VIII. CRITICAL ELEMENTS IN THE REVIEW OF THE SECONDARY STANDARD FOR PARTICULATE MATTER

A. Introduction

This chapter presents critical information for the review of the secondary NAAQS for particulate matter drawing upon the most relevant information contained in the CD and other significant reports. The welfare effects of most concern for this review are visibility impairment, soiling, damage to man-made materials, and damage to and deterioration of property. For each category of effects, the chapter presents (1) a brief summary of the relevant scientific information and (2) a staff assessment of whether the available information suggests consideration of secondary standards different than the recommended primary standards. Staff conclusions and recommendations related to the secondary standard for PM are presented at the end of the chapter.

It is important to note that the discussion of fine particle effects on visibility in chapter 8 of the CD is intended to only include information complementary to several other significant reviews of the science of visibility. These reports include the 1991 report of the National Acid Precipitation Assessment Program, the National Research Council's *Protecting Visibility in National Parks and Wilderness Areas* (1993), and EPA's 1995 *Interim Findings on the Status of Visibility Research*. Where appropriate, this chapter of the staff paper will cite the above reports directly.

The chapter does not address the effects of particles on climate change. As discussed in the criteria document, particles (in the submicrometer size range) can result in perturbations of the radiation field that are generally expressed as radiative forcing. Radiative forcing due to aerosols has a cooling effect on climate through the reflection of solar energy. This is in contrast to "greenhouse gas" that produces a positive long wave radiative forcing which has a warming effect. Given the complex interaction of these two phenomena and the present state of the science, it is the staff's judgment that these effects should not be addressed in this paper, but should instead be considered in the broader context of global climate change.

B. Effects of PM on Visibility

1. Definition of Visibility and Characterization of Visibility Impairment

Visibility can be defined as the degree to which the atmosphere is transparent to visible light (NRC, 1993; CD, 8-3). Visibility effects are manifested in two principal ways: (1) as local impairment (e.g., localized hazes and plumes) and (2) as regional haze. These distinctions are significant both to the ways in which visibility goals may be set and air quality management strategies may be devised.

Local-scale visibility degradation has been generally defined as impairment that is "reasonably attributable" to a single source or group of sources. A localized haze may be seen as a band or layer of discoloration appearing well above the terrain, and may result from complex local meteorological conditions. "Reasonably attributable" impairment may include contributions to local hazes by individual or several identified sources. Plumes are comprised of smoke, dust, or colored gas that obscure the sky or horizon relatively near sources. Sources of locally visible plumes, such as the plume from an industrial facility or a burning field, are often easy to identify. Overall, visible plumes appear to be minor contributors to visibility impairment in Class I areas (i.e., certain national parks, wilderness areas, and international parks as described in section 162(a) of the Clean Air Act) (NRC, 1993).

The second type of impairment, regional haze, is produced from a multitude of sources and impairs visibility in every direction over a large area, possibly over several states. Regional haze masks objects on the horizon and reduces the contrast of nearby objects. The formation, extent, and intensity of regional haze is a function of meteorological and chemical processes, which sometimes cause fine particle loadings to remain suspended in the atmosphere for several days and to be transported hundreds of kilometers from their sources (NRC, 1993). It is this second type of visibility degradation that is principally responsible for impairment in national parks and wilderness areas across the country (NRC, 1993). Visibility in urban areas may be dominated by local sources, but may be significantly affected by long-range transport of haze as well. Fine particles transported from urban areas in turn may be significant contributors to regional-scale impairment in Class I areas.

2. Significance of Visibility to Public Welfare

Visibility is an air quality-related value having direct significance to people's enjoyment of daily activities in all parts of the country. Survey research on public awareness of visual air quality using direct questioning typically reveals that 80% or more of the respondents are aware of poor visual air quality (Cohen et al., 1986). Individuals value good visibility for the well-being it provides them directly, both in the places where they live and work, and in the places where they enjoy recreational opportunities. Millions of Americans appreciate the scenic vistas in national parks and wilderness areas annually. Visibility is also highly valued because of the importance people place on protecting nationally significant natural areas, both now and in the future (i.e., preservation value). Many individuals want to protect such areas for the benefit of future generations, even if they personally do not visit these areas frequently (Chestnut et al., 1994). Tracking changes in visibility provides one measure of the success of efforts to protect such areas from environmental degradation. Society also values visibility because of the significant role it plays in air transportation. Serious episodes of visibility impairment can lead to increased risks in the air transportation industry, particularly in urban areas with high traffic levels (U.S. EPA, 1982b).

Many contingent valuation studies have been performed in an attempt to quantify benefits (or individuals' willingness to pay) associated with improvements in current visibility conditions. The results of several studies are presented in CD table 8-5 (CD, 8-83), table 8-6 (CD, 8-85), and in table VIII-1 (Chestnut et al., 1994). Past studies by Schultze (1983) and Chestnut and Rowe (1990b) have estimated the preservation values associated with improving the visibility in national parks in the Southwest to be quite significant, on the range of approximately $2-6 billion annually (CD, 8-84). Another recent study estimates visibility benefits primarily in the eastern U.S. due to reduced sulfur dioxide emissions under the acid rain program also to be quite significant, in the range of $1.7 - 2.5 billion annually by the year 2010 (Chestnut et al., 1994).

3. Mechanisms of and Contributors to Visibility Impairment

Visibility impairment has been considered the "best understood and most easily measured effect of air pollution" (Council on Environmental Quality, 1978). It is caused by the scattering and absorption of light by particles and gases in the atmosphere. It is the most noticeable effect of fine particles present in the atmosphere. Air pollution degrades the visual appearance of distant objects to an observer, and reduces the range at which they can be distinguished from the background. Ambient particles affect color of distant objects depending upon particle size and composition, the scattering angle between the observer and illumination, the properties of the atmosphere, and the optical properties of the target being viewed.

Fine particles can be emitted directly to the atmosphere through primary emissions or formed secondarily from gaseous precursors. The fine particles principally responsible for visibility impairment are sulfates, nitrates, organic matter, elemental carbon (soot), and soil dust. The efficiency of particles to cause visibility impairment depends on particle size, shape, and composition. Fine particles are effective per unit mass concentration in impairing visibility because their mean diameter is usually comparable to the wavelength of light, a condition that results in maximum light scattering. In the size range from 0.1 to 1.0 µm in diameter, fine particles are more effective per unit mass concentration at impairing visibility than either larger or smaller particles (NAPAP, 1991). Coarse particles (i.e., those in the 2.5 to 10 µm size range) also impair visibility, although less efficiently than fine particles. All particles scatter light to some degree, whereas only elemental carbon plays a significant role in light absorption. In all regions of the country, annual average light extinction is dominated by light scattering as opposed to light absorption (NRC, 1993).

