2. Visibility in Individual Mandatory Federal Class I Areas

A. Introduction

This chapter presents the visibility-related data collected by the IMPROVE particulate monitoring network and examines the trends at the individual IMPROVE monitoring sites. The sites are presented alphabetically by state. This state format allows readers to consider all of the data available for a state in a single section of this chapter. A map is presented for each state to illustrate the location of its mandatory Federal Class I areas and IMPROVE monitoring sites. The actual locations of several IMPROVE particulate samplers are not within the boundaries of the mandatory Federal Class I areas that they represent. However, they are positioned at accessible locations that represent regional visibility conditions in these areas. An additional ten states and one territory have mandatory Federal Class I Areas, but five years of data were not yet available from these areas. National and regional trends are examined in detail in Chapter 3.

The last report to Congress on visibility in mandatory Federal Class I areas (EPA, 1993) was completed in 1993 and examined data at the IMPROVE sites collected up to that time. Therefore, this report concentrates on samples collected from 1994 through 1998. However, in the interest of understanding long-term trends at the individual monitor sites, all of the data associated with monitors (some sites began data collection as early as 1988) are included in this chapter. The IMPROVE sites included in this report were required to operate continuously from 1994 through 1998. Data from the monitors not operating between 1994 and 1998, or not providing five full years of data, were not analyzed for this report.

B. Methodology

The data presented in this chapter were reported by the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University. Both the raw and summary data are available at ftp://alta_vista.cira.colostate.edu/DATA/IMPROVE/. This report shows only the summary data at the seasonal and annual levels. Readers interested in a detailed examination of the data values should contact CIRA directly. Some data points are missing in the graphs of this chapter, due to the data analysis procedures followed by CIRA. This indicates that complete samples measuring all components were not collected during that season or year.

The EPA publishes a National Air Quality and Emissions Trends Report that presents long-term trends data for visibility impairment in the national parks and wilderness areas based on the IMPROVE data. The 1998 Trends Report compiled the data to report annual trends for a group of 10 eastern sites and a group of 24 western sites, but did not report on individual sites. The Trends Report required that 13 daily samples (50 percent of the sample days) be available for each of the four seasons at a site before data from that year was considered complete and included in the regional analysis. This criterion was not employed for the data sets shown in this report. Instead, this report informs the reader when the CIRA data sets contain unusually high or low data values. Referring to the first, third, and fifth figures presenting IMPROVE data for each site, the reader is cautioned that CIRA's annual information is based on fewer than four seasons and will be biased toward the seasons in which data were collected. Please refer to Appendix B for an explanation of the method used to create summary data from raw IMPROVE data and to Appendix C for an explanation of the methodology used to calculate light extinction from monitored aerosol mass data.

The first figure for each IMPROVE monitoring site shows the annual visibility indices for the most-impaired, least-impaired, and mid-range days from the beginning of the monitor's operation through 1998. The most-impaired and least-impaired categories reflect the subsets of data that must be examined to determine compliance with the Regional Haze Rule. The most-impaired (haziest) days have been classified as the 80th to 100th percentile of the measurement days based on calculated fine mass concentrations. The least-impaired (clearest) days are represented by the 0 to 20th percentile of the measurements based on calculated fine mass concentrations. The mid-range days are characterized by averaging the values within the 40th to 60th percentile range.

The discussions addressing the first figure indicate whether or not the data sets show statistically significant trends. To determine a statistically significant trend in a data set, the number of times each point lies above or below its predecessors is first counted. The number of instances of increases and decreases are then summed. If the difference between the number of increases and the number of decreases is statistically improbable to be caused by random data fluctuations, then a statistically significant trend is noted. Appendix D provides a more detailed discussion of the Thiel method utilized to determine whether or not the observed trend is statistically significant.

The second figure presented for each site shows the average visibility indices for each season during the operational time of the monitor. The Regional Haze Rule describes visibility impairment in terms of a deciview haze index. Under this index, uniform changes in haziness correspond to uniform incremental changes in perception across the entire range of conditions, from pristine to highly impaired (Regional Haze Regulations, Final Rule, 1999). A single deciview unit is generally considered the minimal perceptible change that is observed under either clean or polluted conditions. The reader should refer to Section 1.C of this report for a discussion of the relationship between the deciview index and other scales.

The third and fourth figures presented for each site are pie charts showing the contributions of individual pollutant species to the calculated aerosol light extinction coefficients (averaged from 1994 through 1998). At the IMPROVE sites, samples are collected on filters to measure particulate matter less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$) and particulate matter less than 10 microns in diameter (PM_{10}). Both filters are weighed, and the mass difference between PM_{10} and $PM_{2.5}$ is referred to as coarse mass. The $PM_{2.5}$ filter is analyzed to determine the mass of its chemical components. The chemical components of $PM_{2.5}$ are grouped into five categories based on their emission sources (refer to Table 1–1): sulfates, nitrates, organic carbon, elemental carbon, and fine soil (crustal material with an aerodynamic diameter less than 2.5 microns). Based on the relative humidity at the IMPROVE site, the light extinction coefficients are calculated for each of the categories and then summed together to obtain the calculated aerosol light extinction coefficients. The pie charts show the percent contribution from each of the species: sulfates, nitrates, organic carbon, elemental carbon, and crustal material (crustal material is calculated by summing the fine soil and coarse mass light extinction coefficients).

The fifth figure presented for each site shows the annual aerosol light extinction coefficients during the operational period of the monitor. Since this figure is presented as the sum of light extinction from the five species, the reader can see how individual species (i.e., sulfates, nitrates, organic carbon, elemental carbon, and crustal material) varied during the years of operation.

The IMPROVE particulate sampling protocol has changed certain techniques since 1988 (http://vista.cira.colostate.edu/IMPROVE/Data/QA_QC/qa–qc–Branch.htm). Of particular note are the changes in filter mask size at all eastern and some western sites and the addition of glycerine to the denuders. Because of the change to filter mask size, sulfate measurements by ion chromatography are used to examine trends in this report. The addition of glycerine to the denuders beginning June 1, 1996 affected nitrate measurements substantially at all sites. Therefore, this report uses a constant nitrate concentation for all years, chosen as the average measured nitrate concentration for the data set measured from 1997 to 1999. Therefore, no nitrate trends are reported for the fifth figure in each set.

When reviewing the visibility figures in this chapter, readers are cautioned to carefully examine the axes on the plots. Although one figure may appear to have large fluctuations in visibility from year to year, this may be a function of a limited scale on the axis. For example, the aerosol light extinctions at Denali National Park are twelve times smaller than those at Mammoth Cave National Park, so the same fluctuation in extinction at both sites would appear more pronounced at the Denali site. Comparisons between the sites are presented in Chapter 3.

C. General Findings

Investigation into the data at the individual sites revealed some common characteristics among the sites. These general findings may or may not be noted when examining the regional and national summaries of the data, so they are presented here for the interested reader.

The first figure for each IMPROVE monitoring site presents the visibility indices for three different data sets: the most-impaired, mid-range, and least-impaired days. When viewing the long-term trends at the sites, it is apparent that the visibility often improved or declined for one of these data sets while remaining constant for the other two. Of the sixteen sites that showed an increasing or declining trend in at least one of the data sets, only the Pinnacles National Monument (CA) site showed the same trend for all three data sets. To understand why the three data sets may behave differently, the reader must recognize that the data set from the most-impaired days will be collected under different meteorological conditions (e.g., wind direction, relative humidity, or temperature) than the data for the least-impaired days. Since these meteorological conditions affect the formation and transport of ambient pollutants (and thus visibility), actual changes in upwind emissions over the years may be observed for one data set but not another.

Meteorological conditions and variations in emissions affect the ambient particulate matter and visibility indices. Therefore, the reader should not be surprised that the seasonal average visibility indices (reported in the second figure for each site) are generally different. For 32 of the 42 sites presented in this chapter, the data from at least one season consistently had higher or lower visibility indices than the other three seasons. It was also observed that the seasonal figures for the sites showed 29 trends (out of 168) indicating seasonal improvements in visibility and only one that indicated seasonal declines in visibility.

The annual and seasonal pie charts showing the contributions of each species to aerosol light extinction (third and fourth figures for each site) are presented to illustrate the important pollutants that influence visibility at the individual sites. If the visibility indices are higher during one season than another, readers may notice that the annual pie chart is weighted toward the higher season and resembles a particular season's pie chart more than the others. This weighted behavior is an artifact of the method (Appendix B) by which CIRA calculates the percent contributions from the various species.

Furthermore, from the pie charts, the reader will often note that sulfate contributes more to the aerosol light extinction than any of the other species. Indeed, ambient sulfate particles are responsible for more than 30 percent of the light extinction at 37 sites. Both sulfates and nitrates extinguish light to a greater degree than do organic carbon, elemental carbon, and crustal material (Appendix C). For example, at 90 percent relative humidity, sulfate particles will extinguish fourteen times more light than a similar mass of fine crustal material.[1]

The fifth figure for each site presents the long-term trends in annual average light extinction for the five species, and the total aerosol light extinction. Twenty-two sites showed statistically significant reductions in the light extinction from at least one of the species. Four sites (Big Bend, TX; Brigantine, NJ; Jarbidge, NV; and Mesa Verde, CO) showed statistically significant increases in the light extinction from a single species. Only 12 sites showed statistically significant reductions in the annual average total aerosol light extinction. Of the twelve sites that showed reduction in total aerosol light extinction, all showed reductions in at least one of the fine species.

State summaries are provided when data from more than one IMPROVE particulate sampler is reported (Arizona, California, Colorado, Oregon, Texas, Utah, Washington, and Wyoming). The data at the seven California sites suggested regional similarities when the sites were classified as coastal, southern, or eastern sites. In other states, similar light extinction coefficients were observed for the different monitor sites within the state unless the relative humidities varied between sites. Higher relative humidity levels at one site in a state resulted in the calculation of considerably higher sulfate and nitrate light extinction coefficients and, consequently, higher total aerosol light extinction coefficients.

[1] Appendix C shows that the sulfate concentrations (in $\mu g/m^3$) are multiplied by the relative humidity correction factor and 3 m^2/g to calculate light extinction (in Mm^{-1}). The fine crustal material concentration is multiplied by 1 m^2/g to calculate light extinction. At 90 percent relative humidity, the correction factor is 4.67. Therefore, at 90 percent relative humidity, the light extinction coefficient from 1 $\mu g/m^3$ sulfate would be calculated as 14 Mm^{-1} (1 x 3 x 4.67), and the coefficient from 1 $\mu g/m^3$ fine crustal material would be calculated as only 1 Mm^{-1} (1 x 1).

D. Visibility Discussions by State

1. ALABAMA

The only IMPROVE monitoring site in Alabama that operated continuously from 1992 through 1998 was located near the Sipsey Wilderness Area. Figure AL–1 shows the Sipsey monitor location (34.34°N, 87.34°W, elevation 600 feet) in the northern portion of the State.

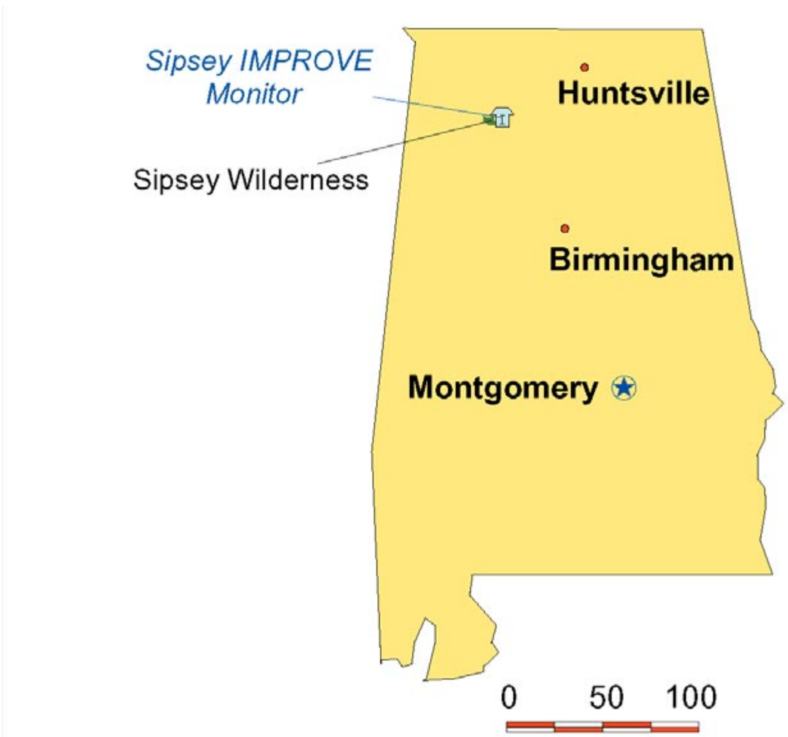

Figure AL–1. Mandatory Federal Class I Area and IMPROVE Monitoring Site in Alabama

Sipsey Wilderness Area

The Sipsey IMPROVE particulate sampler started reporting in March of 1992. Figure AL–2 presents the calculated visibility indices for selected data sets from 1992 through 1998. The figure shows that from 1992 through 1998 there was no significant trend in the annual average of the visibility index for the least-impaired days, which remained near 20 deciviews (VR 33 miles). From 1992 through 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which also remained relatively constant near 32 deciviews (VR 10 miles). However, from 1992 to 1995, the annual average of the visibility index for the mid-range days showed mild improvements in the visibility index as the index dropped from 27 (VR 16 miles) to 24 (VR 22 miles) deciviews but rose again to 25 deciviews through 1998. This does not represent a statistically significant trend towards improved visibility.

