PROTECTING VISIBILITY

AN EPA REPORT TO CONGRESS

EXECUTIVE SUMMARY AND CHAPTER 1

Executive Summary

INTRODUCTION

This report is prepared in response to the requirements of Section 169A(a) of the Clean Air Act. In this section, which was added to the Act in August 1977, Congress established as a national goal "the prevention of any future and the remedying of any existing impairment of visibility in mandatory class I Federal areas*, which impairment results from man-made air pollution." The Act requires a study and report to Congress on methods for meeting the visibility goal, including methods for determining visibility impairment, modeling and other methods for evaluating source impacts, methods for preventing and remedying pollution-derived visibility impairment, and a discussion of pollutants and sources that may impair visibility. In addition to this report, the Act requires the following activities:

1. The Department of the Interior, in consultation with other Federal Land Managers, must compile, and the Environmental Protection Agency (EPA) must promulgate, a list of mandatory class I Federal areas in which visibility is an important value. The list, which includes 156 of the 158 class I areas, was promulgated in November 1979, and is included as Appendix A to this report.

2. EPA must promulgate regulations that (a) provide guidelines to the States on appropriate techniques for implementing the national visibility goal through State Implementation Plans (SIPs) and (b) require affected States to incorporate into their SIPs measures needed to make reasonable progress toward meeting the national visibility goal. The regulations and guidelines must require that certain major stationary sources, likely to impair visibility, install best available retrofit technology (BART). The regulations must also require that the SIPs include a long-term (10-15 year) strategy for making reasonable progress toward the visibility goal. The long-term strategy may require control of sources not otherwise addressed by the BART provision. The Act states that costs, energy and non-air environmental impact, and other factors must be considered in determining BART and reasonable progress.

The language of the national visibility goal and the legislative history of the Act indicate that the national goal of Section 169A mandates, where necessary, control of both existing and new sources of air pollution. It is apparent, however, that adverse visibility impacts from proposed major new or modified sources are to be dealt with through the procedure for prevention of significant deterioration (PSD) mandated in Section 165(d) of the Clean Air Act.

In addition to the activities required of EPA and the States, the Clean Air Act requires that the Federal Land Managers (the Department of Interior and Department of Agriculture, through the National Park Service, the Fish and Wildlife Service, and the Forest Service) play an important role in visibility protection. Land Manager responsibilities include reviewing the adequacy of the state visibility protection strategies and determining whether proposed major air pollution sources have an adverse impact on visibility in Class I areas.

In establishing the national visibility goal, Congress called for explicit recognition of the value of visibility in special class I areas. By requiring consideration of “significant” impairment in BART decisions, “adverse” effects of proposed new sources, and “reasonable progress” in implementing the national goal, Congress has, in effect, mandated that judgements be made on the value of visibility in the context of specific decisions on control and location requirements for sources of visibility impairing air pollution. Preliminary economic studies of the value of visibility and research in recreational psychology and human perception support the notion that visibility is an important value in class I areas and suggest that several approaches are available for estimating the value of an incremental improvement or deterioration in visibility. Such work, however, will require a number of years. Currently, the regulatory process mandated under the Clean Air Act, involving the Federal Land Managers, the States, EPA, and the public, represents the best means for considering visibility benefits in the context of associated costs.

DEFINITION OF VISIBILITY IMPAIRMENT

Although Congressional guidance on the definition of visibility impairment is significant, a number of important areas are left open for additional specification, interpretation, and judgement. Section 169A indicates that visibility impairment includes reduction in visual range and atmospheric discoloration. Visual range, long used as an index of visibility in airport observations, is generally defined as the farthest distance from which one can see a large black object against the horizon sky. Atmospheric discoloration can qualitatively be defined as a pollution-caused change in the color of the sky, distant mountains, clouds, or other objects. Conceptually, virtually any type of visibility impairment could ultimately be expressed as a reduction in visual range or atmospheric discoloration. However, because these effects are often the results of the same pollution impact, it is useful to categorize anthropogenic* visibility impairment into three general types: (1) widespread regionally homogeneous haze that reduces visibility in every direction from an observer, (2) smoke, dust, or colored gas plumes that obscure the sky or horizon relatively near sources (this class is also termed “plume blight”), and (3) bands or layers of discoloration or veiled haze appearing above the surrounding terrain. Examples of these types of impairment are illustrated and discussed in Section 1.5.

The location, degree, and the spatial and temporal extent of visibility impairment must be addressed in the visibility protection programs. In areas such as the Southwest, anthropogenic air pollution occurring outside class I area boundaries can obscure long distance vistas normally visible from within the class I area. Anthropogenic impairment may be frequent, last for long time periods, and be readily apparent to all observers. Conversely, anthropogenic visibility impacts may be so infrequent, short in duration, or small in degree that it is difficult for the unaided observer to distinguish them from existing impairment caused by natural sources. For the purpose of this report, EPA adopts the following position on visibility impairment:

1. Certain vistas extending outside class I area boundaries are important to visitor experience and are part of the visibility value of the area. Such views should be included in the national goal.
2. Anthropogenic visibility impairment in the context of the national visibility goal is defined as any perceptible** change in visibility (visual range, contrast, atmospheric color, or other conveniently measured visibility index) from that which would have existed under natural conditions.

Therefore, in the context of specific control decisions, an increment (or decrement) in visibility impairment must as a minimum be perceptible to be significant or adverse. Further judgements with respect to the significance and adversity of perceptible impairment must be made, at least in part, on a case-by-case basis and must address the degree and spatial and temporal extent of the incremental change. For this reason, and because such judgements must involve States, Federal Land Managers, and the public, it is not possible at this time to specify comprehensive criteria for defining significant or adverse impairment.

CURRENT STATUS OF VISIBILITY IN CLASS I AREA

Some insight into general visibility condition in class I areas can be obtained by examining the regional airport visibility (visual range) data depicted in Figure 1. Although some limitations in airport observations exist, the information is indicative of regional trends. The best visibility occurs in the mountainous Southwest, where annual median visibility exceeds 70 miles (110 km). East of the Mississippi and south of the Great Lakes annual median visibilities are less than 15 miles (24 km), and significantly lower in the summertime. Figure 1 does not address plume blight or discoloration. Ironically, these latter problems can be more severe in “clean” regions. For example, in the Southwest, the region of highest visual range, visible plumes can be seen from great distances.

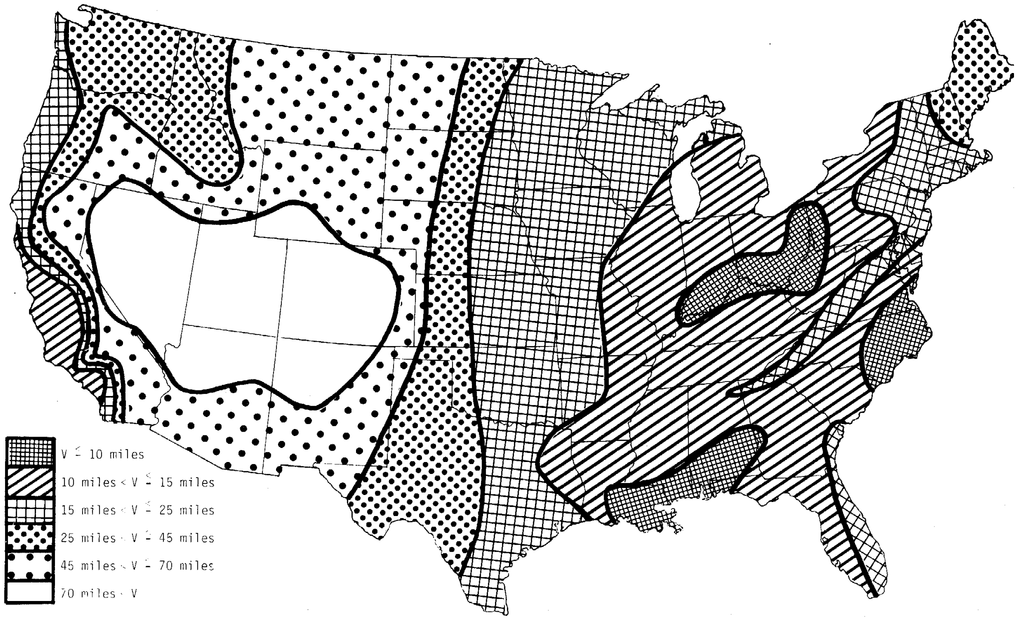


Figure 1. Visual range (V) isopleths for suburban non-urban areas, 1974-76 (Trijonis and Shapland, 1978).

A preliminary analysis of visibility in class I areas has been provided by the Federal Land Managers. The analysis represents observations by individual managers of visual impairment and their subjective judgements on the desirability or acceptability of existing conditions. Because the level of experience, perception, and criteria for judgement vary significantly among these individuals, the results are preliminary and must be confirmed by more detailed analysis. The results are summarized in Figure 2. Class I areas are grouped into regions of similar status. In regions where a number of areas were reported as having undesirable visibility conditions, the major categories reported by the Land Managers are listed.

Approximately one-third of the class I area managers reported undesirable visibility conditions and/or the need to evaluate suspected man-made impacts. The remaining two-thirds of the areas were reported as having desirable or acceptable conditions at all or more of their vistas. On the other hand, it appears that few if any of the class I areas are free from at least some potentially observable anthropogenic visibility influence. Over 90 percent of the class I area managers reported that one of more views from within the area looking outside the area may be, to some degree, important. Nearly all of the managers indicated the need to prevent existing visibility conditions from deteriorating as a result of new source impacts.

