then proceeding to lower pH values. In a number of elicitations, participants elected to begin at pH values around 5.0, working toward both the higher and lower extreme. This is not surprising, because the majority of bioassay experiments, as well as anecdotal literature, note effects at a pH of 5.0 or less in dilute surface waters or their laboratory equivalent. The investigators do not believe that this change in the procedure affected the estimated ranges.

4.2.4 Review and Assessment of the Elicited Damage Functions

The final step in the elicitation interview consisted in a review of the range and weight which resulted from the elicitation. During the review, the participant and the investigator examined the range of impacts listed at the different pH values. If the participant believed that the estimates accurately represented his beliefs, no changes were made. On the other hand, if there were distributions which seemed inappropriate, then these were reconsidered and changed where appropriate. Often this amounted to the alteration of just a few values. In some cases, however, substantial revisions were required before the participant believed the results to accurately reflect his/her perceptions of the possible range of damages or impact.

Following these revisions to the estimates, if sufficient time was available, the interview was closed with a brief discussion concerning the participant's evaluation of the approach and his confidence in the use of its results.

4.3 RESULTS OF THE ELICITATION

This section presents the data obtained from the participating scientists that was directly incorporated within the calculation of regional changes due to the incremental shift of regional fresh water chemistry. Table 4-6 presents the results of each elicitation. The data will be interpreted in Chapters 5 and 6.

Table 4-6a*

Brook Trout - Stocked

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	0		0		0
6.1	0		0		0
6.0	0		0		0
5.9	0		0		0
5.8	0		0		0
5.7	0		0		0
5.6	0		0		0
5.5	0		2.5		5
5.4	0		2.5		5
5.3	0		10	x	20
5.2	0		10	x	20
5.1	0		10	x	20
5.0	5	x	27.5		50
4.9	5	x	27.5		50
4.8	8	x	31.5		55
4.7	8	x	31.5		55
4.6	8	x	31.5		55
4.5	30		50	x	70
4.4	30		50	x	70
4.3	50	x	72.5		95
4.2	50	x	72.5		95
4.1	50	x	72.5		95
4.0	70		85		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6b*

Brook Trout - Stocked

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	0		0		0
6.1	0		0		0
6.0	0		0		0
5.9	0		0		0
5.8	0		0		0
5.7	0		0		0
5.6	0		0		0
5.5	0		12.5		25
5.4	0		12.5		25
5.3	0		12.5		25
5.2	0		12.5		25
5.1	0		12.5		25
5.0	0	x	37.5		75
4.9	0	x	37.5	x	75
4.8	10		42.5	x	75
4.7	10		42.5	x	75
4.6	25		62.5	x	100
4.5	25		62.5	x	100
4.4	40		70	x	100
4.3	40		70	x	100
4.2	50		75	x	100
4.1	70		85	x	100
4.0	70		85	x	100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6c*

Brook Trout - Stocked

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	0		0		0
6.1	0		0		0
6.0	0		0		0
5.9	0		0		0
5.8	0		0		0
5.7	0		0		0
5.6	0		0		0
5.5	0		0		0
5.4	0		2.5		5
5.3	5		7.5	x	10
5.2	15		20		25
5.1	30	x	40		50
5.0	40		55		70
4.9	60		72.5	x	85
4.8	85		90	x	95
4.7	95		97		99
4.6	100		100		100
4.5	100		100		100
4.4	100		100		100
4.3	100		100		100
4.2	100		100		100
4.1	100		100		100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6d*

Brook Trout - Self-sustaining

pH	Low	Weight	Mid Point	Weight	High
7.0	0				0
6.9	0	x	7.5		15
6.8	0	x	7.5		15
6.7	0	x	7.5		15
6.6	0	x	7.5		15
6.5	0	x	7.5		15
6.4	0	x	7.5		15
6.3	0	x	7.5		15
6.2	0	x	7.5		15
6.1	0	x	7.5		15
6.0	0	x	7.5		15
5.9	0	x	7.5		15
5.8	0	x	7.5		15
5.7	0	x	7.5		15
5.6	0	x	7.5		15
5.5	10	x	20		30
5.4	10	x	20		30
5.3	10	x	20		30
5.2	10		35	x	60
5.1	10		35	x	60
5.0	30	x	55		80
4.9	30	x	55		80
4.8	40	x	65		90
4.7	40	x	65		90
4.6	40		65	x	90
4.5	40		65	x	90
4.4	60		75	x	90
4.3	90		95	x	100
4.2	90		95	x	100
4.1	90		95	x	100
4.0	100				100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6e*

Brook Trout - Self-sustaining

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	0		0		0
6.1	0		0		0
6.0	0		5		10
5.9	0		5		10
5.8	0	x	15		30
5.7	0	x	15		30
5.6	0	x	25		50
5.5	0	x	25		50
5.4	0	x	37.5		75
5.3	0	x	37.5		75
5.2	10	x	42.5		75
5.1	10	x	42.5		75
5.0	25		50	x	75
4.9	25		50	x	75
4.8	25		50	x	75
4.7	25		62.5	x	100
4.6	50		75	x	100
4.5	50		75	x	100
4.4	50		75	x	100
4.3	80		90	x	100
4.2	80		90	x	100
4.1	80		90	x	100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6f*

Brook Trout - Self-sustaining

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	0		0		0
6.1	0		0		0
6.0	0	x	5		10
5.9	0	x	5		10
5.8	0	x	5		10
5.7	0	x	5		10
5.6	0	x	5		10
5.5	5	x	17.5		30
5.4	5	x	17.5		30
5.3	5	x	17.5		30
5.2	5	x	17.5		30
5.1	5	x	17.5		30
5.0	10	x	37.5		65
4.9	10	x	37.5		65
4.8	10	x	37.5		65
4.7	10	x	37.5		65
4.6	10	x	37.5		65
4.5	20	x	50		80
4.4	20	x	50		80
4.3	20	x	50		80
4.2	20	x	50		80
4.1	20	x	50		80
4.0	75		87.5	x	100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6g*

Brook Trout - Self-sustaining

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0	x	7.5		15
6.7	0	x	7.5		15
6.6	0	x	7.5		15
6.5	0	x	7.5		15
6.4	0		7.5	x	15
6.3	0		7.5	x	15
6.2	0		7.5	x	15
6.1	0		7.5	x	15
6.0	10		50	x	90
5.9	10		50	x	90
5.8	20	x	55		90
5.7	20	x	55		90
5.6	20	x	55		90
5.5	20	x	55		90
5.4	40		65		90
5.3	40		65		90
5.2	60		80		100
5.1	60		80		100
5.0	80		90		100
4.9	80		90		100
4.8	90		95		100
4.7	90		95		100
4.6	90		95		100
4.5	90		95		100
4.4	100		100		100
4.3	100		100		100
4.2	100		100		100
4.1	100		100		100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6h*

Brook Trout - Self-sustaining

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	0		0		0
6.1	0		0		0
6.0	0	x	7.5		15
5.9	0	x	7.5		15
5.8	0	x	7.5		15
5.7	0		10	x	20
5.6	5	x	17.5		30
5.5	5	x	20		35
5.4	5	x	25		50
5.3	5		30	x	55
5.2	10		32.5	x	55
5.1	10		35	x	60
5.0	10		40	x	70
4.9	20		45	x	70
4.8	25		55	x	85
4.7	35		65	x	95
4.6	45	x	70		95
4.5	50	x	72.5		95
4.4	75		86.5	x	98
4.3	85		92.5	x	100
4.2	95		97.5	x	100
4.1	95		97.5	x	100
4.0	95		97.5	x	100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6i*

Lake Trout - Stocked

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	0		0		0
6.1	0		0		0
6.0	0	x	5		10
5.9	0	x	5		10
5.8	10		20		30
5.7	10		20		30
5.6	10		20		30
5.5	10		20		30
5.4	25		50	x	75
5.3	25		50	x	75
5.2	40		70	x	100
5.1	40		70	x	100
5.0	60		80	x	100
4.9	60		80	x	100
4.8	60		80	x	100
4.7	60		80	x	100
4.6	60		80	x	100
4.5	100		100		100
4.4	100		100		100
4.3	100		100		100
4.2	100		100		100
4.1	100		100		100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6j*

Lake Trout - Stocked

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	0		0		0
6.1	0		0		0
6.0	0		0		0
5.9	0		0		0
5.8	0		0		0
5.7	0	x	12.5		25
5.6	0	x	12.5		25
5.5	0	x	25		50
5.4	0	x	25		50
5.3	0	x	25		50
5.2	10	x	55		100
5.1	10	x	55		100
5.0	30	x	65		100
4.9	30	x	65		100
4.8	50		75		100
4.7	80		90		100
4.6	80		90		100
4.5	100		100		100
4.4	100		100		100
4.3	100		100		100
4.2	100		100		100
4.1	100		100		100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6k*

Lake Trout - Self-sustaining

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0	x	5		10
6.4	0	x	10		20
6.3	0	x	10		20
6.2	0	x	10		20
6.1	10	x	35		60
6.0	40		57.5		75
5.9	40		60		80
5.8	50		70		90
5.7	50		70		90
5.6	50		70		90
5.5	50		70		90
5.4	80		90	x	100
5.3	80		90	x	100
5.2	80		90	x	100
5.1	80		90	x	100
5.0	100		100		100
4.9	100		100		100
4.8	100		100		100
4.7	100		100		100
4.6	100		100		100
4.5	100		100		100
4.4	100		100		100
4.3	100		100		100
4.2	100		100		100
4.1	100		100		100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-61*

Lake Trout - Self-sustaining

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0	x	5		10
6.4	0	x	5		10
6.3	0	x	5		10
6.2	0	x	5		10
6.1	0	x	5		10
6.0	0	x	5		10
5.9	10	x	30		50
5.8	10	x	30		50
5.7	10	x	30		50
5.6	10	x	45		90
5.5	10	x	45		90
5.4	10	x	55		100
5.3	10	x	55		100
5.2	25	x	62.5		100
5.1	25	x	62.5		100
5.0	50		75	x	100
4.9	50		75	x	100
4.8	80		90	x	100
4.7	100		100		100
4.6	100		100		100
4.5	100		100		100
4.4	100		100		100
4.3	100		100		100
4.2	100		100		100
4.1	100		100		100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6m*

Lake Trout - Self-sustaining

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	0		0		0
6.1	0		0		0
6.0	0	x	5		10
5.9	0	x	5		10
5.8	0	x	5		10
5.7	0	x	5		10
5.6	0	x	5		10
5.5	5	x	17.5		30
5.4	5	x	17.5		30
5.3	5	x	17.5		30
5.2	5	x	17.5		30
5.1	5	x	17.5		30
5.0	10	x	37.5		65
4.9	10	x	37.5		65
4.8	10	x	37.5		65
4.7	10	x	37.5		65
4.6	10	x	37.5		65
4.5	20	x	50		80
4.4	20	x	50		80
4.3	20	x	50		80
4.2	20	x	50		80
4.1	20	x	50		80
4.0	75		87.5	x	100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6n*

Small Mouth Bass

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	10		17.5		25
6.1	10		17.5		25
6.0	20		35		50
5.9	20		35		50
5.8	20		35		50
5.7	30		50	x	70
5.6	30		50	x	70
5.5	30		55	x	80
5.4	30		55	x	80
5.3	40		65	x	90
5.2	40		65	x	90
5.1	40		65	x	90
5.0	70		85		100
4.9	70		85		100
4.8	90		95		100
4.7	90		95		100
4.6	100		100		100
4.5	100		100		100
4.4	100		100		100
4.3	100		100		100
4.2	100		100		100
4.1	100		100		100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6o*

Small Mouth Bass

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		0		0
6.2	0		0		0
6.1	0		0		0
6.0	0		0		0
5.9	0		2.5		5
5.8	10		20		30
5.7	30		40		50
5.6	40		50		60
5.5	50	x	65		80
5.4	60		75		90
5.3	100		100		100
5.2	100		100		100
5.1	100		100		100
5.0	100		100		100
4.9	100		100		100
4.8	100		100		100
4.7	100		100		100
4.6	100		100		100
4.5	100		100		100
4.4	100		100		100
4.3	100		100		100
4.2	100		100		100
4.1	100		100		100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6p*

White Sucker

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0		0		0
6.7	0		0		0
6.6	0		0		0
6.5	0		0		0
6.4	0		0		0
6.3	0		2.5		5
6.2	0		2.5		5
6.1	0	x	10		20
6.0	0	x	10		20
5.9	0	x	10		20
5.8	0	x	10		20
5.7	0	x	20		40
5.6	0	x	20		40
5.5	5	x	27.5		50
5.4	5	x	27.5		50
5.3	5	x	27.5		50
5.2	20	x	35		50
5.1	20	x	35		50
5.0	20	x	45		70
4.9	20	x	50		80
4.8	20	x	50		80
4.7	30		55	x	80
4.6	30		55	x	80
4.5	40		67.5	x	85
4.4	50		74.5	x	99
4.3	50		74.5	x	99
4.2	93		96.5	x	100
4.1	93		96.5	x	100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6q*

Common Shiner

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	10		25	x	40
6.7	10		25	x	40
6.6	19		25	x	40
6.5	10		25	x	40
6.4	10		25	x	40
6.3	40	x	60		80
6.2	40	x	60		80
6.1	40	x	60		80
6.0	50		65		80
5.9	50		65		80
5.8	50		65		80
5.7	50		65		80
5.6	50		65		80
5.5	50		70		90
5.4	50		70		90
5.3	70		80		90
5.2	90		95		100
5.1	90		95		100
5.0	100		100		100
4.9	100		100		100
4.8	100		100		100
4.7	100		100		100
4.6	100		100		100
4.5	100		100		100
4.4	100		100		100
4.3	100		100		100
4.2	100		100		100
4.1	100		100		100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

Table 4-6r*

Fat Head Minnow

pH	Low	Weight	Mid Point	Weight	High
7.0	0		0		0
6.9	0		0		0
6.8	0	x	10		20
6.7	0	x	10		20
6.6	10	x	15		30
6.5	10	x	15		30
6.4	10		20		30
6.3	10		20		30
6.2	10		20		30
6.1	10		20		30
6.0	20	x	30		40
5.9	20	x	30		40
5.8	30	x	50		70
5.7	30	x	50		70
5.6	50		60		70
5.5	50		60		70
5.4	50		75		90
5.3	60	x	75		90
5.2	60	x	75		90
5.1	60		75		90
5.0	80		90		100
4.9	80		90		100
4.8	100		100		100
4.7	100		100		100
4.6	100		100		100
4.5	100		100		100
4.4	100		100		100
4.3	100		100		100
4.2	100		100		100
4.1	100		100		100
4.0	100		100		100

* Where no weighting is indicated by the placement of an x, the weighting is placed over the midpoint.

5.0 INTERPRETATION AND USE OF THE ELICITATION DATA

This chapter addresses the use and application of the estimates obtained from the elicitations. Section 5.1 discusses the conversion of the basic data provided by the elicitations into marginal and cumulative probability distributions. Section 5.2 discusses the data bases used by the investigators in order to apply these results to the lakes in the Adirondack region. Section 5.3 presents and discusses the results of applying the cumulative probability distributions developed in Section 5.1 to the data base discussed in Section 5.2.

There are a number of ways to interpret and use the estimates obtained from the elicitation. One way is to simply show the range of estimated effects. Since each expert estimated lower and upper bounds of effects, these can be used to dimension the range of effects due to a change in pH. If two additional assumptions are made, probabilistic estimates of damages from acid deposition can also be obtained.

5.1 STEPS NEEDED TO OBTAIN PROBABILISTIC EFFECTS ESTIMATES

In order to obtain probabilistic estimates of the extent of change occurring to fish populations, the results of the elicitations presented in Table 4-6 must be interpreted as probability distributions. To accomplish this, two assumptions are needed:

1. the range elicited from the scientist at each pH level must be interpreted as a confidence interval; and

2. the weight assigned by the scientist must be interpreted as a relative likelihood.

5.1.1 Assumptions

The initial assumptions made were that the range estimated by the scientist represented a 95 percent confidence interval and that, when a weight was placed on one side of the range mid-point, the effects were twice as likely to occur in the weighted segment as in the unweighted segment. It is important to recognize that both the use of a 95 percent confidence interval and a 2:1 weighting are assumptions. There is no quantative or statistical justification for either assumption. However, a 95 percent confidence interval was felt to be reasonable since during the elicitation the scientists were asked to dimension a range of potential effects so that, in their opinion, the actual impact would almost certainly lie within that range. Assuming that the range represents a high confidence interval is consistent with the way the elicitation was conducted. The assumption of a 2:1 weighting is more problematic since the scientists were not asked during the elicitation to determine what the relative probabilities were between the weighted and unweighted segments. Whenever the scientists were asked to actually assign different probabilities to the different segments, they resisted making the estimate. It was felt that the simple weighting used in the elicitation pushed the limits of the scientists ability to dimension the uncertainty surrounding the effects estimates. The scientists simply did not feel that they could provide reliable estimates of actual probabilities, but they felt they could indicate on which side of the range mid-point the actual outcome would most likely fall. Given that this was all the information that could be reliably obtained, the task facing the project investigators was to design a method that credibly used this sparse data.

