SECTION 6

SUMMARY AND CONCLUSIONS

One of the important effects associated with acid precipitation related pollutants is interference with radiation transfer (light transmission) in the atmosphere. An obvious result of such interference is visibility degradation—the impairment of atmospheric clarity or of the ability to perceive form, texture, and color. Climate modification constitutes another, somewhat less obvious, result.

The links between the acid rain problem and radiation transfer effects, although indirect, are quite strong. The principal link is through sulfur dioxide emissions and sulfate aerosols. Sulfur dioxide, a major contributor to acidic deposition, produces sulfate aerosol (itself a fundamental component of acidic deposition). Sulfate aerosol, in turn, is an important contributor to visibility reduction—in fact, the dominant contributor in the eastern United States. A secondary link occurs through nitrogen oxide emissions—also a major contributor to acidic deposition—which produce gaseous nitrogen dioxide and, in combination with ammonia (which may be the controlling precursor emission), fine ammonium nitrate particles. Ammonium nitrate aerosol sometimes accounts for a significant fraction of visibility degradation, and nitrogen dioxide typically contributes a few percent of visibility reduction.

The purpose of this document is to review, evaluate, and synthesize the current scientific information regarding visibility (including climate). The intent is to provide a technically sound, peer-reviewed summary of the state of visibility science for use by NAPAP in addressing visibility issues. Of particular importance is the relationship of visibility to the air pollutants associated with acid deposition—*i.e.* the relationship of visibility to nitrogen dioxide, nitrate aerosols, and (especially) sulfate aerosols.

6.1 BASIC CONCEPTS

Visibility does not have a precise, universally accepted, definition. Historically, much of the interest in visibility came from aviation and military operations where the most important concept of visibility was the furthest distance at which an object could be discerned—the "visual range". Currently, much of the concern about visibility is related to the aesthetic change from air pollution—the inability to see form, texture, and color of scenic features. This document is mostly concerned with the later concept of visibility, degradation of aesthetics by air pollution, although considerable discussion is also given here to visual range.

Under a variety of viewing conditions, "visibility reduction" or "haziness" is directly proportional to reduction in atmospheric light transmittance. Light transmittance in the atmosphere is attenuated by scattering and absorption from both gases and particles. The extinction coefficient (**Bext**), which measures the total fraction of light that is attenuated per unit distance, is simply the sum of these four components: **Bext** = **Bsg** + **Bag** + **Bsp** + **Bap**, where s = scattering, a = absorption, g = gas, and p = particles. Because the extinction coefficient is an important fundamental optical variable, and because under a variety of viewing conditions it relates directly to how well a landscape feature can be seen, much of the discussion here centers around the concept of light extinction.

Another important issue to emphasize is that particles (aerosols) dominate light extinction except under extremely clean conditions, when natural scatter by air molecules (Rayleigh scatter) predominates. Thus, understanding visibility requires understanding the basic concepts of aerosol air quality. Two of the most important aerosol concepts with respect to visibility are size distribution and chemical composition. For visibility purposes, it is critical to distinguish fine particles ($\leq 2.5\ \mu m$) from coarse particles ($\geq 2.5\ \mu m$), because fine particles usually dominate visibility effects. The composition of ambient particulate matter consists basically of just six species: sulfates, organics, elemental carbon, ammonium nitrate, soil dust, and aerosol bound water. Among these six species, there are significant differences in sources, atmospheric behavior, size distributions, and visibility effects.

6.2 FINDINGS AND CONCLUSIONS

The following subsections summarize the major findings and conclusions of the Visibility State of Science/ Technology Report. Where appropriate, a qualitative uncertainty is attached to each of the conclusion paragraphs according to the following NAPAP uncertainty classification scheme:

o	=	no basis
*	=	limited information with major uncertainties
**	=	broad information with large or unknown uncertainty or limited information with little uncertainty
***	=	broad information with known but sometimes large uncertainty
****	=	ample and certain information.