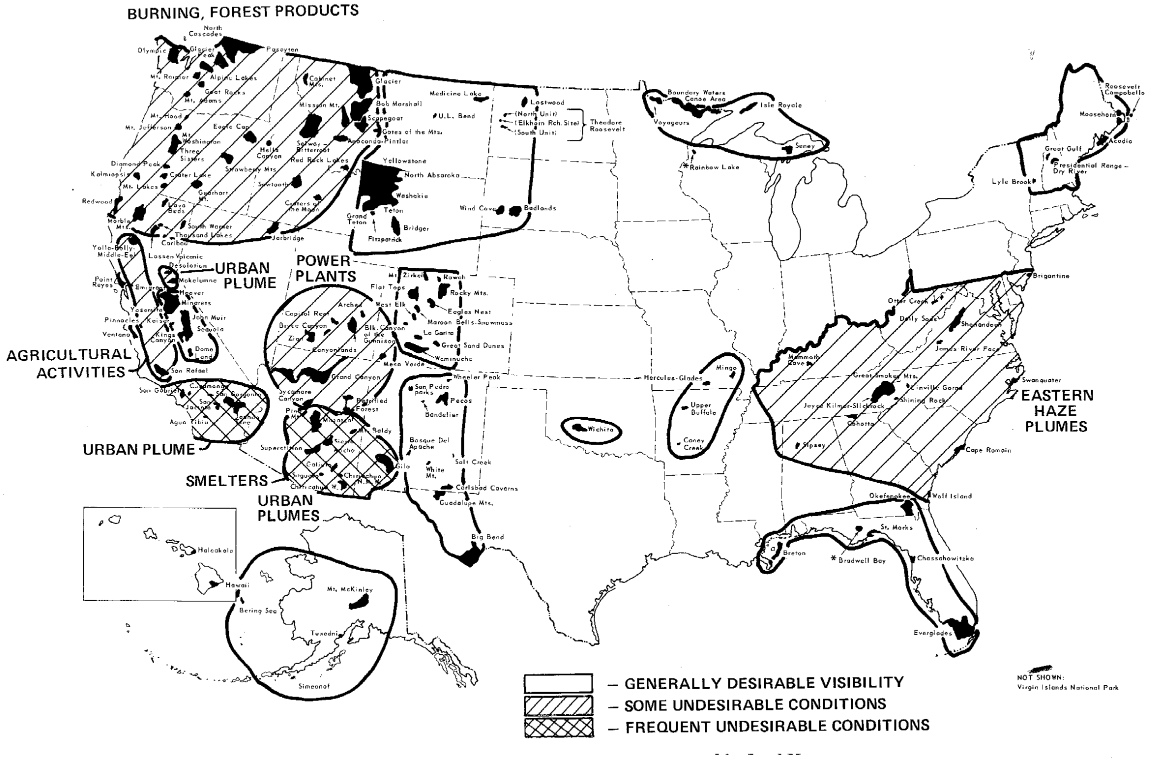


Figure 2. Preliminary class I area visibility status reposted by Land Managers.

VISION IN THE ATMOSPHERE

The ability to define, monitor, model, and control anthropogenic visibility impairment is dependent on available scientific and technical understanding of the factors that affect atmospheric visibility. Because visibility involves the human perception of the physical environment, evaluation of the effects of air pollution on visibility must include:

1. Specification of the process of human visual perception and

2. Quantification of the impacts of air pollution on the optical characteristics of the atmosphere.

Chapter 2 summarizes pertinent information on these areas.

From a scientific and technical point of view, deterioration of visual air quality is probably the best-understood and most easily measured effect of air pollution. However, many important uncertainties and limitations exist in available knowledge. Significant implications of current understanding of vision in the atmosphere may be summarizes as follows:

1. Visibility impairment is caused by the scattering and absorption of light by suspended particles and gases. Fine solid or liquid particles (atmospheric aerosols) and to a

lesser extent nitrogen dioxide are the most important anthropogenic causes of degraded visual air quality. Air molecules, weather variables, and natural emissions also affect visibility.

2. Light scattering and light absorbing pollutants reduce the amount of light received from viewed objects and scatter ambient or “air” light into the line of sight. This scattered air light is perceived as haze. Because these effects vary with the wavelength of light, discoloration can result.
3. These effects can be quantified or approximated through use of theoretical mathematical treatments and experimentally derived pollutant/optics relationships.
4. The perceptibility of pollution effect on light depends on human eye-brain responses. Studies of the eye-brain response to contrast indicate that typical observers can detect a 0.02 (2%) or greater contrast between large dark objects and the horizon sky. Preliminary studies suggest that observers may be able to detect a 0.02 to 0.05 change in apparent contrast caused by incremental pollution. Roughly, this indicates that a reduction in visual range of as little as 5 percent may be perceptible. Additional work is needed on human perception of pollution increments.
5. The perception of color in the atmosphere is less well understood than is contrast. For this reason, theoretical calculations of atmospheric discoloration are useful only as crude indices and guides for experimental measurements. Studies of atmospheric color perception conducted over the next few years should provide an adequate means of predicting atmospheric discoloration, even if a comprehensive theoretical treatment remains unavailable.
6. In many Southwestern class I areas, visibility on some days can approach the theoretical limit imposed by air molecules (blue sky) scattering (200 miles visual range). Visibility in such areas is extremely sensitive to in creased emissions. The addition of 1 microgram per cubic meter of fine particles, spread throughout the viewing path, to such a clean atmosphere could reduce visual range by about 30 percent. Addition of the same amount to a dirtier background (20-mile visual range) would produce only a 3-percent reduction in visual range.
7. Since viewing distances in most class I areas do not exceed 50-100 kilometers (60 miles), a reduction in calculated visual range from, for example, 200 km (120 miles) to 150 km (90 miles) would be noticed principally because of the reduction in contrast and discoloration of nearby objects and sky (haze). Increased haze causes objects to appear "flattened," the horizon sky is whitened, and *the aesthetic value of the vista can be degraded even though the viewing distances are small relative to the visual range.*
8. When particles and light absorbing gases are confined to an elevated haze layer or a coherent plume, the main visual impact will be a discoloration of the sky or a white, gray, or brown plume. The perceived impact depends on a number of factors such as sun angle and condition of background sky. Contrast and brightness effects of elevated haze and plumes can be approximated by available techniques. Additional work is needed to predict the perceived color impacts.

MONITORING

Visibility monitoring is necessary for establishing base line visibility to be used in evaluating impacts of proposed sources or controls, assessing the relative impacts of man-made air pollution and natural sources, identifying specific sources contributing to visibility impairment, and monitoring the effectiveness of visibility protection programs. Meeting these objectives requires measurement of optical parameters, meteorological variables, pollutant characteristics, and scenic characteristics.

The most important optical parameters to be measured include the apparent contrast of distant objects and the extinction coefficient, a parameter related to the light scattering and absorption characteristics of the atmosphere. The basic optical methods include:

Human Observation — measures perceived air quality, visual range (if targets available)

Photography — documents perceived visual air quality

Multiwavelength Telephotometer — measures apparent contrast between target and horizon or other objects, is useful over long path, up to 50 to 100 kilometers

Transmissometer — measures transmission and extinction of light over a fixed path, 10 to 20 kilometers

Nephelometer — measures light scattering by particles at a single point, estimates Extinction coefficient

Each of these measurement approaches has inherent strengths and limitations, which are summarized in Chapter 3. EPA recommends that comprehensive visibility monitoring programs in class I areas include:

1. Baseline monitoring conducted for a year (preferably a meteorologically typical year) or more;

2. Visibility monitoring including color photography, human observation, integrating nephelometer, and a multi-wavelength telephotometer; and

3. Evaluation of anthropogenic and natural source/receptor relationships including a two-stage size-segregating particulate sampler or other device compatible with fine particulate mass and compositional analysis, meteorological measurements, and when necessary, a nitrogen dioxide monitor.

Such comprehensive monitoring is not needed in all class I areas. The results of intensive monitoring in characteristic regions of the country and instrument development over the next few years may indicate some smaller set of measurements, which will be sufficient. Programs with limited resources should rely on structured human observations, photographic documentation, and, where possible, suitable meteorological measurements. Other instruments should be chosen with due consideration of their limitations.

EMPIRICAL METHODS FOR ASSESSING POLLUTION-DERIVED IMPAIRMENT

Relating visibility impairment to its emission sources is a central problem for making progress towards the national visibility goal. Some important general understandings include:

1. Light scattering and particle related light absorption are caused principally by fine aerosols (those smaller than 2.5 micrometers). Understanding the sources of general haze in most areas thus reduced to identification of sources of fine particle mass.

2. High relative humidity significantly increases light scattering of certain water-soluble aerosols.

3. Much of the fine particle mass is of *secondary* origin; that is, most fine particles are formed in the atmosphere from their "precursor" gases, sulfur oxides, nitrogen oxides, and organics. Hence, the emission rate of secondary particles cannot be measured at he source. Furthermore, the gas-to-particle conversion process depends on factors such as solar radiation, the presence of other pollutants, and humidity. Thus, the amount of secondary material formed from a given rate of precursor gases is not constant but depends on the environment.

4. The residence time of fine particles in the atmosphere is through to be about a week or more, and their transport distance can exceed 500 kilometers.

5. The long-range transport of the fine particle/precursor chemical complex results in the superposition and chemical interaction of emissions from different types of sources (e.g., power plant and urban plumes). Many of these interactions currently cannot be adequately predicted on a regional scale.

6. The qualitative evaluation of source receptor relationships will require collection and analysis of monitoring data. Properly calibrated mathematical models are necessary to predict the impact of controls on existing sources or the impact of new sources in a new location.

Empirical approaches to evaluation source impacts range from simple observation of visible plumes to sophisticated aircraft sampling and satellite imagery. The approaches discussed in Chapter 4 include: evaluation of haze chemical composition, analysis of historical trends of emissions and haziness, evaluation of haze/wind-direction relationships, aircraft plume sampling, and application of diagnostic models. Important conclusions from application of these techniques to date include:

1. Direct measurements and statistical analysis indicate that fine sulfate aerosols account for 30 to 60 percent of fine particle related visibility reduction in areas as diverse as the Northeast United States, Los Angeles, and the Southwest mountain states.