Since the specification of a confidence interval and interpretation of the weighting are both assumptions, it is important to perform a sensitivity analysis around any selected values. Confidence intervals of 90 percent and 80 percent were used along with a 95 percent confidence interval to test the sensitivity of the confidence interval assumption. In addition to the 2:1 weighting assumption, sensitivity analysis was performed using a 3:2 and 5:4 weighting.

These different confidence intervals and weighting assumptions were felt to bound the reasonable range of assumptions. The 95 percent confidence interval is quite a high confidence interval (ie., the probability that the actual value would fall outside the scientists' estimated range is only 5 percent). Conversely, the 80 percent confidence interval was felt to be a lower bound. Given that the stated purpose of the elicitation was to have the scientist estimate a range within which he was almost certain the actual effects would fall, it seems reasonable to assume that the range represented at least an 80 percent confidence interval. The weightings used (2:1, 3:2, and 5:4) range from the assumption that, if a weight is placed on one side of the mid-point, the scientist feels that the actual outcome would be twice as likely to fall on the weighted side, to a 5:4 weighting where the scientist would be very uncertain regarding which side of the midpoint the actual outcome will most likely fall, even though he is willing to assign a weight.

The results of the sensitivity analysis are shown in more detail in Appendix A; however, it was found that the assumed confidence interval had a significant effect on the damage estimates, but the assumed interpretation of the weighting had a minor impact. This is an important finding since the interpretation of the weighting is the most uncertain assumption. Further, this result justified the emphasis placed on obtaining accurate estimates of the potential range of effects while settling for a simple weighting scheme to indicate where within this range the most likely outcome might fall.*

Two examples will be presented to show in more detail how these confidence intervals and weighting assumptions are translated into probability distributions.

<u>Example 1</u>

Assume that for fish species X and a pH of 6.4, the scientist estimated the range and assigned the weight as shown below:

pH	Lower Bound	Weight	Range Midpoint	Weight	Upper Bound
6.4	0	(X)	15	( )	30

* This result was not entirely a surprise. In an earlier test application of this technique, the investigators found the assignment of different probability weights to have a minimal effect on the selection of the best control strategy for reducing acid deposition. Also, this same result was found in a pretest of an elicitation on the effects of pH on tree growth. These are reported in Violette and Peterson (1982).

This indicates that the scientist felt that at a pH of 6.4 the percent of Adirondack lakes that could possibly, but no longer can, support fish populations of species X would fall in the range bounded by 0 and 30 percent, and that the expert felt that the outcome was more likely to fall between 0 to 15 percent than between 15 and 30 percent. Assuming a 90 percent confidence interval and a 2:1 weighting results in the cumulative distribution shown in Figure 5-1. Given this cumulative distribution, the following holds true:*

- Probability 0 damages 15 equals .60;
- Probability 15 damages 30 equals .30; and
- Probability 30 damages 100 equals .10.

Example 2

Assume that for fish species X and a pH of 5.9, the scientist estimated the range and assigned a weight as shown below:

pH	Lower Bound	Weight	Range MidPoint	Weight	Upper Bound
5.9	30	( )	55	(X)	80

Using the same definitions of these elicitation results as in Example 1, but assuming a 80 percent confidence interval with a 3:2 weighting results in the cumulative probability distribution shown in Figure 5.2. Given this cumulative probability distribution, the following holds true:

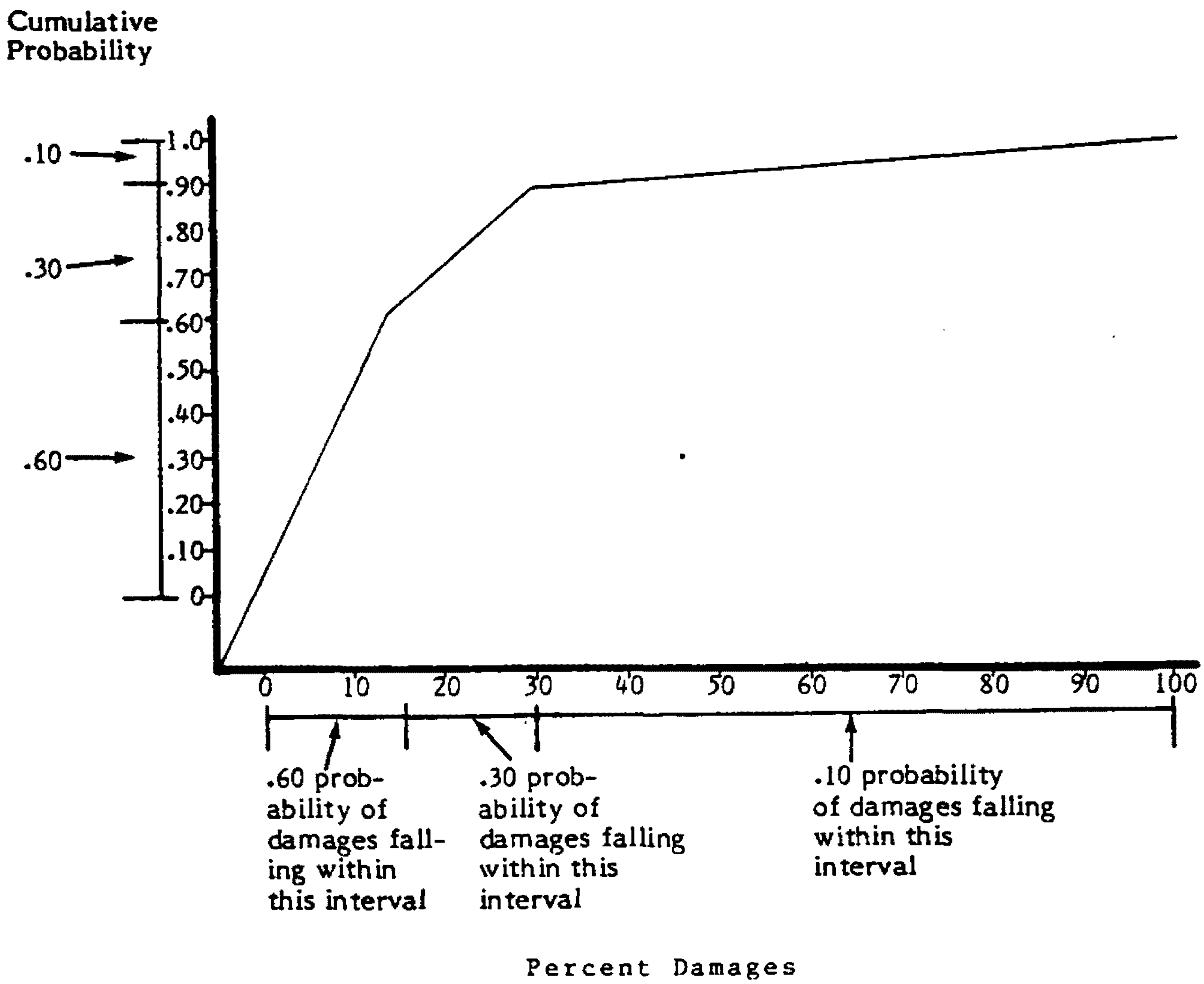
- Probability 0 damages 30 equals .10
- Probability 30 damages 55 equals .32
- Probability 55 damages 80 equals .48
- Probability 80 damages 100 equals .10

* Changing the interpretation of the weights from 2:1 to 3:2 would change the probabilities of damages falling into the three specified intervals from .60, .30, and .10 to .54, .36, and .10. A 5:4 weighting results in probabilities of .50, .40, and .10 for each interval. Recall that the estimate of the number of lakes damaged was found, in this application to be relatively insensitive to the weighting interpretation.

Figure 5-1

Cumulative Probability Distribution for Percent Reduction in Habitat* for Fish Species X Resulting from a pH of 6.4 Using the Data from Example 1

(assumes a 90 percent confidence interval and a 2:1 weighting)

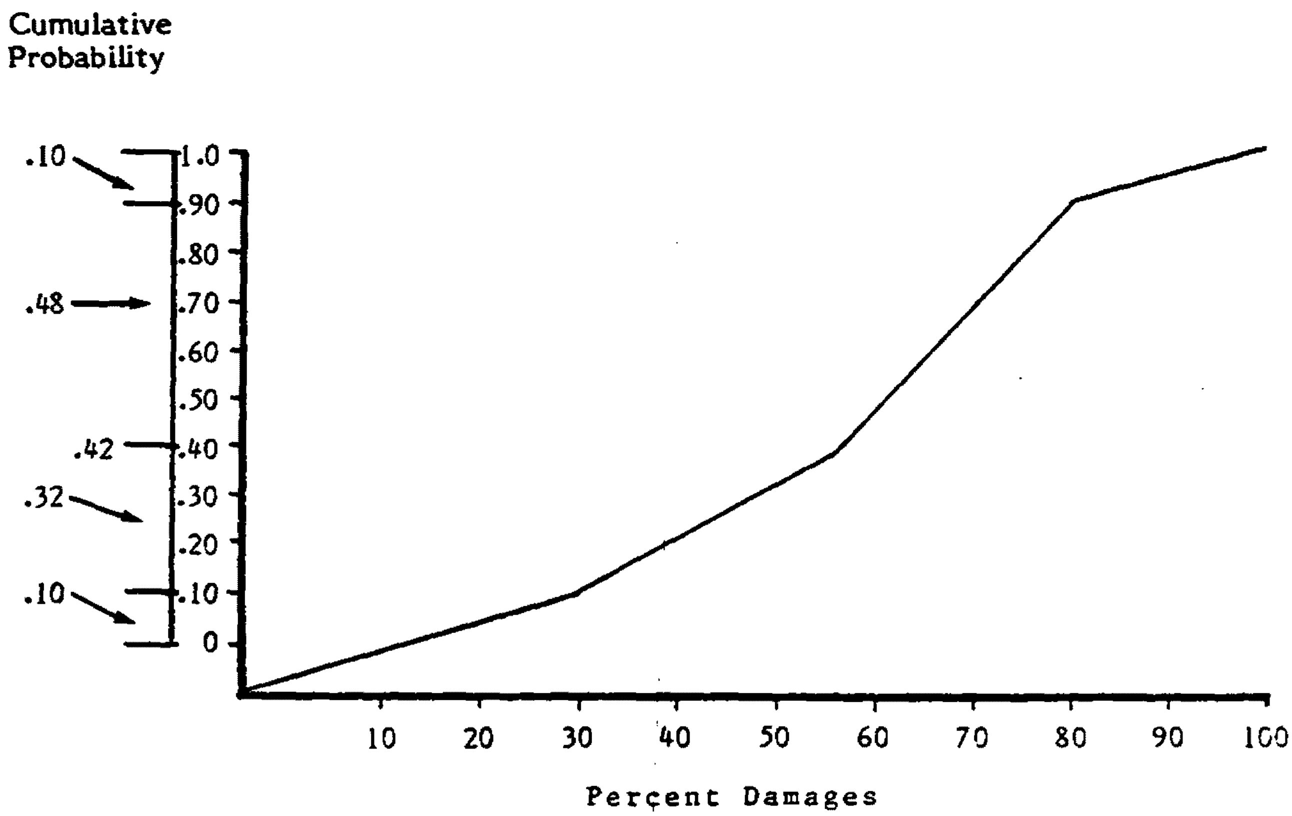


* Percent of lakes which could, but no longer can, support fish populations of species X.

Figure 5-2

Cumulative Probability Distribution for Percent Reduction in Habitat*
for Fish Species X Resulting from a pH of 5.9 Using the
Data from Example 2

(assumes a 80 percent confidence interval and a 3:2 weighting)



* Percent of lakes which could possibly, but no longer can, support fish populations of species X.

5.1.2 Procedure for Estimating Damages from Acid Deposition

The preceding section presented the assumptions required to convert the range of estimated damages and the weight assigned by the scientist at each pH into a cumulative probability distribution for that pH. This section will outline the steps in the estimation of damages from acid deposition based on the elicitations. A simple illustration of these steps and a presentation of results from a test case sensitivity analysis of the confidence interval and weighting assumptions can be found in Appendix A. Table 5.1 shows the steps in the estimation of damages based on the elicitation conducted with the scientists.

Step One is the calculation of aggregate cumulative probability distributions of damages for each species of fish at each pH level. For example, five elicitations were conducted for self sustaining populations of brook trout. Table 5.2 shows the number of elicitations conducted for each fish species. The five different self sustaining brook trout elicitations were combined to form aggregate cumulative probability distributions of damages at each pH by first calculating cumulative probability distributions for each scientist's elicitation and then averaging the distributions. A computer program using simple numeric techniques was constructed to perform these computations.

Step Two involves determining the present distribution of pH levels across Adirondack lakes. The basic source of this data is the Adirondack Water Management System data base maintained by the New York State Department of Environmental Conservation. This data base and others used are described in Section 5.2.

Step Three is the presentation of a hypothetical case used to derive the change in the distribution of pH values caused by increases or decreases in acid loading.

Step Four is the calculation of the incremental damages from the shift in the distribution of pH values calculated in Step Three. This is a conditional probability calculation. It is the probability of incremental damages given the current distribution of fish habitat in the Adirondacks.

Table 5.1

Steps in the Estimation of Damages
Based on Elicitation Results

Step 1:	Obtain aggregated cumulative probability distributions for each species of fish at each pH by averaging the cumulative probability distributions for each scientist.
Step 2:	Obtain current distribution of pH values for Adirondack lakes.
Step 3:	Derive the change in the distribution of pH values across Adirondack lakes caused by increases in acid loading.
Step 4:	Calculate the incremental damages over present damages due to a downward shift in the distribution of pH values across Adirondack lakes.
Output:	Given a predicted change in the distribution of pH values across Adirondack lakes, a cumulative probability function of the incremental number of lakes expected to be damaged.

Table 5-2

Number of Elicitations Performed for Different Fish Species in the Project

Fish Species	Number of Elicitations
Brook Trout	
Self Sustaining Population	5
Stocked Population	3
Lake Trout	
Self Sustaining Population	3
Stocked Population	2
Small Mouth Bass	2
Common Shiner	1
Fat Head Minnow	1
White Sucker	1

The step four calculation of incremental damages requires that the correlation between the different distributions of effects at different pH levels be specified. Since a regional assessment spans lakes with different pH values, estimates of the probability of different levels of damages are derived from the combined probability distribution for all lakes. To calculate this combined distribution, the distributions of damages to lakes segmented by pH class must be convoluted (i.e., combined).* To perform this step, it is necessary to know whether these different probability distributions are independent or whether there is some correlation across these distributions. Referring back to Figure 5-1, the figure shows the probability distribution of damages for a fish species in lakes with a pH of 6.4. A similar distribution could be graphed for lakes with a pH of 6.3. The assumption of perfect correlation between these two distributions would mean that if actual damages at a pH of 6.4 are high, then actual damages at a pH of 6.3 will also be high. In terms of the cumulative probability distributions, this means that if the actual damage outcome turns out to be that outcome associated with a .9 cumulative probability for the 6.4 pH distribution, the actual damage outcome for lakes with a pH of 6.3 will also be that level of damages also associated with the .9 probability. The assumption of perfect independence implies that finding high levels of actual damages in lakes with one pH does not change the probability of high or low damages in lakes at neighboring pH values. Instead of assuming perfect correlation or perfect independence, a compromise assumption of partial correlation between distributions is possible. With partial correlation, a high damage outcome at one pH level does not imply a high damage outcome at a neighboring pH level, but it does imply that the probability of high damages at the neighboring pH levels increases.

As a result, three assumptions are possible — perfect correlation across distributions, some form of partial correlation, or perfect independence. The assumption of perfect correlation results in the most uncertainty (i.e., the greatest dispersion in outcomes away from the mean). This stems from the fact that, with perfect correlation, if damages at one pH turn out to be very high, the damages at neighboring pH levels will also be very high. Thus, extreme values are always coincident. This tends to increase the probability that actual outcomes will fall in the tails of the joint distribution. However, it does not change the upper and lower bounds of the distribution. The assumption of perfect in-

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* Convolution is the term for multiplying probability distributions.

dependence gives the tightest distribution, in terms of measures of central tendency around the mean; and, therefore, results in the lowest amount of uncertainty. Thus, the assumptions of perfect correlation and perfect independence can be used to bound the uncertainty.

The appropriate dependence assumption was discussed with scientists during the pretest phase of the project. The scientists indicated it reasonable to assume that if actual damages at one pH level were in the low part of the distribution, then actual damages at neighboring pH levels will also be in the low portion of their distributions. This implies that underlying factors which make estimates of damages uncertain are correlated across pH levels, and that if scientists learned that actual damages caused by pH 5.4 were in the low part of the range, then they would revise the estimate at a pH of 4.8 downward to account for this finding.* As a result, an assumption of perfect or partial correlation is appropriate, and an assumption of perfect independence is inappropriate. For this study, perfect correlation was assumed. This assumption provides an upper bound to the uncertainty in the estimates and it is mathematically much easier to work with than partial correlation. By assuming perfect correlation, it is possible to sum calculated distributions of damages across different "clusters" of lakes to obtain total distributions of damage to lakes. A "cluster" of lakes is a set of lakes that have the same current pH level and the same ending pH level after the shift in pH levels.

