

Benefit-Cost Implications of Acid Rain Controls: An Evaluation of the NAPAP Integrated Assessment

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Concluding ten years of study, the U.S. National Acid Precipitation Assessment Program (NAPAP) recently issued its integrated assessment report designed to provide guidance to policy makers on the sources and effects of acid deposition, and the costs and benefits of alternative control measures. This paper focuses on an evaluation of the benefit-cost implications of acid rain controls as revealed by two of the five major questions addressed in the NAPAP assessment framework. While the NAPAP effort made significant scientific contributions to the study of acid deposition, key gaps are found in the assessment of benefits and costs most relevant to policy decisions. Lessons learned from NAPAP may be helpful in avoiding similar problems in assessing emerging environmental issues such as global climate change.

In North America and Europe, the dominant environmental issue of the 1980s was acid rain (more properly termed acid deposition). In response to widespread concerns about this issue, Congress, in 1980, created the National Acid Precipitation Assessment Program (NAPAP), a 10-year study of the causes and effects of acid deposition conducted by a team of researchers drawn from twelve agencies of the federal government. Never before had such a massive effort been launched to address a major environmental issue. Through a program of scientific research and assessments, NAPAP's role was to inform the developers of public policy by providing guidance on the benefits and costs of acid rain controls.

The culmination of the NAPAP effort was a series of 27 State-of-Science/Technology (SOS/T) reports, plus a final integrated assessment released in draft form in September 1990.¹⁻³ The three-volume integrated assessment represented NAPAP's effort to tie together the many pieces of the problem in a form most relevant to policy decisions. The assessment was organized around five major questions dealing with precursor emissions and their effects, and the costs and benefits of emission reductions:

1. What are the effects of concern, and what is the relationship between deposition/air pollutant concentrations and these effects?
2. What is the relationship between emissions of precursor pollutants and acidic deposition/air concentrations of pollutants?
3. What is the sensitivity to change?
4. What are the estimates of future conditions based on illustrative scenarios?

5. What do comparative evaluations of illustrative future scenarios indicate?

This paper focuses on an evaluation of Questions 4 and 5 of the integrated assessment. These two questions form the heart of the benefit-cost comparisons sought by policy-makers since NAPAP's inception.

In evaluating NAPAP, other questions must be asked. For example, did the assessment ask the right questions? Did it provide meaningful answers? Did it communicate key uncertainties? And did it help influence decisions? My "bottom line" evaluation is that the assessment either fails or falls short on all these counts. Indeed, it is tempting to draw analogies with a final term report that now must be graded. The NAPAP effort brings to mind the case of a student who was failing badly at mid-semester, but managed to make an impressive sprint in the closing weeks of the term. Nonetheless, the final grade must reflect the actual accomplishments over the full term. While one wishes this student had started earlier and worked to full potential, at best the final report deserves no more than the proverbial "gentleman's C." Passing but disappointing; ordinary rather than outstanding or exemplary.

Let me elaborate on the basis for this evaluation.

Historical Perspective

An historical perspective on the goals of NAPAP's integrated assessment is helpful in understanding the context for expectations. Summaries of the assessment objectives appeared in NAPAP's past annual reports. The first report, issued in 1982, indicates that, "the assessments and policy analysis program will prepare integrated assessments interpreting the importance and quality of research results, developing estimates of the benefits and associated costs

and formulating guidance for policymakers."⁴ Thus, at the outset there was a strong emphasis on policy analysis, policy formulation, and a comprehensive assessment of costs and benefits, as requested by Congress in the enabling legislation.

Several years later, however, under a new director, the 1986 NAPAP Annual Report revealed several important changes in the assessment's goals. Now, "the primary role of assessment is to critically evaluate, synthesize, and present scientific information to provide a basis for policy formulation."⁵ The words "policy analysis" and "integrated" no longer appeared in the assessment program descriptions. Nor were economics or comprehensive benefit-cost analyses mentioned any longer. The clear emphasis and tone of the 1986 annual report was simply on the presentation of scientific information. Help for policymakers was clearly de-emphasized.

By 1989, under its third director, the NAPAP annual report took yet another tact. Now the assessment was characterized as, "a structured compilation of policy-relevant technical information presented in a form suitable to assist decision makers ... concerning questions on causes, effects and control strategies."⁶ While this statement accurately reflects the character of the final assessment, it differs significantly from the original goals of the assessment program. While the initial promise emphasized the interpretation of science for policy, the final product emphasizes technical compilations with relatively little emphasis on policy-relevant interpretation. To its credit, the final assessment does attempt to revive the integrated perspective that was lost during the middle years of NAPAP's activities. But without the continuity of research efforts and staffing needed to support that perspective, the final effort could not help but fall short of the goals initially set by Congress for the NAPAP program.

Assessing the Assessment

As noted earlier, Questions 4 and 5 form the heart of the integrated assessment. The two questions are addressed in a single document which draws upon relevant information from other NAPAP reports.³ My evaluation of this assessment is organized around five new questions:

1. What did they do?
2. How did they do it?
3. What did we learn?
4. What *didn't* we learn?
5. What lessons can we draw for the future?

The answers to these questions will be considerably less structured than the NAPAP assessment. Let us begin, however, with a brief review of what was done. Basically, the benefit-cost analysis is presented for a number of illustrative scenarios for SO₂ emissions over a forty-year time period from 1990 to 2030. The key scenarios involve no new SO₂ controls, and reductions of 8, 10 and 12 million tons per year below 1980 levels. A case with SO₂ emissions trading also is considered. For these scenarios, the assessment estimates the costs of emissions controls, both the direct cost to utilities and the indirect cost to the U.S. economy. Also associated with each scenario are estimates of the environmental benefits to aquatic systems, terrestrial systems, materials, visibility, and human health.