Figure AL–3 shows the seasonal averages for the calculated visibility index from 1992 through 1998. The visibility indices for summer were higher than those during the autumn, while those for the

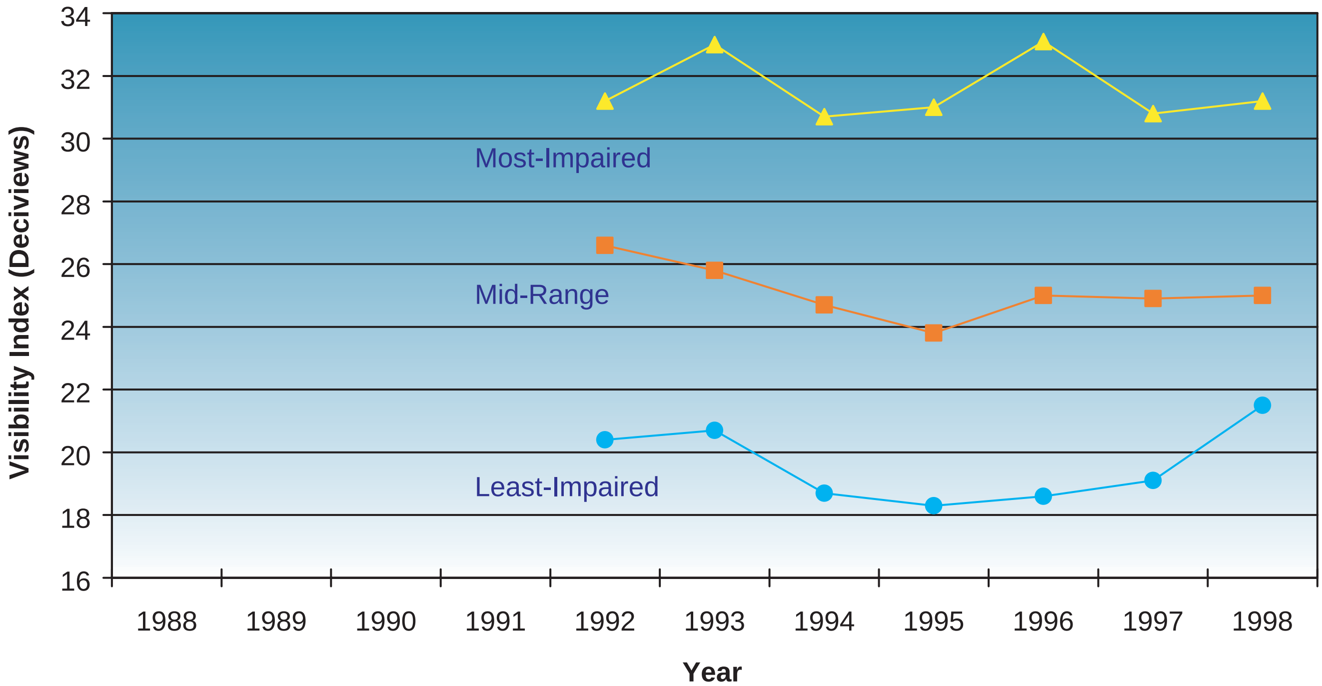

Figure AL–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1992-1998 for the Sipsey IMPROVE Particulate Sampler

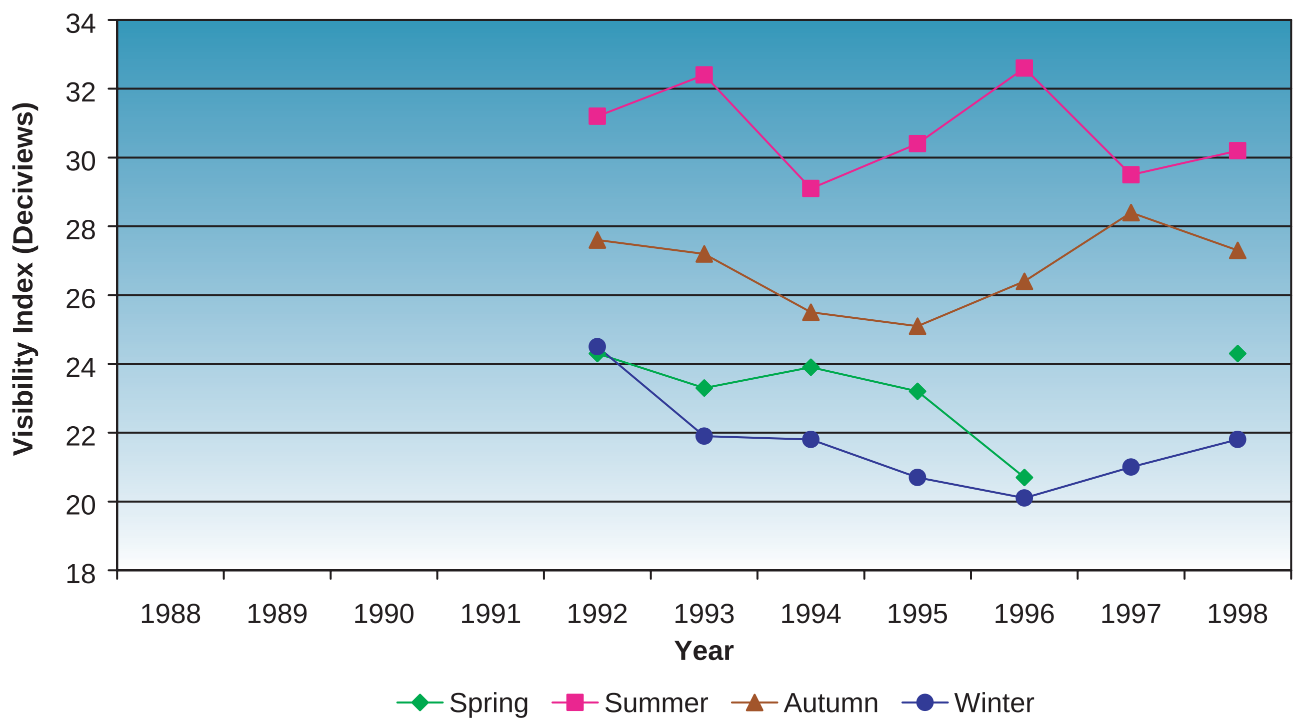

Figure AL–3. Seasonal Deciview Averages from 1992–1998 for the Sipsey IMPROVE Particulate Sampler

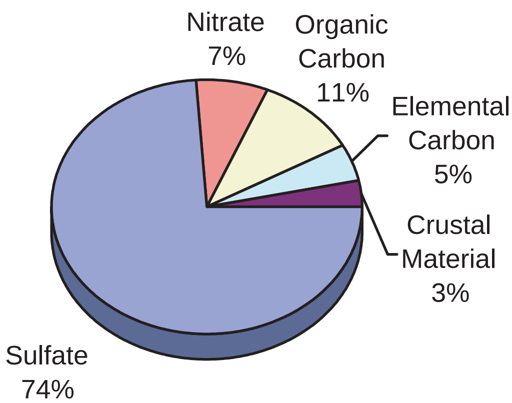

Figure AL–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Sipsey IMPROVE Particulate Sampler

winter and spring remained the lowest (best visibility). No significant seasonal trends were observed in any of the four seasons. No data were collected from Jan 18, 1997 through June 14, 1997 at this site. This lack of data is reflected in Figure AL–3.

Figure AL–4 presents a chart showing the calculated fractional contribution to Sipsey's light extinction by each aerosol component on an annual basis. Figure AL–5 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 66 to 81 percent of the light extinction at the Sipsey site, averaging 74 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the summer and the lowest in the winter. The contributions from nitrates ranged from 6 to 11 percent depending on the season (with the highest observed nitrate percentages in the winter). The contributions from

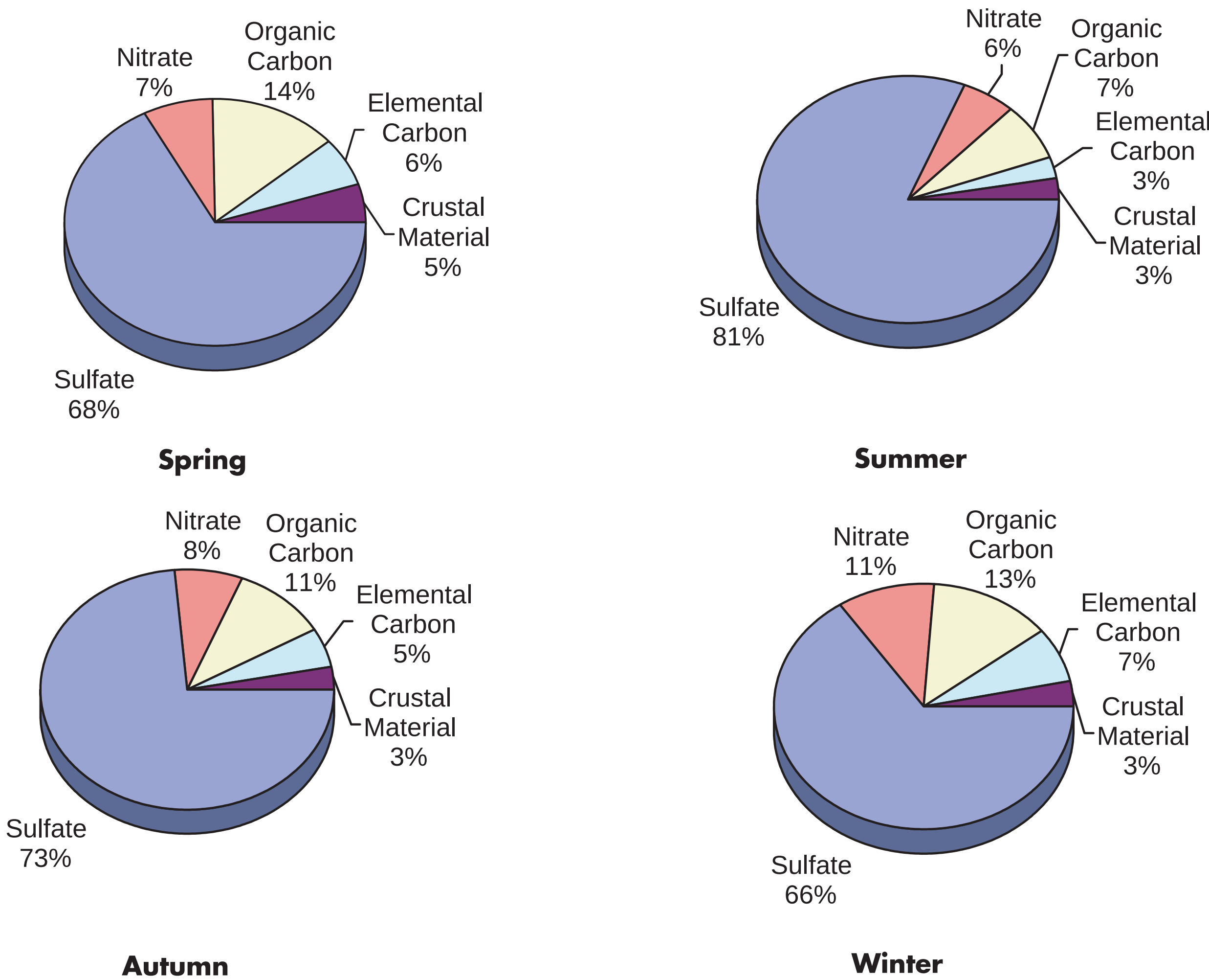

Figure AL–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Sipsey IMPROVE Particulate Sampler

organic carbon ranged from 7 percent in the summer to 14 percent in the spring. Annually, elemental carbon and crustal material measured at the Sipsey site were each responsible for approximately 5 and 3 percent of the calculated aerosol light extinction.

Figure AL–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Sipsey site from 1992 to 1998. Over the seven-year period the total annual aerosol light extinctions remained between 115 and 142 Mm^{-1} (no significant trend). No statistically significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, elemental carbon, or crustal material.

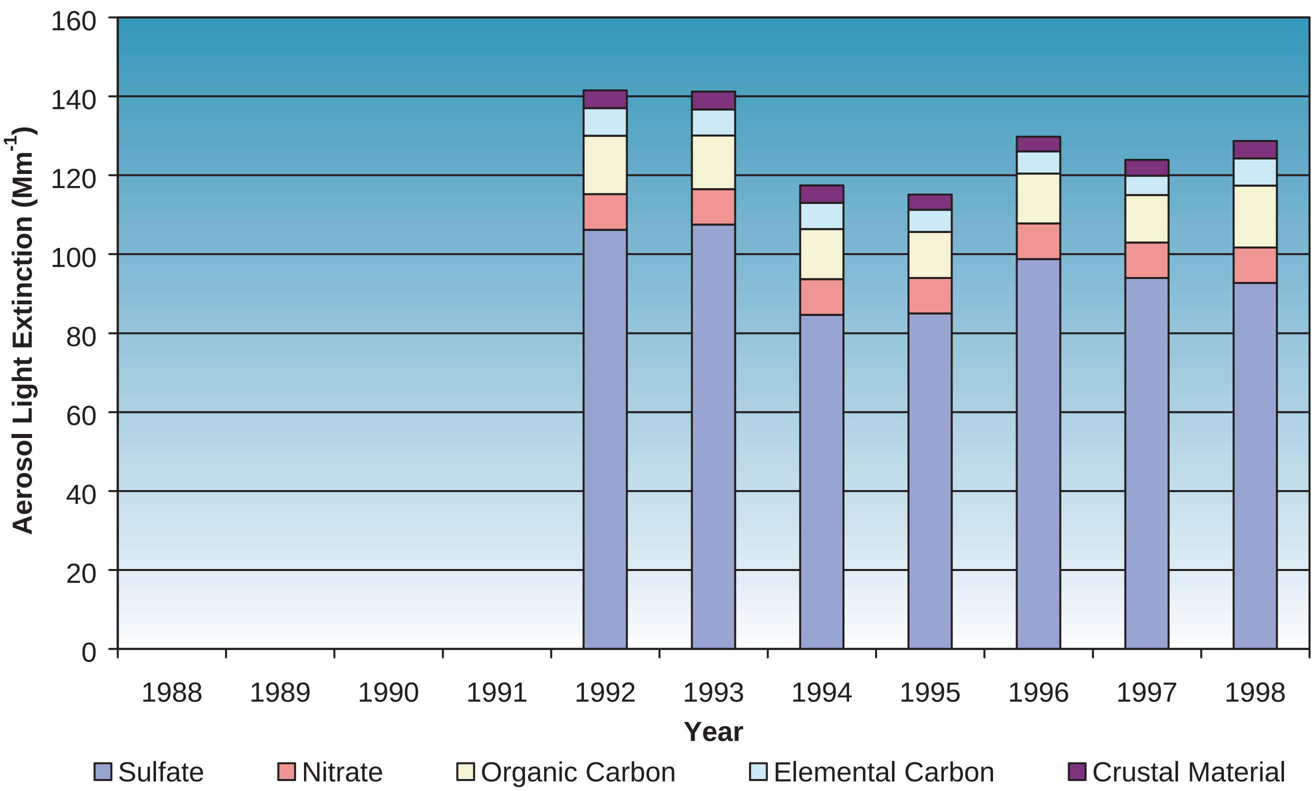

Figure AL–6. Contributions to Calculated Annual Aerosol Light Extinction from 1992–1998 for Sipsey IMPROVE Particulate Sampler

2. ALASKA

The only IMPROVE monitoring site in Alaska that operated continuously from 1994 through 1998 was the one located in Denali National Park. Figure AK–1 shows the Denali monitor location (63.73°N, 148.97°W, elevation 2100 feet) in central Alaska. The Bering Sea, Tuxedni, and Simeonof Wilderness Areas are also covered by the Regional Haze Rule but did not have IMPROVE monitors operating from 1994 through 1998, and thus are not included in the analysis described below.

Figure AK–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in Alaska

Denali National Park

The Denali IMPROVE particulate sampler started reporting in March of 1988. Figure AK–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. From 1988 through 1998 there was no statistically significant trend in the annual average of the visibility index for the most-impaired days, which remained relatively constant, near 11 deciviews (VR 80 miles). Similarly, the annual average of the visibility index for the mid-range days showed no improvements in the visibility index that remained near 6.3 deciviews (VR 130 miles). Figure AK–2 shows that from 1988 through 1998 (except the year 1990) the annual average of the visibility index for the least-impaired days remained near 4.0 deciviews (VR 165 miles) with no statistically significant trend.