Appendix A presents a simple example of these calculations and the results of a "Test Case" sensitivity analysis of the weighting and confidence interval assumptions.

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* In review drafts of this report, some scientists interpreted correlation as meaning that during the elicitation, if the weight was placed on the high side of the midpoint at one pH, then the weight would have to be placed on the high side of the midpoint at other pH levels. This is incorrect. The assumption of perfect correlation implies nothing about the placing of weights during the elicitation. The scientist place the weights in the manner they feel most appropriate. Assumptions of correlation or independence influence how the resulting distributions are combined.

5.2 DESCRIPTION OF ADIRONDACK DATA USED IN THE ANALYSIS

In order to apply the probabilistic damage estimates discussed in Section 5.1, it was necessary to obtain a comprehensive and current water chemistry and fish population data file for the Adirondack Mountain Region. The primary data set used was provided by the New York State Department of Environmental Conservation (DEC). Published and unpublished data provided by a number of other investigators were also used. These included data collected in 1975 by Dr. Carl Schofield (unpublished data); a characterization of 623 Adirondack lakes provided by Dr. Schofield (unpublished data); and the Acidity Status of Lakes in the Adirondack Region of New York in Relation to Fish Resources (Pfeiffer and Festa, 1980) and its 1981 Update. This section will describe salient characteristics of the DEC data as it was represented on the Adirondack Waters Management System Tape, as well as the manner in which the data were interpreted and used in a regional assessment of fish damages.

Data in the Adirondack Waters Data Management System covers 3506 ponded waters in the Adirondack area. To sort the data into meaningful units for analysis, the variables in Table 5-3 were reorganized into a working data base. The data base is not entirely comprehensive, as not every ponded water has a complete record. For example, while there are a total of 3820 pH records within the data base, only 2409 of these are contained within the Chem-Current File (the file containing most current chemistry survey data for those waters which possess chemistry surveys). Similarly, while there are a total of 3820 alkalinity records for Adirondack ponds, only 1516 are contained within the Chem-Current File.* The DEC is, however, augmenting the records with acidification field monitoring programs and increased efforts to record field station data on the Adirondack Waters Management System Tape. Since 1975, the DEC has taken pH and alkalinity measurements in over 937 ponded waters (Pfeiffer and Festa, 1980, unpublished, 1982). The pH measurements were obtained with a pH meter under air-CO_2 equilibrium conditions. In the initially published results, 25 percent of the surveyed waters registered pH readings below 5.0 (Pfeiffer and Festa, 1980).

* The total number of alkalinity records are the sum of the Chem-Historic and Chem-Current Files. There were a total of 509 records for calcium and 560 for magnesium within the Data Base.

Table 5-3

Variables in Project Data Base

DATA BASE

Location and Status Records

1. Record type
2. Watershed
3. P#
4. Record# with P#
5. Watershed
6. P#
7. Record Type
8. Date
9. Name of Water
10. Counties
11. APA State Land Classification
12. Fishery
13. Water Quality Classification

Morphometrics Record

14. Elevation (ft.)
15. Watershed Area (acres)
16. Surface Area (acres)
17. Annual Flushing Rate
18. Volume (acre ft.)

Use Information Records

19. Date
20. Number of Formal Waterfront Campsites/ Parks
21. Total Percent Shoreline Development

Species Records

22. Date of Survey
23. Presently Stocked?
24. Species Presently Stocked
25. NSA Game Species Present?
26. Species Presently NSA
27. Reclamation History
28. Current Management Classification
29. Special Strains
30. Management Needs
31. Gear

Table 5-3

Variables in Project Data Base

(Continued)

Liming Records

32. Date Recorded
33. Month Limed
34. Year Limed

Chemistry Parameter Records
(for pH, alkalinity, NO_2, NO_3, SO_4, Al, Ca, Mg)

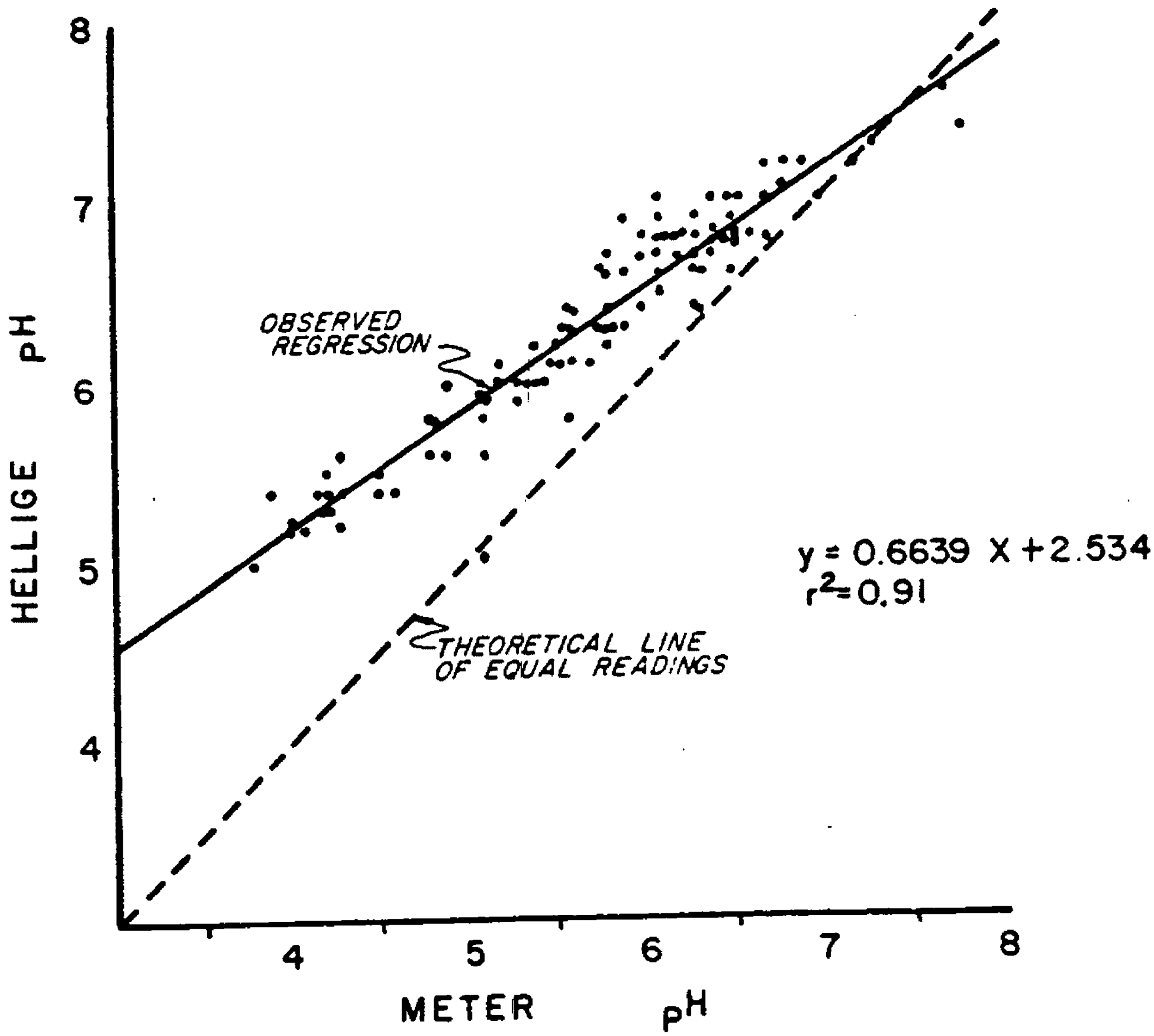
35. Date of Samples
36. Depth (ft.)
37. Measurement
38. Method
39. Remarks
40. Source
41. Sample Type
42. Year
43. Acidification Classification

There is some controversy concerning the accuracy of many of the pH records contained within the data base. This concern resulted from a 1979 survey conducted by the DEC's Lake Acidification Studies Unit. The DEC possessed historical pH records for 138 of these waters collected between 1930 and 1934. In order to compare current levels of acidification with these historical records, the investigators recorded the current pH values using both a pH meter and a Hellige comparitor. In reporting the results, Pfeiffer and Festa (1980) showed that the 1979 colorimetric (Hellige comparitor) readings were consistently higher than the pH meter determinations (see Figure 5-3). However, when Schofield (1981) compared colorimetric measurements to meter pH measurements, he concluded that the agreement between the two methods was much closer than stated by Pfeiffer and Festa. Schofield concluded that the pH meter determinations reported in Pfeiffer and Festa were between .5 and 1.0 pH units too low. Hence, the 396 pH determinations for the ponded waters sampled in 1979 are probably between .5 and 1.0 pH units in error. The investigators have been unable to determine what percentage of pH listings recorded by the DEC and listed in the data base are in error.

In order to assess the potential bias in data base pH records, a regression developed by Schofield (1976) relating pH to pCa was used by the investigators to determine the pH of the 509 Adirondack waters for which both pH and calcium data were available. The mean listed pH value for the sample was 6.1, while the mean pH value calculated using calcium concentration data and the regression relating pH to pCa was 6.3. The standard deviation of the pH values was .84, while the standard deviation of the pH values calculated from calcium concentrations was 1.12. While the difference between the two values is important, the investigators didn't believe it to be large enough to justify not using the pH records contained within the data base. The seasonal variability of the pH within individual lakes caused by biologic production, snowmelt, and in some cases, fall rainstorms, is probably equal to or greater than the variation expressed in the calculation of the lake pH values. Figure 5-4 demonstrates the considerable variation in the pH of one Adirondack lake's summer-ice free-surface pH values. In the case of the example, the values range from a low of 4.9 to a high of 5.50 in late summer. Readers, however, should be aware of this systematic bias in the characterization of pH values in the data base used in this analysis.

Figure 5-3

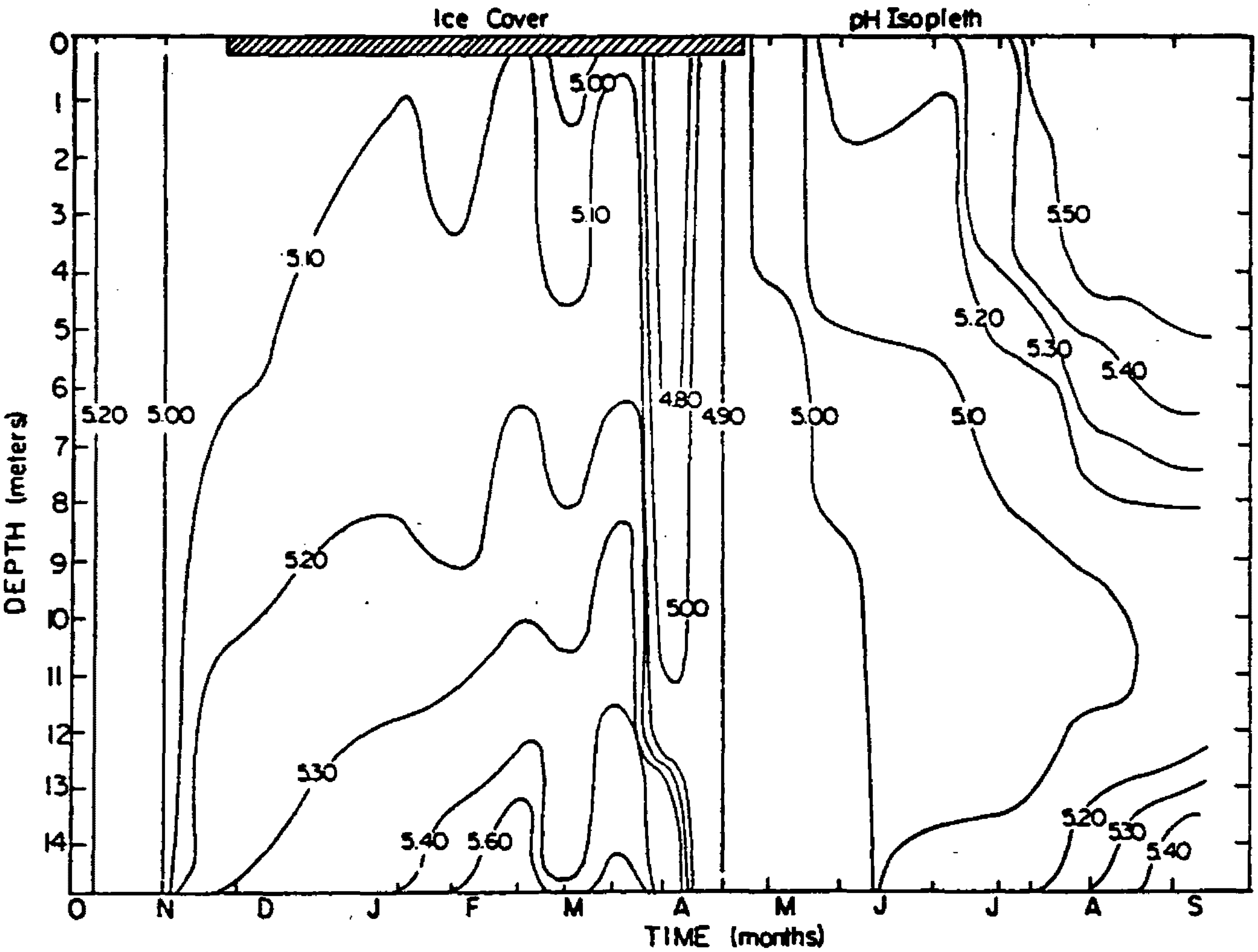
Comparison of Meter pH and Colorimetric (Hellige) pH Readings for 100 Adirondack Lake Samples*



* Taken from Pfeiffer and Festa, 1980.

Figure 5-4

Representation of the Spatial and Temporal Variability Within Dart Lake in the Adirondack Mountain Region*



* (Driscoll, 1982, unpublished data). Dart Lake is an acidic drainage lake located in the Adirondack Region of New York State. It possesses a well-defined inlet and outlet.

Records of fish populations within the Data Base reflect the presence or absence of fish species within the particular ponded water surveyed. All of the fish species for which damage elicitations were performed are included the Data Base. A data sort was performed to establish an inventory of Adirondack lakes posessing both chemistry records and presence-absence data for fish populations. Figure 5-5 illustrates the sort procedure. Since 1975, the DEC has obtained pH and alkalinity measurements for approximately 972 ponded waters in the Adirondack Region of New York.* In searching the Data Base for chemistry records from 1960 to the present, a total of 1217 lakes were recorded. Of these, 550 possessed fish records. Records dated from 1960 to the present were considered current or indicative of the present pH and fish population status. Of the 1217 examined, 280 were surveyed prior to 1975. Assuming some change in the pH of those 280 lakes between 1960 and the present indicates that our data probably overestimates current pH and fish populations status within the region. There has been no published estimate of the rate of acidification in the Adirondack Region between 1960 and the present, but W.D. Watt et al. (1979) estimated that for lakes above pH 5 in Nova Scotia, Canada, pH decreased approximately 0.5 pH from Gorham's measurements taken in 1955 to their own made in 1977. Below pH 5, typical Adirondack waters possess increasing buffer intensities as a result of the mobilization of aluminum, and the shift could be expected to be smaller. In searching the files for a pH record, the algorithm also looked for calcium and alkalinity records. Of the 1217 lakes with pH records, there were 151 which did not possess alkalinity records.

Step 2 calculated the pH range of the ponded water's pH value. Lakes were assigned one out of 42 possible pH ranges. Increments of .1 pH between 8.0. to below 4.0 were used (see Table 5-4). After the assignment of a pH range, the program assigned the lake to an elevation class -- either below or equal to 1500 feet, between 1501 and 2000 feet, and above 2000 feet. If there was no record, or if the elevation was blank, the elevation class was set equal to "unknown". High elevation lakes in the Adirondack Mountain Region have been noted to possess both depressed pH values and reduced fish populations (Pfeiffer and Festa, 1980; Schofield, 1976b, 1981, 1982). In a 1975 survey of 214 lakes above 2000 feet, Dr. Schofield found that approximately 50 percent of the surveyed lakes

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* 937 measurements were recorded between 1975 and 1981. In 1982, an additional 35 lakes were surveyed.

Figure 5-5

Sort Algorithm for Adirondack Ponded Waters

For each lake in the data base:

Read index record (1-7)

NO — Is there a pH value or a pH indicator (Ca, alkalinity) record later than 1960?

YES

Read pH record, choosing lab pH if available, and calculate pH range; or, if no pH record is available, read Ca record and calculate; 0.1, if no Ca record is available, read alkalinity and calculate pH.

Is there an elevation record later than 1960? If so, calculate elevation class. If not, or if elevation is blank, set evaluation equal to "unknown".

Is there an alkalinity record later than 1960? If so, calcualte alkalinity class. If not, or if alkalinity is blank ,set alkalinity class to "unknown".

NO — Is there at least one fish species record later than 1960?