6.2.1 Data Bases

Visibility monitoring includes measurements of aerosol, optical, and scene characteristics. Measurements of particle size and composition can be used to assess visibility cause/effect relationships. The most useful optical index, extinction coefficient, can be directly measured or estimated from monitoring data on scene characteristics.

Over the last decade, much progress has been made in aerosol and optical monitoring techniques. The techniques have been applied in numerous monitoring programs to greatly expand the understanding of aerosols and visibility. However, the most comprehensive sophisticated data sets have been acquired only in the rural West and a few large urban areas. In terms of geographic extent and period of record, the archive of airport visual range observations (which is subject to data quality limitations) is by far the most extensive visibility data base.

6.2.2 Contributions to Light Extinction

**** Scattering by fine particles is generally the dominant contributor to elevated extinction coefficients. Fine particle scattering typically accounts for 75 - 95% of non-Rayleigh extinction in the eastern United States and 50 - 80% of non-Rayleigh extinction in the western United States.

**** Sulfates and organics (with the addition of ammonium nitrates in western urban areas) typically account for about three-fourths of dry fine particle mass. Sulfuric acid and its ammonium salts are most important in the East, where they typically account for at least half of the total dry fine mass. In the West, sulfate contributions to fine mass are less, about 20 - 50% in rural areas and 10 - 20% in urban areas.

**** Although there are theoretical problems in defining precise extinction budgets for aerosol species, certain conclusions are clear. Sulfates are the dominant source of light extinction in the East, contributing slightly more than half of total extinction. This conclusion is insensitive to the details of the apportionment procedure. Sulfates are but one of several major sources of extinction in the West, a finding that is again robust. The relative importance of sulfates is greater in the rural West than in the urban West and varies significantly with region (apparently greatest in the southern interior).

6.2.3 Existing and Natural Background Conditions for Visibility/Aerosols

**** Figure 24-70, a map of median visual range for rural (suburban and nonurban) areas in the United States, illustrates the large difference between the East and West in rural visibility. Several data sources indicate that standard visual range in the rural mountain/desert areas of the Southwest averages about 130 to 190 km. In contrast, rural areas south of the Great Lakes and east of the Mississippi experience median standard visual range of about 20 - 35 km. Most of this factor-of-six East/West difference is due to greater sulfate concentrations in the East and their interaction with the higher humidity of the East.

**** With respect to seasonal visibility patterns, there is only one extremely strong feature occurring on a large geographical scale within the United States—the summertime maximum in extinction coefficient (minimum in visibility) over the region south of the Great Lakes and east of the Mississippi. The predominant cause of the summertime haze peak in the East is the summertime maximum in sulfate aerosol concentrations.

*** On the average, natural background standard visual range is estimated as 230 ± 35 km in the arid parts of the West and 150 ± 45 km in the East. Comparing the natural visibility levels with current visibility levels indicates that man-made contributions account for about one-third of the average extinction coefficient in the rural West and over 80% of the average extinction coefficient in the rural East. Under worst-case pollution episodes, man-made contributions would dominate in both regions.

6.2.4 Historical Visibility Trends

*** Airport observations of prevailing visibility can be used to investigate historical trends in haziness since the late 1940's. The observed trends show significant differences by regions and by season. The most salient feature in the trends is the increase of summertime haze in the eastern United States during the 1950's and 1960's. This increase is especially strong in the southeastern states.

*** In the eastern United States, there are generally good correspondences on a regional and seasonal basis between historical haze trends and historical SOx emission trends. Since the late 1940's, the northeast region has undergone a moderate decline in haziness and emissions during the winter and a moderate increase in both during the summer. Over the same period, the southeast region has experienced a moderate increase in emissions and haziness during the winter and a strong increase in both during the summer. The increasing trends for both emissions and haziness—*i.e.*, the summer case in the Northeast as well as the winter and summer cases in the Southeast—show the greatest rise during the 1950's and 1960's with a leveling off or decrease after the early 1970's. Viewed as a whole, the data suggest that haze trends for the eastern United States have been dominated by sulfur emission trends since the late 1940's.