Most sulfates, nitrates, and a portion of organics begin as gaseous emissions and undergo chemical transformation in the atmosphere (NAPAP, 1991; CD, 3-2). These particle constituents can readily absorb water from the atmosphere (i.e., are hygroscopic) and grow in size in a nonlinear fashion as relative humidity levels increase. In general, soluble organics are considered to be less hygroscopic than sulfates and nitrates (Sisler, 1993). The relationship between humidity and particle size is a significant factor in visibility impairment in the East, where in many locations average relative humidity exceeds 70% on an annual average basis and can surpass 80% on many days, particularly in the summer (see more detailed discussion of humidity in section 5).

Light absorption is caused mainly by elemental carbon, a product of incomplete combustion from activities such as the burning of wood or diesel fuel. Light absorption by nitrogen dioxide typically accounts for a few percent of total light extinction in urban areas and is typically negligible in remote areas (CD, 8-13). It contributes to the yellow or brown appearance of urban hazes since it absorbs blue light more strongly than other visible wavelengths. Nitrogen dioxide also may be a factor in isolated plumes from industrial sources in remote locations.

Atmospheric transport of fine particles is a critical factor affecting regional visibility conditions. Fine particles and their precursors can remain in the atmosphere for several days and can be carried hundreds or even thousands of kilometers from their sources to remote locations, such as national parks and wilderness areas (NRC, 1993).

4. Background Levels of Light Extinction

The light extinction coefficient represents the summation of light scattering and light absorption due to particles and gases in the atmosphere. Both anthropogenic and non-anthropogenic sources contribute to light extinction. The light extinction coefficient is represented by the following equation:

$$\sigma_{ext} = \sigma_{sg} + \sigma_{ag} + \sigma_{sp} + \sigma_{ap}$$

where σ_{sg} = light scattering by gases (also known as Rayleigh scattering)
σ_{ag} = light absorption by gases
σ_{sp} = light scattering by particles
σ_{ap} = light absorption by particles (CD, 8-12).

Light extinction is commonly expressed in terms of inverse kilometers (km^{-1}) or inverse megameters (Mm^{-1}), where increasing values indicate increasing impairment.

a. Rayleigh Scattering

Rayleigh scattering represents the degree of natural light scattering found in a particle-free atmosphere, caused by the gas molecules that make up "blue sky" (e.g., N_2, 0_2, CO_2). It accounts for a relatively constant level of light extinction nationally, between 10-12 Mm^{-1} (NAPAP, 1991; U.S. EPA, 1979). The concept of Rayleigh scattering can be used to establish a theoretical maximum horizontal visual range in the earth's atmosphere. At sea level, this maximum visual range is approximately 330 kilometers. Since certain meteorological circumstances can result in visibility conditions that are close to "Rayleigh," it is analogous to a baseline or boundary condition against which other extinction components can be compared.

b. Light Extinction Due to Background Particulate Matter

Light extinction caused by PM from non-anthropogenic sources can vary significantly from day to day and location to location due to natural events such as wildfire, dust storms, and volcanic eruptions. It is useful to consider estimates of background concentrations of PM on an annual average basis, however, when evaluating the relative contributions of anthropogenic and non-anthropogenic sources to total light extinction.

The CD identifies several alternative definitions of "background" concentrations of PM (CD, 6-32). For the purposes of this document, background PM is defined as the distribution of PM concentrations that would be observed in the U.S. in the absence of anthropogenic emissions of PM and precursor emissions of VOC, NO_x, and SO_x in North America. Table IV-4 describes the range for annual average regional background $PM_{2.5}$ mass in the East as 2-5 $\mu g/m^3$, and in the West 1-4 $\mu g/m^3$. For PM_{10}, the estimated annual average background concentrations range from 5-11 $\mu g/m^3$ in the East, and 4-8 $\mu g/m^3$ in the West. The lower bounds of these ranges, taken from estimates in the 1990 report of the National Acid Precipitation Assessment Program, are based on compilations of natural versus human-made emission levels, ambient measurements in remote areas, and regression studies using human-made and/or natural tracers (NAPAP, 1991; Trijonis, 1982). The upper bounds are derived from the multi-year annual averages of remote monitoring sites in the IMPROVE network (Malm et al., 1994). It is important to note, however, that IMPROVE data used here reflect the effects of background <u>and</u> anthropogenic emissions from within North America and therefore provide conservative estimates of the upper bounds.

Table VIII-2 from the NAPAP report includes estimates of annual average background concentrations of PM by aerosol constituent, as well as their related contributions to light extinction, expressed in inverse megameters (Mm^{-1}) (NAPAP, 1991). On an hourly or daily basis background concentrations will vary considerably depending on seasonal, meteorological, and geographic factors. The table illustrates that estimated extinction contributions from Rayleigh scattering plus background levels of fine and coarse particles, in the absence of anthropogenic emissions of visibility-impairing particles, are 26 plus or minus 7 Mm^{-1} in the East, and 17 plus or minus 2.5 Mm^{-1} in the West. These equate to a naturally-occurring visual range in the East of 150 plus or minus 45 kilometers, and 230 plus or minus 40 kilometers in the West. Excluding light extinction due to Rayleigh scatter, annual average background levels of fine and coarse particles are estimated to account for 14 Mm^{-1} in the East and about 6 Mm^{-1} in the West. Major contributors that reduce visibility from the Rayleigh maximum to the ranges noted above are naturally-occurring organics, suspended dust (including coarse particles), and water. In these ranges of fine particle concentrations, small changes have a large effect on total extinction. Thus, one can see from table VIII-2 that higher levels of background fine particles and associated humidity in the East result in a fairly significant difference between naturally-occurring visual range in the rural East and West.

5. Overview of Current Visibility Conditions

Annual average visibility conditions (i.e., total light extinction due to anthropogenic and non-anthropogenic sources) vary regionally across the U.S. The rural East generally has higher levels of impairment than remote sites in the West, with the exception of the San Gorgonio Wilderness, Point Reyes National Seashore, and Mount Rainier, which have annual average levels comparable to certain sites in the Northeast. Higher averages in the East are due to generally higher concentrations of anthropogenic fine particles and precursors, higher background levels of fine particles, and higher average relative humidity levels.

Visibility conditions also vary significantly by season of the year. With the exception of remote sites in the northwestern U.S., visibility is typically worse in the summer months. This is particularly true in the Appalachian region, where average extinction in the summer exceeds the annual average by 40% (Sisler et al., 1996).