YES

Read all job species records with the same data as the most recent one and set flags for each of the six species being looked for.

Add 1 to total for each fish species found (broken down by alkalinity, pH range, and elevation class).

Add 1 to total for all fish species (broken down by alkalinity, pH range, and elevation class).

→ Add 1 to total for all lakes (broken down by alkalinity, pH range, and elevation class).

→ GO TO NEXT LAKE.

Table 5-4

Distribution of Fish Habitat Represented in Data Files Sorted by pH Range*

pH Range	Brook Trout	Lake Trout	Small Mouth Bass	White Sucker	Fat Head Minnow	Common Shiner	All Fish Species
8.0	2	0	7	8	0	0	15
7.90-7.99	1	0	0	1	0	0	2
7.80-7.89	1	3	5	4	0	0	6
7.70-7.79	1	1	5	3	0	0	8
7.60-7.69	4	0	3	6	0	0	9
7.50-7.59	3	2	7	6	0	0	13
7.40-7.49	6	1	1	5	0	1	8
7.30-7.39	5	2	2	5	0	0	8
7.20-7.29	4	2	5	9	1	0	12
7.10-7.19	10	4	5	9	0	0	16
7.00-7.09	12	4	3	18	0	0	26
6.90-6.99	13	2	3	12	0	1	22
6.80-6.89	12	1	6	9	0	3	22
6.70-6.79	8	1	4	11	0	1	18
6.60-6.69	11	2	2	12	0	1	18
6.50-6.59	17	2	8	16	0	3	27
6.40-6.49	13	1	5	10	0	2	21
6.30-6.39	20	5	5	14	0	1	27
6.20-6.29	19	7	7	17	0	1	30
6.10-6.19	11	3	3	9	0	1	17
6.00-6.09	27	5	8	18	0	1	38
5.90-5.99	16	4	0	13	0	4	19
5.80-5.89	16	5	2	7	0	0	21
5.70-5.79	16	3	2	7	0	1	20
5.60-5.69	8	2	1	5	0	0	11
5.50-5.59	17	0	1	9	0	0	20
5.40-5.49	8	2	2	6	0	0	13
5.30-5.39	5	1	1	3	0	0	8
5.20-5.29	7	2	0	6	0	0	9
5.10-5.19	9	0	0	7	0	0	12
5.00-5.09	11	0	0	3	0	0	13
4.90-4.99	3	0	0	1	0	0	4
4.80-4.89	10	0	0	1	0	0	10
4.70-4.79	6	0	0	2	0	0	7
4.60-4.49	5	0	0	1	0	0	6
4.50-4.59	4	1	0	2	0	1	4
4.40-4.49	1	0	0	0	0	0	1
4.30-4.39	3	0	0	0	0	0	3
4.20-4.29	2	0	0	0	0	0	2
4.10-4.19	2	0	0	1	0	0	3
4.00-1.09	1	0	0	0	0	0	1
4.00	0	0	0	0	0	0	0

* Numbers equal number of lakes within each pH category which have fish records.

had pH values below 5.0. Fish surveys conducted at the same time indicated that 82 percent of these acidic, high elevation lakes are devoid of fish. Of the 1217 lakes examined in the subset of Adirondack ponded waters which had pH, alkalinity, or calcium records, Table 5-5 shows that 141 were above 2000 feet. Of these, 99 or approximately 70 percent, possessed alkalinity readings less than 50 eq/l. The same table indicates that of the 550 lakes which had records of fish populations and chemical records, only 52 were known to be above 2000 feet.*

After assigning the lake to an elevation class, the program determined if there was an alkalinity record entered in 1960 or later. If so, the lake was assigned to one of the following alkalinity classes: above 200 µeq/l alkalinity, between 100-200, 50-100, or below 50 eq/l alkalinity. If there was no alkalinity record, the alkalinity record for that lake was set equal to unknown. 200 µeq/l was established as the lower bound of the highest category because it has commonly been used as the boundary between "sensitive" and "insensitive" waters prior to the initiation of anthropogenic acidification (Hendrey et al., 1980b) According to Glass and Brydges (1981) biological effects due to acidification begin when aquatic systems reach alkalinities of approximately 100 µeq/l. The range below 100 µeq/l was divided into two segments: one between 50 and 100 µeq/l and one below 50 µeq/l. Referring to Figure 5-6, it can be seen that there is a dramatic reduction in lake pH as lakes develop alkalinity values less than 50 µeq/l in the Adirondacks.

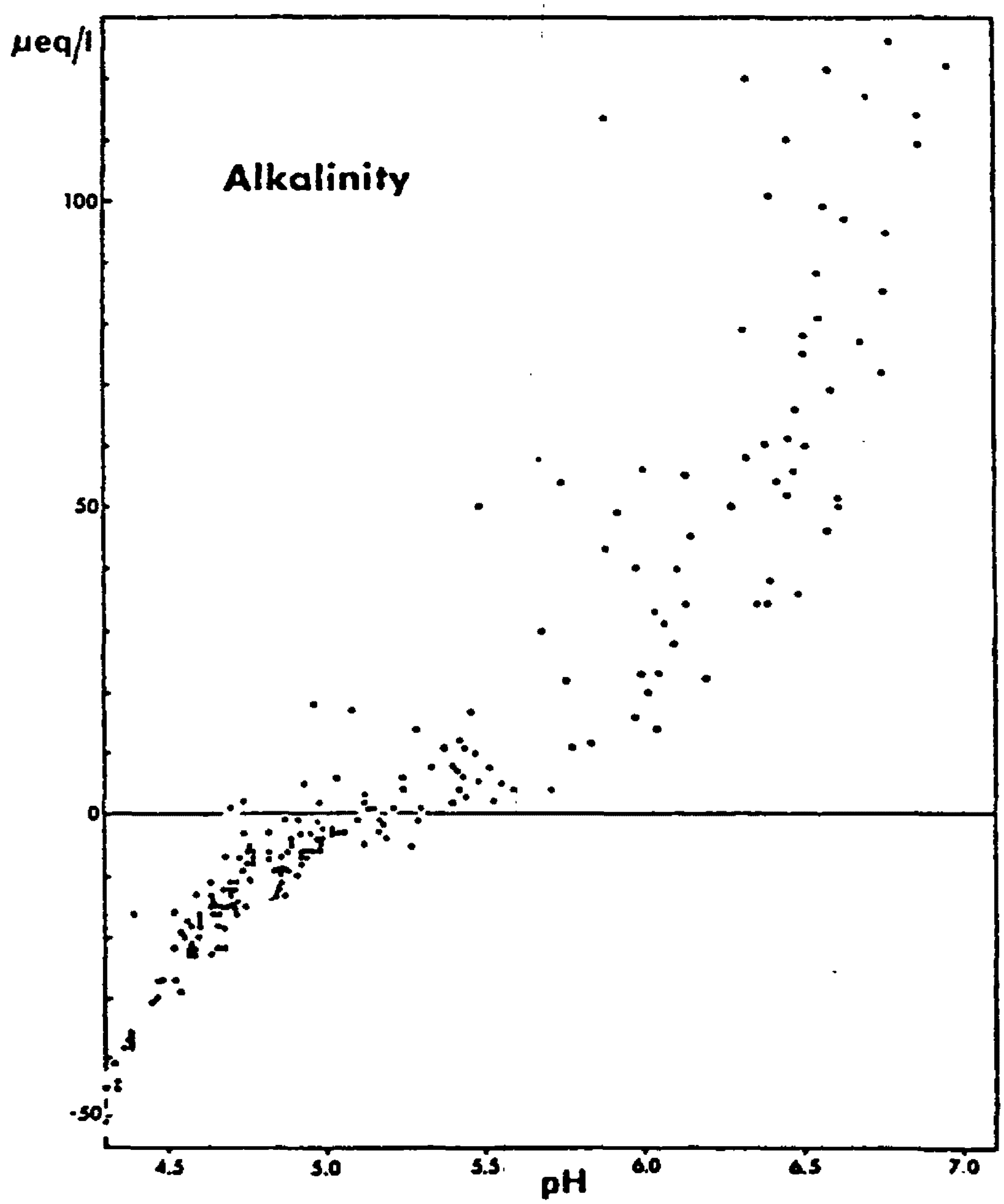
After assigning the lake to a pH, elevation, and alkalinity category, the program recorded which, if any, of the 6 species of fish for which elicitations were performed were present within the lake either in 1960 or later. A summary of this data, not including elevation and alkalinity records, is shown in Table 5-4. Table 5-5 contains a summary of the data excluding pH categories for the Adirondack Mountain Region.

Table 5-6 indicates that of the 350 lakes in the data base for which there were records of brook trout samplings and chemistry records, 14 percent, or 49 lakes, possessed pH values above 7; 43 percent, or 151 lakes, had pH values between 6.00 and 6.99; 32 percent, or 113 lakes, had pH values between 5.0 and 5.99; and 37 lakes had pH values

* In both cases, however, there is a substantial fraction of lakes for which elevation records do not exist; 493 and 201 respectively for the total population of lakes and for the subset containing fish, respectively.

Figure 5-6

The Relationship Between pH and Alkalinity for Adirondack Lakes less than 610 Meters Elevation. June 24-27, 1975.*



* Taken from Schofield, 1976.

Table 5-5

Results of Sort of Adirondack Lakes by Alkalinity, Elevation, and Fish Species

Brook Trout

Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation:						
= 1500 ft.	16	4	7	12	9	48
1501 - 2000 ft.	10	21	24	43	24	122
2000 ft.	1	7	8	30	4	50
Unknown	27	24	21	37	21	130
Total	54	56	60	122	58	350

Small Mouth Bass

Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation						
= 1500 ft.	18	8	2	4	2	34
1501 - 2000 ft.	2	7	9	6	2	26
2000 ft.	0	0	0	0	0	0
Unknown	19	8	7	1	8	43
Total	39	23	18	11	12	103

Fat Head Minnow

Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation						
= 1500 ft.	1	0	0	0	0	1
1501 - 2000 ft.	0	0	0	0	0	0
2000 ft.	0	0	0	0	0	0
Unknown	0	0	0	0	0	0
Total	1	0	0	0	0	1

Lake Trout

Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation						
= 1500 ft.	2	1	3	0	0	6
1501 - 2000 ft.	2	6	5	15	3	31
2000 ft.	0	0	2	3	0	5
Unknown	8	7	5	3	3	26
Total	12	14	15	21	6	68

* Alkalinity values in μeq/l

Table 5-5

Results of Sort of Adirondack Lakes by Alkalinity, Elevation, and Fish Species

Continued

Common Shiner

Alkalinity* Elevation	200	100-200	50-100	50	Unknown	Total
= 1500 ft.	4	0	0	0	0	4
1501 - 2000 ft.	1	3	3	4	0	11
2000 ft.	1	0	2	0	0	3
Unknown	1	0	1	1	1	4
Total	7	3	6	5	1	22

White Sucker

Alkalinity* Elevation	200	100-200	50-100	50	Unknown	Total
= 1500 ft.	31	10	5	9	6	61
1501 - 2000 ft.	12	25	19	30	10	96
2000 ft.	1	2	4	11	0	18
Unknown	35	27	12	17	10	101
Total	79	64	40	67	26	276

Total: All Fish Species

Alkalinity* Elevation	200	100-200	50-100	50	Unknown	Total
= 1500 ft.	53	17	14	18	13	115
1501 - 2000 ft.	16	35	32	63	28	174
2000 ft.	1	7	9	31	4	52
Unknown	58	42	30	45	34	209
Total	128	101	85	157	79	550

Total: All Lakes

Alkalinity* Elevation	200	100-200	50-100	50	Unknown	Total
= 1500 ft.	87	44	25	26	23	205
1501 - 2000 ft.	37	83	69	143	46	378
2000 ft.	1	13	21	99	7	141
Unknown	94	85	60	179	75	493
Total	219	225	175	447	151	1217

* Alkalinity values in μeq/l

between 4.0 and 4.99. There were no records of brook trout lakes below pH 4.0.* The total number of lakes included in our data sort of the Data Base is 1217, or approximately 35 percent of the total 3506 ponded waters in the Adirondack region. Of the 2,759 lakes which comprise the Adirondack Ecological Zone, only 937, or 34 percent, have been entered into the data base. According to the DEC (1982 unpublished data), the average size of the ponded waters in the Adirondack Ecological Zone is 89.3 acres, while the average size of the waters in the 937 lakes sub-sample is 221.1 acres. The DEC calculated the remaining 1822 unsurveyed ponds to have an average size of approximately 21.5 acres. The majority of these smaller ponds are found at high elevation sites on generally more sensitive soils, and, consequently, can be expected to have, on average, lower pH values than those ponded waters contained within the sample constructed for this analysis.

ERC implemented a separate sort algorithm in order to differentiate between those waters containing stocked and naturally reproducing populations of brook trout and lake trout. The results of that sort indicated that there were a total of 77 lakes with stocking records and recorded brook trout populations after 1960. The sort indicated that there were 273 lakes which possessed apparently naturally reproducing brook trout populations.* For lake trout, the sort indicated only one lake which was both stocked and

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* For all lakes with chemistry values reported later than 1960, only 6 had pH values less than 4.0.

* Pfeiffer (1979) states that there are 407 ponds within the Adirondack Ecological Zone open to public fishing. Of these, he records that approximately 368 ponds, representing some 12,694 acres, receive annual stocking with fall fingerling wild x domestic hybrids. 39 of the 407 ponds depend upon natural reproduction. 100 additional public brook trout ponds are said to have lost their capacity to support brook trout. Pfeiffer predicts that "about 25 percent of the existing viable acreage will succumb to acidifiction by 1992. However, in a recent personal communication, Pfeiffer indicated that there had been a slight improvement in the condition of brook trout ponds since the beginning of monitoring in 1965. He indicated that, while the pH of ponded waters in central and western New York had declined over the period, that the pH had increased slightly in eastern and southern New York.

possessed sampling records of lake trout. There were 67 lakes which apparently contained self-sustaining populations of lake trout.*

Consulting Region 5 stocking records for the period between January 1 and December 31, 1981, 287 ponds were found to be stocked with brook trout. Pfeiffer (1979) lists 368 ponds within the Adirondack Ecological Zone as being stocked with brook trout. The DEC confirmed that at present, many stocking records have not been entered on the data base, and that the data base does not accurately represent the stocking history of Adirondack lakes. As a consequence of the incompleteness of the files' current stock records, the investigators did not, as initially planned, apply the damage estimations for the stocked and unstocked populations of lake trout to stocked or non-stocked, lakes. This analysis, however, will be possible when the DEC enters the stocking data in the tape. Damages to stocked and unstocked habitats were estimated.

The Data Base was further analyzed into the six drainage bases which jointly constitute the Adirondack Region. The results of this sort are represented in Table 5-6. Elevations apparently strongly influences alkalinity. 70 percent of the lakes above 2000 feet in the data base have alkalinity values less than 50 μeq/l. 86, 85, and 68 percent of the lakes above 2000 feet in the Raquette, Mohawk and Hudson, and Oswesatchie/Black River Basins have recorded alkalinity values of less than 50 μeq/l. Of the lakes between 1501 feet and 2000 feet, 38 percent had alkalinity values less than 50 μeq/l. There was a substantial increase in lakes which possessed alkalinity values greater than 100 μeq/l. 42 percent of the lakes below 1500 feet have alkalinity records greater than 200 μeq/l. This compares with 1 percent of the lakes above 2000 feet.

Table 5-7 represents the same terrain, according to the calcium level of Adirondack lakes analyzed by elevation and major drainage basin. While direct comparison between Tables 5-6 and 5-7 is difficult, the general trend of increasing alkalinity values and calcium values with decreasing elevation is evident in both.

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* Pfeiffer (1979) indicates that within the Adirondack Ecological Zone there are 61 public lakes with Lake Trout populations. Of these, 37 are maintained through natural reproduction, while 24 receive stocking. There are an additional 33 private lake trout waters, which Pfeiffer assumes have self-sustaining populations. 38 lakes which once contained lake trout are now devoid of this species.