The Reference Scenario

The "reference scenario" plays a critical role in the comparison of costs and benefits. This scenario—called S1 throughout the report—is based on a series of economic and technical assumptions that are summarized (at least partially) in Question 4. Independent assumptions include expectations for the growth rate of gross national product.

GNP is assumed to grow at a rate of 2.56 percent per year to the year 2010, then lower to 1.65 percent per year to 2030. Thus, the trajectory for GNP growth rates is one that declines in the future, with associated implications for lower energy use and emissions. Population growth rates also are assumed to decline in the last 20 years of each scenario, resulting in lower emissions growth. Many other assumptions affecting future U.S. energy use, including residential and industrial production indices, plus oil, gas and coal prices, are imbedded in the S1 scenario. The result is an increase in the annual average demand for electricity of 2.0 percent per year for the first 20 years of the scenario then a decline to 1.3 percent per year for the next 20 years. (Note that the latter figures do not appear anywhere in the assessment report. They were calculated from total electricity consumption levels reported in the separate volume on Question 3).

Other key assumptions specify the electric power system generating mix, power plant lifetimes, plant retirement rates, and capacity additions of new technologies. The reference scenario appears to be rather bullish on lower-emission integrated gasification combined cycle (IGCC) power plants. There are about 30,000 MW expected in the next ten years, increasing to 73,000 MW by 2010. Emission regulations in the S1 scenario remain essentially at their pre-1990 levels.

The NAPAP assessment stresses the importance of the reference scenario for cost-benefit comparisons. It is reasonable, therefore, to ask just what this reference scenario means. However, the assessment says very little about what the reference scenario *is*, only what it is *not*: "It is not NAPAP's best view of the future," and, "It is not the most likely projection." Nor is it even "the middle case within a range of scenarios." The only positive statement explaining the reference scenario is that, "it is the product of considerable thought and discussion."² A major weakness of the assessment is its failure to give us the benefit of that thought and discussion. Inevitably, the value of any scenario analysis depends strongly on its persuasive tone; on the picture it paints of how a particular future might evolve. If the judgments, assumptions and rationale for a scenario are not clearly argued or presented, one has a very hard time judging whether to take it seriously, or whether to view it as a less likely or implausible excursion.

The assessment does provide some very important advice in its discussion of the reference scenario. It notes that "what is important is the range of future emissions obtained by adjusting the variables within plausible bounds; the reader is discouraged from extracting and using any discreet forecast."² Yet, it is only one discreet "base case" forecast that NAPAP uses in all of its scenario comparisons. The whole issue of how uncertainties in the reference scenario influence all subsequent comparisons is never adequately addressed, though the tools for doing so appear readily at hand. For example, Figure 1 shows a graph that appears frequently throughout the assessment. It is a time trend of SO₂ emission projections in the absence of new controls for the period 1990–2030. The S1 reference scenario appears along with two additional scenarios chosen from the set of 25 or so analyzed during the course of the NAPAP effort. The figure illustrates the uncertainty in baseline projections as a function of different assumptions.

One of the questions not addressed by the assessment is whether these two alternative baseline scenarios are any less likely or any less plausible than the S1 used exclusively for later comparisons. Despite NAPAP's statement to the contrary, S1 indeed appears to be simply a middle case among plausible alternatives. Yet, the rather large (factor of two or three) uncertainty in baseline emissions revealed in Figure 1 is never factored into any later comparisons. Despite repeated caveats indicating that other reference

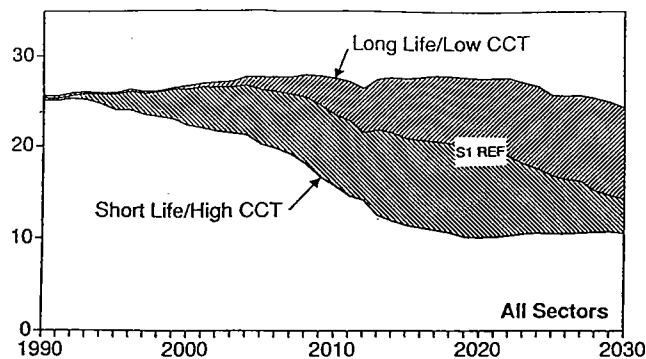


Figure 1. NAPAP scenarios showing a potential range of U.S. SO₂ emissions in the absence of new acidic deposition control legislation. Upper and lower scenarios result from combining alternative power plant ages with two different levels of Clean Coal Technology (CCT).³

scenarios would give different results, there is no analysis to provide such important insights.