Figures VIII-1 and VIII-2 present 3-year (March 1992 - February 1995) averages of monitored visibility levels for 44 IMPROVE protocol sites nationally. The regional variation in current conditions is quite apparent from these figures. Figure VIII-1 expresses conditions in terms of the extinction coefficient. The highest annual average levels are found in the rural

East, where the coefficient ranges from about 100-160 Mm^{-1} (about 23-39 kilometers visual range) for several rural sites south of the Great Lakes and east of the Mississippi River. This means that in certain eastern sites, 3-year average light extinction due to anthropogenic sources is 4 to 6 times natural light extinction levels.

The 3-year average extinction coefficient for many western sites ranges from about 30-70 Mm^{-1} (about 55-150 kilometers visual range), with the lowest extinction found in the intermountain west and Colorado plateau regions. Most of this difference between East and West is due to greater sulfate concentrations and the effect of higher humidity levels on this sulfate in the East (NAPAP, 1991). Studies of historical visibility trends have shown a fairly strong correlation between long-term light extinction levels and sulfur dioxide emissions. This correlation is illustrated for the northeast and southeast U.S. in figure IV-8 and is further discussed in section IV.B. of the staff paper.

Figure VIII-2, which expresses 3-year average visibility conditions in terms of deciviews, shows the same regional variability. Pristine or Rayleigh conditions are represented by a deciview of zero, whereas the highest 3-year average level of impairment in a remote site is 28 deciview in Alabama's Sipsey Wilderness. Under many circumstances, a change of one deciview represents a change perceptible to the average person. By using the deciview scale, the effect of aerosol extinction on human perception is portrayed as a linear scale of visibility degradation. Most of the sites in the intermountain west and Colorado Plateau have impairment of 12 deciviews or less. The northwest and eastern half of the U.S. have values greater than 15 deciviews, with much of the east having values exceeding 23 deciviews.

Figures VIII-3 and VIII-4 present multi-year averages for $PM_{2.5}$ and PM_{10} at IMPROVE sites. Analyses of aerosol constituents from these data are used in determining the light extinction coefficient and deciview. Again, regional variability is apparent, with 3-year average $PM_{2.5}$ levels for most rural western sites in the 2-5 $\mu g/m^3$ range, and levels in the rural East in the 9-15 $\mu g/m^3$ range. Figure VIII-5 compares $PM_{2.5}$ mass to PM_{10} mass for each IMPROVE site. It illustrates that fine PM comprises a larger fraction of PM_{10} in remote eastern (60-70%) versus western (40-50%) locations.

Figures VIII-6 and VIII-7 show the seasonal variability of visibility impairment, expressed in terms of the deciview. One can see that in the rural East, seasonal averages are generally highest in the summer, with values exceeding 30 deciview at Shenandoah National Park and the Sipsey Wilderness in Alabama, and they are generally lowest in the winter. In the Southwest, impairment is slightly higher in the summer and winter, ranging from 10-13 deciview. In the Northwest and northern Rockies, impairment is highest in the autumn and winter. The following subsections further explain significant reasons for the regional variability in visibility impairment.

a. Role of Humidity in Light Extinction

As mentioned previously, humidity plays a significant role in the impairment of visibility by fine particles, particularly in the East, where annual average relative humidity levels are 70-80% as compared to 50-60% in the West (Sisler et al., 1993). Table VIII-2 accounts for relative humidity effects by assigning an extinction efficiency for water associated with aerosols, while extinction efficiencies found in table VIII-3 are modified by a relative humidity adjustment factor in calculating total extinction. The adjustment factor represents 1) the hygroscopic nature of the aerosol constituent, and 2) the average annual humidity for the relevant location (Sisler et al., 1993).

Because annual average relative humidity is higher in the East, the same ambient concentration of sulfate, for example, will on average lead to greater light extinction in an eastern location rather than a western one. The top map in figure VIII-8 illustrates the regional variability of annual mean relative humidity nationwide. The bottom map depicts the variability of the relative humidity correction factor used for sulfates in an analysis of IMPROVE data (Sisler et al., 1993). For example, when corrected for humidity, the overall extinction efficiency for sulfates in the East may exceed 11-12 m^2/g, whereas the extinction efficiency for sulfate in the West may be one-third to one-half of that.

b. Significance of Anthropogenic Sources of Fine Particles

On an annual average basis, the concentrations of background fine particles are generally small when compared with concentrations of fine particles from anthropogenic sources (NRC, 1993). The same relationship holds true when one compares annual average light extinction due to background fine particles with light extinction due to background plus anthropogenic sources. Table VIII-4 makes this comparison for several locations across the country by using background estimates from table VIII-2 and light extinction values derived from monitored data from the IMPROVE network. These data indicate that anthropogenic emissions make a significant contribution to average light extinction in most parts of the country, as compared to the contribution from background fine particle levels. Man-made contributions account for about one-third of the average extinction coefficient in the rural West and more than 80% in the rural East (NAPAP, 1991).

It is important to note that even in those areas with relatively low concentrations of anthropogenic fine particles, such as the Colorado plateau, small increases in anthropogenic fine particle concentrations can lead to significant decreases in visual range. This is one reason why Class I areas have been given special consideration under the Clean Air Act. This relationship is illustrated by figure VIII-9, which relates changes in fine particle concentrations to perceptible changes in visibility (represented by the deciview metric). The graph shows that in cleaner areas, such as the West, perceptible visibility changes are more sensitive to existing fine particle concentrations than is the case in more polluted areas. In other words, to achieve a given amount of perceived visibility improvement, a larger reduction in fine particle concentration is required in areas with higher existing concentrations, such as the East, than would be required in lower concentration areas. This figure also illustrates the relative importance of the overall extinction efficiency of the pollutant mix at particular locations. At a given ambient concentration, areas having higher average extinction efficiencies (expressed in m^2/g in figure VIII-9) due to the mix of pollutants would have higher levels of impairment. In the East, the combination of higher humidity levels and a greater percentage of sulfate as compared to the West causes the average extinction efficiency for fine particles to be almost twice that in the Colorado Plateau.

c. Regional Differences in Specific Pollutant Concentrations

As total light extinction levels vary significantly across the country, so does the mix of visibility-impairing pollutants from region to region. Table VIII-5, taken from the 1993 National Research Council study on visibility, shows the estimated contribution of various anthropogenic pollutants to visibility impairment for three main regions of the U.S. The table takes into account relative emissions levels of each pollutant type within each region. This and other analyses (Sisler et al., 1993) show that sulfates are a significant cause of visibility impairment in all parts of the country, but particularly in the East, where they are responsible for about two-thirds of overall light extinction. In the Southwest and Northwest, organics play a larger role, as does elemental carbon. Suspended dust is also a major constituent in the Southwest. The main categories of sources responsible for visibility-impairing fine particle and precursor emissions are listed in table VIII-6 (NRC, 1993).

d. Regional Variation in Urban Visibility

Visibility impairment has been studied in several major cities in the past decade (e.g. Middleton, 1993) because of concerns about fine particles and their potentially significant impacts (e.g., health-related and aesthetic) on the residents of large metropolitan areas. Urban areas generally have higher loadings of fine particulate matter than monitored Class I areas, suggesting that visibility impairment in urban areas is typically greater than in rural areas. Monitored annual mean and second highest maximum 24-hour fine particle levels for selected urban areas are listed in Table IV-4. These levels are generally higher than those found in the IMPROVE database for rural Class I areas.

