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Volume VIII

THE BENEFITS OF PRESERVING VISIBILITY IN THE NATIONAL PARKLANDS OF THE SOUTHWEST

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Volume 6, The Value of Air Pollution Damages to Agricultural Activities in Southern California, EPA-230-12-85-024.

This volume contains three papers that address the economic implications of air pollution-induced output, input pricing, cropping, and location pattern adjustments for Southern California agriculture. The first paper estimates the economic losses to fourteen highly valued vegetable and field crops due to pollution. The second estimates earnings losses to field workers exposed to oxidants. The last uses an econometric model to measure the reduction of economic surpluses in Southern California due to oxidants.

Volume 7, Methods Development for Assessing Acid Deposition Control Benefits, EPA-230-12-85-025.

This volume suggests types of natural science research that would be most useful to the economist faced with the task of assessing the economic benefits of controlling acid precipitation. Part of the report is devoted to development of a resource allocation process framework for explaining the behavior of ecosystems that can be integrated into a benefit/cost analysis, addressing diversity and stability.

Volume 9, Evaluation of Decision Models for Environmental Management, EPA-230-12-85-027.

This volume discusses how EPA can use decision models to achieve the proper role of the government in a market economy. The report recommends three models useful for environmental management with a focus on those that allow for a consideration of all tradeoffs.

Volume 10, Executive Summary, EPA-230-12-85-028.

This volume summarizes the methodological and empirical findings of the series. The concensus of the empirical reports is the benefits of air pollution control appear to be sufficient to warrant current ambient air quality standards. The report indicates the greatest proportion of benefits fran control resides, not in health benefits, but in aesthetic improvements, maintenance of the ecosystem for recreation, and the reduction of damages to artifacts and materials.

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ABSTRACT

The nation needs to know how much visibility is worth in order to evaluate the benefits of air pollution control for the purpose of visibility protection. This study was designed to measure the economic value of preserving visibility in the National Parklands of the Southwest. During the summer of 1980, over six hundred people in Denver, Los Angeles, Albuquerque and Chicago were shown sets of photographs depicting five levels of regional visibility (haze) in Mesa Verde, Zion and Grand Canyon National Parks. Although our calculations suggest that projected emissions with existing and currently planned S02 controls would not produce a perceived decline in visibility, complete decontrol of S02 emissions by projected power plants in the region in 1990 would result in a decrease in typical summer visibility from that which was represented in the photographs as "average" visibility to that which was represented as "below average" visibility. On the basis of this, the survey participants were asked how much they would be willing to pay in higher electric utility bills to preserve the current average condition--middle picture--rather than allow visibility to deteriorate, on the average, to the next worse condition as represented in the photographs (an estimate of total preservation value). They were also asked about their willingness to pay in the form of higher monthly electric power bills to prevent a plume from being seen in a pristine area. To represent plume blight, two photographs were taken from Grand Canyon National Park, one with a visible plume. The surveying had a very high response rate (few refusals). Individual household bids ranged from an average of $3.72 per month in Denver to $9.00 per month in Chicago for preserving visibility at the Grand Canyon. These average bids were increased by $2.89 to $7.10 per month per household in the four cities if visibility preservation was to be ext.ended to the Grand Canyon Region as a whole as represented by the photographs taken from Mesa Verde and Zion. Prevention of a visible plume at the Grand Canyon was worth on the average between $2.84 and $4.32 per month for the four cities surveyed. Extrapolating these bids to the nation implies that preserving visibility in the Grand Canyon Region is worth almost 6 billion dollars per year. This is the base figure from which the benefits of power plant S02 controls, projected to be in place in the region in 1990, are determined. Adjusting this number for 1990 population levels and using a 10 percent discount rate over a thirty year power plant life gives an annualized value of 7.6 billion dollars as the benefits of power plant SO_2 control. The corresponding control costs are estimated to be approximately three billion dollars annually. Therefore, the existing and proposed control level in the Region is not without economic justification. Additionally, prevention of a visible plume at the Grand Canyon is worth almost two billion dollars to the nation. These results suggest that preservation values derived from knowledge that a unique natural wonder remains preserved may be very large for the Grand Canyon Region. Finally, the methodology used must be considered experimental since this is the first study, to our knowledge, to include an estimate of preservation value for a unique national treasure.

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We thank Phil Wondra and Dave Shaver of the National Park Service for their helpful guidance during the design of the survey methodology. We thank the Park Service for permission to use the photographs taken from the photographic monitoring program at several parks. Additionally, George Tolley and John Hoehn of the University of Chicago and Glen Blomquist of the University of Kentucky collected data in Chicago for this study and contributed greatly to the research preparation. Ralph d'Arge and Thomas Crocker also provided helpful suggestions throughout the research effort. Our thanks also go to LeAnn Lively and Ema Bixler for editing and manuscript preparation. Research Assistants at the University of Wyoming who worked on the project include Morteza Rahmatian, John Hovis, Laura Bibo, William Weirick, Colleen Kalsbeck, Lou Murdoch, Jim Murdoch, Kim Case, Cale Case, and Patricia Smith.