2. Other fine particle constituents are also important and can dominate scattering in various regions. IN the Pacific Northwest, for example, carbon-containing aerosols from wood or other vegetative burning and motor vehicles appear to be significant components of light scattering aerosols.

3. Studies of trends in eastern airport visibility indicate that, while wintertime visibilities improved in some northeastern locations, overall eastern visibility declined. Summer, often the season of best visibility in the early fifties, is currently the worst season. From 1948 to 1974, summertime haze (extinction) increased by more than 100 percent in the central Eastern States, 50 to 70 percent for the Midwest and Eastern Sunbelt States, and by 10 to 20 percent for the New England area. Although the results of airport surveys should be viewed with caution, the results are consistent from site to site.

4. Very close parallels have been noted between the geographical/seasonal features of airport visibility trends and the geographical/seasonal features of trends in atmospheric sulfate concentrations, sulfur oxide emissions, and coal use patterns. These parallels provide strong circumstantial evidence that the historical visibility changes in the East were caused, at lest in part, by trends in sulfate concentrations and sulfur oxide emissions.

5. Similar analyses of visibility trends in the Rocky Mountain Southwest, a region containing numerous class I areas, indicate a gradual decline in visibility with a recent improvement, so that current levels are similar to those in the late forties. A strong, statistically significant association exists between these visibility trends and regional sulfur oxide emissions from copper smelters. The increase in visibility from 1972 to 1976 paralleled significant decreases in smelter emissions due to pollution controls and decreased production. Although the statistical studies do not show causality, the results are consistent with theory and experimental results

6. During a nine-month copper smelter strike, significant increases in Southwestern visibility and decreases in sulfate concentrations were noted at great distances from the smelters. Notably, sulfates dropped by about 60 percent at the Grand Canyon and Mesa Verde, 300 to 450 kilometers from major smelter locations.

7. Aircraft measurements of the plumes of large power plants, smelters, and major urban areas have tracked the visibility impact of these sources to 50 to 200 kilometers downwind. The apparent transformation of SO_2 to light scattering sulfate has been observed in both Eastern and Western plumes.

8. Episodes of regional scale haziness have been observed in the Eastern United States. Examination of airport data, pollution measurements, and satellite photography indicate that these hazy air masses move across the Eastern United States in the manner of high-pressure systems, causing significant visibility reductions in areas with little or no air pollutant emissions.

PREDICTIVE MODELS

Although empirical approaches can be used to identify the impact of manmade air pollution, predictive models are necessary to evaluate the effects of alternative controls on existing sources and the potential impacts of proposed new sources. Visibility models adapt the atmospheric dispersion and transformation features of other air pollution models for the prediction of fine particles and NO_2 concentrations across a sight path. The concentration patterns are coupled with optical equations to predict visibility impacts. Visibility models deal with essentially two distance and time scales: transport of plumes from single sources for short to moderate distances (10 to 100 km) and regional scale transport of single and multiple sources over medium to long range distances (100 to over 500 km).

Important uncertainties in visibility models include:

1. Prediction of atmospheric dispersion characteristics becomes less reliable as distance from the source increases. Mountainous and hilly (complex) terrain, common near class I areas, poses a particularly difficult analytical problem. Nevertheless, because concentration across a sight path and not at a single point is the important parameter, visibility models can be somewhat less sensitive to dispersion assumptions than are conventional air quality models.

2. The chemical transformation and removal processes for sulfur and nitrogen oxides have been experimentally estimated, but are difficult to predict under varying environmental conditions.

3. The models are sensitive to base line visibility conditions. Until monitoring programs provide data for class I areas, base line conditions must be derived from rough estimates.

4. The models are subject to the uncertainties in current understanding of human visual perception and the optical characteristics of modeled air pollutants.

5. An incomplete understanding of large-scale meteorological processes, uncertainties in boundary conditions, and lack of adequate inventories of natural and anthropogenic emission sources significantly limit modeling of regional scale transport of pollutants.

6. Visibility models have generally not been verified through intensive environmental monitoring. Major experimental efforts are under way to confirm the theoretical predictions.

Despite these uncertainties, visibility models can and should, within certain limits, be used to evaluate point source impacts. Single source models can estimate the range of expected visibility impacts of primary particle emissions at distances of up to 50 to 100 kilometers from the source. These models can also be used for relatively isolated sources located in clean environments to provide rough estimates of the impacts of sulfur and nitrogen oxide emissions at similar distances. Thus, the degree of visibility improvement resulting from controls on major, obvious sources of plume blight can be predicted, and the visibility impacts of proposed major facilities can be addressed. In the case of new sources proposing to locate within 100 to 150 kilometers of class I areas, an analysis of prevailing meteorological conditions, background visibility, and application of available single source plume models can provide an improved basis for siting decisions.

Models for evaluating the impact of control of existing or proposed sources on a regional scale require further refinement and validation before they can be used for regulatory applications. Empirical data analyses coupled with mathematical modeling exercises are useful for identifying the scales of time and distance upon which visibility impact may occur. Roughly, changes in the regional emissions of fine particles and sulfur oxides will produce changes in regional visibility levels, although the extent, duration, and location of these changes as a function of emissions cannot be adequately predicted. As noted above, pristine regions such as the Southwest will be most sensitive to the addition of new sources or reductions in regional emissions through control.

MAJOR SOURCES

Vision in the natural "unpolluted" atmosphere is restricted by blue sky scattering, by curvature of the earth's surface and by suspended liquid or solid natural aerosols. The important sources of natural aerosols include water (fog, rain, snow), windblown dust, forest fires, volcanoes, sea spray, vegetative emissions, and decomposition processes. These sources must be addressed in estimating base line visibility in class I areas. The extent to which these natural sources control existing visibility levels in the United States is not well known. Nevertheless, it is reasonable to conclude that manmade sources contribute significantly to visibility impairment in most regions of the country and in some cases dominate visibility.

Anthropogenic emission sources of particulate matter, sulfur oxides, nitrogen oxides, and volatile organics are of some significance to visibility impairment. The significance of volatile organics (hydrocarbons), however, is not well understood. Major sources, projected growth, and controls are discussed in Chapter 6. The most important source categories of visibility-impairing pollutants include utilities, industrial fuel combustion, smelters, pulp mills, urban plumes (the result of point sources, space heating, mobile and other urban sources), fugitive dust from agricultural activities, mining, unpaved roads, off-road recreational vehicles, and the managed use of fire including prescribed burning associated with forestry and agricultural burning. The significance of these sources on an individual and collective basis varies throughout the country. Many of them are not readily amenable to further control.

CONTROL STRATEGY IMPLICATIONS

The results of the preliminary Federal Land Manager analysis of visibility in class I areas provide important implications for control programs. These include:

1. Few, if any, of the class I areas are currently free from some anthropogenic influence on visibility. Given resource limitations and the lack of adequate information on impairment, however, those areas with current or projected unacceptable visibility conditions should receive highest priority in control programs. If, as preliminary subjective Land Manager judgements suggest, current visibility is generally acceptable in two-thirds of the class I areas, there will be little impetus for completely eliminating perceptible man-made impairment. This appears to be consistent with Congressional intent.

2. Protection of integral views extending outside class I areas is important for a number of class I areas. A number of managers reported, however, that the haze occurring in large urban areas are visible from some vantage points within the class I area. It is not clear that Congress intended to remedy these kinds of visibility impairment. Case-by-case judgements can address these issues.

3. The kinds of sources that tend to dominate visibility impairment vary greatly throughout the country. Visibility control programs must account for the diverse nature of sources. Particularly difficult problems include regional haze in the Eastern United States, regional emissions in the Southwest, the impact of urban plumes, and prescribed burning activities. The Land Managers themselves utilize fire as a means for enhancing the production of timber, improving wildlife habitats, and preventing catastrophic natural fires. Such activities impair visibility on a temporary basis.

4. Assessment of existing visibility conditions and projected growth indicate that the highest priority for visibility protection programs in class I areas is the evaluation of the impacts of new sources of visibility impairment. Many of the class I areas in the Western United States are likely to be influenced by increased energy development and utilization, population and urban growth, and associated emission increases. Once such sources are constructed, it is very difficult to mitigate their impacts.

Although available models are limited, they should be used to evaluate new source impacts. The alternative allowing construction of new sources without such analyses as long as prescribed class I increments are met, is not acceptable. Available scientific information supports the contention of the House Committee Report that “mandatory class I increments do not protect adequately visibility in class I areas” in all cases.

Programs for the prevention of significant deterioration will address the impact of major facilities on class I area visibility. These requirements, however, do not adequately deal with the visibility impacts of increases in emissions associated with population growth, such as increased urbanization, automotive emissions, and space heating, or with activities such as agricultural growth and highway construction. Additional studies are needed to quantify the influence of these activities on visibility before adequate guidance can be considered. Control of such sources may ultimately prove to be necessary for making progress toward the national goal.

REGULATORY STRATEGIES

Conceptually, visibility protection under Sections 169A and 165(d) includes the following components:

1. Proposal and promulgation of visibility regulations and guidelines for the States by EPA.

2. Assessment of class I area visibility by the States, Federal Land Managers, EPA, and affected industries.

3. Judgments on significance and adversity of impairment caused by existing and proposed new sources and the need to improve existing conditions in class I areas by the Federal Land Managers, States, and EPA.

4. Development of control strategies by the States, assisted by EPA

5. Monitoring progress toward the national visibility goal.

NEED FOR PHASED APPROACH

Because of the lack of base line visibility data in class I areas, the limitations in scientific and technical understanding of source/air quality perception relationships, the need to consider visibility improvements in the context of control costs, and limitations in resources available to States, EPA, and the Federal Land Managers, EPA recommends a phased approach to visibility protection. Although regulations and guidelines for the States must encompass the full range of Clean Air Requirements, they should, to the extent possible:

1. Permit State control programs to focus initially on the most clearly defined cases of existing impairment and on strategies to prevent future impairment and,

2. Allow for the evolution of guidelines and control strategies made possible with expected improvements in scientific understanding of source/impairment relationships.