Projections 40 years into the future also are hard to take seriously. While scenarios can be a useful means of gaining insights about the consequences of alternative assumptions, they must be carefully interpreted and explained to be useful. For example, one of the key features in Figure 1 is that the maximum uncertainty in SO₂ emissions occurs around the year 2020. As time goes on there is less uncertainty about emission levels than in the earlier years. Is it plausible to expect that as time increases, uncertainty decreases? Certainly that seems counter-intuitive. In this case, that behavior obviously is a result of the specific assumptions of these scenarios. The key question is whether important factors that affect emissions in the out years are adequately reflected in the scenarios chosen by NAPAP. For example, social science teaches us that people tend to be highly anchored in the present, so it is perhaps not unexpected that the NAPAP scenarios assume electricity growth rates around the levels of current near-term forecasts. Had such scenarios been formulated at another time—perhaps 20 years ago when electricity growth rates were 7 percent per year—my guess is that scenarios for the next few decades would have assumed growth rates closer to 6 or 7 percent. The only thing we can be sure of is that none of NAPAP's scenarios will be the way the future actually turns out. Unfortunately, the assessment tends to emphasize many of the scenario results for the year 2030, as opposed to results for the more "foreseeable" future. In failing to amplify on the uncertainty in long-term projections—and despite the caveats sprinkled throughout the report—the assessment

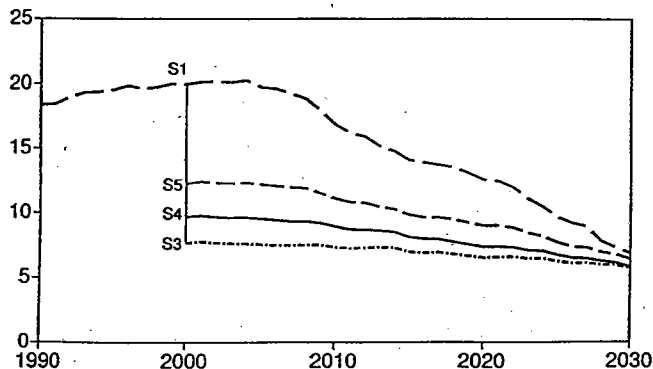
SO₂ Emissions (10⁶ tons)

Figure 2. Emissions of sulfur dioxide from electric utilities without new acidic deposition control (S1) and under control scenarios S3, S4, and S5 representing reductions of 8 to 12 Mtpy.³

inevitably misleads readers into believing that the findings are more robust than they actually are.

Emission Control Scenarios

Cost and benefit comparisons are based on a number of emission reduction scenarios. These scenarios place uniform caps on power plant SO₂ emissions (specified in units of pounds per million Btu) so as to achieve in the year 2000 overall national reductions of 8, 10, and 12 million tons per year (Mtpy) below 1980 emissions. NO_x control is assumed only in one scenario, but that scenario is not used for the comparisons in Questions 4 and 5. Nor is the scenario that models emissions trading given much emphasis in the assessment.

Figure 2 shows the four principal scenarios used for comparative assessments. The reference scenario (S1) shows SO₂ emissions eventually declining to about the same level achieved in the emission reduction scenarios S5, S4 and S3 (which correspond to SO₂ reductions of 8, 10 and 12 Mtpy, respectively). Scenario S4, which is the 10 Mtpy reduction case, is the control scenario discussed most frequently in the assessment.

The Integrated Modeling Set

The question, "how did they do it?" has a simple answer: they used models. Some 20 to 30 different computer-based models were used to perform the integrated analysis, making this an extraordinarily complex effort. Indeed, it is doubtful that anyone in NAPAP fully understands how all of the models interact, and exactly what assumptions and "fixes" were made to allow different models to communicate with one another. Thus, at some level, there is undoubtedly cause to question many details of the integration process that produced the final assessment results. However, that is a task properly left for technical peer review.

A number of more important questions are posed in view of the complexity of the NAPAP modeling set. Of all of the assumptions that went into these models, are we sure we know what the most critical assumptions are? Has the integrated modeling set really been fully tested? Given the enormous time and effort needed to develop and test this complicated system, is all of that complexity and detail really necessary? Are there simplified ways of representing many of the key elements needed for assessment purposes? If we start taking away some of the pieces or replacing them with simpler pieces, how much would we really lose? To what extent is the ability to credibly evaluate different scenarios dependent on the analytical complexity of the modeling system as opposed to the judgments and assumptions provided by the analysts? The impression left with this reviewer is that in its pursuit of the most defensible scientific modeling system, NAPAP inevitably short-changed the final assessment by leaving inadequate time to thoughtfully sort out the things that matter from the things that don't, and to present and interpret modeling results in ways more meaningful for policy decisions.

The Cost of Emission Controls

One of the major results of the assessment was the cost of SO₂ emission reductions. All costs were reported in levelized 1990 dollars, and both direct and indirect costs were considered.

Direct Costs

For the 8 million ton reduction scenario the direct cost to utilities was found to be \$1.7–2.7 billion. Costs for the 10 Mtpy scenario were \$2.7–4.0 billion and for the 12 Mtpy

case \$4.5–7.0 billion. There is an emphasis on the magnitude of marginal costs, indicating that the cost of going from 10 to 12 Mtpy at the margin is several times larger than the costs of going from 8 to 10 Mtpy. Another key result of the scenario comparisons is that emissions trading is about 15–25 percent cheaper for the 10 million ton scenario.³

These kinds of national cost results reported in the integrated assessment certainly are not new; numerous studies over the past six years have reported similar cost figures for similar scenarios.^{7,8,9} This is the first time, however, that cost figures have been published by NAPAP, and in that context the result is noteworthy.