Figure AK–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The visibility indices for the summer and spring were generally slightly higher than those during the fall and winter. No significant seasonal trends were observed in the calculated visibility indices for

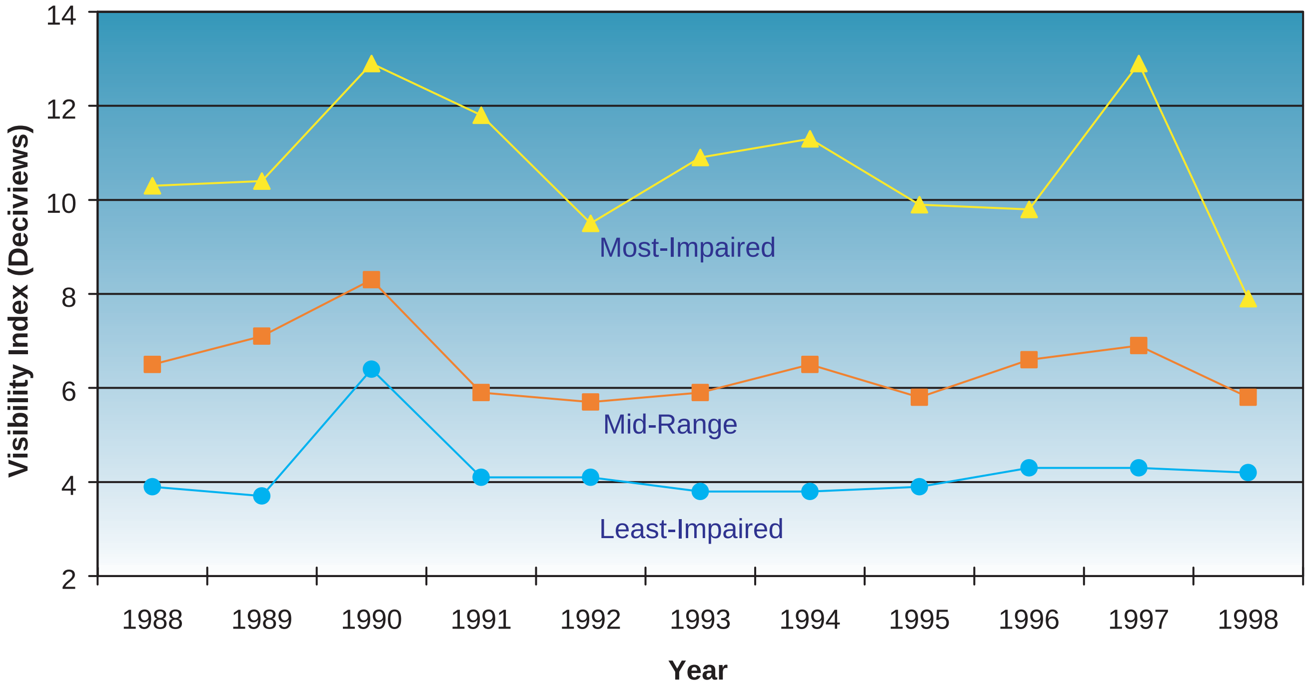

Figure AK–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Denali IMPROVE Particulate Sampler

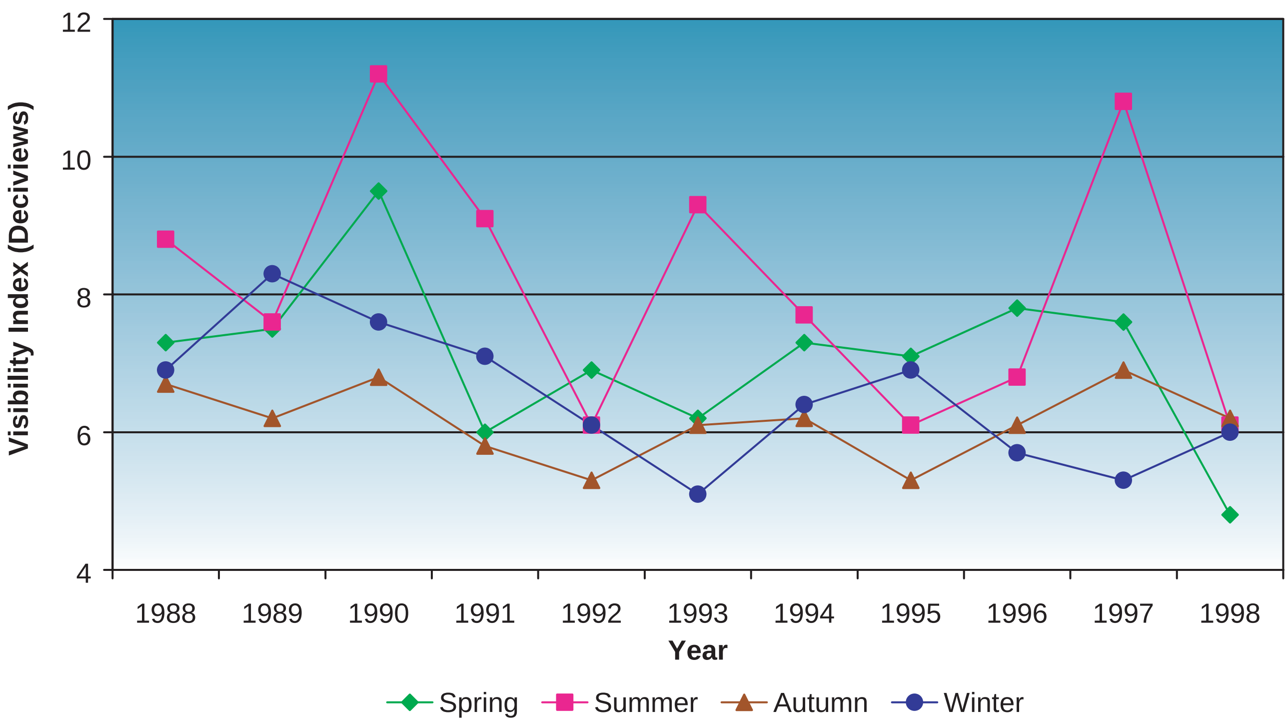

Figure AK–3. Seasonal Deciview Averages from 1988–1998 for the Denali IMPROVE Particulate Sampler

spring, summer, or autumn over this time period, but the indices for winter showed an improvement from 7.5 to 5.5 deciviews (VR from 115 to 140 miles).

Figure AK–4 presents a chart showing the calculated fractional contribution to Denali's light extinction by each aerosol component on an annual basis. Figure AK–5 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 32 to 49 percent of the light extinction at the Denali site, averaging 43 percent on an annual basis over a five-year period. The contributions from nitrates ranged from 4 to 7 percent depending on the season, with the highest observed nitrate percentages in the autumn. The contributions from organic carbon remained relatively constant, near 17 percent in the autumn, winter, and spring, but rose to 36 percent in the summer. On an annual basis, elemen-

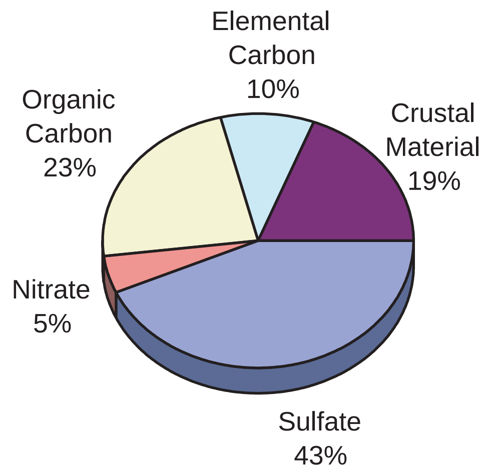

Figure AK–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Denali IMPROVE Particulate Sampler

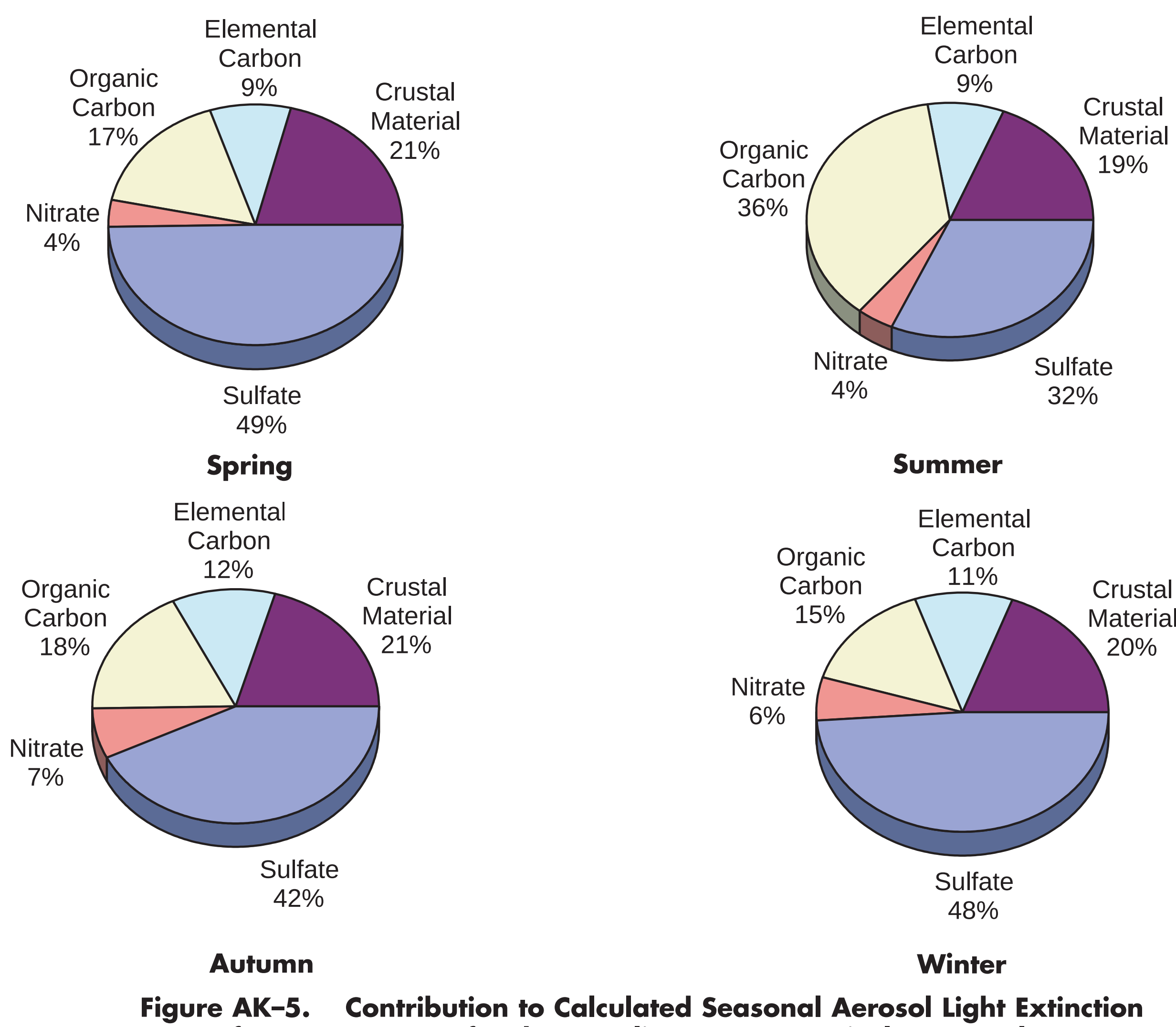

Figure AK–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Denali IMPROVE Particulate Sampler

tal carbon and crustal material measured at the Denali site were each responsible for approximately 10 and 19 percent of the calculated aerosol light extinction.

Figure AK–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Denali site from 1988 to 1998. Over the eleven-year period, there was a decreasing trend in the total annual aerosol light extinctions, but it was not statistically significant. No significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, or elemental carbon. The crustal material contribution to the aerosol light extinction was noticeably smaller in the late 1990's than earlier years, but no statistically significant trend in crustal material contributions was observed over the entire eleven year period.

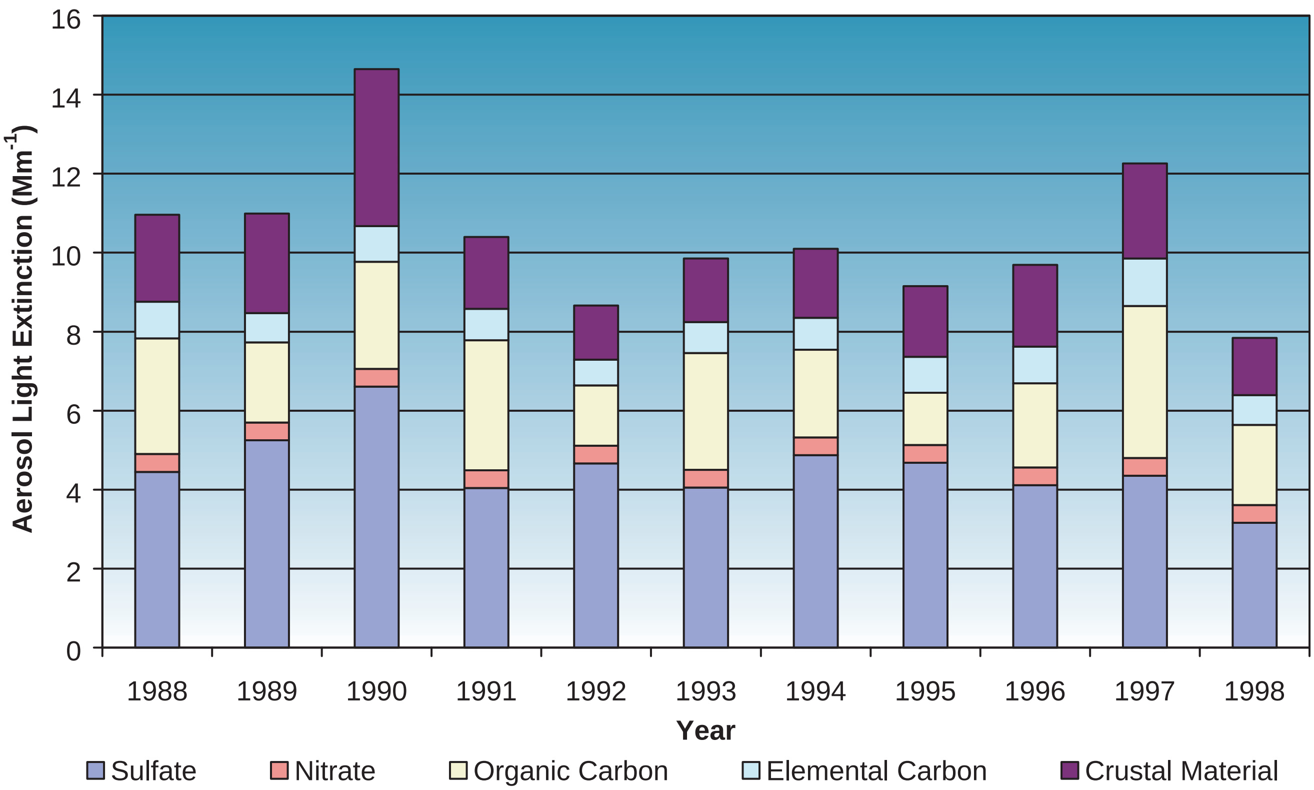

Figure AK–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Denali IMPROVE Particulate Sampler

The variations in visibility and light extinction from year to year appear significant in Figures AK–2, AK–3, and AK–6 compared to the graphs shown for other IMPROVE monitor sites. However, the calculated visibility impairment at Denali National Park was much lower than at other sites, so the smaller scales on the figures exaggerate the variations from year to year.