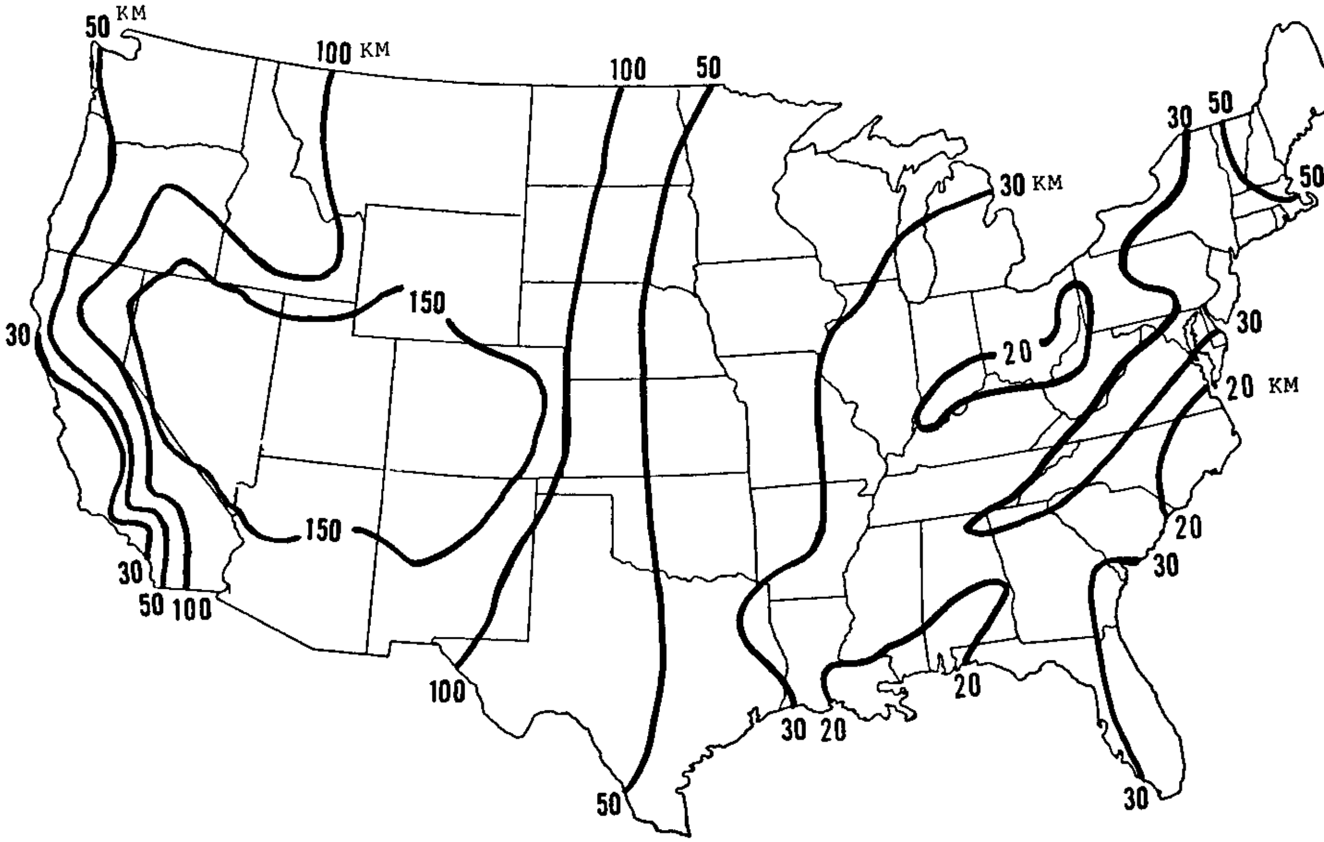

Figure 24-70 Estimated standard median visual range (km) for rural (suburban/nonurban) areas of the United States. Notes: Values are based on airport median visual ranges factored by 1.3 to account for differences in detection thresholds in estimating standard visual range. Data included for all days (all weather conditions). Data are for 1974-1976, but recent studies indicate that current conditions are approximately the same as shown here.