Table 5-6

Alkalinity Distribution of Adirondack Lakes

By Elevation and Major Drainage Basin

Elevation	Alkalinity µeq/l	Champlain	St. Lawrence	Upper Hudson	Raquette	Oswesatchie Black	Mohawk/ Hudson	Total	Percent
2000'	50	0	0	26	13	11	49	99	70
	50-100	0	0	14	2	0	5	21	15
	100-200	0	0	7	0	5	1	13	9
	200	0	0	0	0	0	1	1	1
	Unknown	0	0	6	0	0	1	7	5
	Subtotal	0	0	53	15	16	57	141	
2000-1501'	50	3	17	50	27	28	18	143	38
	50-100	0	16	25	23	3	2	69	18
	100-200	0	13	28	23	18	1	83	22
	200	1	9	16	2	6	3	37	10
	Unknown	2	12	15	6	9	2	46	12
	Subtotal	6	67	134	81	64	26	378	
1500'	50	0	3	10	0	11	2	26	13
	50-100	2	1	14	0	4	4	25	13
	100-200	3	3	26	2	5	5	44	21
	200	13	7	33	2	30	2	87	42
	Unknown	5	3	8	0	7	0	23	11
	Subtotal	23	17	91	4	57	13	205	
Unknown	50	32	4	10	4	120	9	179	36
	50-100	22	6	2	8	22	0	60	12
	100-200	43	9	4	2	25	2	85	17
	200	53	7	4	3	20	7	94	19
	Unknown	42	2	8	2	19	2	75	15
	Subtotal	192	28	28	19	206	20	493	
	Total	221	112	305	119	343	116	1217	
	Unknown	49	17	37	8	35	5	151	
	T-U	172	95	269	111	308	115	1066	
	%-U	22 %	15 %	12 %	7 %	10 %	4 %	12 %	

Table 5-7

Estimated Acidification Status* Distribution of Adirondack Lakes, By Elevation and Major Drainage Basin**

Elevation	Calcium MG/L	Champlain	St. Lawrence	Hudson	Raquette	Oswesatchie Black	Mohawk/ Hudson	Total	Percent
2000'	1.5	5	1	15	2	59	38	120	33
	1.5-2.5	6	0	35	21	64	32	158	44
	2.5	11	0	37	11	15	8	82	23
	Subtotal	22	1	87	34	138	78	360	
2000-1501'	1.5	16	27	21	0	72	16	152	11
	1.5-2.5	15	34	39	51	196	51	387	28
	2.5	197	143	202	197	114	1	853	61
	Subtotal	228	204	262	248	362	68	1392	
1500'	1.5	0	11	0	0	0	0	11	2
	1.5-2.5	0	0	23	0	177	0	200	18
	2.5	199	126	212	50	222	103	912	81
	Subtotal	199	137	235	50	399	103	1123	
		N (%)	N (%)	N (%)	N (%)	N (%)	N (%)		
Totals	1.5	21 (5)	39 (11)	36 (6)	2 (1)	131 (14)	54 (22)	283	10
	1.5-2.5	21 (5)	34 (10)	97 (17)	72 (22)	438 (48)	83 (33)	745	26
	2.5	407 (90)	269 (79)	451 (77)	258 (77)	350 (38)	112 (45)	1847	64
	Total	449	342	584	332	919	249	2875	
Sample Totals+									
	N	82	42	193	59	167	80	623	
	Percent of Total	18	12	33	18	18	32	22	

* Calcium MG/L	Acidification Status(1)
1.5	Chronic, pH 5.0
1.5-2.5	Transitional, pH 5.0-6.0
2.5	Bicaronate, pH 6.0

** From Schofield

\+ Sample frequencies of calcium by elevation were used to estimate basin distributions.

1 Schofield (1982)

Furthermore, there are similarities between the calcium and alkalinity values within the different drainage basins; for example, compare the records for the Mohawk Hudson drainage above 2,000 feet in both tables.

5.3 CALCULATION OF INCREMENTAL DAMAGES CAUSED BY CHANGES IN FRESH WATER CHEMISTRY

The first step in the determination of incremental damages or benefits to fish populations resulting from changes in fresh water chemistry was to propose a simple model of system response for Adirondack lake waters assuming acid or base additions. The base additions can be taken to represent either reductions in the input of acidic deposition; or, presuming no change in the level of acidification, a mitigation strategy of base addition. The change in lake pH was calculated relative to a fixed pH value, when 50 and 100 μeq/l of base and 50 and 100 μeq/l of acid were added to a fresh water system with the following characteristics:*

1. open to the atmosphere
2. in equilibrium with gibbsite solid phase
3. ionic strength is approximately 0.001M
4. DOC (dissolved organic carbon) equal to 5 mg/l
5. sulfate concentration equal to 6 mg/l as SO_4^{-2}
6. F^- concentration equal to .1 mg/l.
7. temperature fixed at 15 degrees centigrade

While the model is useful for the purposes of this project, it is a very unrefined estimation of lake water chemistry and pH change within the Adirondack mountains. It asumes that all Adirondack lakes have the chemistry outlined above, provides no time rate of change for the aquatic chemistry, and makes no attempt to relate the change in aquatic chemistry to changes in the rates or concentrations of acidic deposition. In order to calculate the change in pH, two computer runs were executed. The first fixed or established the pH at values from 4 to 8 in 0.5 pH increments. The model then calculated the amount of acid or base required to shift and fix the pH values at a new steady state. The

* See Figure 5-7. The model calculated the extent of change in the pH of lakes relative to the fixed pH values along the bottom axis of the graph.

second run calculated a theoretical titration based upon the proton demand calculated in the first run. The protons were added with the intention of adding ±50 and ±100 μeq/l more than was required to fix the pH at the predetermined values. The results of the runs are shown in Figure 5-7. 100 μeq/l acid additions were considered the limiting upper bound, and are approximately equal to the concentration of anthropogenic acid in the Adirondacks if Henriksen's predictions are true (Henriksen, 1982). The 100 μeq/l base addition, would shift the distribution of lakes to approximately the original pH distribution found within ponded Adirondack waters prior to anthropogenic acidification. The 50 μeq/l increment acid and base additions were calculated in order to determine the effects of smaller shifts in fresh water acidification.

Changes in lake pH represented in Table 5-8 were calculated using Figure 5-7. Notice that the buffer intensity of the system seems weakest in the pH values ranging from approximately pH 7 to pH 6.* As expected, there was a decreasing shift at either end of the pH range. Lakes below 4.5 are shown not shifting under any scenario of base or acid addition. At pH 4.5 and below, the model results were highly variable due to the increased aluminum buffering in the system. However, lakes with pH records equal to or below 4.5 are very unlikely to support fish populations in the dilute, oligotrophic water characteristic of the Adirondack region.**

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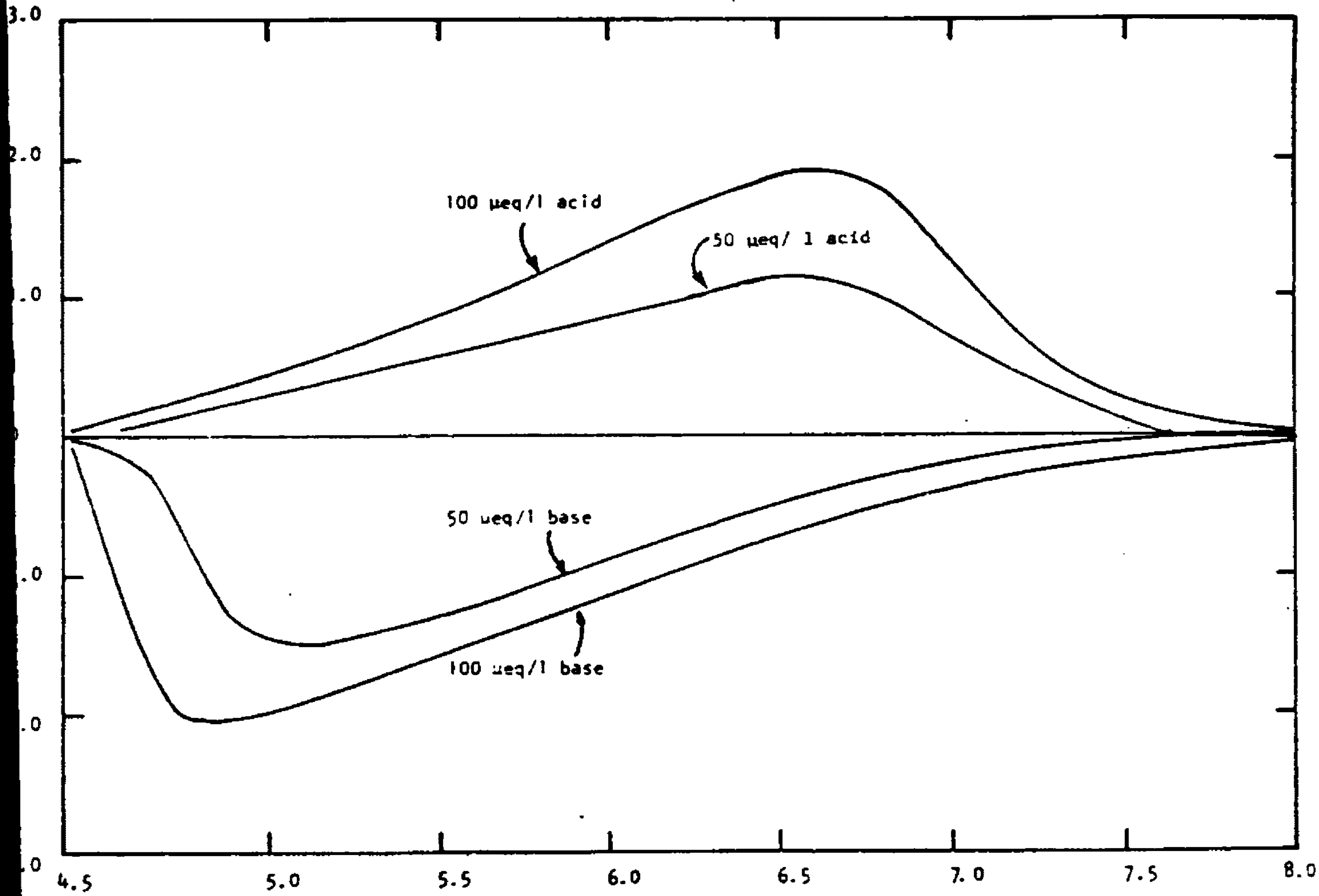
* Schofield (1976b) noted that in his survey there were relatively few lakes with pH values between 5.5 and 6.0. He attributed this to the hypothesis that, for Adirondack waters, this was the region of minimal buffering intensity. The model runs depicted in Figure 5-7 indicate, however, that there is less buffer intensity between pH 7 and pH 6. The model runs indicate that the Adirondack lakes are strongly buffered by the aluminum system rather than the carbonate system. In a carbonate buffered system, the maximum buffering intensity would occur at pH 6.3 as opposed to below 4.9. As discussed previously, while the aluminum buffering system prevents or slows down further lake water acidification, it tends to stabilize the system at very toxic conditions due to the resultant combinations of pH and aluminum levels.

** DEC files indicate that 550 lakes contain at least one of the six species investigated during this project. There are 10 records of fish populations in water with pH less than 4.5. Ninety percent of those low pH lakes contained brook trout, one contained white suckers.

Figure 5-7

Calculated pH Shift Assuming Different Levels of Acid Inputs*



* To calculate the shift in pH of a lake given that lakes pH, select acid or base addition line of interest and read change in pH axis. For example, for a lake with a pH of 6.5 and 100 μeq/l acid addition, the change in pH would be approximately -2 pH units. The lake would shift from a pH of 6.5 to a pH of 4.5.

Table 5-8

Chemical Shift in Adirondack Lakes Given a 100 μeq/l Acid Addition

Current pH	Change in pH	New pH
8.0	0	8.0
7.9	.062	7.8
7.8	.083	7.7
7.7	.125	7.6
7.6	.187	7.4
7.5	.250	7.2
7.4	.375	7.0
7.3	.500	7.2
7.2	.730	6.5
7.1	.950	6.1
7.0	1.30	5.7
6.9	1.58	5.3
6.8	1.78	5.0
6.7	1.87	4.8
6.6	1.95	4.6
6.5	1.87	4.6
6.4	1.81	4.6
6.3	1.75	4.5
6.2	1.62	4.6
6.1	1.50	4.6
6.0	1.42	4.6
5.9	1.31	4.6
5.8	1.19	4.6
5.7	1.06	4.6
5.6	.950	4.6
5.5	.875	4.6
5.4	.800	4.6
5.3	.700	4.6
5.2	.625	4.6
5.1	.500	4.6
5.0	.437	4.6
4.9	.375	4.5
4.8	.312	4.5
4.7	.220	4.5
4.6	.125	4.5
4.5	0	4.5
4.4	0	4.4
4.3	0	4.3
4.2	0	4.2
4.1	0	4.1
4.0	0	4.0

5.4 ESTIMATES OF DAMAGES/EFFECTS DUE TO CHANGES IN ACIDIFICATION

This section presents the results of the calculations described in Section 5.1. Both incremental and decremental pH changes for the six species of fish considered during the elicitation will be reported. Results for brook trout and lake trout are expressed both for stocked and self-sustaining populations. The computations of incremental damage were made using the following assumed parameters:

1. the weighting assignment was fixed at 3:2;
2. confidence intervals were set at both 80 and 90 percent.

Three of the four lake pH shifts calculated using the model described in Section 5.3.1. were used in the final analysis:

1. 100 μeq/l acid addition
2. 50 μeq/l acid addition
3. 50 μeq/l base addition

The first section presents the results for assumed increases in acid input of 50 μeq/l and 100 μeq/l for each cluster of lakes within a given pH range. The second section presents the results of a base addition scenario which would result in the increase in pH of the cluster of lakes. A slightly different procedure was used to examine the effects of base additions to the lakes. The third section presents a comparison of the response of the different fish species habitats and an evaluation of the results using two different calculation procedures.

5.4.1 Increase in Acidification - Predicted Effects Upon Adirondack Fish Habitats

Two scenarios postulating increases in lake water acidification were examined: (1) a 50 μeq/l acid addition, and (2) a 100 μeq/l addition. Both of these scenarios represent rather large increases in acid deposition. Although estimates vary, Henriksen (1982) estimates that approximately 100 μeq/l of acidification can presently be attributed to anthropogenic sources in the Adirondack region. Based upon this estimate, the two scenarios represent roughly a 50 percent and a 100 percent increase over present levels of acidification from antropogenic sources.

Table 5-9

Chemical Shift in Adirondack Lakes Given a 50 μeq/l Acid Addition

Current pH	Change in pH	New pH
8.0	0	8.0
7.9	0	7.9
7.8	0	7.8
7.7	0	7.7
7.6	.062	7.5
7.5	.125	7.4
7.4	.187	7.2
7.3	.333	7.0
7.2	.437	6.8
7.1	.625	6.2
7.0	.75	6.2
6.9	.875	6.0
6.8	.975	5.8
6.7	1.125	5.6
6.6	1.187	5.4
6.5	1.187	5.3
6.4	1.083	5.3
6.3	1.0	5.3
6.2	.937	5.3
6.1	.916	5.2
6.0	.875	5.1
5.9	.833	5.1
5.8	.275	5.0
5.7	.75	4.9
5.6	.666	4.9
5.5	.6	4.9
5.4	.5	4.9
5.3	.475	4.8
5.2	.437	4.8
5.1	.375	4.7
5.0	.333	4.7
4.9	.25	4.6
4.8	.225	4.6
4.7	.125	4.6
4.6	.083	4.5
4.5	0	4.5
4.4	0	4.4
4.3	0	4.3
4.2	0	4.2
4.1	0	4.1
4.0	0	4.0

Table 5-10

Chemical Shift in Adirondack Lakes Given a 100 μeq/l Acid Addition

Current pH	Change in pH	New pH
8.0	0	8.0
7.9	.062	7.8
7.8	.083	7.7
7.7	.125	7.6
7.6	.187	7.4
7.5	.250	7.2
7.4	.375	7.0
7.3	.500	7.2
7.2	.730	6.5
7.1	.950	6.1
7.0	1.30	5.7
6.9	1.58	5.3
6.8	1.78	5.0
6.7	1.87	4.8
6.6	1.95	4.6
6.5	1.87	4.6
6.4	1.81	4.6
6.3	1.75	4.5
6.2	1.62	4.6
6.1	1.50	4.6
6.0	1.42	4.6
5.9	1.31	4.6
5.8	1.19	4.6
5.7	1.06	4.6
5.6	.950	4.6
5.5	.875	4.6
5.4	.800	4.6
5.3	.700	4.6
5.2	.625	4.6
5.1	.500	4.6
5.0	.437	4.6
4.9	.375	4.5
4.8	.312	4.5
4.7	.220	4.5
4.6	.125	4.5
4.5	0	4.5
4.4	0	4.4
4.3	0	4.3
4.2	0	4.2
4.1	0	4.1
4.0	0	4.0

Tables 5-11 and 5-12 list the results for brook trout populations given the aggregate cumulative probability distributions which resulted from the elicitations, the distribution of Adirondack ponded waters containing brook trout records since 1960, and the decremental shifts in lake pH values resulting from the different acid addition runs.* The results expressed in Table 5-11 assume that all 350 lakes examined contained populations of stocked brook trout. Column one represents the cumulative probability of damages occurring to the set of 350 lakes currently supporting brook trout populations for the shift in pH values resulting from a 100 μeq/l addition of acid, assuming a 3:2 weighting and a 80 percent confidence interval. The damages range from a lower bound of 4.7 lakes, or approximately 1.34 percent of the total sample, to an upper bound of 273.4 or 73.11 percent of the total sample. The median value is 166.5 lakes. Because the results represent a cumulative probability distribution, the median represents the number of lakes which divides the range of probabilities of damages into two equally likely segments. The expected value of damages is 159.5 lakes, or 45.57 percent of the total sample. The expected value of damage is the mean of the probability distribution. If the mean, as in this case, is less than the median value, the marginal probability distribution representing the shift would be skewed towards the lower end of the probability range. Conversely, if the mean is greater than the median, the expected changes in the marginal distribution would be skewed towards the upper half of the range. The results expressed in column one indicate that there is a 10 percent chance that damages occurring to the sample of brook trout lakes would be equal to or less than 34.0 lakes. Similarly, .95 indicates that there is a 95 percent probability that damages will be equal to or less than 268.8 lakes.