The degree to which different aerosol constituents contribute to overall light extinction in urban areas can vary significantly. Table VIII-7 illustrates the difference between percentage contributions of aerosol constituents to annual average total light extinction in the Washington, DC urban area and the southern California areas. The dominance of sulfate in Washington, DC exhibits a regional effect stemming from sulfur dioxide emissions outside the metropolitan area. In contrast, nitrate plays the greatest role in the overall light extinction levels in the mountainous areas just outside Los Angeles, with most of the nitrate formation in this area coming from nitrogen dioxide emissions within the urban area.

6. Measures of Visibility Impairment and Light Extinction.

Several atmospheric optical indices and approaches can be used for characterizing visibility impairment and light extinction. The CD discusses several indicators that could be used in regulating air quality for visibility protection, including: 1) light extinction (and related parameters of visual range and deciview) calculated from measurements of fine particle constituents and their associated scattering and absorption; 2) light extinction measured directly by transmissometer; 3) light scattering by particles, measured by nephelometer; 4) fine particle mass concentration; 5) contrast transmittance (CD, 8-125).

In conjunction with the National Park Service, other Federal land managers, and State organizations, EPA has supported since 1986 a monitoring protocol utilizing a combination of the first four measurements. This long-term visibility monitoring network is known as IMPROVE (Interagency Monitoring of PROtected Visual Environments. The following discussion briefly describes the IMPROVE protocol and provides rationale supporting use of the light extinction coefficient, derived from both direct optical measurements and measurements of aerosol constituents, for purposes of implementing air quality management programs to improve visibility.

IMPROVE provides direct measurement of fine particles and precursors that contribute to visibility impairment at more than 40 mandatory Federal Class I areas across the country. The IMPROVE network employs aerosol, optical, and scene measurements. Aerosol measurements are taken for PM_{10} and $PM_{2.5}$ mass, and for key constituents of $PM_{2.5}$, such as sulfate, nitrate, organic and elemental carbon, soil dust, and several other elements. Measurements for specific aerosol constituents are used to calculate "reconstructed" aerosol light extinction by multiplying the mass for each constituent by its empirically-derived scattering and/or absorption efficiency. Knowledge of the main constituents of a site's light extinction "budget" is critical for source apportionment and control strategy development. Optical measurements are used to directly measure light extinction or its components. Such measurements are taken principally with either a transmissometer, which measures total light extinction, or a nephelometer, which measures particle scattering (the largest human-caused component of total extinction). Scene characteristics are recorded 3 times daily with 35 millimeter photography and are used to determine the quality of visibility conditions (such as effects on color and contrast) associated with specific levels of light extinction as measured under both direct and aerosol-related methods. Because light extinction levels are derived in two ways under the IMPROVE protocol, this overall approach provides a cross-check in establishing current visibility conditions and trends and in determining how proposed changes in atmospheric constituents would affect future visibility conditions.

The light extinction coefficient has been widely used in the U.S. for many years to describe visibility conditions and the change in visibility experienced due to changes in concentrations of air pollutants. As noted earlier, the extinction coefficient can be defined as the fraction of light lost or redirected per unit distance through interactions with gases and suspended particles in the atmosphere. Direct relationships exist between measured ambient pollutant concentrations and their contributions to the extinction coefficient. The contribution of each aerosol constituent to total light extinction is derived by multiplying the aerosol concentration by the extinction efficiency for that aerosol constituent. Extinction efficiencies vary by type of aerosol constituent and have been obtained through empirical studies. For certain aerosol constituents, extinction efficiencies increase significantly with increases in relative humidity.

In addition to the optical effects of atmospheric constituents as characterized by the extinction coefficient, lighting conditions and scene characteristics play an important role in determining how well we see objects at a distance. Some of the conditions that influence visibility include whether a scene is viewed towards the sun or away from it, whether the scene is shaded or not, and the color and reflectance of the scene (NAPAP, 1991). For example, a mountain peak in bright sun can be seen from a much greater distance when covered with snow than when it is not.

One's ability to see an object is degraded both by the reduction of image forming light from the object caused by scattering and absorption, and by the addition of non-image forming light that is scattered into the viewer's sight path. This non-image forming light is called path radiance (CD, 8-23). A common example of this effect is our inability to see stars in the daytime due to the brightness of the sky caused by Rayleigh scattering. At night, when the sunlight is not being scattered, the stars are readily seen. This same effect causes a haze to appear bright when looking at scenes that are generally towards the direction of the sun and dark when looking away from the sun.

Though these non-air quality related influences on visibility can sometimes be significant, they cannot be accounted for in any practical sense in formulation of national or regional measures to minimize haze. Lighting conditions change continuously as the sun moves across the sky and as cloud conditions vary. Non-air quality influences on visibility also change when a viewer of a scene simply turns his head. Regardless of the lighting and scene conditions, however, sufficient changes in ambient concentrations of PM will lead to changes in visibility (and the extinction coefficient). The extinction coefficient integrates the effects of aerosols on visibility, yet is not dependent on scene-specific characteristics. It measures the changes in visibility linked to emissions of gases and particles that are subject to some form of human control and potential regulation, and therefore can be useful in comparing visibility impact potential of various air quality management strategies over time and space (NAPAP, 1991).

By apportioning the extinction coefficient to different aerosol constituents, one can estimate changes in visibility due to changes in constituent concentrations (Pitchford and Malm, 1994). The National Research Council's 1993 report *Protecting Visibility in National Parks and Wilderness Areas* states that "[P]rogress toward the visibility goal should be measured in terms of the extinction coefficient, and extinction measurements should be routine and systematic." Thus, it is reasonable to use the change in the light extinction coefficient, determined in multiple ways, as the primary indicator of changes in visibility for regulatory purposes.