EXECUTIVE SUMMARY

THE BENEFITS OF PRESERVING VISIBILITY IN THE NATIONAL PARKLANDS OF THE SOUTHWEST

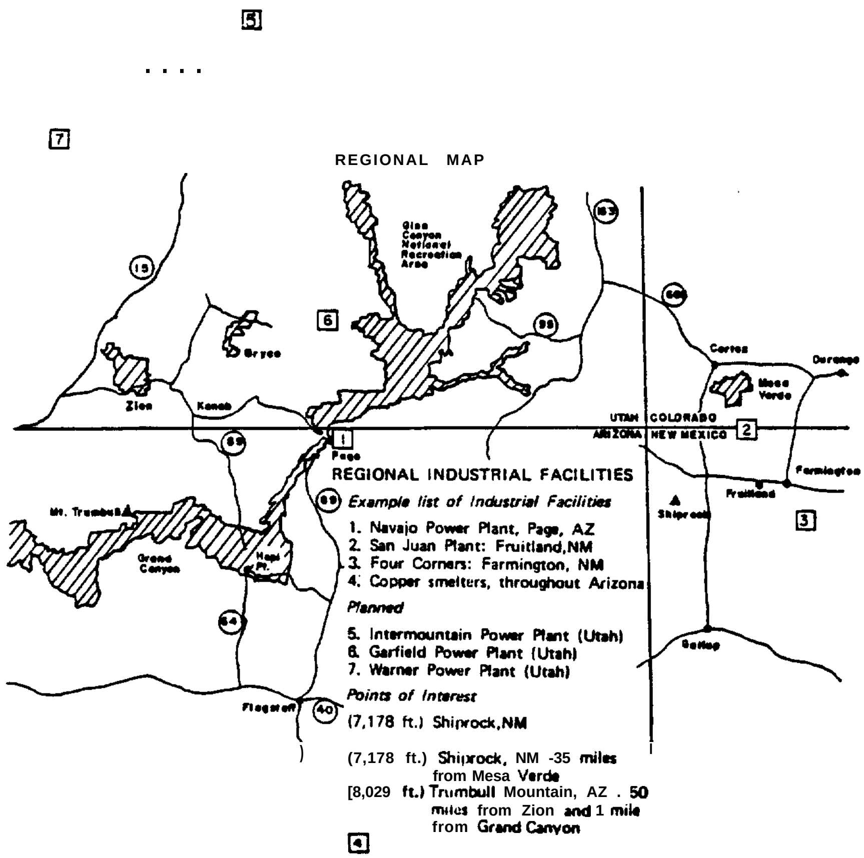
The nation needs to know how much visibility is worth in order to evaluate the benefits of air pollution control for the purpose of visibility protection. This study was designed to measure the economic value of preserving visibility in the National Parklands of the Southwest.

Historically Americans have placed a high value on good visibility, that is, the ability to see distant objects clearly. This yearning for and appreciation of atmospheric visual clarity is evidenced in the country's early literature and art, including the Journals of Lewis and Clark as well as the masterpieces of the great American landscape artists of the 19th century. Today that love of visibility is demonstrated not only by the millions who flock each year to our western parks, but also in the high prices brought by those artists' work of a century ago and by the interest in Ansel Adams' simple, yet dramatically clear black and white photographs of Yosemite and other wonders of the U.S. National Park Service.

Over the past 100 years, Congress has acted to preserve many of our nation's natural wonders. [t did so by creating and continually expanding the National Parks, National Wilderness Areas, National Monuments, National Recreation Areas, and Wild and Scenic Rivers.

Since the 1950s there seems to have been an increasing concern that this beauty is threatened by industrial development and population growth. Pollution from coal-fired power plants became a special concern with the advent in 1963 of the first unit of the Four Corners Power Plant near Farmington, New Mexico. It produced a plume that could be seen clearly for many miles, reducing the clarity of the visual experience in areas of northwestern New Mexico, southeastern Utah, southwestern Colorado and northeastern Arizona.

By the late 1960s and the early 70s, smog began to appear in Yosemite Valley on warm summer days. Battles erupted over proposed coal-fired power plants on the Kaiparowits Plateau and near Capitol Reef National Park, both in southern Utah, because of their possible effects on visibility. The increased publicity and concern resulted in magazine and newspaper articles decrying the loss of visual clarity, particularly in the western United States, and precipitated political pressures in Congress for legislative steps to protect visibility. Those pressures culminated in the August 1977 adoption by Congress of the nation's first specific visibility protection requirements for national parks and national wilderness areas as amendments to the Clean Air Act of 1970. One of the large issues raised by these developments is whether the value of visibility protection outweighs the cost, including air pollution control equipment and the regulatory requirements. The study reported on here is designed to improve our ability to measure the benefits of visibility and to provide some actual estimates of the value of that visibility in several major national parks and for the region in which they are located. The region and the parks located in it are shown on the map below. We refer to this area as the Grand Canyon Region.



Visibility is the ability to clearly see both color and detail over long distances. Human perception of visual air quality is associated with the apparent contrast of distant visual targets with respect to their surroundings. As contrast is reduced, a scene "washes out" both in color and in the ability to see distant detail.

What then is the nature of the preservation value of visibility? That value has at least two possible components.

First, a scenic resource such as the Grand Canyon attracts millions of recreators each year. The quality of the experience of these recreators depends in great part on air quality, because scenic vistas are an integral part of the Grand Canyon "experience." Thus, air quality at the Grand Canyon is valuable to recreators. We might call this economic value user value, or. the willingness to pay by users for air quality at the Grand Canyon. Thus ; recreators in the National Parklands of the Southwest should be willing to pay some amount to preserve air qual ity for each day of their own use if their recreation experience is improved by good air quality. One hypothetical market for collecting user value is an increase in entrance fees to parks to be used to finance preservation of air quality, i.e., purchase of air pollution control equipment. Survey questionnaires can be designed to estimate user value based on such a hypothetical market.

The second component of preservation value is termed existence value. Individuals and households which might never visit the Grand Canyon can still value visibility there simply because they wish to preserve a national treasure. Visitors also may wish to know that the Grand Canyon retains relatively pristine air quality even on days when they are not visiting the park. Concern over preserving the Grand Canyon may be just as intense in New York or Chicago as it is in nearby states and communities.

Thus, preservation value has two additive components, user value and existence value. However, it is difficult to construct even a hypothetical market to capture existence value alone. Rather one could imagine a lump sum fee added, for example, to electric power bills to preserve air quality in the Grand Canyon and the surrounding parklands. Such a hypothetical fee would capture total preservation value, the sum of existence plus user value, if used as the basis of a survey questionnaire. In fact, the survey conducted for this study asked approximately one-third of the respondents a pure user value question (how much would they be willing to pay in higher entrance fees per day for visibility at the Grand Canyon or other parks). The other two-thirds of the respondents were asked how much they would be willing to pay at most as a higher monthly electric power bill to preserve visibility first at the Grand Canyon and second throughout the region as represented by photographs of vistas at the Grand Canyon, Mesa Verde and-Zion National Parks (total preservation value questions). Clearly, if total preservation value is much larger than total user value, then existence value must be large.

During the summer of 1980, over six hundred people in Denver, Los Angeles, Albuquerque and Chicago were shown sets of photographs depicting both clear visibility conditions and regional haze conditions. Each set consisted of 5 photographs ranging from poor to excellent visibility. The middle picture in each case approximated average visibility during the summer (the season of peak visitation). The vistas were 3 different views from the Grand Canyon, 1 view from Mesa Verde and 1 view from Zion. The 8 by 10 inch textured prints were placed on display boards, each vista a separate row, and each row arranged with 5 photographs from left to right in ascending order of visual air quality (i.e., photograph A = “poor” visibility and photograph E = “excellent” visibility).