Although available information is not adequate to develop control strategies that demonstrate ultimate attainment of the national goal, enough is known to develop a series of corrective and preventive measures. An evolutionary or phased regulatory approach would permit these steps to be taken while delaying those actions for which the technical basis is less clear. Moreover, such an approach will allow for a more effective use of the limited manpower and financial resources available to States, Federal Land Managers, and EPA for developing visibility control programs.

In the initial phases of visibility protection, application of BART is likely to be limited to obvious cases of plume blight or single source haze layers. The BART mechanism does not appear to apply to important categories such as prescribed burning, regional power plant and smelter emissions, and urban plumes. Evaluation of new source impacts should focus on major stationary sources, particularly power plants. The visibility impacts of growth of smaller area sources and the effect of regional emission increases from numerous sources are not adequately addressed by current PSD procedures.

LONG TERM STRATEGIES

Because of the limitations in BART and PSD, the eventual development and implementation of long-term strategies will be central to making progress toward the national visibility goal. These strategies should provide for integration of visibility objectives into ongoing air management efforts to account for sources not adequately covered by other mechanisms and to explore innovative approaches for making cost-effective progress toward visibility protection.

A starting point in developing long-term strategies is evaluation of the impact of other air pollution control programs; e.g., standards for air quality, new sources, and mobile sources. The projected impact of existing programs on some of the more difficult visibility impairment problems is outlined below:

1. The Southwestern copper smelters have made progress toward reducing emissions, partially in response to State programs for attaining the National Ambient Air Quality Standards. Although final emission reductions may be deferred, the smelters are under compliance schedules, which should ultimately provide additional reductions in emissions. Preliminary analyses suggest that reductions to date in smelter emissions have resulted in improved regional visibility in the Southwest since 1972.

2. Air quality standards and new source performance standards have halted the general trend toward increased sulfur oxide, particulate, and organic emissions in the Eastern United States. The recently announced new source standard for power plants represents a significant long-term strategy for an ultimate reduction in Eastern sulfur oxide emission levels and a limitation on regional increases in the Western United States. This approach, however, will not begin to effect significant reductions in emissions in the East until after 1995. Accelerated replacement of older uncontrolled oil-fired power plants with coal-fired boilers meeting the new source performance standard under energy initiatives would accelerate the reduction in sulfur oxide emissions.

3. Progress toward meeting air quality standards in urban areas should limit increased impairment and in some cases improve visibility in areas affected by urban plumes.

Once the effect of other regulations on visibility is evaluated, the need for additional control approaches for making progress toward the national goal can be evaluated. Potential long-term control approaches, which may prove desirable in the 1980's, include an accelerated reduction in regional haze occurring in the East, maintaining regional visibility levels in the Southwest and reducing impacts of forest and other burning in the Pacific Northwest. Such approaches must be justified on a technical basis and on a consensus that the improvements are worth the effort. The States and EPA should consider a variety of innovative regulatory strategies for implementing long-term visibility improvement strategies. Some of these include a national secondary air-quality standard for fine particles and economic control approaches, including marketable permits, emission fees, and other economic incentives for improved practices.

VISIBILITY RESEARCH NEEDS

Extension and refinement of visibility protection programs are dependent on improvement of current knowledge and techniques in a number of areas. The most important areas include:

1. Comprehensive characterization of existing visibility conditions in representative regions containing class I areas.

2. Development of improved and simplified visibility monitoring approaches.

3. Field studies of selected single and multiple point and area source impacts.

4. Improvements in predictive models for single sources and for regional scale transport.

5. Studies of human visual perception in clean atmospheres.

6. Studies of the value of visibility.

A combination of programs involving government and the private sector is beginning to address many of these areas. Significant advances in the next several years should enhance our ability to make progress towards the national visibility goal.

1 INTRODUCTION: ESTABLISHING THE NATIONAL VISIBILITY GOAL

1.1 SCOPE OF REPORT

This report is prepared in response to the requirements of Section 169A(a) of the Clean Air Act. In that section, Congress established as a national goal "the prevention of any future, and the remedying of any existing impairment of visibility in mandatory class I Federal areas which impairment results from man-made air pollution." (95th Congress, 1977). The Act requires a study and this report to Congress on available methods for implementing the national visibility goal. The report must include "recommendations for:

A. Methods for identifying, characterizing, determining, quantifying and measuring visibility impairment in (class I) Federal areas, and

B. Modeling techniques (or other methods) for determining the extent to which man-made air pollution may reasonably be anticipated to cause or contribute to such impairment, and

C. Methods for preventing and remedying such man-made air pollution and resulting visibility impairment.

Such report shall also identify the classes or categories of sources and the types of air pollutants which, alone or in conjunction with other sources or pollutants may reasonably be anticipated to cause or contribute significantly to impairment of visibility" (95th Congress, 1977).

This chapter will discuss the establishment of the national visibility goal, including the requirements of the Clean Air Act, the importance of visibility in class I areas, and the definition and nature of visibility impairment.

Chapter 2 will review fundamental scientific concepts related to human perception of light, atmospheric optics, and the means by which man-made air pollutants affect visual air quality. The discussion emphasizes those pollutants that are most important in causing visibility impairment, fine particulate matter (sulfates, "primary" particles, organics, and nitrates) and nitrogen dioxide.

Chapters 3 through 5 discuss and make preliminary recommendations on methods for assessing visibility and relating impairment to sources. Chapter 3 outlines techniques for monitoring visibility. The discussion focuses on operating principles and possible utilization of human observers, photography, telephotometers, nephelometers, and particulate monitoring devices. Existing and planned visibility monitoring networks are also outlined. Chapter 4 reviews the application of several approaches for relating visibility impacts to man-made sources of air pollution. The methods include chemical element balance, statistical studies of air quality, emissions, and visibility trends, diagnostic models, and other empirical approaches. Chapter 5 discusses available mathematical models for evaluating visibility impacts of major sources and assessing alternative controls and siting.

Natural and anthropogenic sources of visibility impairment are discussed in Chapter 6. The general location, impacts, projected growth and possible controls and costs are discussed for major anthropogenic source categories.

Chapter 7 discusses prospects for making progress toward the national goal. A preliminary summary of current class I area visibility status as reported by the Federal Land Managers is presented, key implications of the preliminary summary are discussed, and considerations for developing alternative visibility control strategies are outlined. Chapter 8 summarizes ongoing visibility-related research efforts and makes recommendations for future research.

1.2 STATUTORY REQUIREMENTS AND LEGISLATIVE HISTORY

The Clean Air Act Amendments of 1977 add Section 169A to the Clean Air Act, requiring the following activities of the Federal Government:

1. The Department of Interior, in consultation with other Federal Land Managers, must review all mandatory class I Federal areas and identify those where visibility is an important value of the area. The EP A Administrator, after consulting with Interior, must promulgate a list of mandatory class I Federal areas in which he determines visibility is an important value. The list has been promulgated and is " included as Appendix A to this report.

2. EPA must prepare this report to Congress on methods for meeting the visibility goal, including methods to identify visibility impairment, modeling, and other methods for evaluating source impacts, methods for preventing and remedying pollution related visibility impairment, and a discussion of pollutants and sources that may impair visibility.

3. EPA must promulgate regulations which will (a) provide guidelines to States on appropriate techniques and methods for implementing Section 169 requirements through the State Implementation Plans (SIP) where needed, and (b) require SIPs for affected States to include emission limits, schedules for compliance, and other measures as may be necessary to make reasonable progress toward meeting the national visibility goal.

These regulations must require sources which have been in operation less than 15 years as of August 1977 and which emit any air pollutant that may reasonably be anticipated to impair visibility in the selected class I areas to procure, install, and operate the best available retrofit technology (BART) no later than 5 years after SIP approval.

The regulations must also require that the SIPs include a long-term (10 to 15 years) strategy for making reasonable progress toward the visibility goal. The long-term strategy may require control of sources older than 15 years or sources not otherwise controlled under the BART provisions. BART must be determined for each source by the State (or Administrator, in some cases). In the case of a fossil fuel-fired generating power plant having a total generating capacity of least 750 MW, the emission limitations (BART) must be determined pursuant to EPA guidelines. Guidelines for determining BART must take into consideration the costs of compliance, the pollution control technology in use at the source, the remaining useful life of the source, and the degree of improvement in visibility that may reasonably be anticipated to result from the use of such technology. BART can be expressed as an emission limit or operating practice and must be incorporated into a revised State Implementation Plan.

Enactment of the visibility section of the Clean Air Act was stimulated by public concern about the deterioration of visibility in scenic areas. Examination of the legislative history of the visibility provision indicates that Congress was particularly concerned about evidence submitted by the National Parks and Conservation Association, stating, "that some areas that in the past had 100-mile (160-km) visibility now have only an average of 30-mile (48-km) visibility. Much of this probably can be attributed to emissions from power plants, such as the Navaho and Four-Corners plants." (House Report, 1977). In addition to the recognized threat of power plants to long-range visibility in the western United States, Congress was concerned about reports that "the hazes found in high vegetation areas of the southeast are not dominated by natural organic compounds but by sulfate particles, probably from the oxidation of SO2 emitted from regionally distributed sources. " (House Report, 1977).

As stated in the Conference Report (1977), "a major concern which prompted the House to adopt a visibility protection provision was the need to remedy existing pollution in Federal mandatory class I areas from existing sources. Issues with respect to visibility as an air quality related value and application to new sources are to be resolved within the procedures for prevention of significant deterioration. " This statement is clarified in an attachment to technical changes to the 1977 Clean Air Act Amendments by Congressman Paul Rogers: " ...it does not state or imply that existing sources were the only concern...new sources were also 1-2 of concern. This point is underscored by the statutory language of Section 169A(a)(I), retaining as a national goal: the prevention of any future impairment. ." (Rogers, 1977). With respect to new-sources, Section 165(d)(2)(B) of the Clean Air Act makes it clear that the Federal Land Manager responsible for the management of class I area(s) "shall have an affirmative responsibility to protect the air quality related values (including visibility) of any such lands within a class I area and to consider, in consultation with the Administrator, whether a proposed major emitting facility will have an adverse impact on such values." Thus, the national goal of Section 169A applies to both existing and new sources; implementation includes both 169A(a) and 165(d).