Visual range is a measure of visibility that is inversely related to the extinction coefficient. Visual range can be defined as the maximum distance at which one can identify a black object against the horizon sky. The colors and fine detail of many objects will be lost at a distance much less than the visual range, however. Visual range has been widely used in air transportation and military operations in addition to its use in characterizing air quality. Because it is expressed in familiar units and has a straightforward definition, visual range is likely to continue as a popular measure of atmospheric visibility (Pitchford and Malm, 1994). Conversion from the extinction coefficient to visual range can be made with the following equation (NAPAP, 1991):

$$\text{Visual Range} = 3.91/\sigma_{ext}$$

Another important visibility metric is the deciview, which describes changes in uniform atmospheric extinction that can be perceived by a human observer. It is designed to be linear with respect to perceived visual changes over its entire range in a way that is analogous to the decibel scale for sound (Pitchford and Malm, 1994). Neither visual range nor the extinction coefficient has this property. For example, a 5 km change in visual range or 0.01 km^{-1} change in extinction coefficient can result in a change that is either imperceptible or very apparent depending on baseline visibility conditions. Deciview allows one to more effectively express perceptible changes in visibility, regardless of baseline conditions. A one deciview change is a small but perceptible scenic change under many conditions, approximately equal to a 10% change in the extinction coefficient. The deciview metric also may be useful in defining goals for perceptible changes in visibility conditions under future regulatory programs. Deciview can be calculated from the light extinction coefficient by the equation:

$$dv = 10\log_{10}(\sigma_{ext}/10\ Mm^{-1})$$

Figure VIII-10 graphically illustrates the relationships among light extinction, visual range, and deciview.

7. Policy Considerations Pertaining to the Effects of PM on Visibility

Impairment of visibility in multi-state regions, urban areas, and Class I areas is clearly an effect of particulate matter on public welfare. The staff has considered a number of factors in assessing appropriate regulatory responses.

An initial question is whether the range of recommended primary standards for fine PM would provide adequate protection against visibility impairment across the country. The range being considered for an annual PM-fine standard is 12.5 $\mu g/m^3$ to less than 20 $\mu g/m^3$ and the range under consideration for a 24-hour standard is 18 $\mu g/m^3$ to less than 65 $\mu g/m^3$. Table IV-4 presents monitored fine particle annual averages and second highest maximum levels for several major U.S. cities. Analysis of these data suggests that adoption of an annual fine particle standard in the lower half of the recommended range, in combination with adoption of a 24-hour standard in the lower half of the recommended range, would be expected to lead to reductions in annual average fine particle concentrations in many urban areas nationally. Additionally, reductions could be achieved in broader areas in the East if regional attainment strategies are carried out. To examine expected regional visibility improvements resulting from these reductions requires an understanding of the various factors affecting the relationship between fine particle loadings and visibility, such as background levels, humidity, and pollutant mix, as described in section 5 above.

Expected reductions in fine particle concentrations resulting from adoption of the primary fine particle standards in the lower half of the recommended range is likely to result in maintained or improved visibility in many urban areas and in a broader area in the East. As with reductions in fine particle concentrations noted above, improvement of visibility would be greater if regional fine particle attainment strategies are carried out. In its 1993 Report to Congress on the effects of Clean Air Act programs on visibility in mandatory federal Class I areas, EPA examined the impact of expected regional sulfur dioxide reductions under the acid rain program (U. S. EPA, 1993). This report estimated that regional annual average sulfate levels would be reduced over a wide area in the eastern U.S. by the year 2010, resulting in potential improvements in visibility for the region. The analysis projected no expected improvement in the rural West. Moreover, despite projected improvements in visibility, there is no evidence that adoption of the primary fine particle standards in the lower half of the recommended range will eliminate visibility impairment.

The staff has also considered whether the adoption of a national secondary standard would provide adequate and appropriate protection of public welfare across the country. Due to the regional variability in visibility conditions created by background fine particle levels and humidity, the staff has concluded that a national secondary standard would not be the most appropriate means to achieve this objective. The data presented in table VIII-4 indicates that current annual average light extinction levels on the Colorado Plateau (reflecting effects of anthropogenic and background sources of PM) are about equal to background levels (i.e., those levels representing an absence of anthropogenic contributions) in the East. Thus, a national secondary standard set to maintain or improve visibility conditions on the Colorado Plateau would have to be set at or below natural background levels in the East, effectively requiring elimination of all anthropogenic (and some nonanthropogenic) emissions. Conversely, a national secondary standard that would be both attainable and improve visibility in the East would permit further degradation in the West.

An approach which would be more responsive to visibility protection goals, while recognizing these significant regional variations, would be to establish a regional haze program under section 169A of the Clean Air Act. This program, while designed to address the existing adverse effects of fine particles on visibility in Class I areas, would further contribute to visibility improvement in non-Class I areas as well. Section 169A established a national goal of "the prevention of any future, and the remedying of any existing, manmade impairment of visibility in mandatory Class I areas." The EPA is required to establish programs to ensure reasonable progress toward the national goal. These programs are to be implemented by the States and can be regionally specific. Concern with regional visibility impacts to highly valued national parks and wilderness areas in the U.S. led to the inclusion of specific language in section 169B of the 1990 Clean Air Act Amendments, requiring EPA to form the Grand Canyon Visibility Transport Commission. In June 1996, the Commission provided the Administrator with recommendations for regional approaches to protecting visibility. The work of the Commission will be useful to development of a regional haze program under section 169A of the Act.

Much progress has been made in technical areas important to the successful implementation of a regional haze program, including areas such as visibility monitoring, regional scale modeling, and scientific knowledge of the regional effects of particles on visibility. The National Academy of Sciences 1993 report on visibility protection confirmed this point:

> Current scientific knowledge is adequate and control technologies are available for taking regulatory action to improve and protect visibility. However, continued national progress toward this goal will require a greater commitment toward atmospheric research, monitoring, and emissions control research and development.

In addition, as noted above, it is expected that the development of a regional haze program would have associated benefits outside of mandatory Class I areas. The National Academy of Sciences concluded the following:

> Efforts to improve visibility in Class I areas also would benefit visibility outside these areas. Because most visibility impairment is regional in scale, the same haze that degrades visibility within or looking out from a national park also degrades visibility outside it. Class I areas cannot be regarded as potential islands of clean air in a polluted sea.