The relationship between the five levels of visibility shown in the photographs to regional emissions can be summarized as follows: if (1) all controls on SO_2 for existing power plants in the region were removed; (2) proposed power plants (through 1990) in the region were to emit SO_2 at the maximum uncontrolled rate; (3) existing smelter emissions were held constant; and (4) particulate emissions remain at current levels, visibility would then decline from current average conditions (middle photographs) by one step to the level presented in the photographs just to the left of center. Thus, where the photographs can be described as representing “poor,” “below average,” “average,” “above average” and “excellent” visibility, complete decontrol of

SO_2 emissions by projected power plants in the region in 1990 would result in a decrease in typical summer visibility from that which is represented in the photographs as "average" visibility to that which is represented as "below average" visibility. The calculations which form the basis of the relationship between the levels of visibility which were shown in the photographs and regional emissions are presented in Chapter 3.

The survey participants were asked either (1) how much they would be willing to pay for visibility as shown in the five sets of photographs from worst to best on the day of a visit to the Grand Canyon (an estimate of user value) or (2) how much they would be willing to pay in higher electric utility bills to preserve the current average condition--middle picture--rather than allow visibility to deteriorate, on the average, to the next worse condition as represented in the photographs of the Grand Canyon or of the region (an estimate of total preservation value). They were also asked about their willingness to pay in the form of higher monthly electric power bills to prevent a plume from being seen in a pristine area. To represent plume blight, two photographs were taken from Grand Canyon National Park. Both photographs are essentially identical except one has a plume, a narrow gray band, crossing the entire vista in the sky. The source was not industrial or municipal pollution but a controlled burn in the area around the Grand Canyon. However, the effect was comparable to what a large uncontrolled industrial source might produce.

The bidding game reveals the household's willingness to pay for preserving visibility in specific locations as represented in the photographs. For the interviewees asked the preservation value questions in the survey, the bids include both existence value and user value. Therefore, we concentrate on the preservation value section of the survey here, since user values are included in the preservation estimates.

The surveying had few refusals, partly because of the nature of the interviews. Typically, interviews were conducted in the late afternoon or early evening hours in residential neighborhoods. Due to the large size of the display boards, most interviews were conducted on the front lawn of the respondent's home. Often, both husband and wife participated jointly in answering the questions. This was viewed as appropriate since the principal question was "how much would you be willing to pay in higher monthly electric utility bills to preserve visibility at the Grand Canyon or in the entire Grand Canyon region?" Household members would often engage in extensive discussion before giving a dollar amount. Individual bids ranged from an average of $3.72 per month in Denver to $9.00 per month in Chicago for preserving visibility at the Grand Canyon. These average bids were increased from $2.89 to $7.10 per month per household in the four cities if visibility preservation was to be extended to the Grand Canyon region as a whole. Prevention of a visible plume in the Grand Canyon was worth on the average between $2.84 and $4.32 per month for the four cities surveyed.

The. validity of these survey results depends on the perception by individuals of visibility conditions as represented by photographs. A linear relationship has been shown to exist between perceived visibility as quantified by individuals in a numerical one to ten ranking of visual air quality as represented in an actual view and with the scientific measure of the apparent contrast in the vista by a multiwavelength teleradiometer. This close linear relationship between perception of an actual vista and the apparent contrast of the vista also extends to perception of visibility conditions represented by slides or 8" x 10" color photographs as is shown in the research presented in Chapter 4.

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The benefit estimates derived from the interview results can be extrapolated from the sample population to the country as a whole by applying statistical extrapolation techniques to the results of the survey. The bids offered by interviewees to preserve visibility are statistically related to income as well as other demographic characteristics. Using the estimated linear relationship of bids to population characteristics, it is possible to estimate the value of benefits to residents both for the entire Southwest region and for the entire nation. This is done by substituting the average value for these characteristics for each state into the relationship and calculating the average value of the bid of a person in that state. This value is then multiplied by the number of households in the state to get a total bid or benefit.

When the analysis is performed for the southwestern U.S. (for residents of California, Colorado, Arizona, Utah, Nevada, and New Mexico), the following values are obtained.

Yearly Benefits from:	Total ($million)
Preserving Visibility at the Grand Canyon	470
Preserving Visibility at the Grand Canyon Region	889
Preventing Plume Blight at the Grand Canyon	373

To estimate the aggregate national benefits for preserving visibility, a similar analysis is done for the entire U.S. and the following values are obtained.

Yearly Benefits from:	Total ($million)
Preserving Visibility at the Grand Canyon	3,370
Preserving Visibility in the Grand Canyon Region	5,760
Preventing Plume Blight at the Grand Canyon	2,040

The benefits of preserving visibility can be related to emissions by noting the following. Projected emissions with existing and currently planned levels of SO_2 control would not produce a perceived decline in visibility in 1990 according to our calculations as shown in Chapter 3. However, complete decontrol of projected regional power plant emissions of S02 in 1990 would decrease visibility by approximately the same amount as the decrease shown in the photographs which form the basis of the preservation value questions in the survey. Thus, the regional benefit figure forms the base from which benefits from power plant S02 controls, projected to be in place in 1990, are calculated.

Two modifications of the regional benefit figure are necessary. First, benefits in 1990 must reflect the expected population levels in that year. Second, the present value of future benefits, based on a thirty year power plant life and a 10 percent real discount rate which is consistent with the Office of Management and Budget guidelines, must be determined. These modifications yield an annualized value of 7.6 billion dollars as the benefits of power plant S02 controls.

The corresponding control costs, which include initial capital expenditures, recurring expenditures and the regulatory system cost, are estimated to be approximately three billion dollars annually. Therefore, estimated national benefits exceed control costs and the proposed level of S02 control is not without some economic justification.

Several other observations on the outcomes of the analysis of the interview results are worth mentioning.

First, in the conventional view of the demand for environmental quality, there is a smooth tradeoff between higher successive levels of environmental quality and economic benefits, with successive units commanding less incremental willingness to pay.

The survey respondents in the user portion of the study, however, placed a much higher value on a small initial diminution in visual clarity than on comparable subsequent decreases. This would produce a very unusual upward sloping demand curve for visibility.

Second, again somewhat contrary to expectations, neither past nor prospective visits to the Grand Canyon Region were shown to be important determinants of preservation value. On the average those who had never seen the Canyon valued it as highly as those who had.