3. ARIZONA

Arizona has twelve mandatory Federal Class I areas. The five IMPROVE particulate samplers in Arizona that operated continuously from 1994 through 1998 were located at Chiricahua National Monument (32.02°N, 109.35°W, elevation 5400 feet), south rim of Grand Canyon National Park (36.07°N, 112.15°W, elevation 6800 feet), Indian Garden in Grand Canyon National Park (36.07°N, 112.13°W, elevation 3800 feet), Petrified Forest National Park (35.07°N, 109.77°W, elevation 5800 feet), and Tonto National Monument (33.65°N, 111.11°W, elevation 2600 feet). Figure AZ–1 shows the monitoring locations in the national parks and wilderness areas throughout the state. The Sycamore Canyon, Pine Mountain, Mazatzal, Mount Baldy, Sierra Ancha, Superstition, Galiuro, and Saguaro Wilderness Areas are also covered by the Regional Haze Rule, but did not have an IMPROVE particulate sampler operating from 1994 through 1998. Limited monitoring was also done during this period at Saguaro National Park and Sycamore Canyon, Sierra Ancha, Galiuro, Mazatzal, and Chiricahua Wilderness Areas. The Yavapai-Apache Tribal Government has redesignated their lands as Class I, although this area is not covered by the Regional Haze Rule.

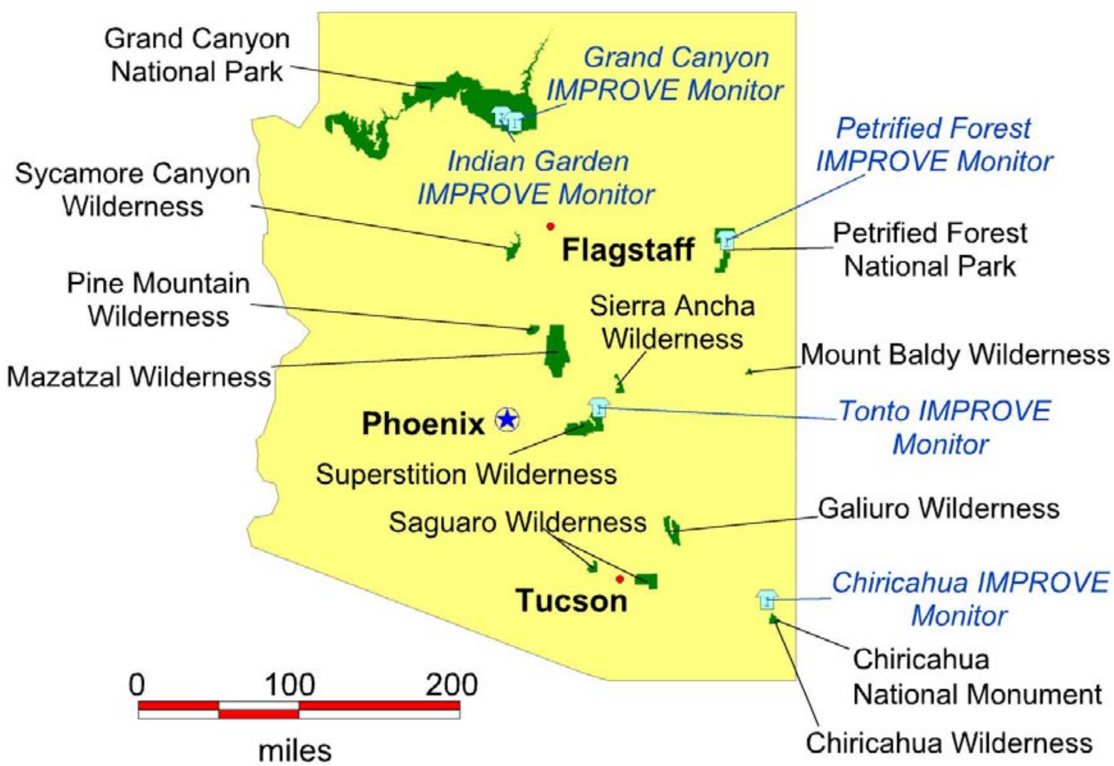

Figure AZ–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Sites in Arizona

Chiricahua National Monument

The Chiricahua IMPROVE particulate sampler started reporting in March of 1988. Figure AZ–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. From 1988 through 1998 there was no statistically significant trend in the annual average of the visibility index for the most-impaired days, which remained between 12 and 15 deciviews (VR between 75 and 55 miles). Similarly, from 1988 through 1998 there was no statistically significant trend in the annual average of the visibility index for the mid-range days, which remained near 10 deciviews (VR 90 miles). However, the visibility indices on the least-impaired days rose from 6 to 7 deciviews (VR from 135 to 120 miles), showing a statistically significant trend toward greater visibility impairment.

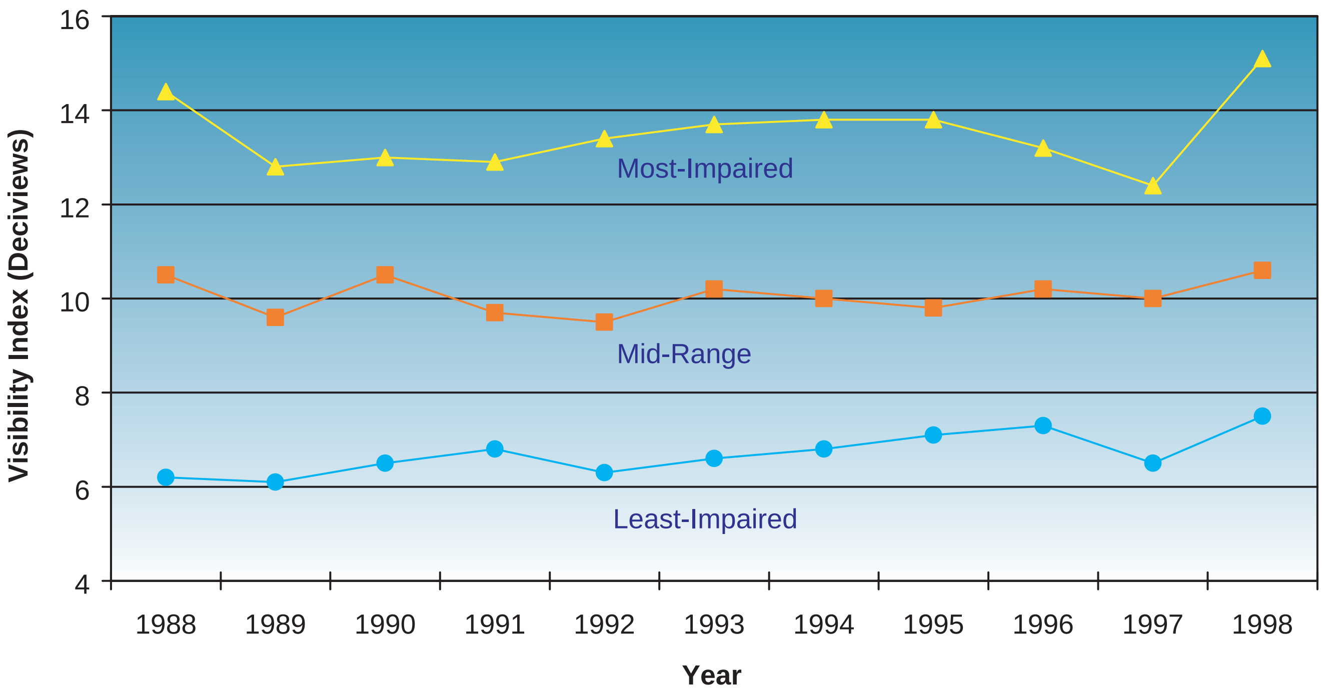

Figure AZ–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Chiricahua IMPROVE Particulate Sampler

Figure AZ–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The visibility indices for summer (VR 75 miles) were higher than the other seasons, followed by autumn (VR 90 miles), then spring (VR 95 miles), and finally winter (VR 100 miles). No significant seasonal trends were observed in any of the seasons over the time period from 1988 to 1998.

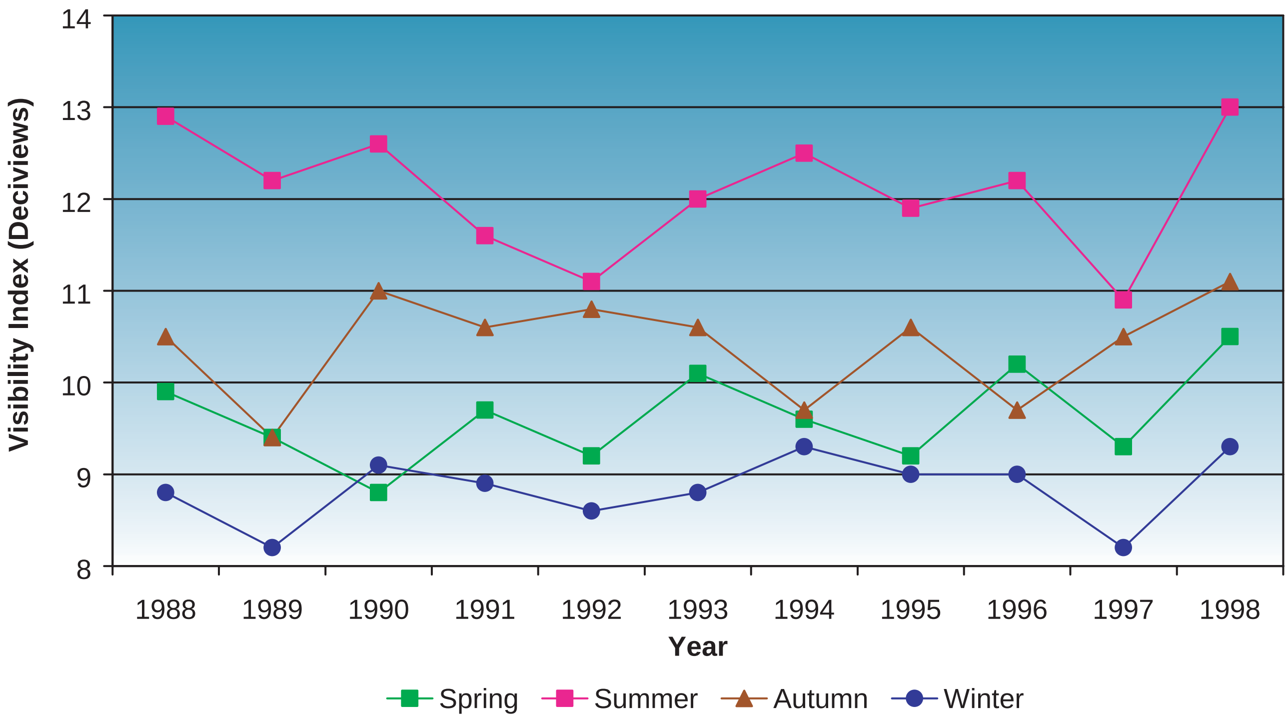

Figure AZ–3. Seasonal Deciview Averages from 1988–1998 for the Chiricahua IMPROVE Particulate Sampler

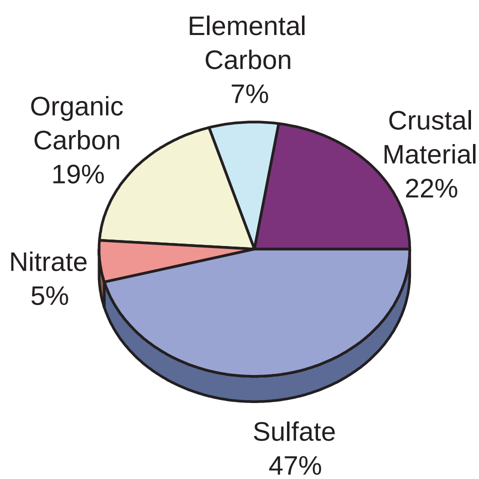

Figure AZ–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Chiricahua IMPROVE Particulate Sampler

Figure AZ–4 presents a chart showing the calculated fractional contribution to Chiricahua's light extinction by each aerosol component on an annual basis. Figure AZ–5 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 33 to 52 percent of the light extinction at the Chiricahua site, averaging 47 percent on an annual basis over a five-year period. The contributions from nitrates ranged from 4 to 8 percent over the seasons, and the contributions from organic carbon remained relatively constant, near 20 percent in all four seasons. Elemental carbon measured at the Chiricahua site was responsible for 6 to 9 percent of the calculated aerosol light extinction in all four seasons. The contributions from crustal material remained near 19 percent in the summer, autumn, and winter, but rose to 34 percent in the spring season.