Based on the above considerations, the staff recommends that the Administrator consider establishing a regional haze program under section 169A of the Act, in conjunction with the recommended fine particle primary standards, as the most effective means of addressing the welfare effects associated with visibility impairment. Together, the two programs and associated control strategies should adequately protect against the effects of fine particle pollutants on visibility and make reasonable progress toward the national visibility goal for Class I areas.

C. Effects of PM on Materials Damage and Soiling

The deposition of airborne particles can become a nuisance, reducing the aesthetic appeal of buildings and culturally important articles through soiling, and contribute directly (or in conjunction with other pollutants) to structural damage by means of corrosion or erosion. These potential effects are discussed more fully below. The relative importance of particle size, composition, and other environmental factors (i.e., moisture, temperature, sunlight, and wind) in contributing to the effects is also considered.

1. Materials Damage

Particles affect materials principally by promoting and accelerating the corrosion of metals, by degrading paints, and by deteriorating building materials such as concrete and limestone. Particles contribute to these effects because of their electrolytic, hygroscopic, and acidic properties, and their ability to sorb corrosive gases (principally sulfur dioxide). The staff review suggests that only chemically active fine mode or hygroscopic coarse mode (mainly sea or road salt) particles contribute to such effects (U.S. EPA, 1986b). While particles have been qualitatively associated with damage to materials, there are insufficient data at present to relate such effects to specific particle pollution levels. The following discussion briefly outlines the available information on PM-related effects associated with each category of material presented in the criteria document.

a. Effects on Metals

The rate of metal corrosion depends on a number of factors, including the deposition rate and nature of the pollutant; the influence of the metal protective corrosion film; the amount of moisture present; variability in the electrochemical reactions; the presence and concentration of other surface electrolytes; and the orientation of the metal surface (CD, Chapter 9). This section briefly discusses the factors affecting metal corrosion set forth in the criteria document.

Nriagu (1978) and Sydberger (1977) conducted studies that highlighted the ability metals have to form a protective film that slows corrosion rates. Metals initially exposed to low concentrations of SO_x corroded at a slower rate than did samples continuously exposed to higher concentrations. This protective corrosion layer may, however, be affected by either dry or wet deposition (CD, Chapter 9).

The rate of metal corrosion decreases in the absence of moisture (CD, Chapter 9). Moisture influences corrosion rates by providing a medium of conduction paths for electrochemical reactions and a medium for water soluble air pollutants. Schwartz (1972) established that the corrosion rate of a metal could increase by 20 percent for each one percent increase in relative humidity above the minimum atmospheric moisture content that allows corrosion to occur (i.e., critical relative humidity). Later studies by Haynie and Upham (1974) and Sydberger and Ericsson (1977) supported Schwartz's theory.

While particles alone have some effect on the early stages of metal corrosion, there is insufficient evidence to relate such effects to specific particle levels. One study (Goodwin et al. (1969)) reported damage to steel, protected with nylon screen, exposed to quartz particles larger than 5 µm; but the exposure time and concentration were not reported. Barton (1958) also found that dust contributed to the early stages of metal corrosion. A number of the studies evaluated concluded that particulate matter increased the corrosion rate of sulfur dioxides (Sanyal and Singhania, (1956); Yocom and Grappone, (1976); Johnson et al., (1977); Russell, (1976); Walton et al., (1982)). Laboratory studies show mixed results as to whether catalytic species or conductance of the thin-film surface electrolyte is the cause of the increases in corrosion rates (Walton et al., 1982; Skerry et al., 1988 a,b; Askey et al., 1993).

Results of actual field studies have not established a quantitative relationship between particles and corrosion. Thus, the independent effect of particles is not evident since SO_2 is the controlling factor for determining corrosion rate (U.S. EPA, 1986b). Edney et al. (1989) exposed galvanized steel panels to actual field conditions in Research Triangle Park, NC and Steubenville, OH between April 25 and December 28, 1987. The panels were exposed under the following conditions: (1) dry deposition only; (2) dry plus ambient wet deposition; and (3) dry deposition plus deionized water. The average concentrations for SO_2 and particulate matter was 22 ppb and 70 $\mu g/m^3$ and < 1 ppb and 32 $\mu g/m^3$ for Steubenville and Research Triangle Park, respectively. The runoff from the steel panel was analyzed and it was concluded that the dissolution of the steel corrosion products for both sites was likely the result of deposited gas phase SO_2 on the metal surface and not particulate matter. Another study conducted by Butlin et al. (1992) also demonstrated that the corrosion of mild steel and galvanized steel was SO_2-dependent. Butlin et al. monitored the corrosion of steel samples by SO_2 and ozone under artificially fumigated environments, and NO_2 under natural conditions. Annual average SO_2 concentrations ranged from 2.1 $\mu g/m^3$ in a rural area to 60 $\mu g/m^3$ in one of the SO_2-fumigated locations. Annual average NO_2 concentrations ranged from 1.5 to 61.8 $\mu g/m^3$. The study concluded that corrosion of the steel samples was primarily dependent on the long-term SO_2 concentration and was only minimally affected by nitrogen oxides.

b. Effects on Paint

Paints undergo natural weathering processes from exposure to environmental factors such as sunlight, moisture, fungi, and varying temperatures. In addition to the natural environmental factors, studies show particulate matter exposure may give painted surfaces a dirty appearance (CD, Chapter 9). Several studies also suggest that particles serve as carriers of other more corrosive pollutants, allowing the pollutants to reach the underlying surface or serve as concentration sites for other pollutants (Cowling and Roberts, 1954).

A number of studies have shown some correlation between particulate matter and damage to automobile finishes. Fochtman and Langer (1957) reported damage to automobile finishes due to iron particles emitted from nearby industrial facilities. General Motors conducted field tests in Jacksonville, Florida to determine the effect of various meteorological events, the chemical composition of rain and dew, and the ambient air composition during the event, on automotive paint finishes. Painted (basecoat/clearcoat technology) steel panels were exposed for varying time periods, under protected and unprotected condition. The researcher concluded that calcium sulfate formed on the painted surface by the reaction of calcium from dust and sulfuric acid contained in rain or dew. The damage to the paint finish increased with increasing days of exposure (Wolff et al., 1990).

Paint films permeable to water are also susceptible to penetration by acid forming aerosols (U.S. EPA, 1995). Baedecker et al. (1991) reviewed studies dealing with solubility and permeability of SO_2 in paints and polymer films. These studies showed permeation and absorption rates varied depending on the formulation of the paint.