Congress noted that the current national ambient air quality standards were not adequate to protect visibility in class I areas. Congress also recognized that, as a matter of equity, it would be impractical to require the same national ambient air quality standard for visibility protection in cities such as New York or Los Angeles as for areas such as the Grand Canyon or Yellowstone National Park (House Report, 1977). In requiring an analysis of the visibility values in various class I regions before determining whether visibility protection would be required, Congress recognized that it might be unreasonable to have uniform visibility objectives even for all national parks or other class I areas.

1.3 IDENTIFICATION OF CLASS I AREAS

Mandatory class I areas are defined by the Clean Air Act as including all international parks, national wilderness areas, and national memorial parks exceeding 5,000 acres and national parks exceeding 6,000 acres. Such areas that were in existence when that Act was passed may not be redesignated. The original 158 class I areas are depicted in Figure 1-1. The Department of the Interior used an II-step process for applying criteria to determine whether visibility is an important value in each of these areas. The areas were examined with respect to the following:

1. Legislation establishing the area and authorizing the boundaries to determine whether protection of visibility was intended in designating the area a park or a wilderness area;

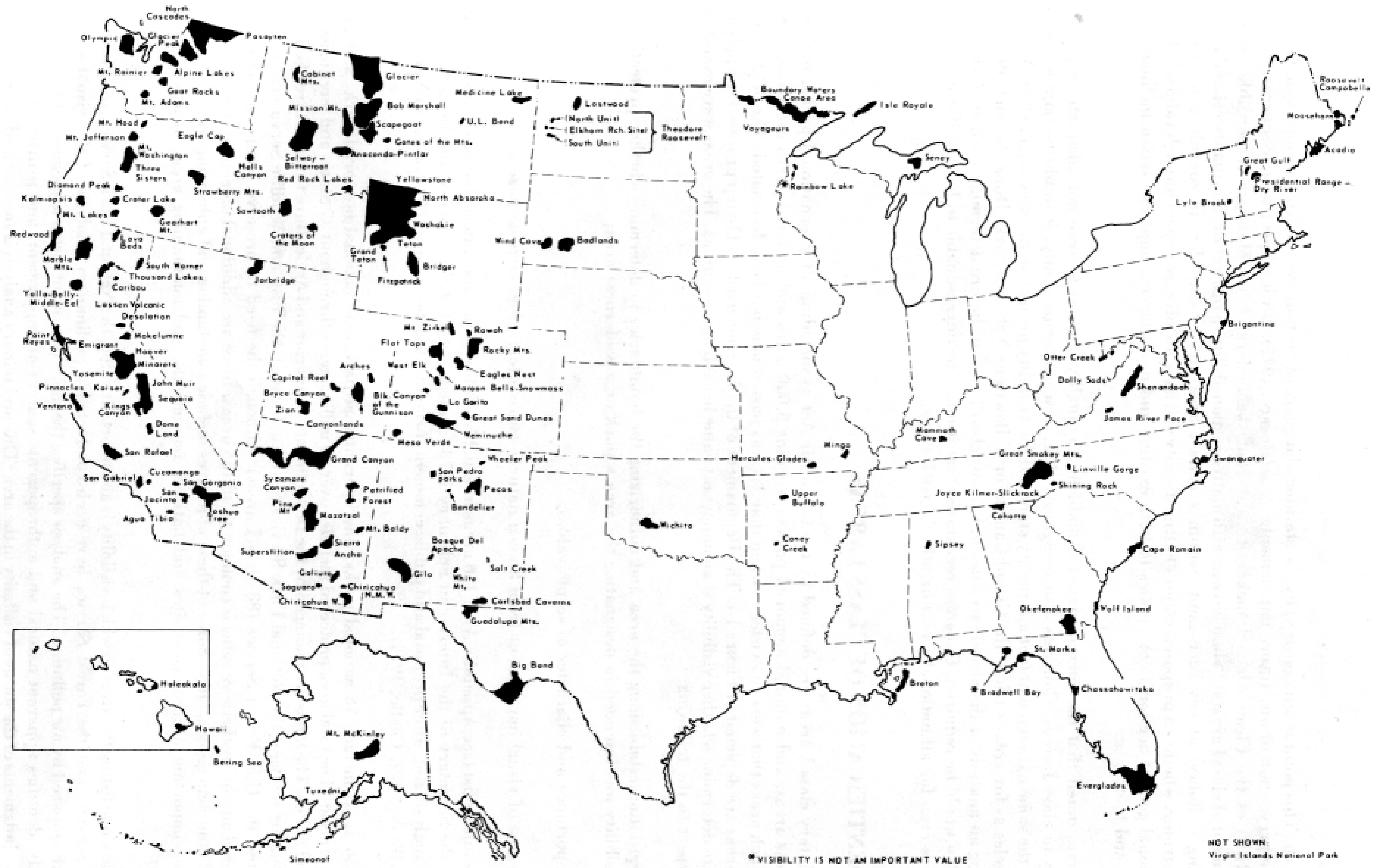
2. Importance and character of scenic values;

3. Degree of visual impairment from known natural sources (e.g., fog, terpene haze).

The resulting list (see Appendix A) of 156 areas in which visibility is an important value was transmitted to EPA by the Secretary of the interior in February 1978 (Andrus, 1979). EPA reviewed the Department of Interior analysis and, after proposal and public comment, promulgated the same list of156 areas in November of 1979 (Blum, 1979, Costle, 1979).

The 156 areas include 36 national parks, one international park, one national memorial park, and 118 wilderness areas. The total area protected includes over 29 million acres throughout 37 States and territories of the United States. The lands are managed by the Departments of Interior and Agriculture through three Federal land managing services; the National Park Service (45 class I areas), the Fish and Wildlife Service (23 class I areas), and the U.S. Forest Service (88 class I areas). Although the need to preserve scenic character for recreational and/or aesthetic reasons is common to all 156 areas, there are additional objectives that vary with area and land managing agency. Some of these objectives include maintaining and enhancing wildlife habitat, preserving important archeological sites and national monuments, and maintaining areas in a wilderness condition.

In addition to listing the areas in which visibility is an important value, the National Park Service, the Fish and Wildlife Service, and the Forest Service have each conducted a preliminary analysis of the visual values potentially impaired by air pollution. The analysis specifies the more important vistas associated with the area, tentatively identifies apparent natural and anthropogenic sources of impairment, and provides preliminary subjective judgments of the status of visibility in the area. This preliminary analysis is summarized in Chapter 7.



*VISIBILITY IS NOT AN IMPORTANT VALUE

NOT SHOWN:
Virgin Islands National Park

Figure 1-1. Mandatory class I areas.

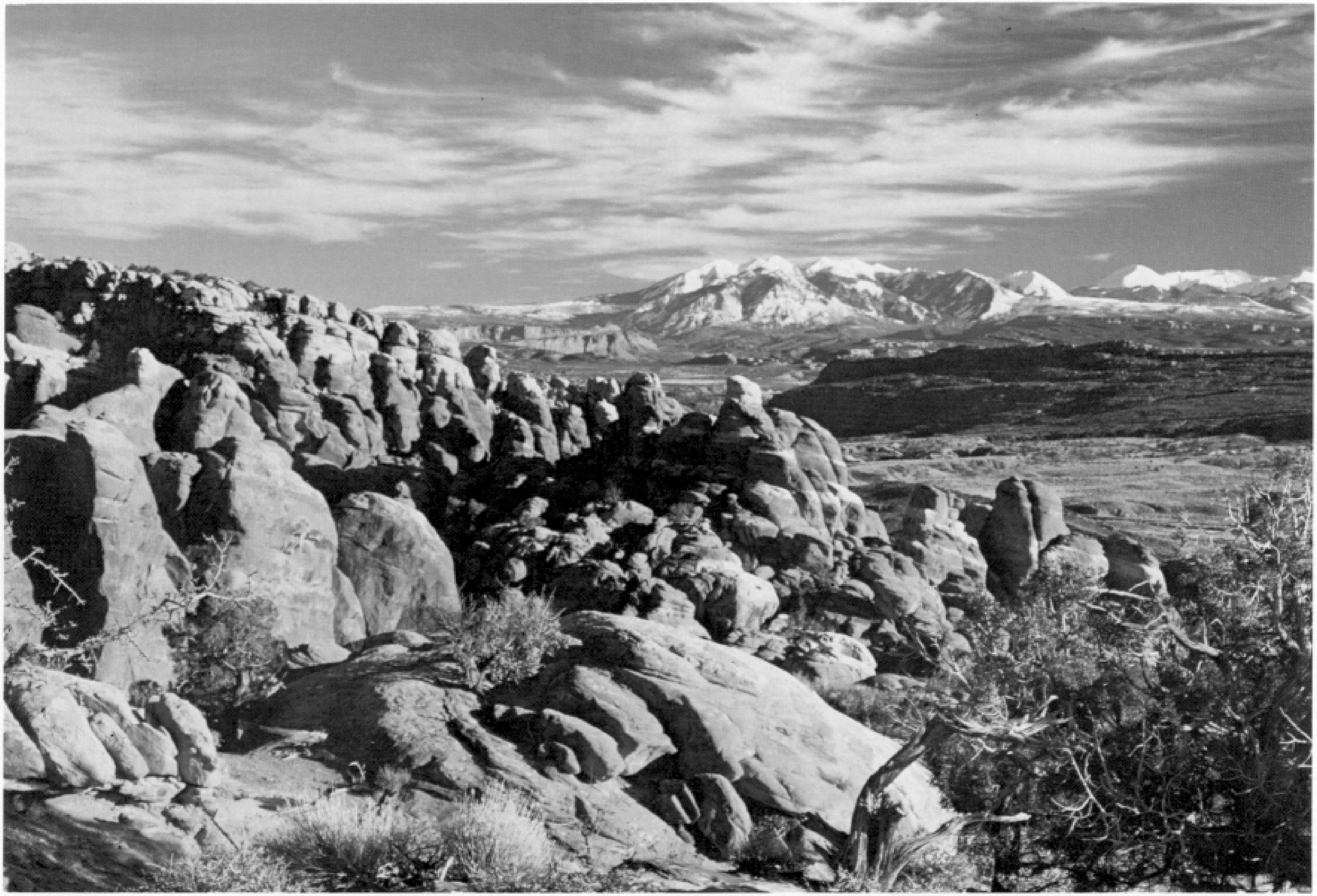


Figure 1-2. La Sal Mountains, southern Utah. This view illustrates the value of unimpaired visibility in a natural setting (Anderson, 1979).