Given the importance of costs for policy formulation and analysis, it is disappointing, and rather surprising, that the assessment presented direct cost results only as national totals. This assessment has a variety of audiences with widely different interests. Therefore, it is especially important that key results be reported in a variety of ways to insure they are fully understood by all concerned. For example, the levelized costs of several billion dollars (does everyone understand what “levelized” means?) seems like a lot of money. Certainly if it were in my bank account it would be a big number. But in terms of the national situation, just how significant is it? No such context appears anywhere in the integrated assessment. Yet there are many ways it could have been done. For example, a simple “back of the envelope calculation” using results found elsewhere in the NAPAP assessment can provide context in terms of the increased cost of electricity. From Question 3 the total electricity sales in 2000 is projected to be 3382 billion kilowatt-hours (kWh). No average price of electricity is reported, so assume 7¢/kWh as a rough estimate (up from today’s average of 6.5¢/kWh). That would give a total U.S. electric bill of \$237 billion. The cost of the S4 scenario thus translates into about a 1.1 to 1.7 percent increase in the national electric bill. For the case with emissions trading, the average is closer to about a one percent increase for a 10 Mtpy SO₂ reduction. This *relative* measure provides a different perspective than the absolute costs reported in the assessment. One could even take it a step further and use the NAPAP population projections for the year 2000 to estimate the per capita cost of pollution control. This turns out to be about \$10 a year per person for the S4 scenario. Thus, scenario S4 can be described as a “three 10s” scenario: a ten million ton reduction in ten years costing ten dollars a year per person.

Of course, national average costs, be they absolute or relative, don’t begin to convey the kind of detail one would hope to find in an assessment of acid rain controls, namely, the regional and distributional effects of emission reduction strategies. Given the importance of regional issues in the acid rain debate, and the resources and effort that went into developing the NAPAP modeling set, it is a major disappointment that virtually nothing was said about this critical issue. Indeed, for most policy makers, utilities and citizen groups, one of the important “bottom lines” regarding the cost of control is, what will it do to electric bills? In particular, what will it mean for utilities and consumers in the Midwest which bear the brunt of controls? Though many of the NAPAP models were designed specifically to address such issues, there is absolutely nothing in the assessment document on this topic.* It is a major flaw in the assessment.

Finally, let’s consider how the assessment dealt with the issue of uncertainty in reporting emission control costs. The cost ranges reported by NAPAP seem not to be a result of an uncertainty analysis across several of their own scenarios, but the result of a comparison with two indepen-

*The only apparent statement regarding electricity rates appears in the Summary and Conclusions for the section on emissions: “Under the control policies, electricity rates would increase with increased reduction.”³

Annual Costs (10⁹ 1990 \$)

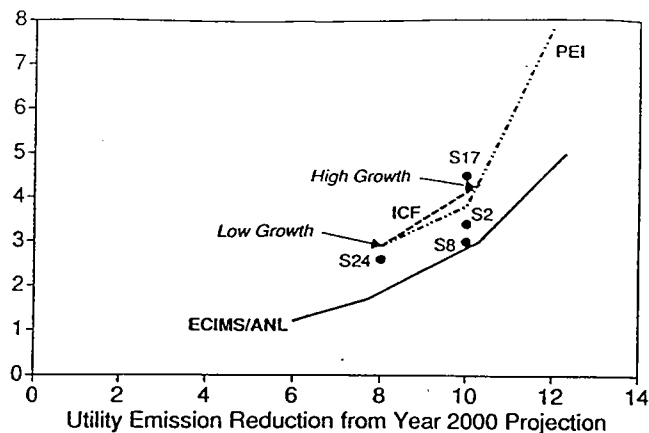


Figure 3. SO₂ control costs in the year 2000 for NAPAP scenarios and other studies.³

dent studies for the U.S. Environmental Protection Agency (EPA) using different analytical models. The results, shown in Figure 3, indicate that the NAPAP costs were on the low side of the reported range. Elsewhere in the assessment, however, NAPAP reports other sensitivity studies based only on its own models. Figure 4 shows the same results as Figure 3, but in terms of actual emissions rather than emission reductions. It is acknowledged in the report that the total cost of the scenarios is quite sensitive to future coal prices.** Figure 4 shows that the effect on total cost results is considerable. Coupled with uncertainty in the discount rate, NAPAP’s own cost estimates could double. Yet nowhere are these kinds of cost uncertainties discussed or factored into the overall conclusions.

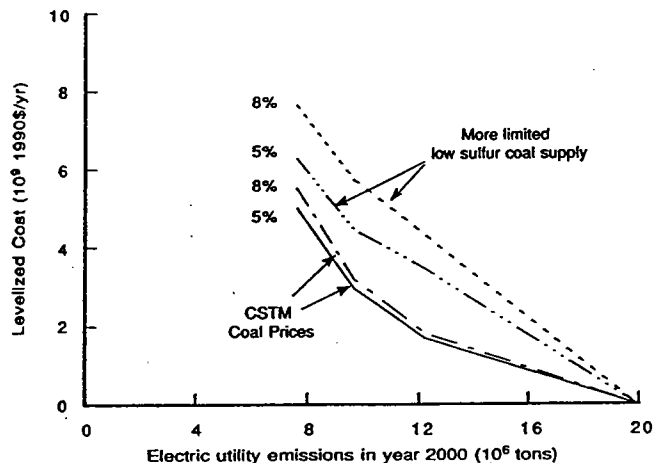


Figure 4. Policy cost vs. projected emissions in year 2000 for NAPAP scenarios.³

Indirect Costs

To its credit, NAPAP goes beyond estimating direct costs alone and reports also on some of the secondary costs of SO₂ emission controls. The most policy-relevant impacts have to do with coal mining employment and effects on gross national product (GNP). Shifts in coal production patterns are reported in a fashion similar to that found in other studies of acid rain controls (Table I). One of the major

**NAPAP also acknowledges that the model used to project coal prices, the Coal Supply and Transportation Model (CSTM), appears to have some deficiencies. In particular, it does not account for depletion effects which could significantly increase the cost of low sulphur coal. Although the depletion issue was recognized many years ago, it appears that at the end of the day NAPAP did not have a coal model that adequately accounted for this factor. Thus, ad hoc adjustments were made to the existing model to account for depletion of low sulphur coal. The assessment does not report what was done, however.