Third, once more unexpected, distance from the region had no significant relationship to the size of household bids. People in Chicago bid fully as high as those closer by for preserving visibility at the Grand Canyon.

Fourth, whereas total annual preservation value of the Grand Canyon Region for the nation approaches six billion dollars, user value is on the order of tens of millions of dollars. Thus, existence value dominates the benefits of preserving visibility.

Because the Grand Canyon is the dominant feature in a region with many visitor attractions, one must be especially cautious in extending these findings to other recreational attractions. It seems likely that there are only a very few natural phenomena in the United States about which Americans have such strong feelings. Obvious candidates for this short list would be Old Faithful in Yellowstone National Park, Niagara Falls and perhaps a few others.

The main conclusion of this study is that the magnitude of the annual yearly benefits for preserving visibility when aggregated across households is impressive: nearly one billion dollars in the southwest and about six billion in the nation.

While these are necessarily rather crude extrapolations, the survey results reveal that Americans place great value on preservation of air quality in the Grand Canyon Region and that this valuation is not localized in the southwest. Again, it is worth noting that pure existence value overwhelms user value for the National Parks in the region.

The accuracy of these estimates, given the difficulty of quantifying environmental value in dollar terms, is probably on the order of plus or minus 50 percent. However, the methodology used must still be considered experimental.

The report is organized as follows: Chapter 1 presents the historical, legal and institutional background for visibility protection. Chapter 2 describes the photographs of vistas in the National Parklands used in surveying people in four metropolitan areas about the value of preserving visibility in National Parks. Chapter 3 relates the levels of air quality shown in the photographs to regional industrial emissions under three alternative scenarios. Chapter 4 reports on a study of the relationship between perception of air quality by direct observation as opposed to that presented in slides and photographs. Chapter 5 describes the economic theoretical basis for the survey design, which is presented in Chapter 6. Chapter 7 gives the survey results while Chapter 8 develops an aggregate benefit measure for preserving visibility in the National Parklands of the southwest. The overall study thus brings together work from atmospheric physics (Chapters 2 and 3), psychology and sociology (Chapter 4), and economics (Chapters 5-8) to provide an estimate of the benefits of preserving visibility in the Grand Canyon Region. Only with knowledge of (1) how emissions affect visibility, (2) how people perceive changes in visibility and (3) how people value changes in perceived visibility in dollar terms can a valid estimate of such benefits be made.

CHAPTER 1

INTRODUCTION

. . .

A. Why This Study?

The nation needs to know how much visibility is worth in order to evaluate the benefits of air pollution control for the purpose of visibility protection. This study was designed to measure the economic value of preserving visibility in the National Parklands of the Southwest.

B. The Value of Good Visibility to Society

Historically Americans have placed a high value on good visibility, that is, the ability to see distant objects clearly. This yearning and appreciation of atmospheric visual clarity is evidenced in the country's early literature and art, including the Journals of Lewis and Clark as well as the masterpieces of the great American landscape artists of the 19th Century. Today that love of visibility is demonstrated not only by the millions who flock each year to our western parks, but also in the high prices brought by those artists' work of a century ago and by the interest in Ansel Adams' simple, yet dramatically clear black and white photographs of Yosemite and other wonders of the U.S. National Park Service.

Over the past 100 years, Congress has acted to preserve many of our nation's natural wonders. It did so by creating and continually expanding the National Parks, National Wilderness Areas, National Monuments, National Recreation Areas, and Wild and Scenic Rivers.

Since the 1950s there seems to have been an increasing concern that this beauty is threatened by industrial development and population growth. Pollution from coal-fired power plants became a special concern with the advent in 1963 of the first unit of the Four Corners Power plant near Farmington, New Mexico. It produced a plume that could be seen clearly for scores of kilometers, reducing the the 'clarity of the visual experience in areas of northwestern New Mexico, southeastern Utah, southwestern Colorado and northeastern Arizona.

By the late 1960s and the early 70s, smog began to appear in Yosemite Valley on warm summer days. Battles erupted over proposed coal-fired power plants on the Kaiparowits Plateau and near Capitol Reef National Park and Zion National Park, both in southern Utah. The increased publicity and concern resulted in magazine and newspaper articles decrying the loss of visual clarity, particularly in the western United States, and precipitated political pressures in Congress for legislative steps to protect visibility. Those pressures culminated in the August 1977 adoption by Congress of the nation's first specific visibility protection requirements for national parks and national wilderness areas as amendments to the Clean Air Act of 1970.

c. History of Federal Visibility Protection

The 1977 Clean Air Act Amendments

The increasing public concern about and Congressional interest in protecting visibility resulted in specific visibility provisions-being included in the Clean Air Act Amendment of 1977 (P.L.95-95; August 7, 1977). The House Commerce Committee in its report accompanying the amendments to the Clean Air Act, summarized the Congressional intent as follows:

> There are certain national lands, including national parks, national monuments, national recreation areas, national primitive areas, and national wilderness areas, in which protection of clean air quality is obviously a critical national concern. In fact the 1916 National Parks Organic Act states the purpose of such lands "is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations" (16 U.S.C.I). Similarly, the 1964 Wilderness Act provides that wilderness areas:
>
> Shall be administered in such manner as will leave them unimpaired for future use and enjoyment as wilderness, and so as to provide for the protection of these areas (and) the preservation of their wilderness character. (16 U.S.C. 1131 (c))
>
> In the Committee's view, these unique national lands should not be despoiled or heavily shrouded in dense industrial pollution. Indeed, the millions of Americans who travel thousands of miles each year to visit Yosemite or the Grand Canyon or the North Cascades will find little enjoyment if, for example, upon reaching the Grand Canyon it is difficult if not impossible to see across the great chasm. if that were to come to pass - and several of our great national parks, including the Grand Canyon, are threatened today by such a fate - the very values which these unique areas were established to protect would be irreparably diminished, perhaps destroyed. Former Secretary of Interior Rogers Morton recognized the value of these lands and their threatened loss when in June 1973 speaking of the national park lands in the southwest, he stated:
>
> > The scenic beauty of the rugged Southwest landscape, coupled with the clarity of the air in the vicinity, are national assets of major importance, worthy of protection for the enjoyment of future generations of Americans.
>
> Unless a policy of prevention of significant deterioration of air quality provides special protection for these national lands belonging to all Americans, their beauty may be lost forever.