1.4 THE VALUE OF VISIBILITY IN CLASS I AREAS

1.4.1 Background

The value of the "wilderness experience” and the importance of preserving our natural heritage have long been recognized in the United States (Grasvenor, 1979). For example, the National Park Service Act of 1916 created the National Park Service, directing it to "conserve the scenery and the natural (objects) and provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired..." (Andrus, 1978).

In establishing the national visibility goal, Congress called for explicit recognition of the value of visibility in these special (class I) areas. In requiring consideration of "significant" impairment, "adverse" effects and "reasonable progress" in implementing the goal, Congress has, in effect, mandated judgments on the value of visibility in the context of specific decisions on control and location requirements for sources of visibility impairing air pollution. The Department of Interior has taken the first step in valuing visibility by specifying the 156 class I areas in which visibility is an important value. Because of their key role in implementing the national goal, the Federal Land Managers have also initiated a number of activities to assist in making visibility value judgments for control and siting decisions. The following discussion of the concept of the value of visibility and some value measurement techniques is largely based on a workshop supported by the Forest Service, National Park Service, and Bureau of Land Management held in February 1979 on the subject of the Social Values of Visibility (Fox, Loomis, and Greene, 1979).

1.4.2 Establishment of Visibility Values: Overview

A major challenge in establishing visibility values is to develop ways to measure quantitatively visibility impairment as perceived by the human eye. Recent research on environmental quality indices has developed procedures for relating such indices to measurable quantities. Craik (1979) outlines the steps required based on soliciting opinions from users of “visibility” in class I areas. A successful perceived environmental quality index must relate the human perceived experience to a physical setting, and the experience should be integral to or typical for that setting. Peterson's (1979) discussion at the visibility values conference serves as a prototype for relating visibility to the more comprehensive human experience of a class I area. The Park Service in their brochure entitled "My Eyes Need a Good Stretching" (NPS, 1978) attempted to summarize this relationship between visibility and experience by relating the views of artists, humanists, and scientists on the subject of visibility degradation.

Establishing visibility values must, therefore, involve relating the whole visual experience to indices such as visual range, contrast transmittance, and color alteration. Such human visual experiences might be protected by different levels of these visibility related parameters in different locations. Although the visual experience is a significant component of, for example, visits to both the Grand Canyon and Great Smoky National

Parks, protection of that experience might require different magnitudes of visibility protection for each area. Both the perception of anthropogenic impairment and visibility related values are likely to vary from location to location.

It is difficult to estimate the number of people who are affected by class I area visibility. The numbers of scenic area users are rather high; for example, estimated visitor days in 1978 for all Park Service management units are approximately 277 million and for Forest Service Wilderness areas 7 .6 million visitor days. The Park Service collected a total of approximately $17 million in entrance and use fees in the same year (Fox, 1979). Research done in 1966 suggests that approximately $1 per visitor day is an appropriate estimate of the economic benefit of recreation. (Beardsley, 1970). This estimate is of course, subject to considerable inflation by 1979. These numbers provide an indication that direct use of class I areas is high and significant economic impacts are involved. Forest Service estimates on various forms of dispersed recreation use suggest a minimum of 50 percent and a maximum of 250 percent increase over current use in the next 50 years (Fox, 1979). Since a prime philosophy in the preservation of wilderness and establishment of parks is not the concept of use but rather the concept of preserving the existence of unique areas for the benefit of society at large, the value of visibility in class I areas is greater than that suggested by current use estimates alone.

Although the value of visibility may prove to be intangible, it is conjectured that it is to some extent quantifiable (can be identified as a discrete point on a scale) and, hence, can be generalized for display to the public. Given the lack of consistent units for the evaluation of aesthetic qualities such as visibility, values can be categorized according to: 1) economic criteria, the dollar cost/benefit associated with visibility, 2) psychological criteria, the individual need and benefits resulting from visibility and 3) social/political criteria, community opinions and attitudes held in common with regard to visibility. Preliminary results of past studies in each of these areas and suggestions for future work are discussed below.

1.4.2.1 Economic Criteria - Economists have made some progress toward quantifying the values of visibility using dollars as the measure. While in the market place, the market value or price reflects marginal value; total value can be estimated from revealed consumer preference either in a market or market like simulation.

The economic value of visibility can be broken into sub-categories, depending on the nature of benefits anticipated. These anticipated benefits or values could be classified as activity, option, and existence benefits. One may be willing to pay $X to actually visit the Grand Canyon without any visibility impairment (an activity value), $Y for keeping the Grand Canyon's visibility sufficiently clear so that one might enjoy it in the future (an option value) and $Z simply to know that the Grand Canyon will never have degraded visibility (an existence value).

The principal approach to economic evaluation of visibility has been the "iterative bidding technique." Brookshire (1979) explains the iterative bidding technique as "a direct determination of economic values from data which represent responses of individuals to contingencies posited to them via a survey instrument. "

The iterative bidding technique in the current form was first developed and applied by Randall et al. (1974 a, b) in the Four Corners region of the Southwest. Three contingencies were considered: (a) limited visibility reductions and a view of a power plant with limited visible emissions; (b) moderate emissions from the plant, moderate visibility reductions and moderate existence of unreclaimed soil bank and transmission lines; and (c) extensive emissions, visibility reductions and unreclaimed soil bank and transmission lines. Given this selection of scenarios, the results cannot be disaggregated into component values for visibility, power plant location, and unreclaimed soil banks and transmission lines. Employing a sales tax vehicle, the yearly mean bids were $85 (a to c) and $50 (b to c) per household. No bias tests were conducted in this experiment.

The Lake Powell experiment (Brookshire et al., 1976) addressed the potential visibility reduction from the proposed Kaiparowits power plant, which would have impaired the scenic vistas of the Glenn Canyon National Recreation Area. An estimate using the iterative bidding techniques was obtained for the aggregate visitor willingness to pay to prevent construction of the proposed Kaiparowits power plant. One of the principal motivations for the study in addition to the Kaiparowits power plant issue was an attempted replication of a subset of the Randall study results. Three scenarios depicted by verbal description and picture sets were employed in the Lake Powell experiment where visibility and plant sitting varied from best (a) to worst (c). The study tested for strategic bias in the bidding procedure and concluded that the bias was not prevalent in this experiment. Using entrance fees as a vehicle, the aggregate marginal willingness to prevent one additional power plant near Lake Powell was over $700,000. Employing the bids and considering the assumptions and structure of the experiment, an indication of worth via the preferences expressed in the study of the canyon lands of southeastern Utah can be obtained. Extrapolating to recreation areas within a hundred mile radius, the aggregate bid for a similar visibility reduction would be up to $20 million per year (Brookshire, 1979).

The Farmington experiment (Blank, et al., 1978) attempted to value visibility in the Four Corners Region of the Southwest. The study had three principal goals which represented extensions of the previous experiment: (1) to attempt to link visible range and the valuation measures, (2) to develop a theoretical cross check for the iterative bidding process and (3) to systematically test for a vehicle, starting point and information bias in the iterative bidding process. Starting point and vehicle bias in varying degrees were detected in the results. Later Thayer and Schulze (1977), Brookshire and Randall (1978) and Brookshire et al. (1978), biases and found none. Various reasons have been suggested as to why only the Farmington experiment encountered multiple biases. One possibility is the definition of the "good" being valued was poorly specified.

The South Coast Air Basin, California (SCAB) experiment (Brookshire et al., 1978) was the first urban test of the iterative bidding technique. The SCAB experiment included several improvements in the experimental process. The results of the study did not suffer from vehicle starting point information or strategic bias. The dollar bid per household per month was $29 for a 60 percent improvement in air quality. In addition, the independently conducted property value study produced the same order of magnitude valuation results as the iterative bidding portion. Air quality was partitioned into an aesthetic effect, including visibility, and acute and chronic health effects. Utilizing the aggregate bids for all sample areas, 22 to 55 percent of the total for aesthetic effects. The result suggests that, indeed, the aesthetic component of visibility is a of visibility valuation. Furthermore, this result is for an urban area where the preliminary reason for residence is not vistas as would be the case upon a visit, for example, to the Grand Canyon. One might infer that aesthetics, not health effects, would be the principal consideration for scenic national vistas.

These preliminary studies are subject to a number of uncertainties and limitations. The preliminary results largely represent *activity* values for use of class I areas in view of the situations where the iterative approach ate. Option and existence values are more complex concepts, which have not been studied for visibility. Moreover, to say that visibility is worth, for example, $30 to $80 per annum per household does not convey the total magnitude of the visibility issue. There is more to the enjoyment of the visibility in the natural can be qualified with dollars. Nevertheless, the economic studies support the notion that visibility is an important value in class I areas and in urban areas as well.

1.4.2.2. Psychological Benefits - There are certain psychological benefits, actual or perceived, associated with class I areas which would be foregone if visibility were degraded. At the visibility values workshop, the area of psychological benefits received considerable attention and a number of research formats address the quantification of these benefits. Currently, assessment of the benefits is related or can be derived from more general studies. For example, for many years scientists have attempted to measure the psychological benefits of outdoor recreation, including enjoyment of scenic vistas unencumbered with obvious signs of human development.