Table I. Effect of regional coal production share in year 2000 (percent).

Region	S1 (No controls)	S4 (10 Mtpy)
Northern Appalachia	21.0	17.8
Southern Appalachia	25.8	32.6
Illinois Basin	22.1	15.5
Great Plains	5.4	4.2
Rocky Mountain	25.7	30.0

Table II. What we didn't learn about policy costs.

- Details of technical assumptions embedded in model and database structure
- Basis for ad hoc adjustments to model inputs (e.g., coal depletion effects)
- Effect on electricity bills for customers, nationally and regionally
- Effects on coal mining employment
- Macroeconomic effects of environmental benefits (e.g., on agriculture, recreation, etc.)
- A clear understanding of the cost implications of major uncertainties

voids of the assessment, however, is a discussion of the implications of those coal production shifts. The issue of coal mining employment, which has been a key issue for many years, is not discussed quantitatively at all. The assessment does allude to a rich literature on the subject but none of that literature is brought to the table.

The macroeconomic effects of emission reductions are assessed using an input-output model of the U.S. economy. An important result is that NAPAP projects overall GNP losses to exceed the direct cost of control by 50 to 70 percent, with about 8,000 job losses per billion dollars of GNP.³ By that arithmetic, the \$3-4 billion dollar cost of the ten million ton scenario would translate into a GNP loss of roughly \$5 billion, with about 40,000 jobs lost over the next forty years. It is not clear, however, if this estimate includes jobs in the coal industry, nor exactly what the time profile of these costs and job losses are. The assessment reports only that GNP initially is stimulated by emission control expenditures but later declines, yielding a net loss relative to no controls. Elaboration of these findings would have been valuable; they are precisely the kinds of things that assessments are intended to discover.

Table III. Some NAPAP measures of environmental benefits.

- Reduction in deposition
 - Annual and hourly concentrations
- Aquatic effects
 - Lake and stream ANC
 - Lake and stream pH
 - Loss of habitat for fish species
- Terrestrial effects
 - Mean export of photosynthate to trunk
 - Mass of branch foliage
 - Yield of agriculture crops
 - Soil base saturation
- Materials effects
 - Critical surface loss
 - Increased rate of patina formation
 - Maintenance frequency
- Visibility effects
 - Change in light extinctions
 - Standard visual range
 - Just Noticeable Change (JNC)
- Health effects
 - Population exposed to NAAQS
 - Hourly sulfate levels
 - Water-borne lead concentrations

Table II briefly summarizes a number of policy-related issues not fully addressed in the NAPAP assessment. Most of these issues already have been discussed, but two additional points merit a mention. One concerns details of many key technical assumptions calculated in the model and database structure. As an example, things like the assumed costs of scrubbers, which are imbedded in the utility simulation model, are mentioned only briefly. Yet, changes in those assumptions could have a major impact on results. Recent studies by EPRI, for example, indicate that scrubber costs have declined in real terms since 1982,¹⁰ which is when NAPAP's cost models were first developed. In addition, more innovative scrubber designs, as now employed by Japanese and European utilities, could yield 20-30 percent additional reductions in capital cost. In turn, lower scrubber costs could reduce the displacement of high sulfur coal. Thus, many basic assumptions in the NAPAP analysis need to be more fully understood to determine whether they might have significant impacts on policy-relevant results.

Another point, which NAPAP acknowledges, is that the macroeconomic effects of environmental benefits are not considered in the assessment. Input-output models, by their very nature, predict adverse impacts on GNP when the cost of electricity rises. But if, as a result of acid rain controls, there are increased opportunities for recreation, agriculture, and so on, might those activities not have positive benefits to the economy? The qualitative answer is yes, though the quantitative answers are still lacking.

The Benefits of Emission Controls

Let me turn now to the benefits side of the assessment, which is a much more difficult subject to analyze. Indeed, perhaps the greatest challenge for the NAPAP assessment was an adequate and thoughtful discussion of the benefits of alternative policy measures to control acid deposition.

Measures of Benefits

The first question one must ask is how do you talk about benefits? What measures of benefits are most appropriate for policy deliberations and public understanding? Table III shows some of the measures used in the integrated assessment. Most benefits are characterized in physical or chemical terms, not economic ones. For example, reductions in annual and hourly concentrations of SO₂ and sulfate are one way of defining the benefits of emission controls. But what we really want to know is something about the value of reduced deposition. For aquatic effects, the benefits of deposition reduction are characterized in several ways, including changes in the acid neutralizing capacity (ANC) of lakes and streams, the pH of lakes and streams, and the "loss of habitat" for fish species. For terrestrial effects, the reported measures involve terms like the mean export of photosynthate to tree trunks. For materials effect, the assessment reports changes in the rate of patina formation and critical surface losses, among others. For visibility effects the assessment talks about changes in light extinction and changes in a measure called a Just Noticeable Change or JNC. For health effects, the benefits include changes in hourly sulphate levels, waterborne lead concentrations and the population exposed to air quality levels above national standards.