Another way to use the information contained in the cumulative probability distribution is to calculate the probability that damages from the shift in distribution of pHs across Adirondack lakes exceed a given level. Since the cumulative probability indicates the likelihood that damages are equal to or less than a given level, one minus the cumulative probability will equal the likelihood that damages exceed a given level. Column 1 (Table 5-11 — 80% confidence interval — indicates that with an increase of 100 μeq/l of acid, the probability that 25 percent of the lakes or 87.5 lakes, which currently support stocked brook trout populations, would no longer be capable of sustaining stocked popula

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* Tables 5-13 through 5-18 present the results of the acid additions to the remaining fish populations in the Adirondack mountains.

Cumulative Probability Distributions Showing the Expected Value of Damage to Stocked Brook Trout at Acidification Increases of 100 μeq/l and 50 μeq/l.

The Results are Expressed with 80 and 90 Percent Confidence Intervals

(350 Lakes Examined)

Cumulative Probability	100 μeq/l 80% Confidence Interval	100 μeq/l 90% Confidence Interval	50 μeq/l 80% Confidence Interval	50 μeq/l 90% Confidence Interval
1.25	4.7	9.6	1.5	2.3
5	18.3	29.2	6.0	8.3
10	34.0	43.1	11.6	13.2
15	47.3	56.6	16.9	18.1
20	60.3	69.4	22.1	23.0
25	73.3	81.5	27.4	27.9
30	88.1	95.7	32.8	32.9
35	104.6	110.6	38.8	38.4
40	121.3	125.4	45.3	44.2
45	138.1	1413	52.1	50.4
50	166.5	169.1	60.4	58.1
55	193.3	195.3	72.7	66.8
60	221.8	222.7	86.1	80.7
65	247.4	245.3	100.1	92.8
70	246.6	246.7	109.6	102.0
75	249:6	248.2	117.2	109.1
80	252.7	251.3	125.2	116.2
85	256.9	254.4	139.0	123.9
90	262.7	257.7	164.3	132.0
95	268.8	265.3	196.7	165.8
98.75	273.4	273.4	222.2	214.6
Expected Value	159.5	162.5	76.8	70.6

Table 5-12

Cumulative Probability Distributions Showing the Expected Value of Damage to Self-Sustaining Brook Trout at Acidification Increases of 100 μeq/l and 50 μeq/l.

The Results are Expressed with 80 and 90 Percent Confidence Intervals

(350 Lakes Examined)

	100 μeq/l		50 μeq/l	
Cumulative Probability	80% Confidence Interval	90% Confidence Interval	80% Confidence Interval	90% Confidence Interval
1.25	7.0	14.3	3.1	6.2
5	27.1	38.1	12.6	18.5
10	47.9	61.7	22.4	29.1
15	69.0	85.9	31.7	37.8
20	91.1	109.0	40.0	45.5
25	110.3	120.7	47.6	51.7
30	122.3	130.4	54.4	57.9
35	132.8	140.1	61.4	64.4
40	143.6	150.0	68.7	71.0
45	154.5	159.9	76.6	78.4
50	165.9	170.9	84.7	85.8
55	178.7	183.4	93.5	94.0
60	191.8	195.1	103.6	102.7
65	205.2	207.7	115.5	113.4
70	218.7	221.1	126.9	125.4
75	231.4	233.1	140.3	138.6
80	236.6	238.1	154.3	154.2
85	243.2	244.4	166.8	166.6
90	249.6	251.4	180.9	182.5
95	259.0	259.7	195.7	203.9
98.5	270.0	276.5	208.8	229.5
Expected Value	160.9	167.3	94.2	97.0

Cumulative Probability Distributions Showing the Expected Value of Damage to Stocked Lake Trout at Acidification Increases of 100 μeq/l and 50 μeq/l.

The Results are Expressed with 80 and 90 Percent Confidence Intervals

(68 Lakes Examined)

Cumulative Probability	100 μeq/l 80% Confidence Interval	100 μeq/l 90% Confidence Interval	50 μeq/l 80% Confidence Interval	50 μeq/l 90% Confidence Interval
1.25	1.9	3.8	.6	1.1
5	7.7	15.4	2.4	4.4
10	15.4	27.6	4.7	7.7
15	23.2	30.1	7.6	9.9
20	28.4	32.6	9.7	12.1
25	31.0	35.1	11.9	14.3
30	33.7	37.0	14.1	16.5
35	36.3	37.8	16.3	18.2
40	37.6	38.5	18.3	19.6
45	38.4	39.3	20.0	21.1
50	39.3	40.1	21.7	22.7
55	40.1	40.8	23.4	24.4
60	40.9	41.5	25.3	26.0
65	41.8	42.3	27.2	27.5
70	42.7	43.1	28.9	29.0
75	43.5	43.9	30.6	30.6
80	44.4	44.7	32.4	32.2
85	45.4	45.5	34.3	33.9
90	47.0	46.4	36.3	35.6
95	48.6	48.0	40.3	37.8
98.5	49.8	50.1	43.2	43.6
Expected Value	35.6	37.8	21.4	22.3

Table 5-14

Cumulative Probability Distributions Showing the Expected Value of Damage to Self-Sustaining Lake Trout at Acidification Increases of 100 μeq/l and 50 μeq/l.

The Results are Expressed with 80 and 90 Percent Confidence Intervals

(68 Lakes Examined)

	100 μeq/l		50 μeq/l	
Cumulative Probability	80% Confidence Interval	90% Confidence Interval	80% Confidence Interval	90% Confidence Interval
1.25	1.6	3.3	.6	1.3
5	5.6	6.6	2.4	3.4
10	9.3	9.9	4.1	5.0
15	13.1	13.3	5.7	6.7
20	17.3	17.0	7.4	8.4
25	23.3	22.2	9.2	10.5
30	29.4	27.7	11.6	12.8
35	43.8	43.9	13.6	14.6
40	44.4	44.4	15.4	16.4
45	45.1	45.1	18.1	19.4
50	45.8	45.8	22.0	23.6
55	46.6	46.6	25.9	27.6
60	47.3	47.5	29.7	32.8
65	48.1	48.0	34.7	36.9
70	48.9	48.7	37.4	38.2
75	49.6	49.4	38.8	39.5
80	50.4	50.2	40.4	40.8
85	51.2	50.9	41.8	42.1
90	52.6	51.9	44.6	43.6
95	54.3	53.3	48.3	46.7
98.5	56.2	55.9	50.9	51.8
Expected Value	37.8	37.6	23.8	24.8

Table 5-15

Cumulative Probability Distributions Showing the Expected Value of Damage to Small Mouth Bass at Acidification Increases of 100 μeq/l and 50 μeq/l.

The Results are Expressed with 80 and 90 Percent Confidence Intervals

(103 Lakes Examined)

	100 μeq/l		50 μeq/l	
Cumulative Probability	80% Confidence Interval	90% Confidence Interval	80% Confidence Interval	90% Confidence Interval
1.25	48.1	49.3	3.1	6.3
5	51.6	55.8	12.7	19.9
10	55.9	56.4	20.9	22.9
15	56.5	57.0	24.1	25.9
20	57.2	57.6	27.3	28.7
25	57.8	58.1	30.2	31.2
30	58.4	58.6	32.7	33.2
35	58.9	59.1	34.6	34.8
40	59.4	59.5	36.4	36.5
45	59.8	59.8	38.7	37.9
50	59.9	59.9	40.3	40.3
55	60.6	60.6	41.9	41.7
60	60.9	60.9	43.0	42.7
65	61.1	61.1	44.1	43.8
70	61.4	61.3	45.2	44.8
75	61.7	61.6	46.3	45.8
80	62.1	61.9	47.7	46.9
85	62.4	62.3	49.2	48.3
90	62.8	62.6	0.9	49.8
95	63.4	62.9	54.7	51.4
98.5	66.9	65.7	60.2	58.5
Expected Value	59.5	59.7	37.6	37.9

Table 5-16

Cumulative Probability Distributions Showing the Expected Value of Damage to White Suckers at Acidification Increases of 100 μeq/l and 50 μeq/l.

The Results are Expressed with 80 and 90 Percent Confidence Intervals

(276 Lakes Examined)

	100 μeq/l		50 μeq/l	
Cumulative Probability	80% Confidence Interval	90% Confidence Interval	80% Confidence Interval	90% Confidence Interval
1.25	6.2	12.4	2.3	4.8
5	24.9	50.6	9.5	19.6
10	50.5	56.6	19.4	22.5
15	57.2	62.7	22.7	25.5
20	64.1	68.8	26.1	28.5
25	71.1	75.0	29.5	31.6
30	78.2	81.4	33.0	34.7
35	85.4	87.8	36.5	37.9
40	92.7	94.3	40.1	41.1
45	98.7	99.2	43.7	44.2
50	103.8	103.8	47.2	47.4
55	109.1	108.4	50.7	50.6
60	114.5	113.2	55.1	54.2
65	120.0	118.1	60.4	58.8
70	125.7	123.1	66.0	63.7
75	131.5	128.1	70.5	68.8
80	137.4	133.3	71.8	74.0
85	138.9	138.6	77.8	79.4
90	140.5	138.9	79.8	84.9
95	154.0	143.9	93.6	70.5
98.5	165.4	161.6	110.9	105.1
Expected Value	99.2	100.6	49.5	49.6

Table 5-17

Cumulative Probability Distributions Showing the Expected Value of Damage to Common Shiner at Acidification Increases of 100 μeq/l and 50 μeq/l.

The Results are Expressed with 80 and 90 Percent Confidence Intervals

(22 Lakes Examined)

Cumulative Probability	100 μeq/l 80% Confidence Interval	100 μeq/l 90% Confidence Interval	50 μeq/l 80% Confidence Interval	50 μeq/l 90% Confidence Interval
1.25	19.1	19.1	1.6	2.3
5	19.3	19.5	3.6	6.3
10	19.5	19.5	6.3	11.6
15	19.5	19.5	8.9	11.8
20	19.5	19.6	11.8	12.0
25	19.6	19.6	12.0	12.2
30	19.6	19.6	12.2	12.3
35	19.6	19.6	12.4	12.5
40	19.6	19.6	12.6	12.7
45	19.6	19.6	12.8	13.0
50	19.7	19.7	13.1	13.2
55	19.7	19.7	13.4	13.5
60	19.7	19.7	13.7	13.8
65	19.7	19.7	14.2	14.1
70	19.8	19.8	14.6	14.6
75	19.8	19.8	15.1	15.0
80	19.8	19.8	15.6	15.4
85	19.9	19.8	16.2	15.9
90	19.9	19.9	16.8	16.5
95	20.0	19.9	17.2	17.0
98.5	20.0	20.0	17.5	17.6
Expected Value	19.7	19.7	12.6	13.2

Table 5-18

Cumulative Probability Distributions Showing the Expected Value of Damage to Fat Head Minnow at Acidification Increases of 100 μeq/l and 50 μeq/l.

The Results are Expressed with 80 and 90 Percent Confidence Intervals

(1 Lake Examined)

	100 μeq/l		50 μeq/l	
Cumulative Probability	80% Confidence Interval	90% Confidence Interval	80% Confidence Interval	90% Confidence Interval
1.25	.1	.1	0.0	0.0
5	.2	.4	0.1	.2
10	.4	.8	.2	.2
15	.6	.8	.2	.2
20	.8	.8	.2	.2
25	.8	.8	.2	.2
30	.8	.8	.2	.2
35	.8	.9	.3	.3
40	.9	.9	.3	.3
45	.9	.9	.3	.3
50	.9	.9	.3	.3
55	.9	.9	.3	.3
60	.9	.9	.3	.3
65	.9	.9	.3	.3
70	.9	.9	.3	.3
75	.9	.9	.4	.4
80	.9	1.0	.4	.4
85	1.0	1.0	.4	.4
90	1.0	1.0	.4	.4
95	1.0	1.0	.7	.4
98.5	1.0	1.0	.9	.9
Expected Value	.8	.9	.3	.3

tions is equal to one minus .30 or 70 percent. Using this interpretation, the following hold:

- o probability that the number of lakes damaged will exceed one quarter of the lakes (i.e., 87 lakes or more) is approximately .70.

- o probability that the number of lakes damaged will exceed one half of the lakes (i.e., 175 lakes or more) is approximately .45.

- o probability that the number of lakes damaged will exceed three quarters of the lakes (i.e., 262 lakes or more) is .10.

Column two represents the same calculation with a 90 percent rather than an 80 percent confidence interval. As expected, the range has narrowed somewhat, especially at the lower probability levels. The change in the expected value shifted from 159.5 to 162.5 lakes. This represents a change of .71 percent in the sample of lakes capable of sustaining fish populations. The change in the median value is equal to .74 percent.

Columns three and four represent acid additions of 50 μeq/l. Column three is calculated with an 80 percent confidence interval and column four with a 90 percent interval. As can be seen the expected value of damage in both columns three and four is greater than half the expected value of damages in columns one and two. This result was expected based upon the aquatic chemistry model output shown in Figure 5-7. The change in the pH level of the "typical" Adirondack lakes is not linear with respect to changes in the amount of acid or base added to the system.

Table 5-19 compares the means, or expected values, for shifts occurring to stocked and unstocked populations of brook trout given different acid additions. Comparing the results expressed at the 90 percent confidence interval reveals that if the current distribution of Adirondack lakes were to be further acidified with 100 μeq/l of acid, the expected value of damages would be 46 percent of the stocked lakes and 48 percent of

Table 5-19

Comparison of the Expected Values for 100 and 50 μeq/l Acid Additions to Stocked and Self Sustaining Brook Trout Populations

+100 μeq/l Acid			
Stocked Population		Self Sustaining Population	
Confidence Intervals		Confidence Intervals	
80%	90%	80%	90%
-159.5	-162.5	-160.9	167.3

+50 μeq/l Acid			
Stocked Population		Self Sustaining Population	
Confidence Intervals		Confidence Intervals	
80%	90%	80%	90%
-76.8	-70.6	-94.2	-97.0

the self-sustaining lakes.* The stocked lakes are considerably less sensitive in the 50 μeq/l acid addition, with expected losses of approximately 20 percent of 70 lakes as compared with the approximate 28 percent reduction in self-supporting populations. Presumably, the 8 percent difference can be attributed to the smaller pH shift in the 50 μeq/l addition.

The 100 μeq/l addition the water chemistry model predicted that lakes with pH values equal to or less than 6.6 would shift to pH 4.6 or less (see Table 5-8). On the other hand, the 50 μeq/l shift allowed lakes with initial pH values of 5.0 or greater to shift to pH levels equal to or greater than pH 4.7 (Table 5-9). An examination of the lower bounds and upper bounds from the elicitation for self-sustaining brook trout populations at pH 4.7 showed the average elicited lower bound to be a 40 percent loss of lakes and the average upper bound to be 90 percent loss. Average lower and upper bounds for the stocked populations were 37.7 percent to 76.3 percent at pH 4.7. The stocked population at pH 4.5, however, was quite sensitive. The average lower bound was 51.7 percent, while the upper bound was 90 percent. The average upper and lower bounds for the self-sustaining population at 4.5 was almost identical, ranging from a lower bound of 50 percent to an upper bound of 93 percent. These results are similar to those found in the laboratory analyses conducted by Baker and Schofield (Baker, 1981). In that study, Dr. Baker determined that in order to prevent measurable reductions in the survival of early life history stages of brook trout, the pH of the typical Adirondack surface water should be greater than or equal to 4.8. This implies that as the pH declines, the difference in sensitivity between stocked and unstocked lakes declined. At some pH levels, all fish are affected.

Table 5-20 presents the expected values for changes occurring to the remaining five species of fish considered during the project. Comparing the sensitivities of different fish habitats considered in the analysis (50 μeq/l acidification and 90 percent confidence intervals) a ranking of fish population habitat sensitivities in Adirondack lakes can be generated. From least sensitive to most sensitive, they are:

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* Because of incompleteness in the stocking records entered in the DEC data base, stocked populations and unstocked populations were differentiated by assuming that all of the lakes are either stocked or self-sustaining. Damage calculations were then performed on the entire set of lakes for which the investigators possessed both chemistry and any population data concerning brook trout and lake trout.

Table 5-20

Expected Value of Change Occurring to Fish Excluding Brook Trout*

() = percent of baseline number of lakes

	+100 μeq/l		+50 μeq/l	
	Confidence Interval 80%	Confidence Interval 90%	Confidence Interval 80%	Confidence Interval 90%
Lake Trout Stocked	-35.6	-37.8	-21.4	-22.3
68 Lakes Total	(52)	(56)	(31)	(33)
Lake Trout Self Sustaining	-37.8	-37.6	-23.8	-24.8
68 Lakes Total	(56)	(55)	(35)	(41)
Small Mouth Bass	-59.5	-59.7	-37.6	-37.9
103 Lakes Total	(58)	(58)	(37)	(37)
White Sucker	-99.2	-100.6	-49.5	-49.6
276 Lakes Total	(36)	(36)	(18)	(18)
Common Shiner	-19.7	-19.7	-12.6	13.2
122 Lakes Total	(90)	(90)	(57)	(60)

* For brook trout, see Table 5-19. Fat head minnow results were not included because of the small size of the sample contained within the DEC files.