Driver et al. (1979) have identified a number of direct and indirect psychological benefits and behavior related to visibility in class I areas. The benefits of viewing a scenic vista include a variety of user activities. There are also psychological benefits associated with options or existence values. For example, many people wish to preserve the option for a clear view into the Grand Canyon. Some derive psychological benefits from just knowing that pristine areas exist, even though there is no intention of visiting all or any of them.

Several approaches to quality and quantity psychological benefits were suggested at the visibility values et al., 1979). These include:

1. Scenic Beauty Estimation Index (Daniel, 1979),
2. Psychophysiological Measurements (Ulrich, 1979),
3. Perceived Psychological Benefits (Driver et al., 1979) and

4. Social Value Estimation (Loomis and Green, 1979).

Application of these and other techniques of valuing visibility for use in visibility protection programs represent a considerable challenge, which will require a number of years of research.

1.4.2.3 Social Benefits - Available economic studies suggest mechanisms for developing the value of visibility. The discussion of human perception and psychological benefits discussions at the Visibility Values Workshop provide research perspectives and a list of very general techniques, which could be employed to estimate psychological benefits of scenic vistas and of unimpaired visibility. In one sense, social benefits represent the aggregate of individual benefits and any associated disbenefits. In order to resolve these extremes, there exists a value seeking system which functions well in practice, namely the political process. As noted above, the presence of the visibility provisions in the Clean Air Act Amendments suggests that the political process has ascribed significant value to the protection of class I area vistas. It has also mandated mechanisms for considering visibility benefits and associated societal costs. These decision-making mechanisms must involve the Federal Land Managers, States, and the general public.

Additional research is needed in understanding the economic, psychological, and social benefits and costs of class I visibility protection. This research must be tied to studies of human perception of various forms of visibility impairment. The results of such work will significantly enhance the decision making process.

1.5 Definition of Visibility Impairment

In establishing the national goal, Congress provided the following guidance on the definition of visibility impairment:

1. Visibility impairment "include(s) reduction in visual range and atmospheric discoloration";

2. The goal applies to impairment from man-made (as opposed to natural) air pollution;

3. The visibility impairment must be observed from a vantage point within a mandatory class I area (as opposed to a vantage point outside a class I area);

4. The ultimate goal is to remedy or prevent "any" man-made impairment;

5. In the application of controls or restrictions to pollution from man-made sources of impairment, consideration must be given to the "significance" of the impairment from existing sources and whether a new source visibility impact is "adverse."

This general guidance is significant, but a number of important areas are left open for additional specification, interpretation, and judgment. Examples of visibility impairment, areas requiring further resolution, and preliminary recommendations are illustrated and discussed below.

1.5.1 Categories of Visibility Impairment (Latimer, et al., 1978)

Although it may be desirable and useful to classify visibility impairment in a number of ways (Charlson et al., 1978; Latimer et al., 1978; Malm, 1979a), virtually any type of visibility impairment can ultimately be expressed as a reduction in visual range or atmospheric discoloration. Visual range is generally defined as the farthest distance at which one can see a large, black object against the sky at the horizon. Airport weather observers and others often use the term "visibility" synonymously with visual range. One can make subjective evaluations of "visibility" every time objects are viewed outdoors. Although large black objects are not generally available for observing and evaluating visual range, dark objects such as buildings, television towers, hills, or mountains can be viewed against the horizon sky.

Even if no distant objects are within view, subjective judgments about visual range can be made by noting the coloration and light intensity of the sky and nearby objects. For example, one perceives reduced visual range if a distant mountain that is usually visible cannot be seen, if nearby objects look "hazy" or have diminished contrast, or if the sky is white, gray, yellow, or brown rather than blue. In this latter case, both reduced visual range and atmospheric discoloration are apparent.

Atmospheric discoloration, "unlike visual range, has not been routinely defined or quantified in traditional pollution programs. Qualitatively, atmospheric discoloration is a pollution-caused change in color of the sky, distant mountains, clouds, or other objects. This statement implies that some natural or “not discolored” of atmospheric colors can be defined. Obvious examples of atmospheric discoloration include hazes associated with reduced visual range, distinct haze bands or layers, and visible brown, black, gray, or white plumes.

Because visual range reduction and atmospheric discoloration are often the results of the same pollution impact, it is useful to categorize anthropogenic visibility impairment into three general types: (1) widespread, regionally homogeneous haze that reduces visibility in every direction from an observer, (2) visible smoke, dust, or colored gas plumes that obscure the sky or horizon relatively near sources (this class is also termed "plume blight,” and (3) bands or layers of discoloration or veiled haze appearing well above the surrounding terrain.

Figure 1-3 shows an example of general haze conditions in the Grand Canyon. As seen in this photograph, range is detectable because the distant features of the canyon are difficult to distinguish. The contrast between the given object (part of the canyon) and the background (the horizon or a more distant terrain feature) is reduced by light scattered from particles in the intervening atmosphere. Even if terrain features were not discernible, the intensity and coloration of the scattered light would degrade the aesthetic quality of the atmosphere. In the Western United States, where most of the class I areas are located, spectacular scenery is enhanced by generally excellent visibility, which makes the colorful terrain features stand out with great clarity. Even in flat areas (e.g., the big sky country of the Northern Great Plains), however, a slight reduction in visual range or a slight atmospheric discoloration can change what originally appeared to be an "infinite" horizon to a white, yellow, gray, or brown horizon.

Figure 1-3 General Haze in the Grand Canyon. The source of light scattering particles (natural or manmade) is unkown (Anderson, 1979).

Figure 1-4 provides a "before and after" comparison of the impact of regional haze. Although the visual range is significantly reduced in 1-4b, the distant mountains are visible in both pictures. The most noticeable effect is the overall reduction in contrast and detail.

Near-source visibility impairment or plume blight is illustrated in Figure 1-5. The spatial extent of visibility impairment is defined by the dimensions of the plume. The plume is visible because the light intensity and color of the plume are different from those of the clouds and sky in the background. Because of the resultant relatively sharp boundary between the plume and the background, the visual impact on the observer is dramatic. Light scattering and absorbing particles are responsible for these impacts. Figure 1-6 shows a different kind of plume blight: a coherent brown plume. The discoloration in this case may be due to light absorption by NO_2 gas and/or particle scattering.

Bands of discoloration (Figure 1-7) can result from the transport and mixing of plumes. Airplane travelers are familiar with the noticeable boundary between the more polluted "mixing layer" and cleaner upper air. In Figure 1-7, the haze layers are clearly visible because of the sharp demarcation line between them and the clean air "sandwich." Figure 1-8 shows an example of possible discoloration, the source of which is unclear.

1.5.2 Causes of Visibility Impairment

It is obviously important to distinguish the causes of visibility impairment and, in particular, whether the cause is natural or anthropogenic. Clearly, Congress has been concerned only with anthropogenic visibility impairment. Reducations in visual range caused by precipitation, fog, clouds, windblown dust, sand, snow, or "natural" aerosols are natural occurrences and cannot be controlled by man. Indeed, some forms of natural visibility impairment may contribute to the enjoyment of class I areas. Examples of such phenomena are the blue haze of forested areas and the fog and hazes along the California and Oregon coast. Natural sources are discussed more fully in Chapter 6.

1.5.3 Location of Impairment

The location of visibility impairment is extremely important in terms of visibility protection because the national goal states that visibility *in* class I areas is to be restored and protected. It is uncertain whether this definition includes impairment caused by pollution outside of a class I area. It is reasonable and consistent with traditional (airport) usage to assume that visibility in an area includes the view of unobstructed objects located inside and outside of the area. Figure 1-9 shows a visible haze layer surrounding Navajo Mountain. The mountain, not in a class I area, is usually visible from Bryce Canyon. In EPA's view, important views extending outside the boundaries of class I areas are part of the visibility value of the area, and are included in the national goal. This issue is discussed further in Chapter 7.

1.5.4 Degree and Extent of Impacts Constituting Impairment

Each of the three major categories of visibility impacts can be further specified with respect to degree as well as to spatial and temporal extent. Judgments are necessary to specify where a pollution impact becomes impairment and whether the impairment is significant or adverse.

The degree of impairment can be characterized by the reduction in visual range from some reference value, by a reduction in contrast between an object and the horizon sky at a known distance from the observer, or by a shift in coloration or light intensity of the sky or distant objects, such as clouds or terrain features, compared to what is perceived on a "clear" day. In all cases, the magnitude of visibility impairment can be characterized by the change in light intensity or coloration of an object (or part of the sky) compared to that of some reference object. For example a distant mountain is visible because the intensity and coloration of light from the mountain is different from that of the horizon sky. Another example is a plume or haze layer seen against the background sky or terrain features. The pollution is visible (perceptible) only if the light intensity or coloration of the plume contrasts with that of the surrounding sky or terrain.

Figure 1-4 (a). **La Sal Mountains from EPA monitoring site in Canyonlands. Visual range was estimated to be approximately 260 km. Under these conditions, visual range must be calculated because curvature of the earth limits horizontal viewing distances to less than the visual range. Mountains are about 50 km from camera.**

Figure 1-4 (b). **Same view as in (a). Estimated visual range approximately 110 km. Although visual range is significantly lower, the major visual impact is the reduction in contrast between sky and mountain. The comparison is made difficult because of the difference in snow cover in this scene (Malm, 1979b).**

Figure 1-5. Near-source visibility impairment. Plume blight from particulate emissions extends downwind from the Four Corners Power Plant in New Mexico. As the plume mixes to ground level, the visibility of distant terrain features is degraded (Anderson, 1979).

Figure 1-6. Coherent brown plume. Plume is from the Navajo Power Plant near Paige, Arizona. The plume coloration may be due to absorption of blue light by NO_2 and/or back scattering of brown light by particles. (Williams, 1979).