The measures above are the kinds of things that scientific models reveal. They are the measures that scientists working on various parts of the NAPAP assessment understand. But the critical need of the assessment is to translate these scientific measures into terms that policy-makers and citizens also can understand and appreciate. That is one of

the biggest challenges of an integrated assessment. On balance, the NAPAP report falls sadly short of what was needed. The measures that scientists and engineers understand and use typically are not the things that policymakers respond to or understand. Indeed, no one measure is likely to be sufficient to characterize the nature of specific benefits or damage. The challenge is to present and interpret scientific information in a variety of ways that have meaning for public decision-making. To do this, much more thought and care needs to have been exercised over the course of the NAPAP program to develop and interpret the benefits side of the equation.

Assessment Results

The lack of adequate interpretation of benefit measures is particularly evident in the summary conclusions of Question 4. Table IV lists some examples. I would argue that none of the NAPAP conclusions in Table 4 fulfill the objective of providing policy-relevant information. Most are either too general or too technical. Just imagine how useful it would be for your Congressman to learn that "carbonate stone objects would gain an inconsequential additional erosion-limited life span," or that "the average visibility change would be a 21 percent decrease in light extinction."

The summary statements of benefits also provide little or no sense about the total resources at risk. While there is a lot of such information in the NAPAP State-of-Science and Technology (SOS/T) reports, and in answers to the first few assessment questions, little of it finds its way into Questions 4 and 5. The aquatic assessment does report percentage changes in lake populations, but gives no indication of the total numbers of lakes and streams at risk. Nor is there any discussion of whether the regions that were studied are the only regions where effects are important or simply the only ones for which data were available. The same is true for other effects areas: there is very little sense of the "big picture" in summarizing the comparative costs and benefits of emission reduction scenarios.

Quantifying the value of damages from acid deposition clearly has a long way to go. There are only two or three areas where ad hoc economic evaluations were made in the NAPAP assessment. These included the dollar value of aquatic benefits to sports fisherman in the Northeast and the dollar value of fertilizers and chemicals that might be needed by farmers to replace sulphur and nitrogen now coming out of the air. No systematic or comprehensive attempt was made to value other benefits or damages of acid deposition, either in monetary terms or other measures (e.g., utility, risk preference, etc.). The physical/chemical measures discussed earlier provide the only means of valuing environmental change.

A discussion of the benefits from ozone reduction also appears in the assessment, but lacks context in terms of the illustrative SO₂ emission reduction scenarios. In the discussion of terrestrial effects many of the major conclusions are associated with reductions in ozone. Yet the magnitude of ozone changes that are talked about (reductions of 40 percent or more) have nothing at all to do with the SO₂ control scenarios that were analyzed. Nor were any other scenarios offered that could achieve these significant reductions in ozone. Overall, the responses to Questions 4 and 5 tended to confuse, rather than enlighten, the relationships between acid deposition controls and ozone control measures (i.e., NO_x and VOC reductions).

What We Didn't Learn

There is a tendency throughout the assessment of benefits to elaborate on what is known and downplay or avoid discussions of the potential significance of major unknowns. At times this brought to mind the story of the man

Table IV. Some summary conclusions of the benefit-cost comparisons.

- "Under the control policies, electricity rates would increase with increased [emissions] reductions. . . ."
- "Carbonate stone objects would gain an inconsequential additional erosion-limited life span under Scenario 4 than under Scenario 1."
- A 50% reduction in deposition "would cause a slight increase in base saturation of some shallow sensitive soils with low cation exchange capacity. . . ."
- "The average visibility change would be a 21% decrease in light extinction or a 27% increase in standard visual range . . . [which] corresponds to about three cumulative just noticeable changes (JNCs)."
- ". . . for the year 2000 under scenario S1, . . . one additional county [of the 21 counties analyzed] would exceed the [24-hour SO₂] NAAQS, increasing the total baseline population potentially at risk to 2,364,536 [from 2,170,247 currently]."

who kept searching under the lamppost for the key lost at the dark end of the street, simply because that was where the light was. One example is the area of materials damage. There is virtually no analysis in Question 4 of the value of damage to paint and other materials even though this has long been suspected to be one of the most potentially significant sources of economic damage from acid deposition. Certainly, the assessment process should have guided research toward the most important issues. But this does not appear to have happened in all cases. In many instances, the final assessment simply states that certain issues were not evaluated, with no comment or sense of their potential importance. In avoiding any summary of expert judgments about unanswered or controversial questions, the assessment takes the safe route appropriate for scientific studies (and perhaps unavoidable for interagency government efforts), but fails to deliver on one of the key needs of a policy-relevant integrated assessment, i.e., a clear sense of what we still *don't* know.

The comparative assessments of Questions 4 and 5 also contain very little discussion of the differences in benefits among the emissions scenarios considered. NAPAP's focus was primarily on the S4 scenario, i.e., the 10 Mtpy reduction (which is what Congress already has legislated). But if one asks what the differences are in the benefits from different levels of emissions reduction, there are no clear answers. Nor, with one exception, are there any clear statements that there are no clear answers. This is especially troubling since, as noted above, part of the job of an assessment should be to report on what is *not* known. Only in the discussion of aquatic effects does NAPAP explicitly say that we can't really tell the difference in benefits between the 8, 10 and 12 Mtpy reduction scenarios.

If indeed that is the case, then why the strong emphasis on the 10 Mtpy reduction scenario? Rather than *leading* the policy process, the assessment focuses on the same three scenarios that people have been thinking about and analyzing for the past six or seven years. The assessment does not take the lead in answering or posing other key questions. For example, as in Europe and Canada, one could first ask what critical loads or changes in deposition are needed to avoid effects, then "work backwards" to determine the appropriate emission reductions. Indeed, others already have done this to arrive at the 8-12 Mtpy reduction range. By not asking some of the right questions to begin with, the NAPAP assessment simply missed the boat in terms of influencing key public policy decisions.