1. white sucker
2. stocked brook trout
3. self-sustaining brook trout
4. stocked lake trout
5. small mouth bass
6. self-sustaining lake trout
7. common shiner

Laboratory results indicate that the white sucker is more sensitive to acidification in Adirondack waters than brook trout (Baker, 1981). Our results do not necessarily contradict those studies, but can be explained by the distribution of white sucker lake habitat compared with brook trout habitat recorded in the DEC data base. Twenty-seven percent of the lakes possessing records of white sucker have a pH greater than 7.00, while only 14 percent of the brook trout lakes have a pH equal to or greater than 7.00. 27 percent of the white sucker habitat was predicted to shift to pH values no lower than 6.24 with an acid addition of 50 μeq/l. Similarly, 46 percent of the lakes with white sucker have pH records where 6.0^{o} is the base case. Assuming a 50 μeq/l acid input, these lakes would decrease to pH 5.12 or above. Only 43 percent of the brook trout lakes have intial pH values equal to or greater than pH 6.0. While 73 percent of the white sucker lakes won't shift below 5.12, only 57 percent of the brook trout lakes — under this scenario -- remain above 5.12.

Caution must be used in interpreting the results listed above. They are not simply relations of sensitivity of different fish species to acidification. Rather, the results must be interpreted as being the relative sensitivities of regional fish habitats. The results listed in Table 5-21 and Tables 5-12 through 5-19 should not be interpreted as representing the sensitivity of different fish species to pH stress as expressed by the scientific participants within the study. These results are a sample application of the data developed in the elicitation interviews, and are based upon additional inventory data and water chemistry modeling information.

5.4.2 Decrease in Acidification — Predicted Effects Upon Brook Trout Habitat

One scenario was examined in which acidification was reduced by 50 μeq/l. This reduction could be achieved either by reductions in acidic inut into the lakes or by direct base

Table 5-21

Results of Secondary Sort Representing Lakes Which Contained Both Fish Records and Chemistry Data

Brook Trout

Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation:						
= 1500 ft.	16	4	7	12	9 48	
1501 - 2000 ft.	10	21	24	43	24122	
2000 ft.	1	7	8	30	4 50	
Unknown	27	24	21	37	21130	
Total	54	56	60	122	58350	

Small Mouth Bass

Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation						
= 1500 ft.	18	8	2	4	2 34	
1501 - 2000 ft.	2	7	9	6	2 26	
2000 ft.	0	0	0	0	0 0	
Unknown	19	8	7	1	8 43	
Total	39	23	18	11	12103	

Fat Head Minnow

Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation						
= 1500 ft.	1	0	0	0	0 1	
1501 - 2000 ft.	0	0	0	0	0 0	
2000 ft.	0	0	0	0	0 0	
Unknown	0	0	0	0	0 0	
Total	1	0	0	0	0 1	

Lake Trout

Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation						
= 1500 ft.	2	1	3	0	0 6	
1501 - 2000 ft.	2	6	5	15	3 31	
2000 ft.	0	0	2	3	0 5	
Unknown		8	8	5	3 3	26
Total	12	14	15	21	6 68	

* Alkalinity expressed in µeq/l.

Table 5-21

Results of Secondary Sort Representing Lakes Which Contained Both Fish Records and Chemistry Data

(Continued)

Common Shiner						
Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation						
= 1500 ft.	4	0	0	0	0 4	
1501 - 2000 ft.	1	3	3	4	0 11	
2000 ft.	1	0	2	0	0 3	
Unknown	1	0	1	1	1 4	
Total	7	3	6	5	1 22	
White Sucker						
Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation						
= 1500 ft.	31	10	5	9	6 61	
1501 - 2000 ft.	12	25	19	30	10 96	
2000 ft.	1	2	4	11	0 18	
Unknown	35	27	12	17	10101	
Total	79	64	40	67	26276	
Total: All Fish Species						
Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation						
= 1500 ft.	53	17	14	18	13115	
1501 - 2000 ft.	16	35	32	63	28174	
2000 ft.	1	7	9	31	4 52	
Unknown	58	42	30	45	34209	
Total	128	101	85	157	79550	
Total: All Lakes						
Alkalinity*	200	100-200	50-100	50	Unknown	Total
Elevation						
= 1500 ft.	87	44	25	26	23205	
1501 - 2000 ft.	37	83	69	143	46378	
2000 ft.	1	13	21	99	7 141	
Unknown	94	85	60	179	75493	
Total	219	225	175	447	151217	

* Alkalinity express in µeq/l.

addition, i.e., liming. According to Henriksen's estimate of the present level of Adirondack acidification, a 50 μeq/l reduction in acidity would equal approximately a 50 percent reduction in anthropogenic acidification. A new algorithm was required to predict the effects of a base addition to Adirondack waters. The algorithm developed for predicting incremental damages, which has been previously described, could not be used to calculate decremental changes in acidification.*

The calculation of the increase in fish habitat resulting from a decrease in acidification involved a four step process, see column 4 of Table 5-22. <u>First</u>, the number of lakes which could support fish, in our case, self-sustaining brook trout populations in a natural, pre-acidified condition, was estimated. Only populations of self-sustaining brook trout were evaluated in this scenario. The baseline distribution was calculated by assuming the addition of 100 μeq/l base to each lake cluster. This base addition was interpreted as if it were equivalent to the removal of 100 μeq/l of acidity. To evaluate the effects of varying levels of acidification, it was necessary to make an assumption concerning the ability of lakes in this baseline chemical condition to support fish populations. It was assumed that 80 percent of the lakes with pH values between 7.2 and 5.0 in the baseline distribution were originally capable of supporting self-sustaining brook trout populations. Examination of the actual current pH data indicates that only 14 percent of the lakes containing brook trout populations have pH values above 7 and it is highly unlikely that self-sustaining populations could have proliferated in the dilute waters characteristic of the Adirondack region at pHs below 5.0.** A second sort of the Adirondack Ponded Waters Data Management System tape was performed in order to classify those lakes for which both fish survey records and pH records were available. Table 5-21 reports the results of this work. A total of 742 such lakes were identified. 350 of these

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* This was because the original algorithm back calculated the original number of lakes able to support fish from the ration of the number of lakes presently supporting fish and the estimated damage levels. Where the estimated damages were very high, this caused division by a very small number and this, in turn, caused unacceptable imprecision in the results. For example, if damages at a given pH were estimated at 95 percent and 5 lakes were found in that cluster, then the original number of lakes capable of sustaining fish would be calculated as 5/(1.0 - .95) = 100. If, alternatively, the damages were estimated as 97.5 percent, the original number of lakes would be 5/(1.0 - 97.5) = 200.

** This underestimates the number of lakes capable of supporting brook trout by not considering organic acid waters with pH 5.0. It is known that these waters can sustain brook trout populations at or below pH 5.0.

Table 5-22

Results of Reducing Present Acidification by 50 μeq/l*

Cumulative Probability	100 μeq/l Acid Addition	50 μeq/l Acid Addition	Estimated Decrease in Present Acidification to 50 μeq/l**
1.25	5.3	1.8	3.5
5	16.0	5.6	10.4
10	25.2	8.4	16.8
15	33.1	10.8	22.3
20	39.9	12.6	27.3
25	45.3	13.9	31.4
30	50.7	15.2	35.5
35	56.2	16.5	39.7
40	61.8	17.8	17.8
45	67.7	19.1	48.6
50	73.6	20.4	53.2
55	79.8	21.7	58.1
60	86.3	23.1	63.2
65	96.2	26.3	69.9
70	107.6	29.8	77.8
75	123.1	33.8	89.3
80	152.0	39.1	112.9
85	180.0	45.9	134.1
90	209.2	53.5	155.7
95	241.0	62.2	178.8
98.5	359.6	138.9	220.7
Expected Value	96.3	27.3	69.0

* The large difference between the extreme numbers (at the 98.5 percent probability level) for the two distributions is due to the greater probability assigned to values lying outside the range given in the elicitation. For the 90 percent confidence level, there is assumed to be a 10 percent probability that the true value lies outside the range given. For the 80 percent confidence level, this probability is assumed to be 20 percent, effectively doubling the assumed probability of the occurrence of very high or low damages. The result is that when base additions are considered, the upper end of the distribution will be very sensitive to the elicitation results and the assumed confidence interval. To adequately handle scenarios where there are base additions, changes should be made in the numeric algorithm that calculates incremental change. For acid additions, the current algorithm for the calculations of damaged lakes is appropriate. The results were calculated assuming a baseline distribution of 424 Adirondack lakes between pH values of 7.2 and 5.0 which were capable of sustaining populations of brook trout prior to acidification

** Calculated by subtracting values of the 50 μeq/l acid addition from the 100 μeq/l addition.

lakes were reported as containing brook trout. Using the pH shift presented in Figure 5-7, the number of lakes which were contained within the range between pH 5.0 and 7.2 were calculated after 100 μeq/l of base was added to each lake cluster.

The second step calculated the reduction in the number of lakes capable of supporting self-sustaining brook trout populations given a 50 μeq/l addition of acid to the baseline distribution of lakes.

The third step consisted of the calculation of the shift in brook trout habitat that would result from a 100 μeq/l acid addition to the baseline distribution of lakes. Such an addition is equivalent to a return to the present level of acidification from the predicted baseline.

The fourth step consisted in the calculation of the effect of a 50 μeq/l reduction in acidity from the present distribution. This was accomplished by calculating the difference between the 100 μeq/l acid addition and the 50 μeq/l acid addition, The difference represents the improvement which could be expected by moving from a current state of 100 μeq/l of anthropogenic acidification to a future state of 50 μeq/l of anthropogenic acidification. The results shown on Table 5-22 indicate that brook trout habitat could be expected to increase from a lower bound of 3.5 to an upper bound of 220.7 out of 424 lakes. The expected value of the change is equal to 16 percent, or 69 out of 424 lakes.

5.4.3. Alternative Damage Calculation

In order to further evaluate the validity of the damage estimates generated using the elicitation results, an alternative method of calculating damages was used for "self-sustaining" brook trout lakes in the Adirondacks. This method involved utilization of the "baseline" pH distribution assumed to represent the chemical condition of the lakes prior to anthropogenic acidification discussed in 5.4.2. Damage estimates were calculated by considering changes from this calculated "baseline" pH distribution to new pH distributions reflecting varying levels of acidification. In order to evaluate the effects of varying levels of acidification, it was necessary to make the same assumption concerning the ability of lakes in this baseline condition to support fish populations; see Section 5.4.2.* The calculation used the additional sort of the Adirondack Ponded Waters Data Management System tape depicted in [illegible]. The pH shift program, which was derived from Figure 5-7, was then used to estimate damages due to a shift in pH from the baseline. The following shifts were considered:

(1) the addition of 100 μeq/l of acid to the baseline distribution of lakes. This amounted to a return to the present state, as the baseline was calculated by removing 100 μeq/l of acidity from the present distribution of lakes possessing brook trout records.

(2) the addition of 50 μeq/l of acid to the baseline.

(3) the addition of 150 μeq/l of acid; equivalent to the current distribution plus 50 μeq/l of acidification.

(4) the addition of 200 μeq/l of acid; equivalent to the current distribution plus 100 μeq/l of acidification.

A summary of these additions is shown in Table 5-23.

The results of the third shift, from the assumed baseline to the present state, are particularly interesting, since it can be used to provide some information on the accuracy of the elicitations and algorithms. Of course, the elicitations were designed to estimate the effects of pH on fish populations. If other factors are causing damages to fish populations, then these figures would not necessarily correspond.

The present number of Adirondack lakes listed on the data base which are capable of maintaining self-sustaining brook trout populations is 275. Using the incremental damages generated by the elicitation results and the assumption that 80 percent of the lakes between 5.0 and 7.2 could sustain brook trout populations, our approach predicted that 327.7 lakes would be capable of sustaining brook trout populations. This discrepancy can be explained by either:

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* The investigators assumed that 80 percent of the lakes with pH values between 7.2 and 5.0 in the baseline distribution were originally capable of supporting self-sustaining brook trout populations.

Table 5-23

Damages Occurring to Lakes Capable of Sustaining Self-Sustaining Brook Trout Populations Between the Original pH Values of 5.0 and 7.2

	Shift	Predicted Number of Damaged Lakes	Predicted Number of Surviving Lakes	Actual Number of Surviving Lakes
(1)	Assumed baseline reduction of (100 μeq/l acid)	0	424*	
(2)	Addition of + 50 μeq/acid to baseline	27.3	396.7	
(3)	Present State estimated by adding 100 μeq/l acid to baseline	96.3	327.7	275**
(4)	150 μeq/l acid addition to baseline	192.0	232.0	
(5)	200 μeq/l acid addition to baseline	277.1	146.9	

* 424 lakes equal the total number of lakes between pH values 5.0 and 7.2 after the chemical shift caused by the addition of 100 μeq/l base (530) multiplied by .8. It is assumed that 80 percent of the lakes between 5.0 and 7.2 could support brook trout.

** 275 lakes are the number of observed lakes which contain brook trout populations on the data base between a pH of 5.0 and 7.2.

(1) the estimate that 80 percent of the lakes could sustain brook trout populations is too high, or

(2) that the scientific elicitations were conservative estimates of the damage, which is actually larger than they would predict, or

(3) there are factors other than pH that contribute to a reduction in brook trout fish populations.

6.0 CONCLUSIONS

6.1 PROJECT OVERVIEW

This project demonstrated a framework for organizing scientific information in a manner useful for policy assessment. In accomplishing this, two different sets of results were developed. The first set of results, which is shown in Table 4-6, represents the results of the elicitation interviews with participating scientists. The second set of results, which are based on the elicitation results, are contained and discussed in Chapter 5. The results in Chapter 5 provide an example of how the data generated in the elicitation interviews can be applied. Because they are based upon inventory data that is expected to be significantly improved prior to 1985, and because the uncertainty surrounding this data wasn't specifically dimensioned, the conclusions to be drawn from these results should pertain to the adequacy of the procedure, instead of the specific numeric dimensioning of the effects of acidification on Adirondack fish populations.

The framework was designed to interpret the scientific uncertainty in estimates of the relationship between acidification and aquatic effects and to further assist in extrapolating spatially limited scientific data to regional areas. If successful, it will augment scientific research by reframing effects information so that non-scientists can better evaluate the probability of different levels of regional environmental damage. The framework does not, however, replace effects research, as it does not generate new hypotheses or data. It simply organizes existing data and interpretation into a format complementary to conventionally presented scientific results. To evaluate whether the framework accomplishes its primary goal, two questions need to be answered:

1. Are the analytic procedures and the results of the framework credible to the scientific community?

2. Are the results of the framework helpful to economists, policy analysts, and decision makers?

A framework designed to interpret scientific data and knowledge must have scientific credibility and endorsement if it is to be a useful tool for the assessment of acid deposition policy alternatives. The framework developed and applied within this project has not received general or widespread scientific comment. As a result, the credibility of the approach is generally untested. The project has, however, been reviewed by a number of the participating scientists and a review panel at the National Acid Precipitation Program Effects Research Review Meeting.* Preliminary scientific review suggests that scientists generally recognize the need to present the results of effects research in a manner that enables decision makers to evaluate the regional importance and uncertainty of acid deposition effects. A recognized advantage of the framework is that members of the scientific community directly extrapolate from and interpret the results of their investigations, rather than having less scientifically knowledgeable policy analysts performing this extrapolation. Given the considerable uncertainty surrounding the performance of regional damage estimates, which depend upon uncertain damage-relations and inventory data, it seems unlikely that any framework addressing this problem will receive unequivocal scientific endorsement.

The second question concerns whether the outputs of the procedure will be useful as inputs to policy analysis and economic benefits studies. Here a more definitive answer is available. The type of information produced by this project is required by all policy assessment frameworks, and is also necessary for economic benefits studies. Policy analysis cannot be performed without a regional characterization of the resources at risk and the likelihood of different levels of damage on a regional level. To know that effects have occured at dispersed sites, mainly in the northeastern U.S., is significant, yet incomplete knowledge for the assessment. By dimensioning the uncertainty for the aquatic and the other acid deposition caused effects many important policy questions can be addressed. In particular, any policy assessment based on uncertain information must have the uncertainty in the parameters dimensioned if responsible decisions are to be made. In the past, ad hoc procedures for incorporating uncertainty into assessments have been used by policy analysts. Procedures directly utilizing scientific expertise can significantly improve this aspect of policy evaluation. In addition, it would allow analysts to determine the value of additional scientific research and whether reductions in acid deposition should be sought while additional effects research is being performed.

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* Effects Research Review Meeting of the National Acid Precipitation Assessment Program, Raleigh, North Carolina. February 21-25, 1983.