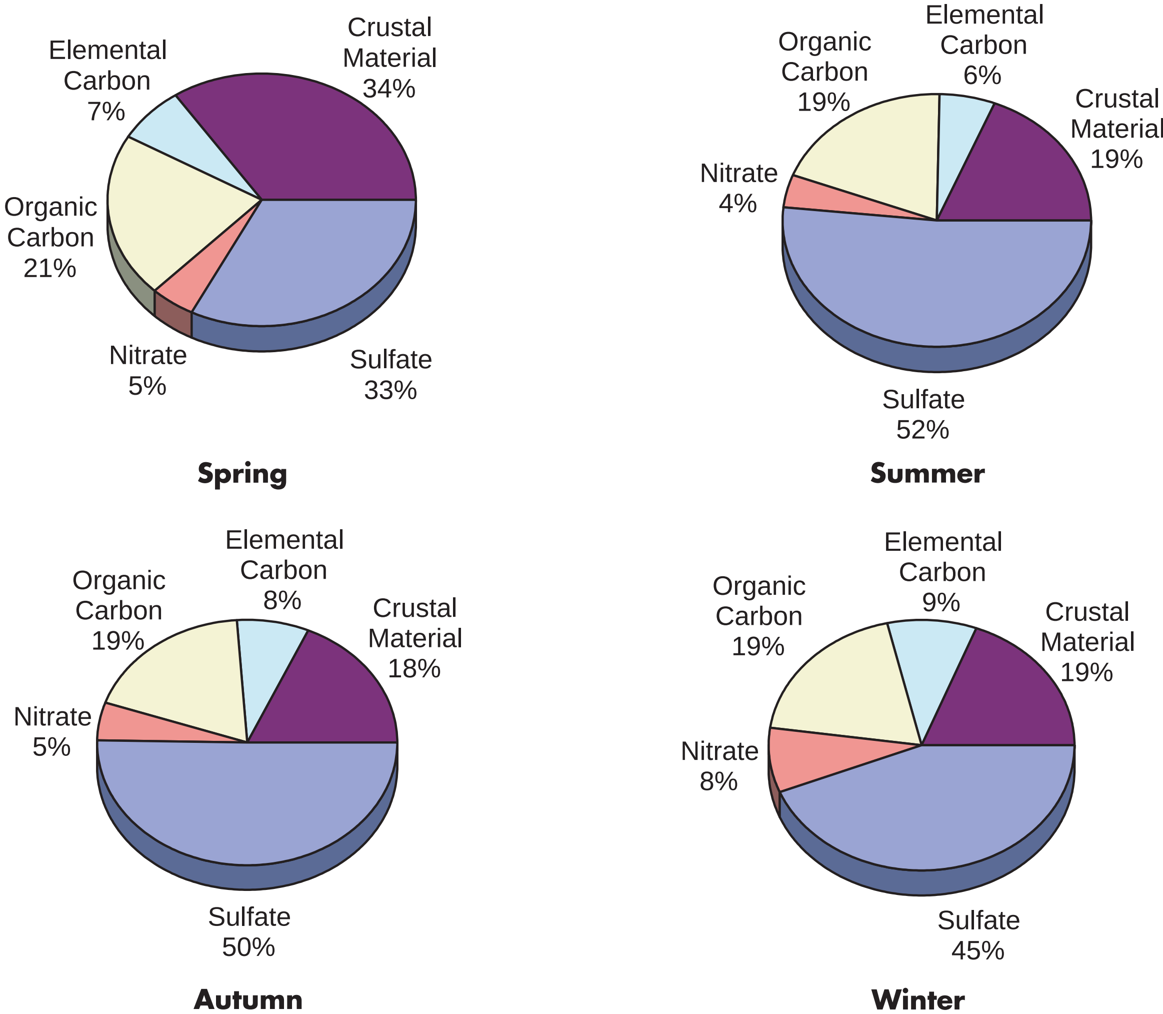

Figure AZ–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Chiricahua IMPROVE Particulate Sampler

Figure AZ–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Chiricahua site from 1988 to 1998. Over the eleven-year period the total annual aerosol light extinction remained near 18 Mm^{-1} (no significant trend). No significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, elemental carbon, or crustal material.

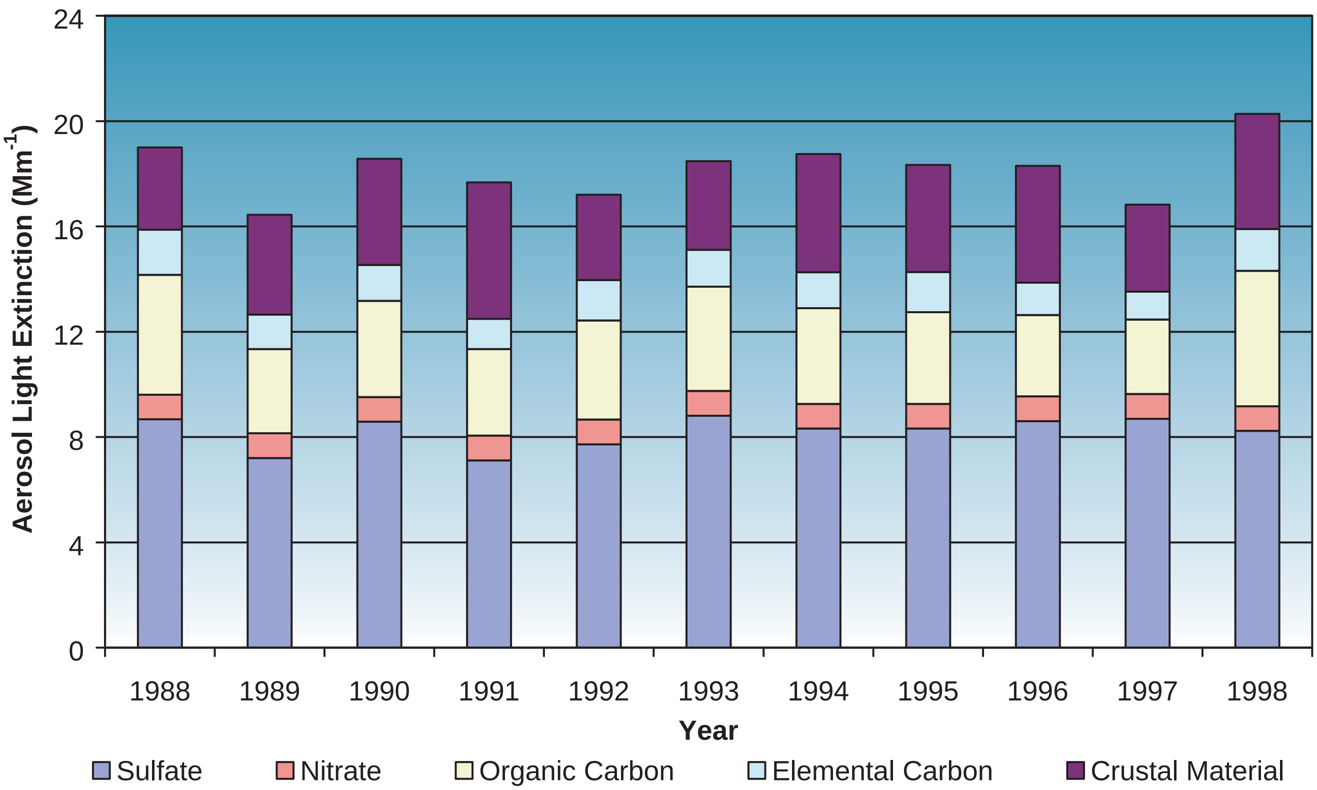

Figure AZ–6. Contributions to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Chiricahua IMPROVE Particulate Sampler

Grand Canyon National Park (South Rim)

The Grand Canyon (South Rim) IMPROVE particulate sampler (GRCA) operated at the Hopi Fire Tower from March 1988 through August 1998. This site discontinued monitoring in August 1998 after the new Hance station was fully established at Grandview Point approximately 15 miles away. The movement of the IMPROVE monitoring location was based on several factors. Two important reasons (Bowman, 2000) included: 1) the transmissometer and nephelometer devices (instruments that monitor light extinction) were set to operate at the Hance site, and 2) the Hopi Fire Tower site is close enough to roads and Grand Canyon Village to be affected by local emission sources under certain wind conditions. Because of the importance of the Grand Canyon to the Regional Haze Rule, the information available from that site is included in this report despite the lack of a complete data set between 1994 and 1998.

Figure AZ–7 presents the calculated visibility indices for selected data sets from 1989 through 1997. The figure shows that from 1989 through 1997 there was no statistically significant trend in the annual average of the visibility index for the most-impaired days, which remained near 12 deciviews (VR 75 miles). From 1989 through 1997 there was no statistically significant trend in the annual average of the visibility index for the mid-range days, which remained relatively constant near 9 deciviews (VR 100 miles). Similarly, from 1989 through 1997 there was no significant trend in the annual average of the visibility index for the least-impaired days, which remained near 5.6 deciviews (VR 140 miles).

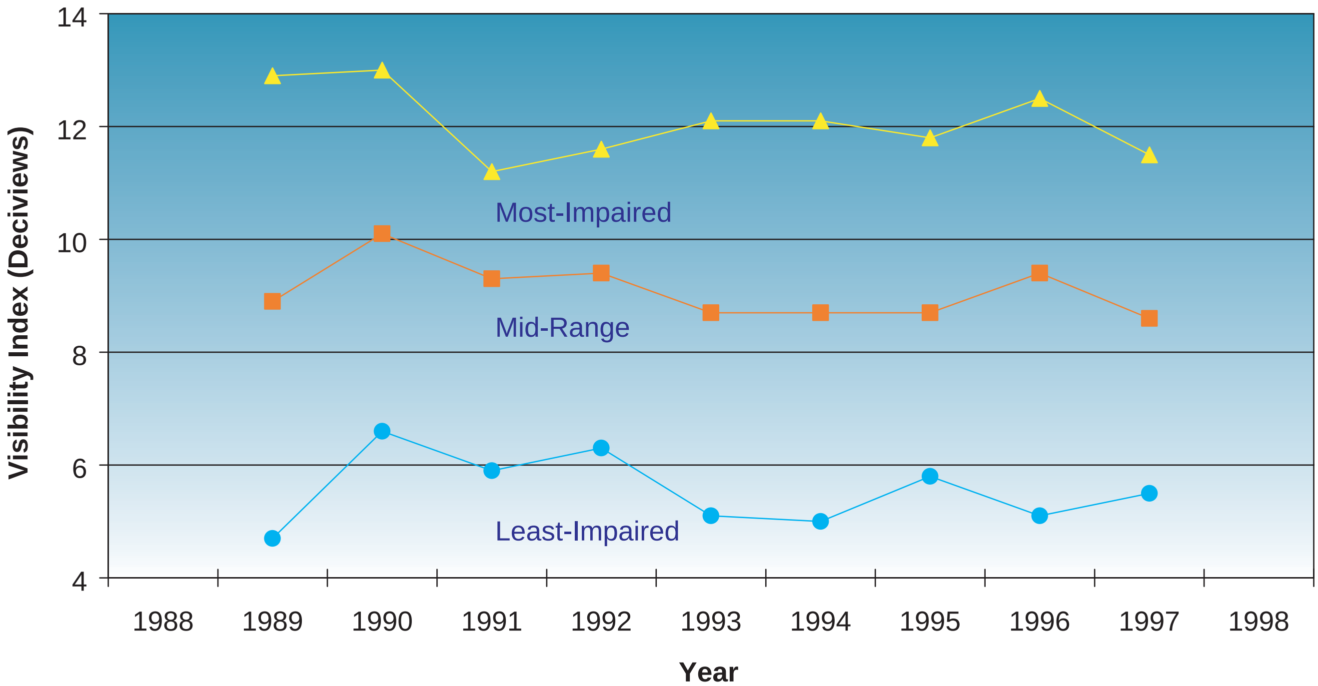

Figure AZ–7. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1989–1997 for the Grand Canyon IMPROVE Particulate Sampler

Figure AZ–8 shows the seasonal averages for the calculated visibility index from 1988 through 1998. No data were available for the Grand Canyon site from August 29, 1998 through December 31, 1998, so the autumn and winter 1998 summary data points were not available for Figure AZ–8 or for inclusion in the summaries of Figures AZ–9 and AZ–10. The visibility indices for all four seasons are similar. From 1988 to 1998, the seasonal visibility indices ranged from 7 to 12 deciviews, and no significant seasonal trends were observed for any of the seasons.

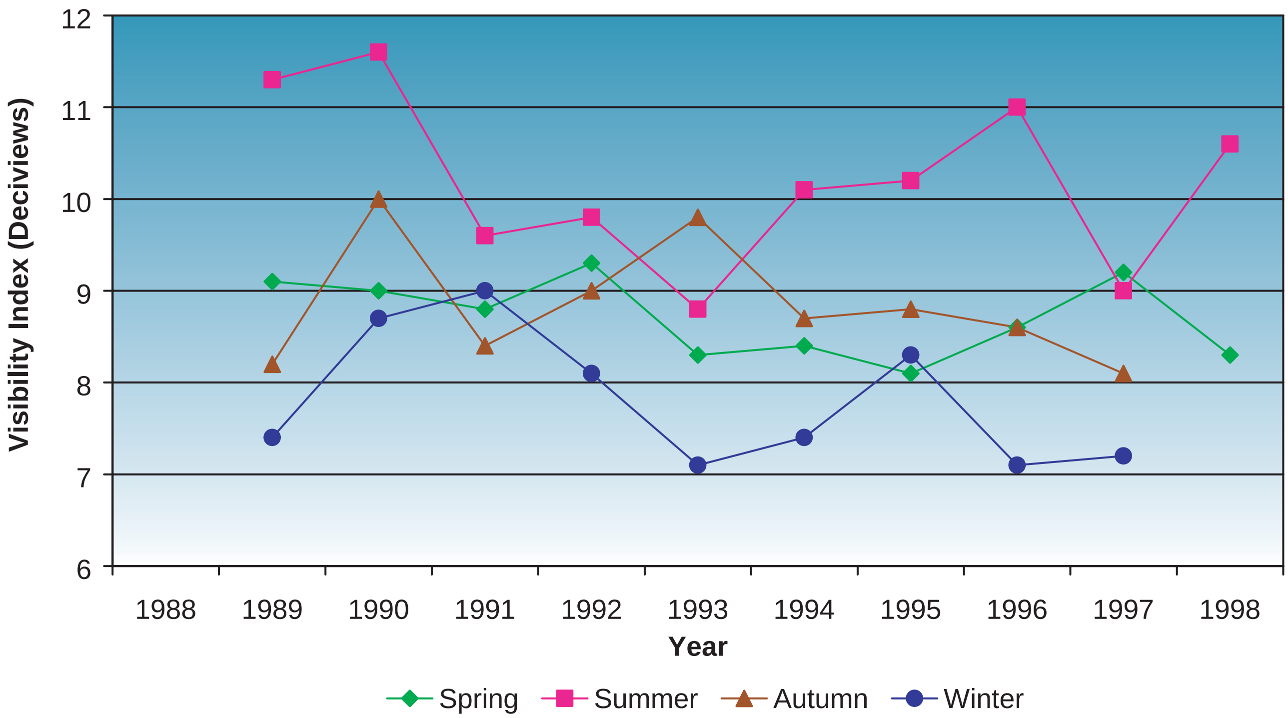

Figure AZ–8. Seasonal Deciview Averages from 1989–1998 for the Grand Canyon IMPROVE Particulate Sampler

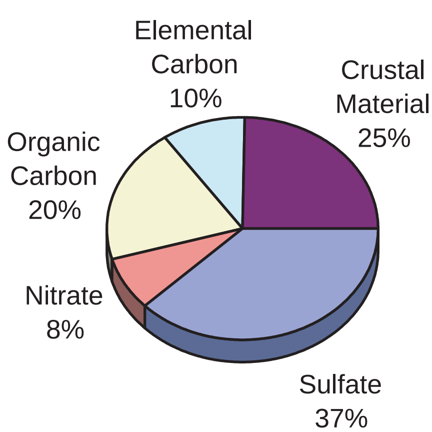

Figure AZ–9. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1997 for the Grand Canyon IMPROVE Particulate Sampler

Figure AZ–9 presents a chart showing the calculated fractional contribution to Grand Canyon's light extinction by each aerosol component on an annual basis. Figure AZ–10 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 34 to 38 percent of the light extinction at the Grand Canyon site, averaging 37 percent on an annual basis over a five-year period. The contributions from nitrates ranged from 5 to 14 percent over the seasons, and the contributions from organic carbon ranged from 15 to 22 percent. Elemental carbon measured at the Grand Canyon site was responsible for 9 to 12 percent of the calculated aerosol light extinction in all four seasons. The contributions from crustal material represented between 22 and 30 percent of the seasonal aerosol light extinctions.