Characterizing Uncertainty

I have commented already on the assessment's failure, in many instances, to adequately discuss key uncertainties

uncertainty.

****	High Confidence
***	Reasonable Confidence
**	Best Judgment—Limited Confidence
*	Best Judgment—Low Confidence
0	Unsupported Hypothesis

Table VI. Four-star conclusions of the NAPAP integrated assessment: Questions 4 and 5.

- “Cost uncertainty bands are large because of the large sensitivity of results to assumptions about the price of low-sulfur coal and scrubbers in a seller’s market.”
- “High sulfur and low-sulfur coal production shifts under the policies.”
- “Although trading provisions such as proposed in the CAAA can result in reduced costs the impact with regard to what states or regions will be buying or selling emission reductions is highly uncertain.”
- “Gypsum would accumulate on sheltered surfaces less rapidly under scenario 4 for a period of 30 years.”
- “The contribution of sulfates to total light extinction is calculated to be 57%—baseline annual and spatial average for the rural East.”
- “There are two sources of day-to-day variation in the visibility improvements at any given location: (1) daily variation in the contribution of sulfates to light extinction and (2) daily variation in the percent reduction in sulfate concentrations. Assuming that these two distributions are independent, it is calculated that, on the 15 days per year of least impact, the light extinction reduction would be 1.4%—definitely imperceptible.”
- “Improvements in visibility, which occur immediately after emissions are reduced, are expected to occur earlier under S4 compared with S1.”

associated with scenario assumptions. Here, I comment briefly on the method NAPAP did choose to characterize uncertainty in the summary statements and conclusions that highlight each section of its report.

Table V shows the “star” system used by NAPAP. Statements carrying either two or three stars are the most frequent. Four-star statements, which have the strongest degree of confidence, tend to be either technically narrow or not very substantive (see Table VI). One statement simply indicates a high degree of certainty that the result is uncertain: “the impacts of emissions trading . . . is highly uncertain (****).” There are relatively few one-star statements, and no zero-star statements that I could detect. Indeed, the very notion of reporting an unsupported hypoth-

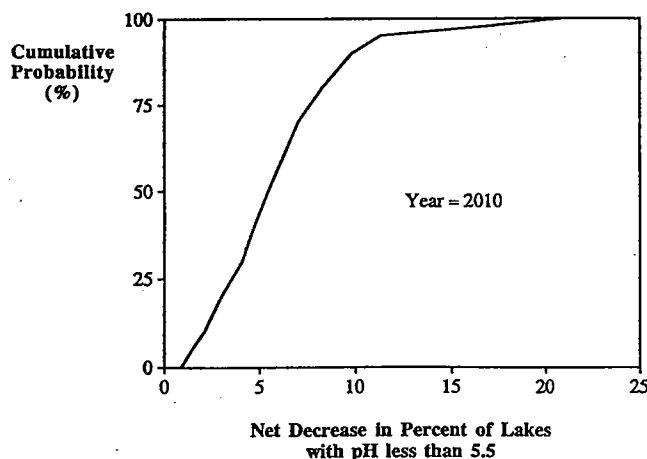


Figure 5. Effect of emission reduction scenario on lake acidity at Adirondacks Park.¹¹

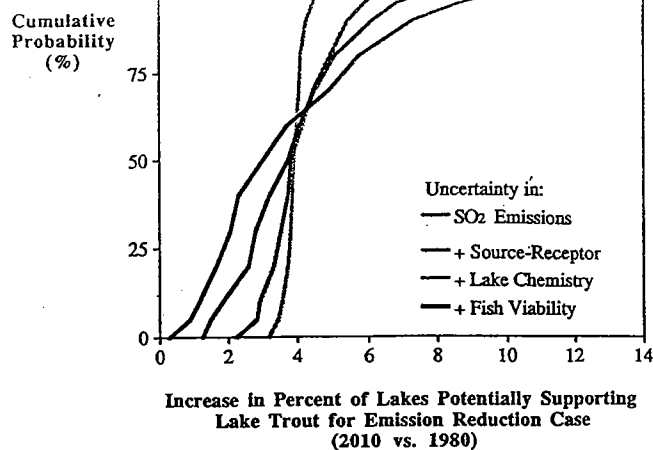


Figure 6. Effect of emission reduction scenario on fish viability at Adirondacks Park.¹¹

esis appears to be anathema to this assessment though, properly presented, it might have made for some of the most thought-provoking reading.

Could NAPAP have found a better way to characterize uncertainty? Many practical considerations undoubtedly posed serious limits in trying to do a better job, but certainly a more meaningful analysis was possible. However, because of the complexity of both the science and its institutional arrangements, NAPAP would have had to start a lot earlier to do significantly better than it did.