1980 Visibility Regulations

On December 2, 1980, the Environmental Protection Agency promulgated regulations[1] to implement the Clean Air Act's visibility protection provisions. Key provisions of these regulations include:

a) Phased Approach - The regulations recognize two distinct types of air pollution which impair visibility:

1) smoke, dust, colored gas plumes or layered haze emitted from stacks which obscure the sky or horizon and are reasonably attributable to a single source or a small group of sources, called "plume blight"; and

2) widespread regionally homogeneous haze from a multitude of sources which impairs visibility in every direction over a large area, called "regional haze."

Because of ". . . certain scientific and technical limitations . . ." EPA promulgated a phased approach to visibility protection regulations.[2] Phase I of the program requires control of impairment that can be traced to a single existing stationary facility or small group of stationary facilities.[3]

b) BART Analysis/Re-analysis and implementation - The States must perform a "Best Available Retrofit Technology" (BART) analysis on any applicable existing source to which the State can reasonably attribute (through visual observation or other monitoring technique) visibility impairment in any applicable Class I area or integral vista. In the Bart Analysis, the States determine what additional controls, if any, are needed on the sources of existing impairment in order to remedy or reduce the visibility impairment.

In this analysis, the States should consider the cost of control, energy and environmental impacts of control, air pollution controls already in place at the source, the remaining useful life of the source, and to what degree the control alternatives would improve visibility.

c) New Source Review - The regulation also requires the melding of the visibility protection requirements of Section 165(d) with those of Section 169A, for purposes of preventing new impairment resulting from proposed major emitting facilities.

Section 165(d) applies to air pollution impacts within a Class I area and does not provide for the balancing of economic, energy and other non-air factors with air quality factors. Under Section 169A, the States may weigh other factors, such as economics, with protection of integral vistas.

d) Long-Term'-'Strategy - The regulations require each applicable State to develop and include in its State Implementation Plan (SIP) a long-term (10 to 15 year) strategy for making reasonable progress toward remedying existing and preventing future visibility impairment.

In judging reasonable progress, the States may weigh economics, energy, and other non-air qual ity factors against improvements in air quality.

D. Issues

The overall issue is the value of visibility protection compared to the cost, including air pollution control equipment and the regulatory system. Part of the value of visibility is economic, expressed in many ways such as the extra price people pay for homes with good vistas and the price people pay to travel long distances to see vistas with high visual air quality. A related issue is what people see when they look at a vista. What instrument measurement and visibility-related variables describe visibility in a way consistent with human perception? How should vistas be presented to people in order to question them about the economic value of visibility? These issues are the subjects of on-going research. This study is based on the most up-to-date understanding of these issues, much of which was developed by our research efforts.

E. Organization of the Report

Chapter 2 describes the photographs of vistas in the National Parklands used in surveying people in four metropolitan areas about the value of preserving visibility in National Parks. Chapter 3 relates the levels of air quality shown in the photographs to regional industrial emissions under three alternative scenarios. Chapter 4 reports on a study of the relationship between perception of air quality by direct observation as opposed to that presented in slides and photographs. Chapter 5 describes the economic basis for the survey design, which is presented in Chapter 6. Chapter 7 gives the survey results while Chapter 8 develops an aggregate benefit measure for preserving visibility in the National Parklands of the Southwest. The overall study thus brings together work from atmospheric physics (Chapters 2 and 3), psychology and sociology (Chapter 4), and economics (Chapters 5-8) to provide an estimate of the benefits of preserving visibility in the Grand Canyon Region. Only with knowledge of (1) how emissions effect visibility, (2) how people perceive changes in visibility and (3) how people value changes in perceived visibility in dollar terms can a valid estimate of such benefits be made.

REFERENCES

1. 45 FR 8008 4 December 2, 1980.

2. Impairment - Visibility impairment is defined as "any humanly perceptible change in visibility (visual range, contrast, coloration) from that which would have existed under natural conditions."

3. EPA has determined ". . . that the present mathematical models and monitoring techniques show promise for being used in regulatory manner. However, these techniques must be further evaluated . . . ." Teleradiometry and photography are two visibility monitoring approaches that have been widely used over the past three years.

CHAPTER 2

REPRESENTING VISIBILITY WITH PHOTOGRAPHS

. . .

A. Photographs Used In The Survey

During the summer of 1980, over 600 people in Denver, Los Angeles, Albuquerque and Chicago were shown 5 sets of photographs depicting regional haze, each set consisting of 5 photographs of a national park vista with different visual air quality. The vistas are from Grand Canyon, Mesa Verde and Zion National Parks. The observation sites, vista names and specifications are given in Table 1. Summer visibility conditions were chosen for the survey because it is the season of peak park visitation.

These photographs were placed on display boards as full frame 8 by 10 inch textured prints, arranged from left to right in ascending order of visual air quality with each vista a separate row (see Figure 1 representing visibility at the Grand Canyon and F gure 2 representing visibility conditions throughout the Grand Canyon Region). The participants were asked how much they would be willing to pay for visibi ity as shown in the five sets of photographs.

Participants in the survey were also asked about their willingness to pay to prevent a plume from being seen in a Class I area. Two photographs were used, one with and the other without a plume. The photographs were taken from Grand Canyon National Park at the Hopi firetower observation point and towards Mt. Trumbull (west). These two photographs, shown in Figure 3, were both taken at 9 a.m. so the lighting on the canyon wall and other features are the same. Both photographs have the same light high cirrus cloud layer. The plume is a narrow gray band crossing the entire vista in the sky, except where it is in front of the top of Mt. Trumbull. We believe the source was a controlled burn near the Grand Canyon. The photograph specifications are in Table 2.