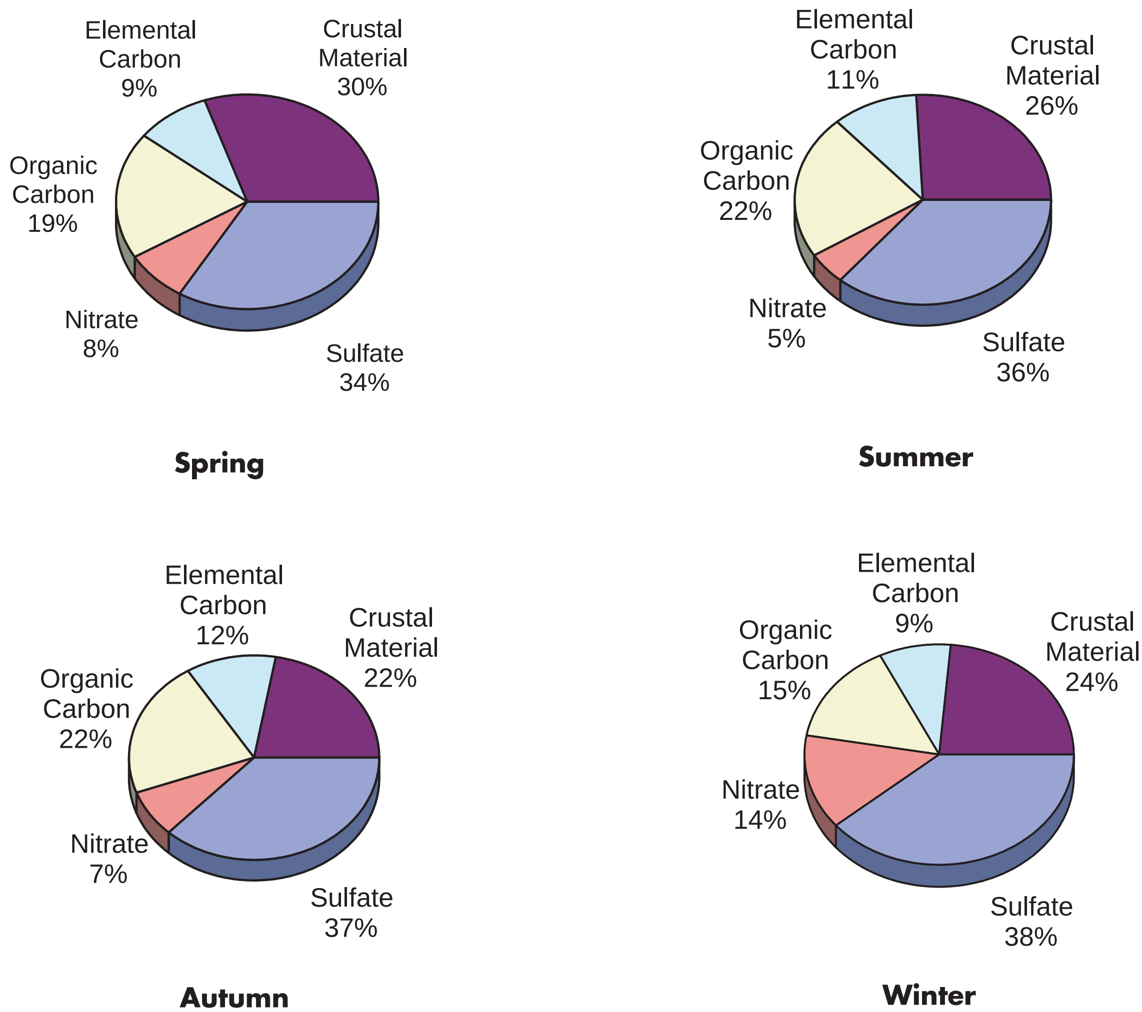

Figure AZ–10. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Grand Canyon IMPROVE Particulate Sampler

Figure AZ–11 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Grand Canyon site from 1989 to 1997. Over this period there was no statistically significant trend toward improved visibility, despite the high value observed in 1990. No significant trends were noted in the annual light extinctions calculated for sulfates, elemental carbon, or crustal material. However, the contributions from organic carbon to the light extinction coefficient decreased over the time period due to a significant decrease in the concentrations of this species.

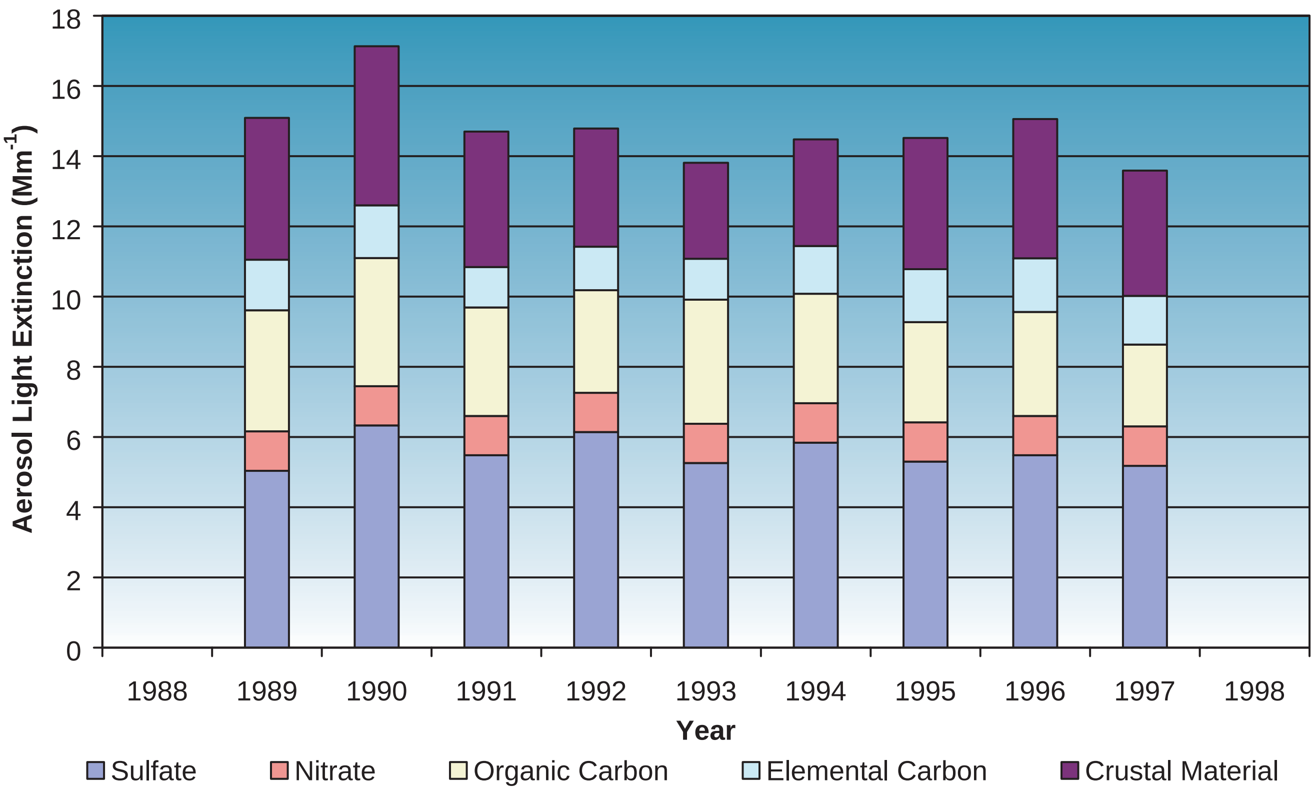

Figure AZ–11. Contributions to Calculated Annual Aerosol Light Extinction from 1989–1997 for the Grand Canyon IMPROVE Particulate Sampler

Grand Canyon National Park (Indian Garden)

The Grand Canyon (Indian Garden) IMPROVE particulate sampler (INGA) started reporting in October of 1989. Figure AZ–12 presents the calculated visibility indices for selected data sets from 1990 through 1998. The figure shows that from 1990 through 1998 there was no significant trend in the annual average of the visibility index for the least-impaired days, which remained near 6.5 deciviews (VR 130 miles). From 1990 through 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained near 13 deciviews (VR 65 miles). Similarly, from 1990 through 1998 there was no significant trend in the annual average of the visibility index for the mid-range days, which remained near 10 deciviews (VR 90 miles).

Figure AZ–13 shows the seasonal averages for the calculated visibility index from 1990 through 1998. The visibility indices for summer (VR 75 miles) were higher than the other seasons (VR 90 miles). No statistically significant seasonal trends were observed in spring, summer, or autumn over the time period from 1990 to 1998. The summer coarse mass concentrations at the monitor site almost tripled from 1996 to 1997, causing the elevated visibility index for summer 1997. Similarly, unusually low sulfate concentrations were observed during the autumns of 1996 and 1997, causing depressed visibility indices for these two autumns (Figure AZ–13,) but no statistically significant trend resulted. However, the winter indices did show a statistically significant improvement in visibility conditions (VR rose from 90 to 105 miles).

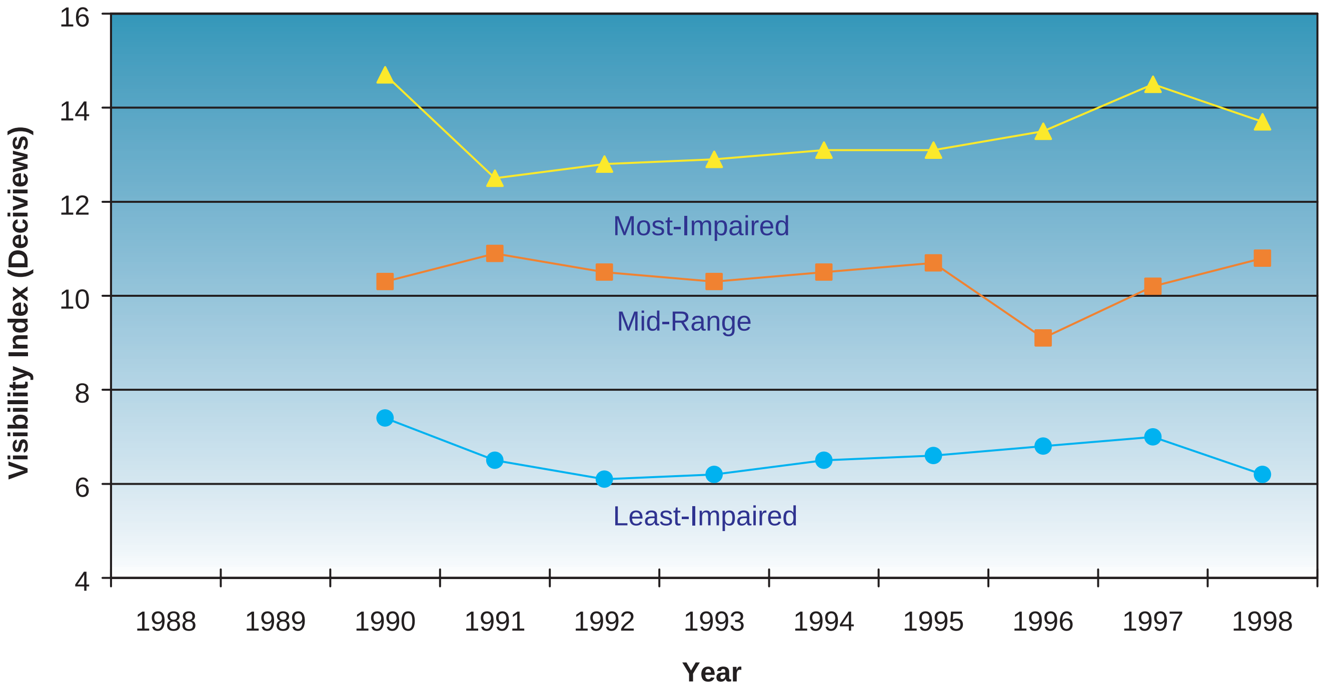

Figure AZ–12. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1990–1998 for the Indian Garden IMPROVE Particulate Sampler

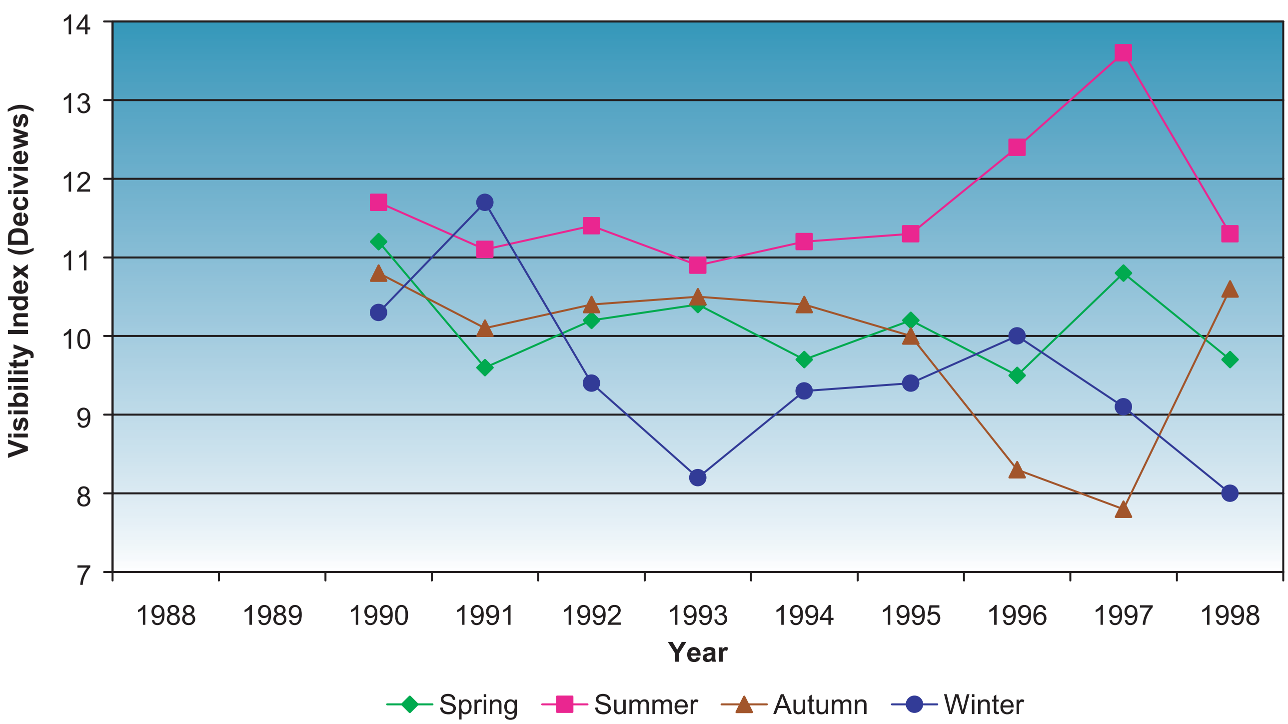

Figure AZ–13. Seasonal Deciview Averages from 1990–1998 for the Indian Garden IMPROVE Particulate Sampler

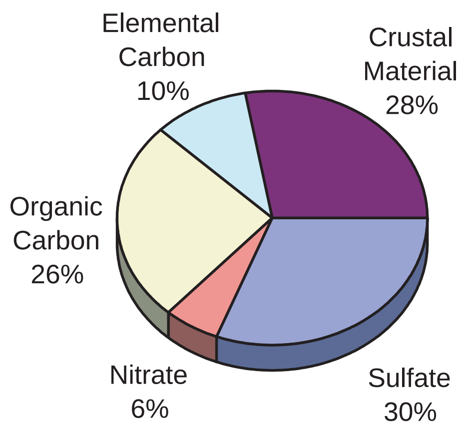

Figure AZ–14. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Indian Garden IMPROVE Particulate Sampler

Figure AZ–14 presents a chart showing the calculated fractional contribution to Indian Garden's light extinction by each aerosol component on an annual basis. Figure AZ–15 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 27 to 35 percent of the light extinction at the Indian Garden site, averaging 30 percent on an annual basis over a five-year period. The contributions from nitrates ranged from 4 to 10 percent over the seasons, and the contributions from organic carbon remained relatively constant, between 24 and 29 percent in all four seasons. Elemental carbon measured at the Indian Garden site was responsible for 9 to 12 percent of the calculated aerosol light extinction in all four seasons. The contributions from crustal material remained near 32 percent in the spring and summer, but then dropped to 25 percent in autumn and 20 percent in the winter.