6.2.5 Characterization of Visibility

A full description of how images are transmitted through the atmosphere to an observer requires a knowledge of both the atmospheric transmittance (*i.e.*, the extinction coefficient) and the path radiance between the observer and the landscape feature of interest as well as the average brightness of the scene. These three variables combine to form what is known as the atmospheric modulation transfer function (*Mtf*).

*** Pollution control evaluations assume constant illumination conditions and usually involve situations where fine particle scattering is dominant. In this case, changes in the modulation transfer function are very closely related to changes in the extinction coefficient (because path radiance as well as transmittance is affected by changes in light scattering). Therefore, a knowledge of only the extinction coefficient can yield significant insight into how air pollution controls affect visibility. Furthermore, atmospheric transmittance relates well to how people judge scenic quality. Accordingly, extinction coefficient (or its reciprocal, standard visual range) is an important parameter in characterizing visibility.

** In addition to changes in extinction coefficient (or standard visual range), another method of quantifying visibility impairment is the number of cumulative "just notable changes" in scene appearance. The index, just noticeable changes, is scene specific, includes all aspects of the *Mtf* formulation, and relates directly to perception. The best way to communicate the visual effects is to create pictorial representations through image processing techniques. It should be noted, however, that the least certain part of visibility science is the part dealing with human perception and values; the JNC index and the photographic simulations are still subject to some uncertainties and scientific debate.

*** Figures 24-66 through 24-69 (Color Plates 24-9 to 24-12) illustrate the difference between natural and current average visibility for the urban East, rural East, urban West, and rural West, respectively. In the first three cases, the differences are very dramatic (representing 18 to 38 cumulative just noticeable changes). In the rural West, the differences are less dramatic, although still very perceptible (8 cumulative just noticeable changes).

6.2.6 Climate Relationships

** The *direct* climatic effects of fine particles are reflection of solar radiation back into space and absorbtion of solar radiation. Over an area of approximately 10^7 km^2 in eastern North America (and evidently over similarly sized areas in Europe and eastern Asia), the average total decrease in solar radiation at the ground is on the order of 10 $watt/meter^2$ (about 7%). This effect acts opposite to the direct radiative effects of greenhouse gases.

* In addition to the direct radiative effect of fine particles, the potential exists for a large cooling effect due to the *indirect* role of man-made particles acting as cloud condensation nuclei and thereby increasing cloud albedo. There is also some potential for a direct heating effect by coarse dust particles.

The cloud albedo and coarse particle climatic effects are not well characterized. The overall meteorological consequences of the various aerosol effects on heat balance might be large but remains uncertain.

6.3 UNCERTAINTY

Compared to many other effects of air pollutants, visibility is fairly well understood. Unlike certain acid deposition effects that are multi-media, involve cumulative buildup, or are delayed, atmospheric optical parameters are instantaneous properties of atmospheric composition. The fundamental physics relating light extinction (and other optical parameters) to atmospheric gases and particles is well established. Also, light extinction is a simple linear sum of scattering and absorption by gases and particles. Furthermore, additional sub-divisions of light extinction contributions are either exactly additive (*e.g.* coarse versus fine particles) or approximately additive (*e.g.* allocations among chemical species). In fact, even before the past decade of visibility research, visibility was called the "best understood and most easily measured effect of air pollution" (Council on Environmental Quality, 1978). The most uncertain aspect of visibility science is the part dealing with human perception and values, *i.e.* the second link in the chain from air pollutant concentrations to atmospheric optics to human evaluations.