B. Data Base

The photographs were taken with a 35mm lens on single lens reflex automatic exposure came-ras at Grand Canyon, Mesa Verde and Zion National Parks during the periods shown in Table 1. These cameras are operated as part of the photographic program in the EPA/NPS regional visibility monitoring network. The network also provides teleradiometer measurements of the apparent green contrast of targets viewed from these parks, from which standard visual range, attenuation coefficient and other visibility-related variables are computed. The apparent green contrast is measured on each slide with a manual multiwavelength teleradiometer. To do so, the slide is projected on a screen and the apparent green radiance N_r is measured on the target used in the network and the adjacent sky. The apparent contrast C_r is computed with equation (2) from

Table 1

Vistas for Survey

Park	Observation Site	Vista	Direction (°true)	Time of Day (Local)	Target Distance (km)	Period Photographed
Grand Canyon	Hopi Point	Desert View	96	9AM	30	Oct. 79 to present
Grand Canyon	Hopi Point	Trumbull Mt.	293	9AM	96	Oct. 79 to present
Grand Canyon	Hopi Point	Trumbull Mt.	293	3PM	96	Oct. 79 to present
Mesa Verde	Far View Visitor Center	Shiprock and Lukachukai Mts.	208	9AM	68 to Shiprock 130 to Lukachukai Mts., Target Number 1	Oct. 79 to present
Zion	Lava Point	Trumbull Mt.	190	10AM	105	July-November 1979