An integrated assessment framework developed at Carnegie Mellon University provides one model for a more rigorous analysis of uncertainty. A stochastic simulation method is used to propagate uncertainties through a series of linked models, and results are quantified in a probabilistic form. Details of the modeling framework and the rationale for its development are described elsewhere.¹¹ Illustrative results, however, show the kinds of insights a probabilistic analysis can provide for both assessment and research planning activities. Figure 5, for example, shows a probability distribution for the change in lake acidity between a base case scenario (with uncertainty) and a 10 Mtpy emissions control scenario (similar to the NAPAP S4 case) for the Adirondacks Park region in the year 2010. Uncertainty distributions were assigned to approximately 30 different parameters describing SO₂ emissions, atmospheric transport processes, aquatic chemistry, and potential fish viability. The results in Figure 5 show a 90 percent confidence interval of about a 2 to 11 percent increase in the number of lakes which increase their pH above 5.5 as a result of the SO₂ emissions reduction. This corresponds to roughly 30 to 100 lakes greater than 4 hectares in size. The resulting effect on potential fish habitat for lake trout is illustrated in Figure 6. This figure also shows how the various component uncertainties contribute to the overall result for a particular scenario. For example, the uncertainty in SO₂ emissions—which reflects a broad range of baseline scenarios developed by different government, industry and environmental organizations—in fact, made relatively little difference to the final result compared to uncertainties in the results for lake chemistry and fish viability. These kinds of analyses help identify and focus attention on the things that matter most, with respect to both policy and research planning. Other approaches for characterizing uncertainty in integrated models¹² can also serve the needs of an integrated assessment.

Conclusion

While it is unlikely that scientific research can provide all the definitive answers to complex problems like acid deposition, integrated assessments, properly conducted, can help focus and interpret research to get better, more meaningful answers sooner than might otherwise be the case.

While the NAPAP program has yielded many important scientific accomplishments over the past ten years, the final integrated assessment, intended primarily to help inform public policy, unfortunately, falls far short of what might have been hoped for at the outset of the program, specifically with regard to the benefits and costs of acid rain controls. Similar sentiments have been expressed in more recent reviews of the NAPAP program.^{13,14} In this paper I have outlined some of the weaknesses in the assessment and some of the underlying reasons. Undoubtedly, some of these problems will be addressed in the final version of the assessment when it is eventually released.* But major deficiencies still will remain.

The principal lesson for future large-scale assessments (Table VII) is to start early, stick with it, and iterate often. The assessment should be driven by policy-oriented questions that serve to shape the research agenda. In the case of NAPAP, organizational arrangements and institutional barriers prevented this from happening. The result was a fragmented effort, which while impressive relative to the expectations of several years ago, inevitably produced too little, too late.

As we look ahead to the major new environmental issue of global warming, lessons from the NAPAP assessment are especially relevant. Assessments are part of a learning process that pulls people together to develop information and insights that might not otherwise be developed. In the last analysis, a lot of interesting scientific research simply does not matter in driving and shaping public policy. Thus, we need to work hard at sorting out the things that matter most from those that are less important, and at identifying critical gaps in on-going R&D activities. This is part of what integrated assessments can help to do. The process must be iterative. Over time, assessments should shape the "conventional wisdom" that eventually emerges. Doing this right requires not only good science, but sustained efforts to communicate technical results to policymakers and policy needs to scientists, because there is resistance and communication gaps in both directions. Finally, we should understand that the best scientific models alone are not necessarily the best tools for integrated assessments. There is a need for a hierarchy of models, data and judgments with different levels of complexity and complementary strengths and capabilities that can help provide a range of insights for addressing complex environmental problems.

*As of May 1991 the final assessment has not yet been released.

Table VII. Lessons for the future.

- Start early. Iterate often.
- Use assessments to direct the research agenda and identify policy-related priorities.
- Work hard at communicating results to policymakers and policy needs to scientists.
- The best scientific models aren't necessarily best for integrated assessments. Use a hierarchy of models with complementary strengths and capabilities.

References

1. "Integrated Assessment: Questions 1 and 2," External Review Draft, National Acid Precipitation Assessment Program, Washington DC, August 1990.
2. "Integrated Assessment: Question 3," External Review Draft, National Acid Precipitation Assessment Program, Washington DC, August 1990.
3. "Integrated Assessment: Questions 4 & 5," External Review Draft, National Acid Precipitation Assessment Program, Washington DC, September 1990.
4. "Annual Report, 1982," National Acid Precipitation Assessment Program, Washington DC, 1982.
5. "Annual Report, 1986," National Acid Precipitation Assessment Program, Washington DC, 1986.
6. "Annual Report, 1989," National Acid Precipitation Assessment Program, Washington DC, 1989.
7. "Analysis of Alternative Emission Reduction Strategies: Four/Eight Twelve Million Ton Reductions and Ten/Twelve State Reductions," ICF, Inc., Washington, DC, 1984.
8. Morrison, M. B.; Rubin, E. S. "A linear programming model for acid rain policy analysis," *JAPCA* 35:1137 (1985).
9. Rubin E. S.; Cushey, M. A.; Marnicio, R. J.; Bloyd, C. N.; Skea, J. F. "Controlling acid deposition: the role of FGD," *Environ. Sci. Tech.* 20:960 (1986).
10. Keeth, R. "1990 Update of FGD Economic Evaluations," in *Proceedings of 1990 SO₂ Control Symposium*, Electric Power Research Institute, Palo Alto, CA, May 1990.
11. Rubin, E. S.; Small, M. J.; Bloyd, C. N.; Henrion, M. "An integrated assessment of acid deposition effects on lake acidification," *J. Environ. Engineer.* in press.
12. Rubin, E. S. "Characterizing Uncertainty in Integrated Environmental Models," in *Proceedings of Riso International Conference on Environmental Models: Emissions and Consequences*, Elsevier Scientific, New York, 1990.
13. Roberts, L. "Learning from an acid rain program," *Science*. 251:1302 (1991).
14. *The Experience and Legacy of NAPAP*, Report of the Oversight Review Board, National Acid Precipitation Assessment Program, Washington, DC, April 1991.

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