Figure 1-7. Layered haze. A band of blue sky is visible between two haze layers near the Southern California Desert. The origin of the layers in this case is transport of Los Angeles area urban plume (Niemann, 1978).

Figure 1-8. Atmospheric discoloration? The yellowish brown coloration in this view from Mesa Verde National Park is characteristic of NO_2 absorption. Because of photographic limitations, the actual coloration and cause cannot be specified (Malm, 1979b).

Figure 1-9. Navajo Mountain from Bryce Canyon (Niemann, 1978).

The spatial extent of visibility impairment is important to both the perception and the significance of impairment to observers in class I areas. The sensitivity of an observer to brightness and color differences between objects depends on the spatial relationship between the objects. If each of the objects is uniformly colored and there is a sharp line of demarcation between the objects, such as when a mountain is viewed against a horizon sky, a smaller change in light intensity or color can be perceived than if the boundary between the two objects is vague, as in the case of a plume viewed against the horizon sky. If the observer is located in a uniformly colored atmosphere, atmospheric discoloration is perceived, not by comparison of two colored fields but by comparison with the recollection of a clear atmosphere.

The temporal extent (duration, frequency of occurrence, and time of occurrence) is of great importance in determining the significance of air pollution levels. Short term or infrequent phenomena or both are less likely to be of concern. Visibility impairment occurring during times of maximum visitor attendance is of greater significance than the same impact during minimum attendance. With sufficient measurements, the frequency of occurrence can be characterized as the number of days or hours in a year that the degree of visibility impairment is greater than some specified amount.

Qualitatively, the degree and extent of anthropogenic impairment increases through four levels: 1) natural baseline, no anthropogenic pollution; 2) a measurable or predictable pollution increment that is so small or short that it is not perceptible by human observers; 3) an observed or predicted perceptible impact which, because of degree or extent, is generally considered to be insignificant; and 4) an impact that is generally considered significant or adverse.

For the purpose of this report, EPA interprets man-made visibility impairment, in the context of the national visibility goal, as any *perceptible* change in visibility (visual range, contrast, atmospheric color or other index) from that which would have existed under natural conditions. Judgments with respect to the *significance* and *adversity* of perceptible impairments should consider the degree and the spatial and temporal aspects of impairment in the context of control programs. Such judgments must be made, at least in part, on a case-by-case basis. For this reason and because these judgments must involve States, Federal Land Managers and the public, it is difficult at this time to specify general criteria. As a minimum, however, significant or adverse impairment must be perceptible. These issues are discussed further in Chapter 7.

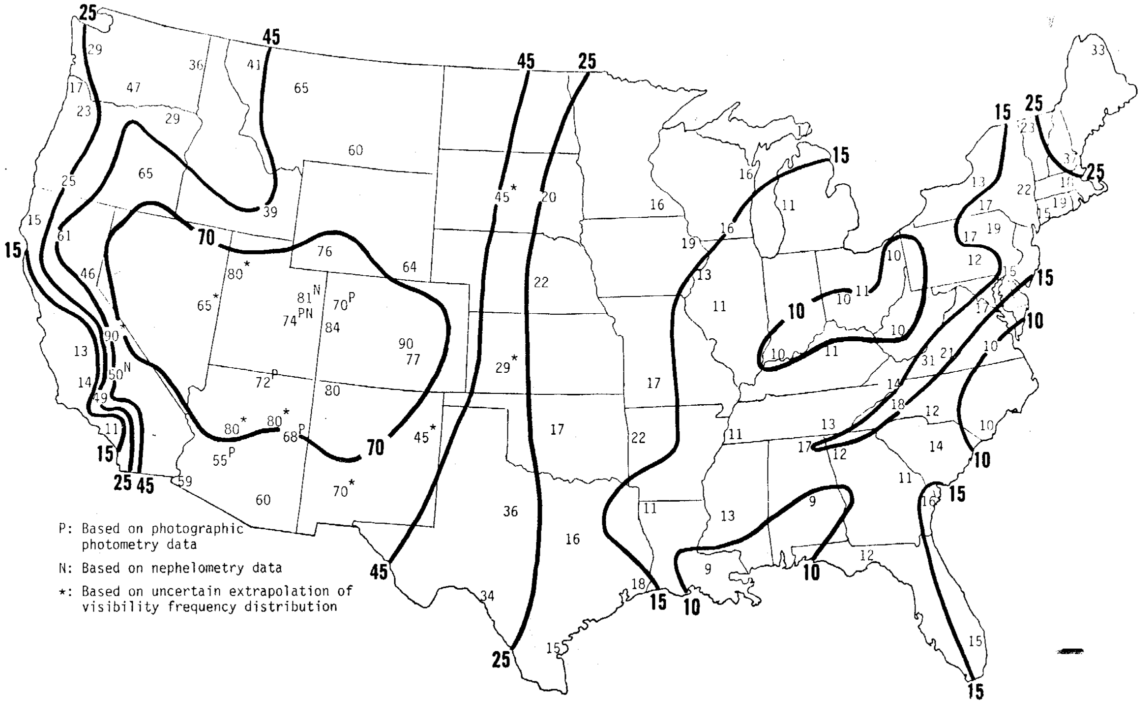
1.6 OVERVIEW OF CURRENT U.S. VISIBILITY

Until recently, visibility parameters have not been routinely monitored in any class I area. Some insight into general visibility conditions in these locations can, however, be obtained by examining available regional airport visibility data throughout the United States. The status of visibility in class I areas is discussed further in Chapter 7.

Figure 1-10 presents median yearly visibilities and visibility isopleths (Trijonis and Shapland, 1978). The data represent midday, median visual ranges for 1974-1976 from 100 suburban and non-urban locations. Visibilities at 93 of the locations are determined from airport observations.

The airport data were checked for consistency, quality, and completeness. Instrumental visibility measurements from seven sites in the southwest are also included. Although some uncertainties arise from the use of airport data*, there is reasonably good consistency between airport observations within regions and between airport and in instrumental results in the Southwest.

The best visibility (70+ miles, 110 km) occurs in the mountainous Southwest. Visibility is also quite good (45-70 miles) north and south of that region, but sharp gradients occur to the east and west. Most of the area east of the Mississippi and south of the Great Lakes exhibits median visibilities of less than 15 miles (24 km) annually.



P: Based on photographic photometry data
N: Based on nephelometry data
*: Based on uncertain extrapolation of visibility frequency distribution

Figure 1-10. Median yearly visual range (miles) and isopleths for suburban /non-urban Areas, 1974-76 (Trijonis and Shapland, 1978).

Figure 1-11 represents median summertime (third quarter) visibilities for the same data. Comparison of these figures shows that summertime visibility is significantly lower than yearly visibility in the East. Most of the Western states show little change in the summer, with mixed increases and decreases. Visibility increases, however, during the summer in the Pacific Northwest.

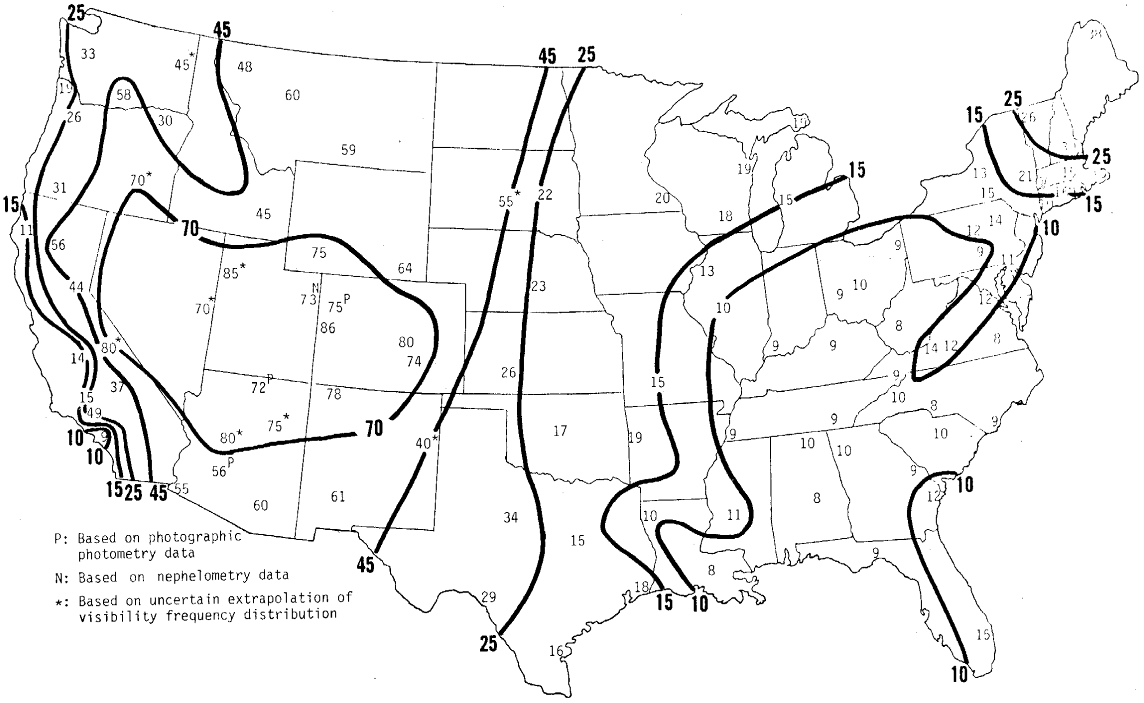


Figure 1-11. Median summer visual range (miles) and isopleths for suburban/ non-urban areas, 1974-76 (Trijonis and Shapland, 1978).

Although natural sources of visibility impairment and prevailing meteorological conditions are undoubtedly an important factor in producing these geographical and seasonal patterns, analysis of visibility trends and other information discussed in later sections suggest that man-made air pollution has a significant impact. The regions with the best existing visibility levels are most sensitive to additional impairment and most responsive to incremental pollution reductions. The reasons for this are discussed in the next chapter.

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