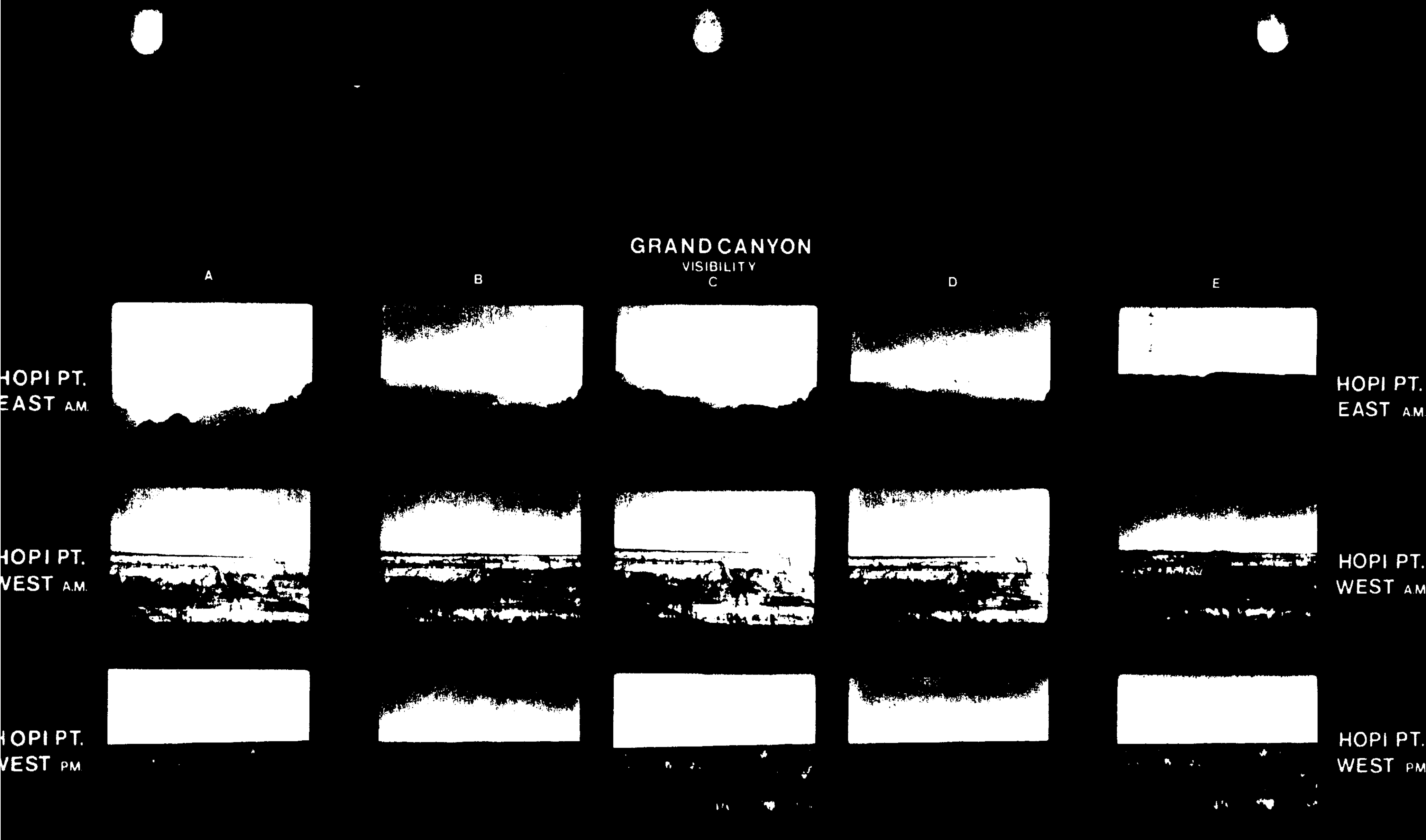

Figure 1
Grand Canyon Photograph Board

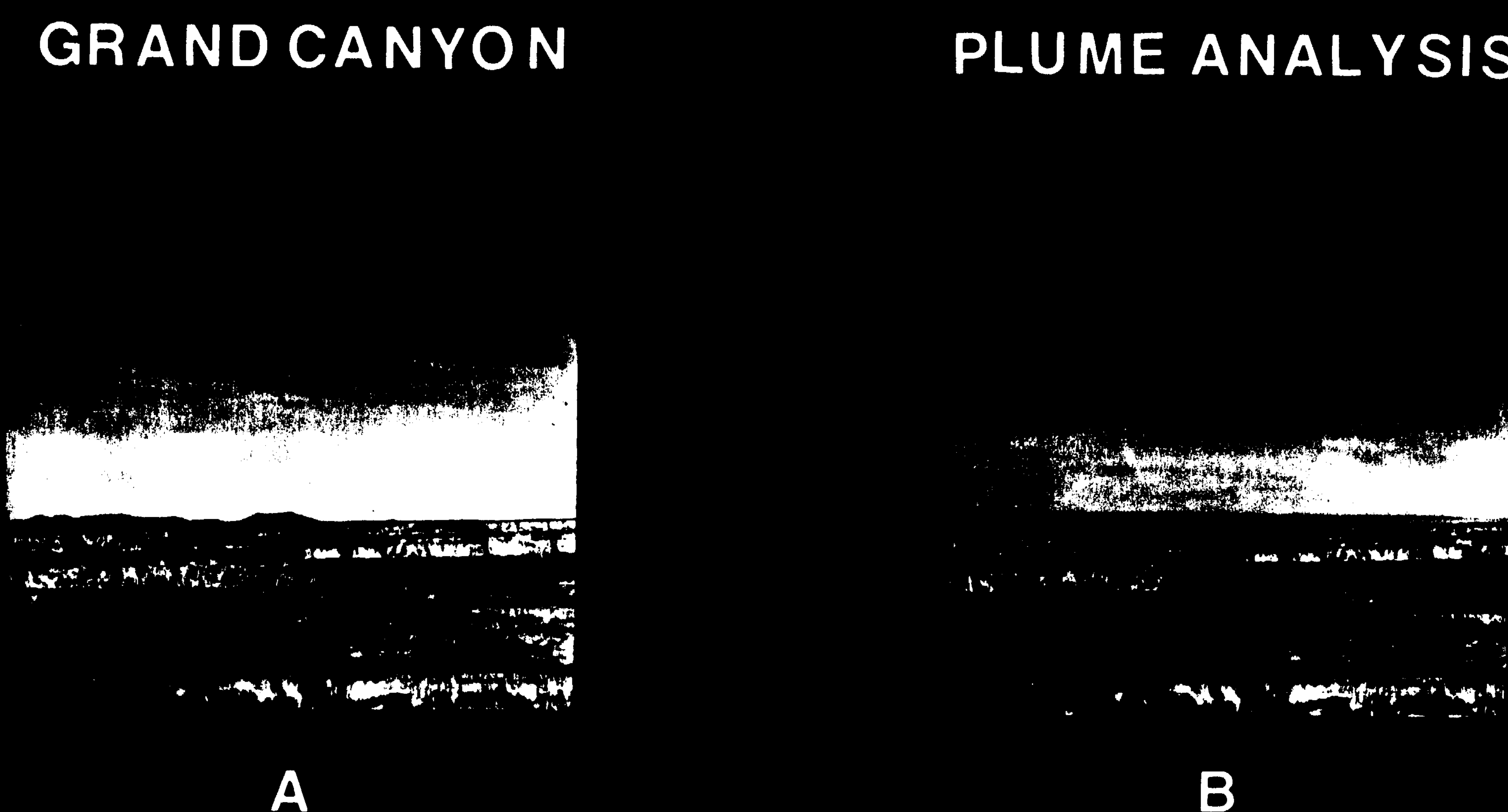

Figure 3
Grand Canyon Plume Board

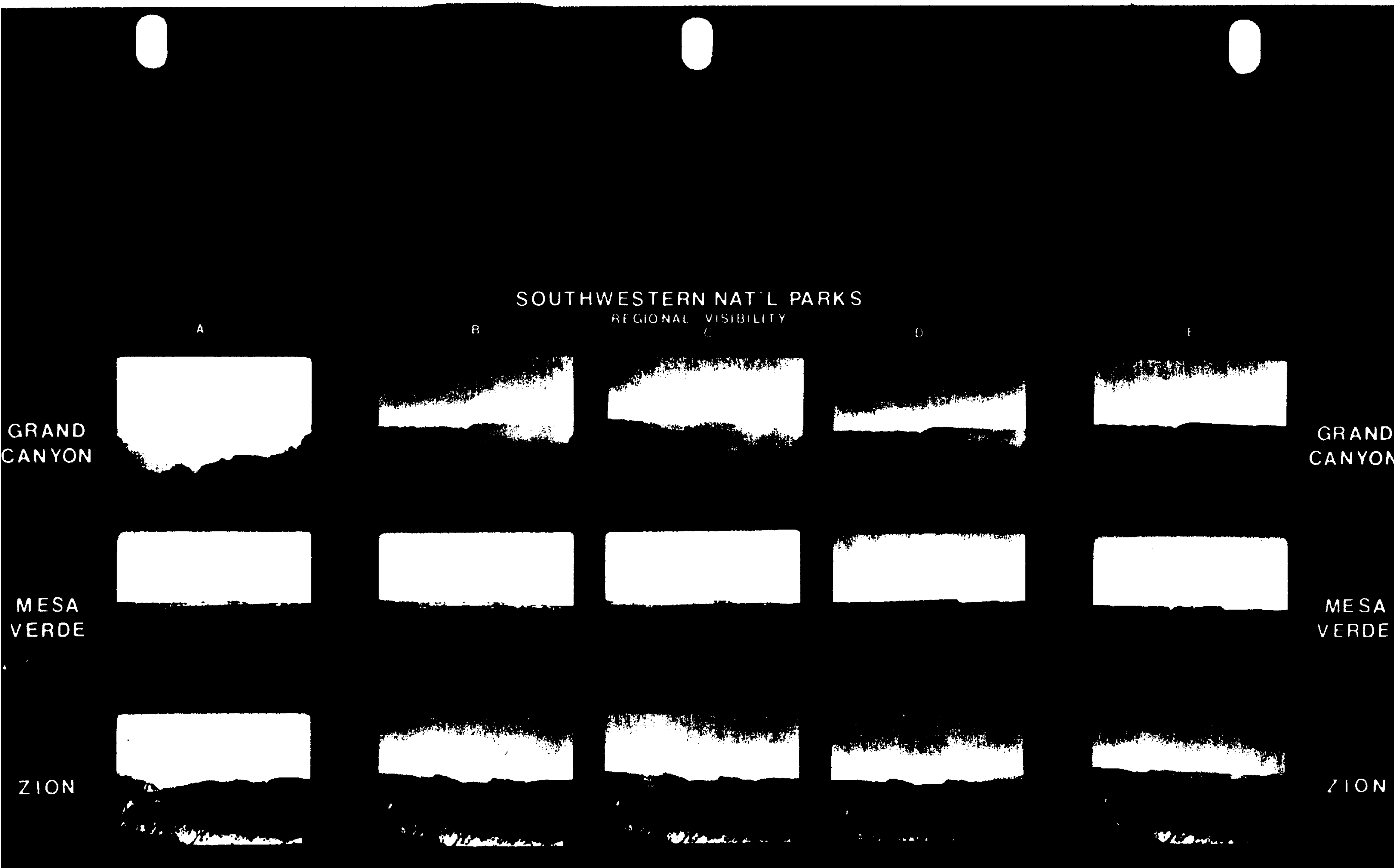

Figure 2
Regional Photograph Board

Table 2

Photographs for Plume Question

Photograph	Archive #	Date	Time (MST)	Cloud
without plume	GC 395	27 Nov. 1979	8:5o a.m.	Cirrus
with plume	GC 405	28 Nov. 1979	9:20 a.m.	Cirrus