The elicitations used in this project accomplished several important objectives. Estimates of damage to fish populations were made directly by scientists participating in the research. These effects estimates are not directly available from published scientific experiments since most of these experiments are performed in the laboratory and cannot easily be extrapolated to natural habitats or, where research results are available for fish damages in natural habitats, few sites have been studied. The implications of the current scientific research for estimating the effects of acid deposition on fish populations are not straightforward and require the considered judgment of the scientists performing the research. Since point estimates would be unreasonably precise given the current uncertainties, the elicitation focused on estimating the expected range of potential effects for a given pH value.

The estimates developed in this project have the advantage of being expressed quantitatively. As such, they can be easily reviewed and, if need be, revised in the light of new scientific information. For example, the damage relationships specified in this project estimate effects as a function of pH, aluminum, and calcium concentrations. If new research determines that some other variable is important to the prediction of effects, then that variable can be incorporated. Similarly, scientists can easily revise the estimates of effects either upwards or downwards as new information becomes available from completed projects.

Another accomplishment of the elicitations used in this project is that the damage relations which resulted from the application of the framework integrate many different mechanisms and possible causal agents of fish population decline, e.g., variations in lake water chemistry due to groundwater upwellings, episodic pH shocks, and lake morphometry. This characteristic of the damage relation allows for a relatively simple and understandable dimensioning of the predicted effect and its uncertainty which will be easily understood by policy analysts. This allows for the explicit representation of current scientific opinions and the development of a regional perspective for acid deposition effects.

The probabilistic structure of the project and its reliance upon explicitly represented expert judgement in the development of regional effects estimates does, however, generate considerable scientific skepticism. Scientists have tended to assume that this framework is designed to find out something new about the world, rather than to provide a structure for the incorporation of scientific information and advice within a highly uncertain policy debate. In this project, scientists were required to perform an assessment role in addition to their responsibilites as effects researchers. Consequently, some confusion exists concerning the status of the project, i.e., is it really new scientific research? The obvious answer is no. Recall that it is an assessment device useful for organizing technical information. Its outputs represent the considered judgement of the scientific community. As such, it is part of an integrated assessment intended to organize and present scientific descriptions of the causal mechanisms and regional extent of acid deposition effects. The rationale for the framework assumes that:

- Data sets containing statistically valid samples of observations on effects will not be available prior to 1985, and in some cases the 1989 assessments.

- Policy assessment requires the best information on scientific uncertainty available. This is most likely to come from the scientists performing the actual research.

6.2 CONCLUSIONS REGARDING THE SPECIFIC PROCEDURES USED IN THIS PROJECT

A number of conclusions can be drawn that are specific to the implementation of this, or similar, assessment techniques. First, projects of this type require an iterative process with extensive interaction between scientists and the project investigators. Both the variables to be explicitly considered in the elicitation and the structure of the elicitation should be determined in conjunction with participating scientists. This helps to assure that the judgements being elicited can, in fact, be reasonably evaluated by the scientists.

One example of the importance of interactive communication between the project investigators and the participating scientists is the specification of variables for use in the elicitation. The determination of the appropriate variables for use in policy assessment can become as complex as it is important. For example, the independent and dependent variables of the damage relations were changed several times during the project as a result of communication between the investigators and participating scientists. The process was iterative, with each succeeding set of variables being more appropriate to the assessment than their predecessors. Primary factors influencing their selection were the scientists' understanding of effect mechanisms; the extent of ava[illegible]'s inventory information; and the size of the region over which effects were to be estimated. While the project investigators suggested the original variables for the analysis, subsequent specifications were the products of discussions with scientific participants.The linkage between the information needs of the policy analyst and the scientific investigator is not straightforward. Policy analysts are not able to adequately specify information needs to the effects scientists without considerable and extended dialogue. As scientific information and estimation improves, policy analysts will attempt to incorporate that information within their assessments.

A second conclusion is that, when dimensioning the uncertainty in effects estimates, it is important to try to achieve only that degree of resolution which is scientifically credible or responsible. Scientific judgements regarding the uncertainty of different acid deposition effects estimates are imprecise. This makes it difficult for scientists to provide judgemental estimates of a precise probability distribution for effects outcomes. If the approach for dimensioning uncertainty requires a level of precision that the scientist cannot achieve, then the scientist will not view the resulting estimates as being credible. The elicitation used in this project explicitly recognizes the difficulty in making meaningful point estimates for the probability of different levels of effects. Instead of point estimates, the elicitation estimated the range of potential effects (i.e., upper and lower bounds) with only a simple weighting scheme to express the likelihood of different outcomes within the range. The lack of information on causal mechanisms associated with acid deposition effects and the extreme variability in different ecosystem's response to acid deposition warrants conservative expectations regarding the precision with which scientists can estimate the probability of different effects outcomes.

A third conclusion is that inventory data concerning resources at risk may be the limiting factor in the performance of assessments concerning acidification effects upon fish populations. While there is considerable uncertainty concerning the effects of acidification upon fish populations, there may be even more uncertainty in the current status of regional fish populations and aquatic chemistry inventories. This project focused on dimensioning the uncertainty in estimates of damages to lakes presently containing fish. However, no attempt was made to dimension the uncertainty in estimates of the number of lakes that currently support fish populations. If explored, it seems possible that the uncertainty in the dose-response relationship for certain species of fish. Because of this relative absence of complete inventory data, statistical generalization over the outputs of mechanistic or empirical effects models will be very uncertain. Techniques similar to the approach employed in this project could be useful in dimensioning the uncertainty in estimates of resources at risk.

Interpretation of the project results should be guided by the following remarks. First, the project was designed to evaluate the utility of a particular device for incorporating scientific knowledge and advice within policy debates. As such, the damage estimates generated should be viewed as preliminary. Furthermore, the proper emphasis of the report should be the results listed in Chapter 4, which are the outcomes of the different elicitation interviews with participating scientists. Chapter 5 consists of a sample application of those results utilizing a very simple water chemistry model and a data base provided by the New York State DEC. The data from the elicitation interviews, however, can be easily coupled with other data bases and water chemistry models in order to yield different predictions of fish population damage due to acidification. This report does not connect fish population response to acid deposition. The independent variable throughout was the pH of Adirondack ponded waters. No attempt was made to estimate the effect of acidification upon stream populations. Because stream fishing is important in the Adirondacks, future regional effects estimates should address this area as well. Finally, the damage estimates generated in Chapter 5 should not be interpreted as damages to fish per se, but rather to fish populations within their recorded lake habitats. The sensitivity of these fish habitats to acidification is a function of many factors, and is different from sensitivity recorded for the same species in bioassay experiments. For example, while brook trout are known to be resistant to acidifcation effects, much brook trout habitat is vulnerable to acidification because of its morphometric and biogeochemical characteristics.

6.3 AREAS FOR FUTURE RESEARCH

There are a number of other techniques that could be used to dimension uncertainty. All use some variant of subjective probability elicitations. The only exception is the use of statistically derived confidence intervals. However, the use of statisical confidence intervals for dimensioning uncertainty around acid rain estimates suffers from two severe shortcomings. First, they are based on a set of statistical assumptions and model specifications (e.g., functional form) that may not be correct; and second, statistically valid examples are unlikely to exist for most effects areas. Still, there are techniques for combining sample information with the type of information generated by this project. These techniques, based on Bayesian methods, should be explored whenever sample data is available.

The elicitation technique used in this project estimated the range of possible effects with very little information on the shape of the probability distribution within this range. This process was selected because of the extreme uncertainty characteristic of acid deposition caused fish population effects. It might be possible, however, to estimate more accurately the form of the probability distribution within the lower and upper boundaries of the predicted effects.

Recall that the project segmented the range between the lower and upper bounds of the effects by calculating the midpoint and then asking the scientist to indicate which segment of this range was more likely. For example, see line A in Figure 6-1:

Figure 6-1
Possible Techniques for the Estimation of
Probability Distributions

A.	pH. 4.6	10				30		X		50
B.	pH. 4.6	10		20		30	X	40		50
C.	pH. 4.6	10	4	20	3	30	1	40	2	50

A more precise estimate of the cumulative probability distribution can be obtained by segmenting the range into fourths rather than halves as in line B of Figure 6-1. More information could be obtained by having the scientist rank each segment within the range from most likely to least likely, as shown on line C of Figure 6-1.

Another alternative would be to have the scientist directly estimate a probability distribution for effects at each pH level. This would require the scientist to estimate, for each pH level, the precise probability associated with each effects outcome or range of outcomes. In this project, the effects outcome was a reduction in fish habitat. An elicitation that would directly estimate the cumulative probability distribution was briefly considered in the pretest and one trial application of this technique was conducted. This elicitation technique was not used in the project because the estimation of a precise cumulative probability distribution proved to be extremely difficult for the scientist given the current state of knowledge. Further, the estimation of a cumulative probability distribution for each of the pH levels and the different species of fish would have proven to be even more lengthy than the four to five hour interview required by this process. Still, a more complete exploration of this approach is probably warranted.

In recent work, Feagens and Biller (1981) have designed elicitation techniques that estimate upper and lower bounds to the probability of different effects outcomes. This result is a direct estimate of the cumulative probability distribution accompanied with bounding upper and lower distributions. This variation could also be explored. These and other details of the application of subjective probability analysis deserve further consideration with any application to deposition effects areas. The structure of the device used to develop the probability distribution can be expected to vary across different effects areas depending upon the level of uncertainty present in estimating regional effects.

As suggested in the previous section, another useful research project would involve a dimensioning of the uncertainty in estimates of resources at risk (e.g., fish population data). To estimate effects, both dose-response and inventory data are needed. At present, the fish inventory data is very limited and, therefore, the fish populations at risk are uncertain.

The framework used in this project presents damage relationships based upon the judgements of selected scientific participants. The opinions and decision making characteristics of the participating scientists clearly influence the results presented in this report. Selection criteria for participants and their justification are, therefore, important for future studies. These could be developed in conjunction with scientists already participating within the National Acid Precipitation Program and a number of external reviewers.

6.4 CONCLUDING REMARKS

Regional damage assessments of acid deposition effects will continue to be characterized by scientific uncertainty. As new scientific information and interpretation becomes available, earlier estimates will be revised. If regional assessments are going to be performed, direct scientific participation within the planning and implementation of regional assessments is necessary. This project established that scientists are willing to perform such a role. This role involves both the specification of the effects' model parameters and the estimation of the parameter values. The importance of having scientists help develop the parameters for effects assessment models has often been overlooked. Conventionally, members of the scientific community have requested policy analysts to provide a "wish list" describing the parameters necessary for the performance of an analysis. This approach has led to considerable confusion. We recommend a joint specification of assessment parameters where the scientist suggests appropriate parameters on the basis of current and predicted scientific information. Secondly, the participating scientist should directly estimate the extent of effects resulting from acid deposition. This project has determined that this can be credibly performed. In many cases, the damage estimates were characterized by wide ranges, yet this doesn't indicate that the estimates are inaccurate. It simply represents the degree to which scientists are uncertain concerning the relationship between the parameters selected for analysis.

The credibility of the results and the process itself has been difficult to determine. In large part, the readers of this report will be responsible for either adopting or rejecting the technique and results. It must be remembered, however, that it is the first attempt to explicitly dimension the uncertainty surrounding acid deposition effects. Regardless of the technique used to develop regional damage estimates, those estimates will be uncertain. This, or a similar technique, provides important additional information concerning the confidence of those regional estimates. Finally, since the uncertainty in the scientific information is so important in the assessment process, the uncertainty in the scientific estimates must be dimensioned. If this approach is felt to be unacceptable, then another must be suggested. The project investigators are aware of the shortcomings and problems in this approach. The question is how to best perform a difficult task.

APPENDIX A

TEST CASE SENSITIVITY ANALYSIS OF THE WEIGHTING AND CONFIDENCE INTERVAL ASSUMPTIONS

APPENDIX A
TEST CASE SENSITIVITY ANALYSIS OF THE WEIGHTING AND CONFIDENCE INTERVAL ASSUMPTIONS

This appendix contains a brief illustration of the procedure developed to estimate damages to fish populations caused by acidification. Table A-1 presents the input pH distribution data required by the analysis. It shows the "current" distribution of pH values across Adirondack lakes containing brook trout as well as the shift in the distribution of pH values assumed for a "sensitivity test case." This current distribution of pH values was obtained from the Adirondack Water Management System data base maintained by the New York DEC. In calculating the final results presented in Section 5.3, refinements in this pH distribution were made (see Section 5.2). However, this distribution of pH values was used to test the sensitivity of the confidence interval and weighting assumptions. A simple .2 pH shift across all the lakes was assumed. For example, the 55 lakes with a current pH of 7.0 were assumed to shift to a pH of 6.8.* Given this pH shift, a cumulative probability distribution of the number of additional damaged lakes, i.e., lakes which can no longer support brook trout, is calculated.

This simple assumed shift of .2 pH was used to test the sensitivity of the results to the confidence interval and weighting assumptions. Nine cases were considered:

Confidence Intervals of 95 percent, 90 percent and 80 percent
Weightings of 2:1, 3:2, 5:4

Table A-2 presents the results of four of these cases: 1) 95 percent confidence interval with a 2:1 weighting; 2) 80 percent confidence interval with a 2:1 weighting; 3) 95 percent confidence interval with a 5:4 weighting; and 4) 80 percent confidence interval with a 5:4 weighting.

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* Since these 55 lakes have the same starting pH and same ending pH, they would represent a "cluster" of lakes as defined previously. The assumption of perfect correlation allows the simple summing of the cumulative probability distributions across all "clusters" of lakes to obtain an aggregate cumulative probability distribution of damages.

Table A-1

Data Input: Assumed Change in the Distribution of pH Values Across Adirondack Lakes Currently Containing Brook Trout

Sensitivity Test Case: A .2 pH Reduction

Current Distribution of pH Values Across Adirondack Lakes		Example Decremental Change in the Distribution of pH Values Across Adirondack Lakes	
pH	Number of Lakes	pH	Number of Lakes
7.0	55	7.0	-
6.9	13	6.9	-
6.8	14	6.8	55
6.7	9	6.7	13
6.6	11	6.6	14
6.5	19	6.5	9
6.4	14	6.4	11
6.3	22	6.3	19
6.2	22	6.2	14
6.1	13	6.1	22
6.0	34	6.0	22
5.9	16	5.9	13
5.8	17	5.8	34
5.7	17	5.7	16
5.6	8	5.6	17
5.5	23	5.5	17
5.4	11	5.4	8
5.3	6	5.3	23
5.2	9	5.2	11
5.1	11	5.1	6
5.0	16	5.0	9
4.9	10	4.9	11
4.8	20	4.8	16
4.7	17	4.7	10
4.6	16	4.6	20
4.5	11	4.5	17
4.4	4	4.4	16
4.3	8	4.3	11
4.2	4	4.2	4
4.1	3	4.1	8
4.0	4	4.0	4
3.9	0	3.9	3
		3.8	4

Table A-2

Sensitivity Test Case Results: Cumulative Probability Distribution Showing the Probability That a Given Number of Lakes Will Be Damaged

Case 1 95% Confidence Interval 2:1 Weighting		Case 2 80% Confidence Interval 2:1 Weighting	
Cumulative Probability	Number of Damaged Lakes	Cumulative Probability	Number of Damaged Lakes
.05	20.5	.05	23.1
.10	37.2	.10	36.0
.20	48.9	.20	43.7
.30	56.7	.30	54.8
.40	59.6	.40	60.6
.50	62.2	.50	63.8
.60	65.5	.60	68.1
.70	71.9	.70	76.4
.80	79.8	.80	80.2
.90	82.5	.90	87.3
.95	93.0	.95	126.5

Case 3 95% Confidence Interval 5:4 Weighting		Case 4 80% Confidence Interval 5:4 Weighting	
Cumulative Probability	Number of Damaged Lakes	Cumulative Probability	Number of Damaged Lakes
.05	23.5	.05	26.4
.10	41.4	.10	39.5
.20	52.5	.20	48.5
.30	58.0	.30	57.3
.40	61.0	.40	62.3
.50	63.0	.50	64.9
.60	66.1	.60	69.5
.70	72.7	.70	77.7
.80	81.0	.80	82.8
.90	87.5	.90	88.7
.95	94.9	.95	126.1

A comparison of Case 1 with Case 2 and Case 3 with Case 4 shows the sensitivity of the calculated distribution of damages to differences in the assumed confidence interval. This comparison shows a reasonably significant difference in the endpoints of the range of damages when different confidence intervals are assumed. The same comparison also shows the sensitivity of the distribution of damages due to different weighting assumptions. The differences between both the 50th fractile value and endpoints of the distributions using different weightings are quite small. Based on this test case sensitivity analysis, it was decided that future sensitivity analyses would focus on the confidence interval assumption rather than on the assumed weighting. The standard set of runs for each species was decided to be comprised of two scenarios: a 90 percent confidence interval with a 3:2 weighting assumption and a 80 percent confidence interval also with a 3:2 weighting. However, a full sensitivity analysis was performed for brook trout.

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