Studies reported in the criteria document (Spence et al., (1975); Campbell et al., (1974); Haynie and Spence, (1984); Yocom and Grappone, (1976); and Yocom and Upham, (1977)) support the conclusion that gaseous pollutants contribute to the erosion rates of exterior paints.

c. Effects on Stone

Damage to calcareous stones (i.e., limestone, marble and carbonated cemented stone) has been attributed to deposition of acidic particles. Moisture and salts are considered the most important factors in building material damage (CD, Chapter 9). However, many other factors (such as normal weathering and microorganism damage) also seem to play a part in the deterioration of inorganic building materials. The relative importance of biological, chemical, and physical mechanisms has not been studied to date. Thus, the relative contribution of ambient pollutants to the damage observed in various building stone is not well quantified.

Baedecker et al. (1991) reported that 10 percent of chemical weathering of marble and limestone was caused by wet deposition of hydrogen ions from all acid species. Dry deposition of SO_2 between rain events caused 5 to 20 percent of the chemical erosion of stone, and dry deposition of nitric acid was responsible for 2 to 6 percent of the erosion (Baedecker et al., 1991). Under high wind conditions, particulates result in slow erosion of the surfaces, similar to sandblasting (Yocom and Upham, 1977).

d. Effects on Electronics

Exposure to ionic dust particles can contribute significantly to the corrosion rate of electronic devices, ultimately leading to failure. Particles derived from both natural and anthropogenic sources and ranging in size from tens of angstroms to one µm can cause corrosion of electronics because many are sufficiently hygroscopic and corrosive, at normal relative humidities, to react directly with non-noble metal and passive oxides, or to form conductive moisture films on insulating surfaces to cause electrical leakage. The effects of particles on electronic components were first reported by telephone companies who reported that particles high in nitrates caused corrosion, cracking, and ultimate failure of wire spring relays (Hermance, 1966; McKinney and Hermance, 1969). More recently, Sinclare (1992) and Frankenthal (1993) have reported that anthropogenically-derived particles penetrating into indoor environments can contribute to the corrosion of electronics.

2. Staff Considerations Pertaining to the Effects of PM on Materials Damage

While particles, particularly in conjunction with sulfur dioxide, have been qualitatively associated with damage to materials, there is insufficient data available to relate such damage to specific particle levels in the ambient air. Absent better quantitative data, the staff does not believe the Administrator should consider a separate secondary standard based on materials damage.

3. Soiling

Soiling is the accumulation of particles on the surface of an exposed material resulting in the degradation of its appearance. When such accumulation produces sufficient changes in reflection from opaque surfaces and reduces light transmission through transparent materials, the surface will become perceptibly dirty to the human observer. Soiling can be remedied by cleaning or washing, and depending on the soiled material, repainting.

Determination of what accumulated level of particulate matter leads to increased cleaning or repainting is difficult. For example, Carey (1959) found that the appearance of soiling only occurred when the surface of paper was covered with dust specks spaced 10 to 20 diameters apart. When the contrast was strong, e.g., black on white, it was possible to distinguish a clean surface from a surrounding dirty surface when only 0.2 percent of the areas was covered with specks, while 0.4 percent of the surface had to be covered with specks with a weaker color contrast.

Hancock et al. (1976) found that with maximum contrast, a 0.2 percent surface coverage (effective area coverage; EAC) by dust can be perceived against a clean background. A dust deposition level of 0.7 percent EAC was needed before the object was considered unfit for use. The minimum perceivable difference between varying gradations of shading was a change of about 0.45 percent EAC. Using the information on visually perceived dust accumulation, Hancock et al. (1976) concluded that dustfall rates of less than 0.17 EAC/day would be tolerable to the general public. Similar studies have not been reported for other soiling effects.

Despite the observation that airborne particles soil a wide range of man-made materials, there is only limited information available with respect to size and composition of the culpable particles. In general, the soiling of fabrics and vertical surfaces has been ascribed to fine particles, particularly dark, carbonaceous materials. Soiling of horizontal surfaces may result from deposition of a wide range of particles, including coarse mode dusts.

An important consideration in assessing soiling potential is deposition velocity, which is defined as flux divided by concentration. Deposition velocity is a function of particle diameter, surface orientation and roughness, wind speed, atmospheric stability, and particle density. As a result, soiling is expected to vary with the size distribution of particles within an ambient concentration, whether the surface is positioned horizontally or vertically, and whether the surface is rough or smooth (CD, Chapter 9).

Theoretically, coverage of horizontal surfaces will be related to particle surface areas and deposition velocity. Particle surface areas per unit mass decreases linearly with diameter (assuming spherical particles), while, under quiescent conditions, deposition velocity increases with the square of the diameter. Under such conditions, large particles would result in more soiling than an equivalent mass of smaller particles. Although second order effects may enhance fine particle deposition relative to larger particles, deposition velocity data still suggest substantially higher deposition on horizontal surfaces for particles larger than 10 µm than for smaller particles (U.S. EPA, 1982b).

The increasing soiling potential associated with increased particle size is mitigated by lighter particle color, effects of rainfall, smaller transport distance from sources and markedly lower penetration of larger particles to indoor surfaces (relative to smaller particles). Because these conflicting factors have not been fully evaluated, it is not possible to make clear particle size divisions with respect to soiling of horizontal surfaces.

The time interval that it takes to transform horizontal and vertical surfaces from clean to perceptibly dirty is generally determined by particle composition and rate of deposition. The process is influenced by the location (sheltered or unsheltered) and spatial alignment of the material, the texture and color of the surface relative to the particles, and meteorological variables such as moisture, temperature, and wind speed.

Haynie and Lemmons (1990) conducted a soiling study in a relatively rural environment in Research Triangle Park, North Carolina. The study was designed to determine how various environmental factors contribute to the rate of soiling of white painted surfaces, which are highly sensitive to soiling by dark particles and represent a large fraction of all man-made surfaces exposed in the environment. Hourly rainfall and wind speed, and weekly data for dichotomous sampler measurements and TSP concentration were monitored. Gloss and flat white paints were applied to hardboard house siding surfaces and exposed vertically and horizontally for 16 weeks, either sheltered or unsheltered from rainfall. Measurements, including reflectance, were taken at 2, 4, 8, and 16 weeks. Based on the results of this study, the authors concluded that: (1) coarse mode particles initially contribute more to soiling of both horizontal and vertical surfaces than fine mode particles; (2) coarse mode particles, however, are more easily removed by rain than are fine mode particles; (3) for sheltered surfaces, reflectance changes are proportional to surface coverage by particles, and particle accumulation is consistent with deposition theory; (4) rain interacts with particles to contribute to soiling by dissolving or desegregating particles and leaving stains; and (5) very long-term remedial actions are probably taken because of the accumulation of fine rather than coarse particles (Haynie and Lemmons, 1990).