Table 3

Target Specifications and Slides for Summer 1980 Survey

Target	Observation Site	Time of Day (local time)	C_o	α_R (km^{-1})	r (km)	Photograph Archive Number	C_r	F(%)[a]	X_{fp} ($\frac{\mu g}{m^3}$)
Trumbull	Hopi Fire Tower, Grand Canyon	9AM	-.735	.00927	96	GC 84	-oh	8	4.21
						GC 92[b]	-.10	35	2.30
						Median	-.12	50	1.92
						GC 171	-.20	92	0.86
						GC 268	-.26	99	0.31
						GC 204	-.30	99.9	0.01
Trumbull	Hopi Fire Tower Grand Canyon	3PM	-.8	.00927	96	GC 519	-.08	9	2.94
						GC 102	-.14	30	1.78
						Median	-.17	50	1.37
						GC s36	-.18	55	1.25
						GC 313	-.24	85	0,6s
						GC 54s	-.30	97	0.19
Desert View	Hopi Fire Tower Grand Canyon	9AM	-.88	009349	30	GC 9	-.26	4	6.26
						GC 501	-.37	23	3.91
						GC 94	-.43	44	2.90
						Median	-.45	50	2.6o
						GC 311	-.59	90	0.80
						GC 406	-.71	99.1	0
.ukachuka I I (hiprock View)	Far View Visitor Center, Mesa Verde	9AM	-.7	.009076	106	MV 54	-.02	3	4.89
						MV 48	-.04	8	3.59
						MV 133	-.08	32	2.28
						Median	-.10	50	1.86
						MV 234	-.14	89	1.22
						MV 21	-.24	99.99	0.20
Trumbull	Lava Point , Zion	10AM	-.82	.009181	105	2 2	-.02		5.24
						z 16	-.07		2.85
						Median	-.12	50	1.82
						2 190	-.15		1.40
						2 119	-.18		1.05
						2 146	-.24		0.50

[a]Cumulative frequency (less than or equal) of occurrence of specified target apparent green contrast

[b]Median of measurements taken during Summer 1979.

Appendix A which gives a summary of the theory of visibility applicable to this study.

It is important to know the frequency of occurrence of the photographed visual air quality at each of the vistas. The cumulative frequency of the apparent contrast of the official network target in each photograph is computed from teleradiometer measurements taken during summer 1979 (see Table 3). The 5 photographs for each vista were chosen to have perceptible differences (Maim, et al. 1980a), between adjacent pairs, and the middle photograph is nearest the median visibility observed during summer 1979. Only the Mt. Trumbull morning series is slightly skewed, with the observed median being closer to the second photograph.

CHAPTER 3

REGIONAL EMISSIONS AND VISIBILITY

A. Introduction

The principal objective of this study is to measure the benefits of preserving visibility. However, benefit measures associated with ambient air quality must be related to emissions by industrial sources so that a comparison of benefits to control costs can be made. This chapter, along with Appendix A, provides the basis for relating benefits to industrial emissions.

B. Relating Visibility to Emissions

The apparent target contrast, C_r, distance between the target and observer, r, and inherent green contrast, C_o, of the target allow us to compute the mean attenuation coefficient, α, of the sight path, using equation (11) from Appendix A.

$$\alpha = \frac{1}{r} \ln \frac{C_o}{C_r} \qquad (1)$$

The mean attenuation coefficient comprises three parts, contributed by fine particulate, NO_2 and the normal gaseous constituents of air, so that

$$\alpha = \alpha_{fp} + \alpha_{NO_2} + \alpha_R \qquad (2)$$

where α_{fp} = fine particulate attenuation coefficient (km-'),
α_{NO_2} = NO_2 attenuation coefficient (km^{-1}) and
$\bar{\alpha}_R$ = sight path weighted Rayleigh attenuation coefficient (km-').

Only the fine particulate is shown here, rather than total particulate, because the fine particulate dominates the coarse particulate contribution to visibility (Macias, et al., 1979), except possibly in dust storms.

In order to evaluate the relative magnitude of α_{NO_2}, information is needed on its concentration in clean air and the attenuation per unit path length and per unit concentration. The attenuation coefficient for a gas that absorbs light much more than one that scatters light is given by:

$$\alpha \simeq A = aC$$

where A = absorption coefficient (km^{-1}), a = absorptivity (km'mole $liter^{-1}$) and C = concentration (liter mole-'). Background concentrations of NO_2 in the Southwest are about 6 parts per billion (Walther, et a]., 1978) and the absorptivity (Hall and Blacet, 1952) at 550 nm is 31.1 mole^{-1} cm^{-1}, hence the NO_2 absorption coefficient is $8.3 \cdot 10^{-4}$ km^{-1}. In comparison, a typical Rayleigh attenuation coefficient is about 10^{-2} km^{-1}, over one magnitude larger. The fine particulate attenuation coefficient is usually at least as large as the Rayleigh attenuation coefficient (Maim, et al., 1980c), and hence also *over* one magnitude larger than the NO_2 attenuation coefficient. Therefore, we assume the nitrogen dioxide concentration is low enough, so that

$$\alpha \simeq \alpha_{fp} + \alpha_R. \tag{3}$$

Combining (1) and (2), we get

$$\alpha_{fp} + \alpha_R = \frac{1}{r} \ln \frac{C_o}{C_r}$$

or

$$\alpha_{fp} = \frac{1}{r} \ln \frac{C_o}{C_r} - \bar{\alpha}_R. \tag{4}$$

We know $\bar{\alpha}_R$ for the sight path because we know the elevation of the observation sites and each target.

A constant of proportionality, k, between fine particulate attenuation coefficient and concentration, was derived by others (Macias and Husar, 1976):

$$\alpha_{fp} = k\chi_{fp} \tag{5}$$

where $k = 5 \cdot 10^{-3} \text{km}^{-1} (\mu g m^{-3})^{-1}$ and

χ_{fp} = fine particulate concentration ($\mu g m^{-3}$).

In the EPA/NPS regional visibility network, standard visual range (SVR) is computed with the relation

$$SVR = \frac{3.912}{\bar{\alpha} - \bar{\alpha}_R + .01} \tag{6}$$

Combining (3) and (6),

$$SVR = \frac{3.912}{\alpha_{fp} + .01} \tag{7}$$

and combining (5) and (7), we get the equation for k as a function of SVR and χ_{fp}:

$$k = \frac{1}{\chi_{fp}} \left(\frac{3.912}{SVR} - .01 \right) \tag{8}$$