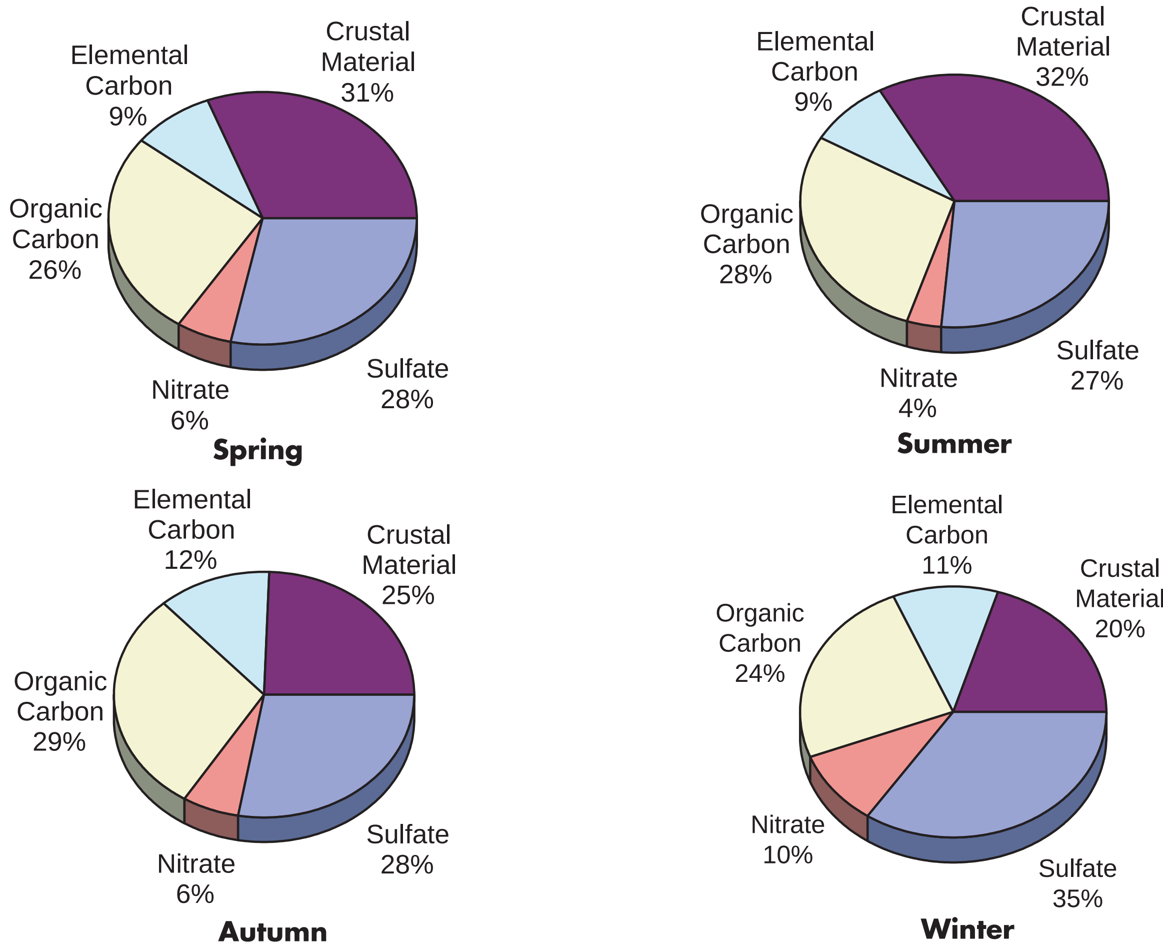

Figure AZ–15. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Indian Garden IMPROVE Particulate Sampler

Figure AZ–16 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Indian Garden site from 1990 to 1998. Over the nine-year period, the total annual aerosol light extinctions remained near 18 Mm^{-1} (no significant trend). No significant trends were noted in the annual light extinctions calculated for organic carbon, elemental carbon, or crustal material. The sulfates showed significant decreases in their contribution to the light extinction coefficients, indicating lower ambient concentrations.

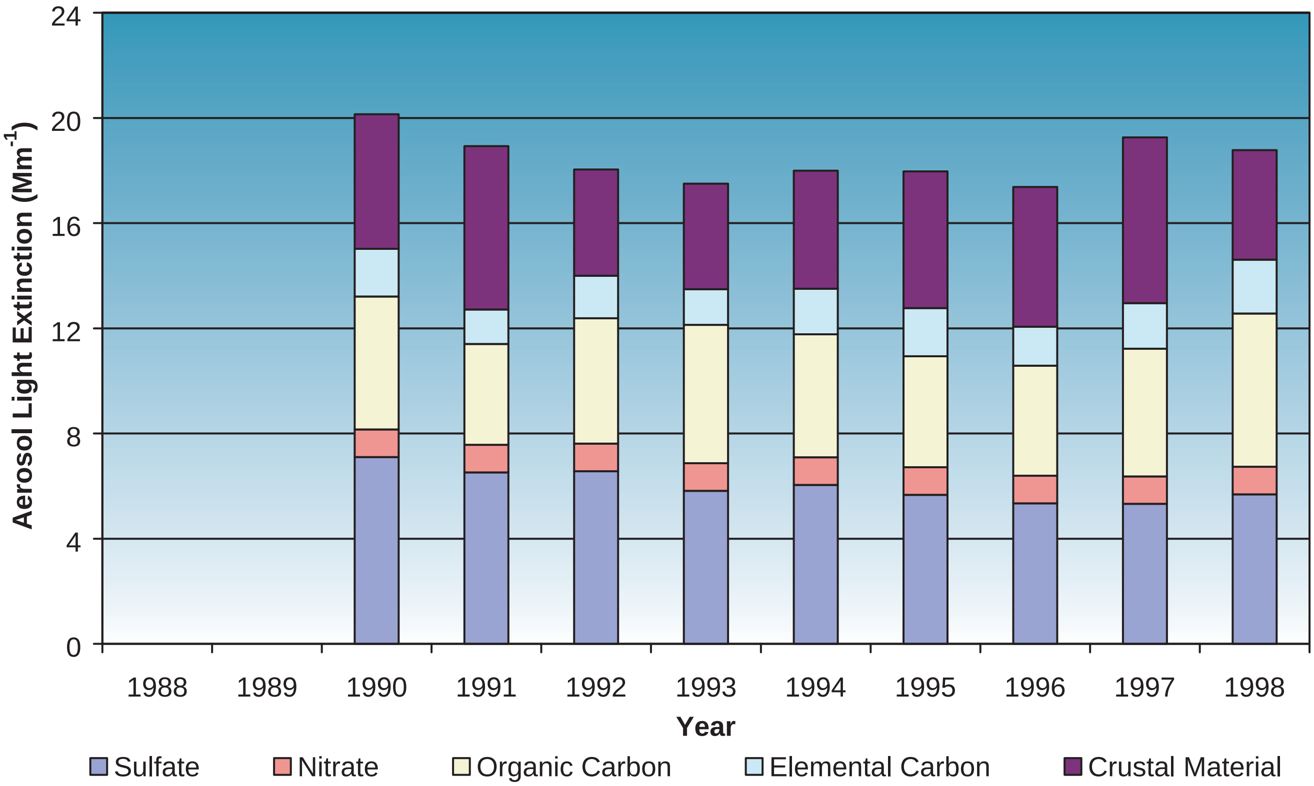

Figure AZ–16. Contributions to Calculated Annual Aerosol Light Extinction from 1990–1998 for the Indian Garden IMPROVE Particulate Sampler

Petrified Forest National Park

The Petrified Forest IMPROVE particulate sampler started reporting in March of 1988. Figure AZ–17 presents the calculated visibility indices for selected data sets from 1988 through 1998. From 1990 through 1993 there was a decreasing trend in the annual average of the visibility index for the mid-range days, which dropped from 11 to 9.5 deciviews (VR from 80 to 95 miles). However, the trend did not continue long enough to be considered statistically significant. From 1990 through 1993 there appears to be a trend toward improved visibility in the annual average of the visibility index for the least-impaired days, but this drop from values greater than 8 deciviews to 7 deciviews in the late 1990s did not qualify as statistically significant because the downward trend did not continue after 1993. Similarly, the drop from 14 to 13 deciviews on the most-impaired days (Figure AZ–17) was not statistically significant because the trend did not continue.

Figure AZ–18 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The seasonal visibility indices were not discernibly higher in one season than the others. The

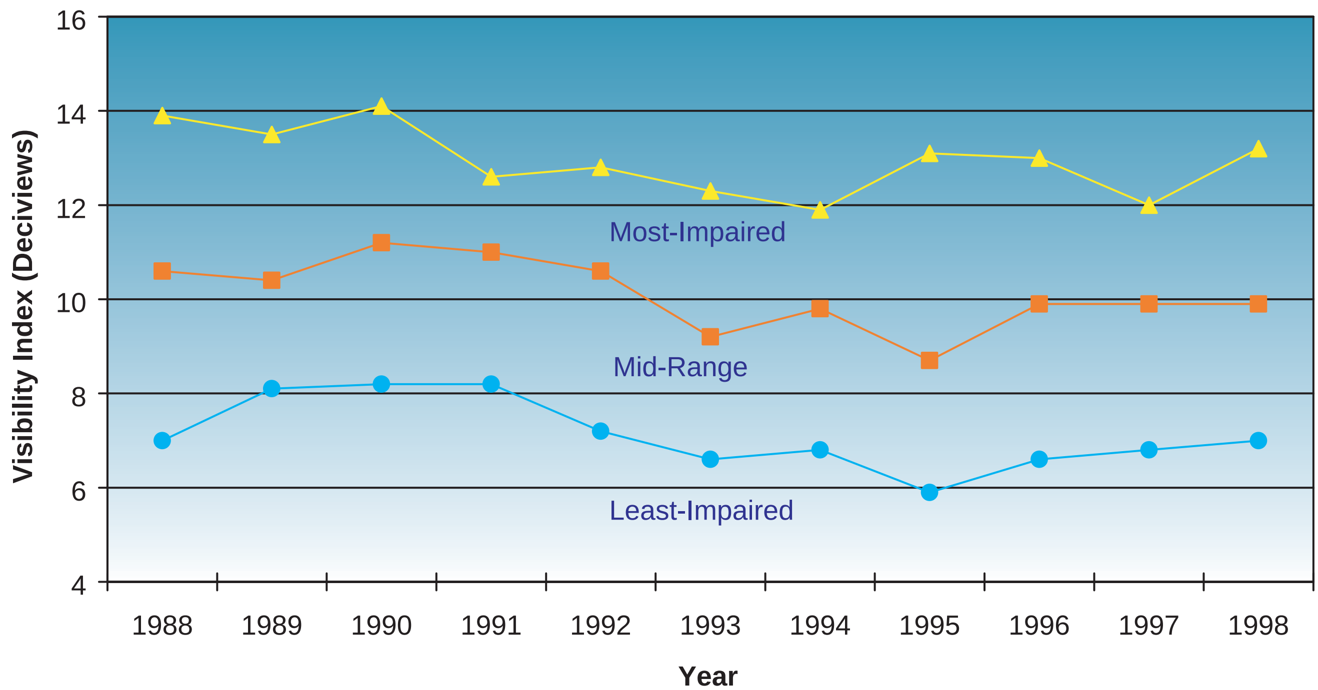

Figure AZ–17. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Petrified Forest IMPROVE Particulate Sampler

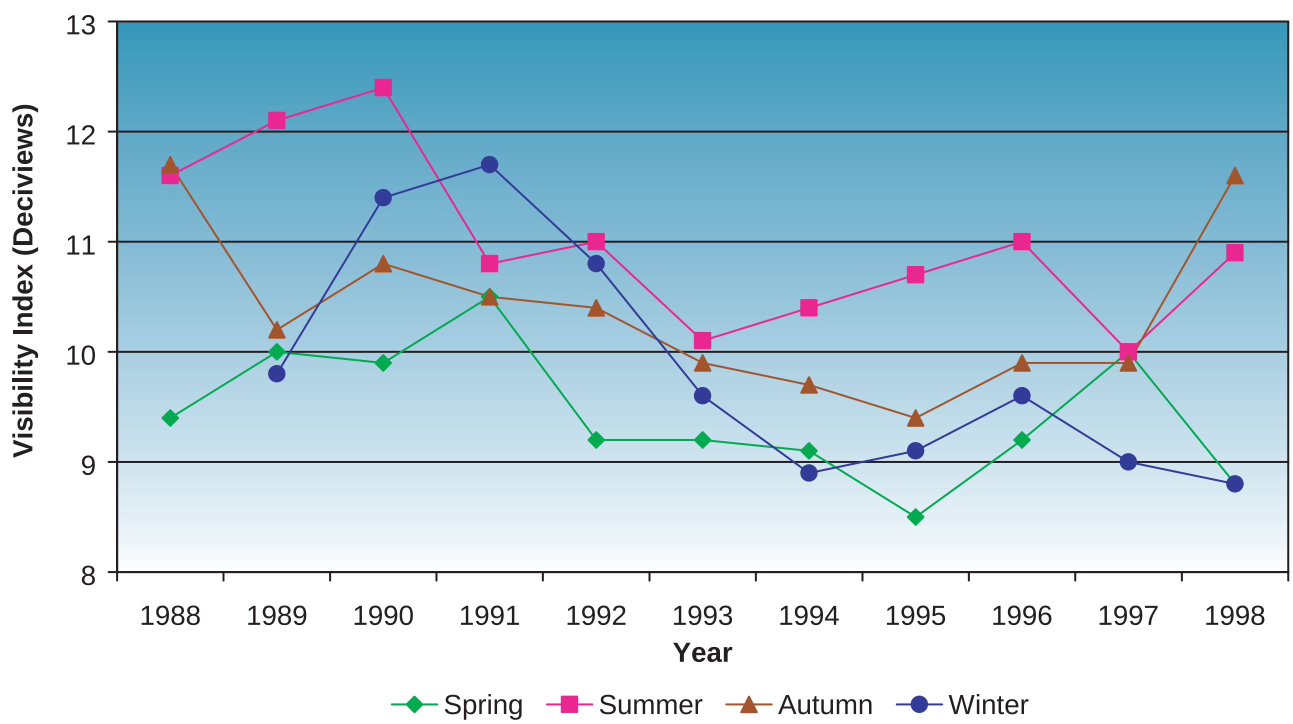

Figure AZ–18. Seasonal Deciview Averages from 1988–1998 for the Petrified Forest IMPROVE Particulate Sampler