Creighton et al. (1990) reported that horizontal surfaces soiled faster than vertical surfaces and that large particles were primarily responsible for the soiling of horizontal surfaces not exposed to rainfall. Soiling was related to the accumulated mass of particles from both the fine and coarse fraction. Fine mode black smoke and motor vehicle exhaust have been associated with the soiling of building material and facades (Tarrat and Joumard, 1990; Lanting, 1986).

Ligocki et al. (1993) studied the potential soiling of art work in five Southern California museums. The authors concluded that a significant fraction of fine elemental carbon and soil dust particles had penetrated to the indoor atmosphere of the museums studied and may constitute a soiling hazard to displayed art work. The seasonally averaged indoor/outdoor ratios for particulate matter mass concentrations ranged from 0.16 to 0.96 for fine particles and from 0.06 to 0.53 for coarse particles, with lower values observed for building with sophisticated ventilation systems that include filters for particulate removal.

4. Societal Costs

a. Soiling/Property Value

The effect of particles on aesthetic quality depends in part on human perception of pollution. The reduction of aesthetic quality may arise from the soiling of buildings or other objects of historical or social interest from the mere dirty appearance of a neighborhood. A number of studies have indicated that such perceptions of neighborhood degradation are revealed indirectly through effects on the value of residential property. That is, when residential properties similar in other respects are compared, the properties in the more highly polluted areas typically have lower value.

Freeman (1979), reporting on 14 property value studies that used particulate matter or dustfall as one of their pollutant measures, noted that the results generally supported the premise that property values are affected by the full range of particle pollution. He cautioned, however, that direct comparison of the monetary results is not possible since the studies cover a number of cities and use different data bases, empirical techniques, and model specifications.

The extent to which the city-specific results represent soiling as opposed to perceptions of the effects of particles on health and visibility is not clear. Therefore, the results of these studies cannot provide reliable quantitative estimates of the effects of soiling on property values (U.S. EPA, 1982b).

b. Soiling/Materials

Airborne particles soil a wide range of materials in all sectors of the economy. Assuming that these sectors are not as well off in a dirtier state as a cleaner one, soiling will result in an economic cost to society. While the household sector has been examined by a number of investigators, their results have been questioned because of methodology problems and their failure to appropriately address particle size, composition, and deposition rates. As a result, no single study has produced a completely satisfactory estimate of soiling costs for the household sector. It is unfortunate that little or no effort has been expended to account for soiling costs in the commercial, manufacturing, or public sectors. Results from MathTech, Inc. (1983) suggest that soiling costs for the manufacturing sector alone could be significant.

In the review of effects of household soiling, the staff paper has relied principally on Booz, Allen and Hamilton, Inc., (1970); Watson and Jaksch, (1978, 1982) [which was cited in the CD and discussed in more detail in the 1982 criteria document]; and MathTech, Inc., (1983) to derive estimates of household soiling costs. For the year 1970, the estimate for amenity loss due to exterior household soiling was estimated to range form 1 to 3.5 billion dollars (1978 dollars). The 14 $\mu g/m^3$ reduction in U.S. annual TSP levels between 1970 and 1978 was estimated to have resulted in an annual benefit for the year 1978 of 0.2 to 0.7 billion dollars or 14 to 50 million dollars for each $\mu g/m^3$ of reduction (U.S. EPA, 1982a). MathTech, Inc. (1983) estimated household soiling costs in the range of $88.3 million to $1.2 billion (1980 dollars) for attaining the primary PM_{10} standard nationwide. Gilbert (1985) used a household production function framework to design and estimate the short-run costs of soiling. The results were comparable to those reported by MathTech (1983). Finally, McClelland et al. (1991) concluded that households were willing to pay $2.70 per $\mu g/m^3$ change in particle level to avoid soiling effects.

Haynie (1989), using fine and coarse mode particle levels calculated from 1987 EPA

AIRS data for PM_{10} and TSP, estimated that $1.74 billion of annual national residential repainting costs could be attributed to soiling (using national average painting costs and frequencies). Haynie and Lemmons (1990) estimated that the national soiling costs associated with repainting the exterior walls of houses probably were within the range of $400 to $800 million a year in 1990. This lower estimate, as compared to Haynie (1989), reflects that households in dirtier areas may not respond with average behavior but mitigate their behavior by (1) accepting greater reductions in reflectance before repainting, (2) washing surfaces rather than painting as often, or (3) selecting materials or paint colors that do not tend to show dirt. Haynie and Lemmons (1990) extrapolated their findings for houses to all exterior paint surfaces and produced a range from $570 to $1,140 million per year.

5. Staff Considerations Pertaining to the Effects of PM on Soiling

It is clear that, at high enough concentrations, particles become a nuisance and result in increased cost and decreased enjoyment of the environment. The available data are limited, however, and do not permit any definitive findings with respect to societal costs or provide clear quantitative relationships between ambient particle loading and soiling. Absent sufficient data, the staff concludes that there is not a sufficient basis to set a separate secondary standard based on soiling effects alone. The recommended suite of primary ambient air quality standards and the regional haze program should reduce the soiling and nuisance effects associated with particle pollution. The effects associated with dustfall are likely to be very localized and thus, more appropriately addressed at the local level.

D. Summary of Staff Conclusions and Recommendations on Secondary NAAQS

This summary of staff conclusions and recommendations for the PM secondary NAAQS draws from the discussions contained in the previous sections of this Staff Paper. The key findings are:

1) Anthropogenic fine particles impair visibility. The level of this impairment varies greatly from East to West, in terms of total loadings, pollutant mix, and the resulting total light extinction. Background levels of fine particles, humidity, and resulting total light extinction vary regionally as well, with the East having generally higher levels than the West.

2) The levels recommended in this staff paper for protection of public health from the adverse effects of fine particles will not completely address the visibility impairment of fine particles on visibility or fully achieve the national visibility goal across the country.

3) Because of regional variations in visibility conditions created by background levels of fine particles, annual average humidity, pollutant mix, and resulting total light extinction, the staff concludes that a national secondary standard to protect visibility would not be an appropriate approach for addressing visibility impairment due to fine particles. Therefore, to address the impairment of visibility from fine particles and to make reasonable progress towards the national visibility goal, the staff recommends that the Administrator consider establishing regional haze regulations under section 169A of the Act.

4) The available data assessed in the CD does not provide an adequate basis to establish a unique national secondary standard to protect against soiling and materials damage effects. The staff recommends setting a secondary standard equivalent to the primary standards for the purposes of addressing soiling and materials damage.