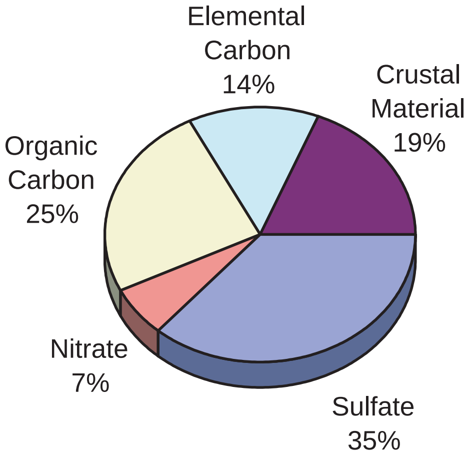

Figure AZ–19. Contribution to Calculated Annual Aerosol Light Extinction from1994–1998 for the Petrified Forest IMPROVE Particulate Sampler

winter and summer seasons showed statistically significant trends toward lower visibility indices, indicating improvements in visibility of approximately 2.3 and 1.5 deciviews. The indices for the spring and autumn did not show statistically significant trends toward improved visibility.

Figure AZ–19 presents a chart showing the calculated fractional contribution to the Petrified Forest's light extinction by each aerosol component on an annual basis. Figure AZ–20 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 29 to 41 percent of the light extinction at the Petrified Forest site, averaging 35 percent on an annual basis over a five-year period. The contributions from nitrates ranged from 5 to 10 percent over the seasons, and the contributions from organic carbon remained relatively constant, between 23 and 26 percent. Elemental carbon measured at the Petrified

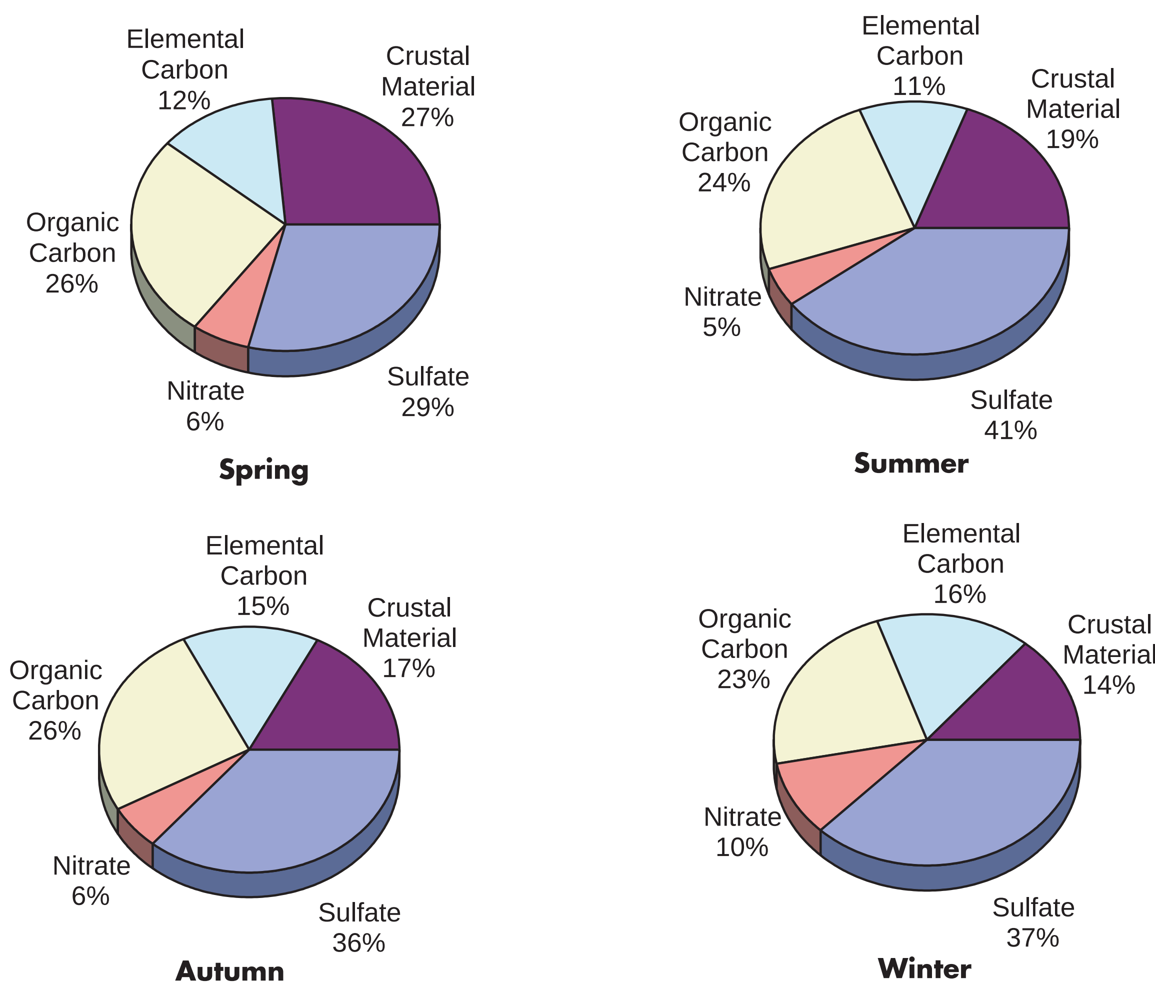

Figure AZ–20. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Petrified Forest IMPROVE Particulate Sampler

Forest site was responsible for 11 to 16 percent of the calculated aerosol light extinction in all four seasons. The contributions from crustal material were near 27 percent in the spring but then dropped in the subsequent seasons to 19, 17, and 14 percent in summer, autumn, and winter.

Figure AZ–21 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Petrified Forest site from 1988 to 1998. Over the eleven-year period, there was a significant decreasing trend in the total annual aerosol light extinction from approximately 20 to 17 Mm^{-1}, indicating improved visibility. No significant trends were noted in the annual light extinctions calculated for sulfates or crustal material. However, the organic and elemental carbons showed significant decreases in their contribution to the light extinction coefficients, indicating lower ambient concentrations.

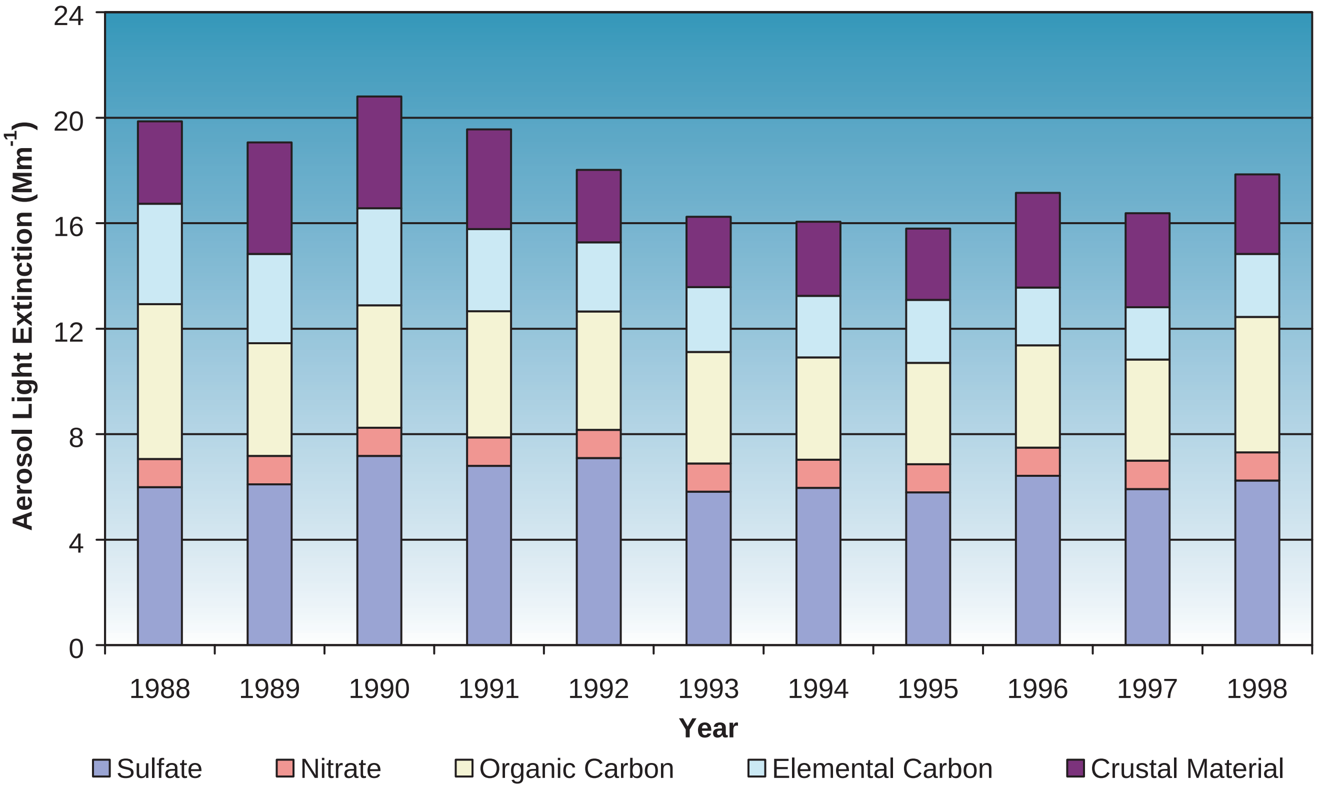

Figure AZ–21. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for Petrified Forest IMPROVE Particulate Sampler

Tonto National Monument

The Tonto IMPROVE particulate sampler started reporting in April of 1988. Figure AZ–22 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that between 1988 and 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained constant near 14 deciviews (VR 60 miles). From 1988 to 1998 there was no statistically significant trend toward improved visibility in the annual average of the visibility index for the mid-range days, which remained near 11 deciviews (VR 80 miles). Similarly, from 1988 to 1998 there was no statistically significant trend toward improved visibility in the annual average of the visibility index for the least-impaired days, which remained near 7.7 deciviews (VR 110 miles).

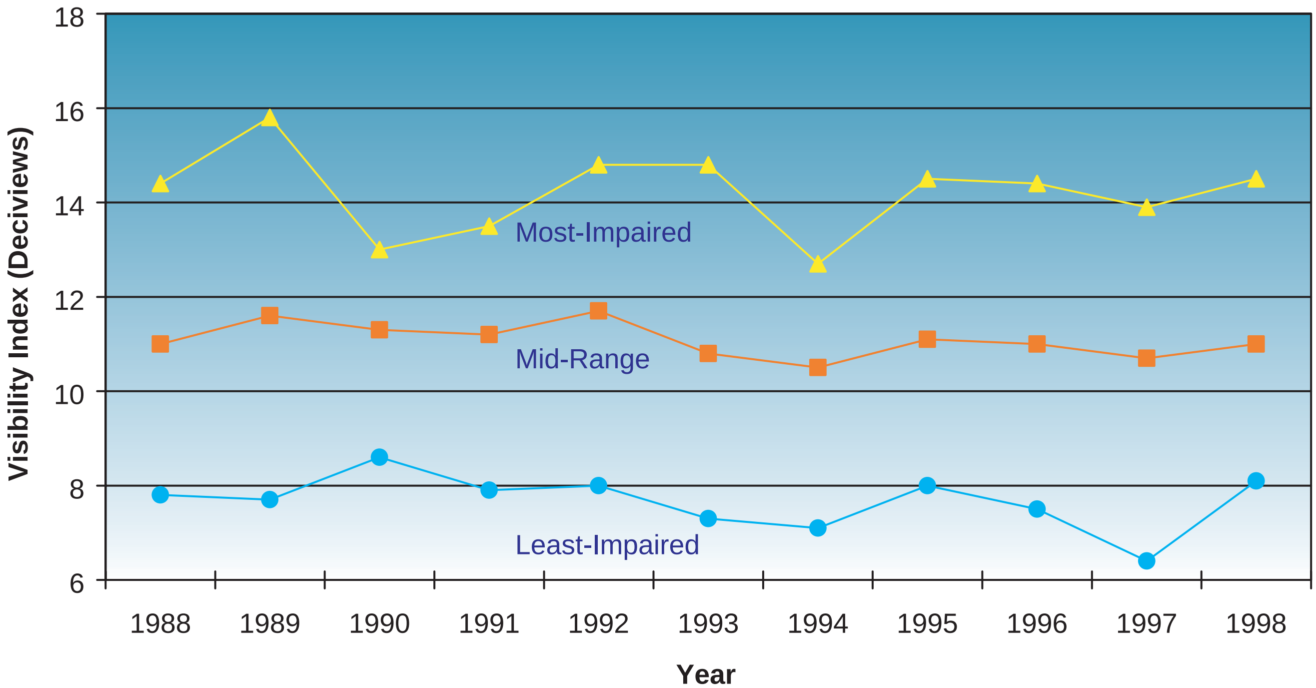

Figure AZ–22. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Tonto IMPROVE Particulate Sampler

Figure AZ–23 shows the seasonal averages for the calculated visibility index from 1988 through 1998. Coarse mass was not measured at this site between July 8, 1992 and December 2, 1992, and therefore, no autumn 1992 value was calculated. Interested readers can view the data for other species at http://improve.cnl.ucdavis.edu/cgi-bin/SSDisplay.cgi. No significant seasonal trends were observed in the spring, summer, or autumn from 1988 to 1998. However, the winter season showed a statistically significant trend toward lower visibility indices, indicating an improvement in visibility of more than 1 deciview.

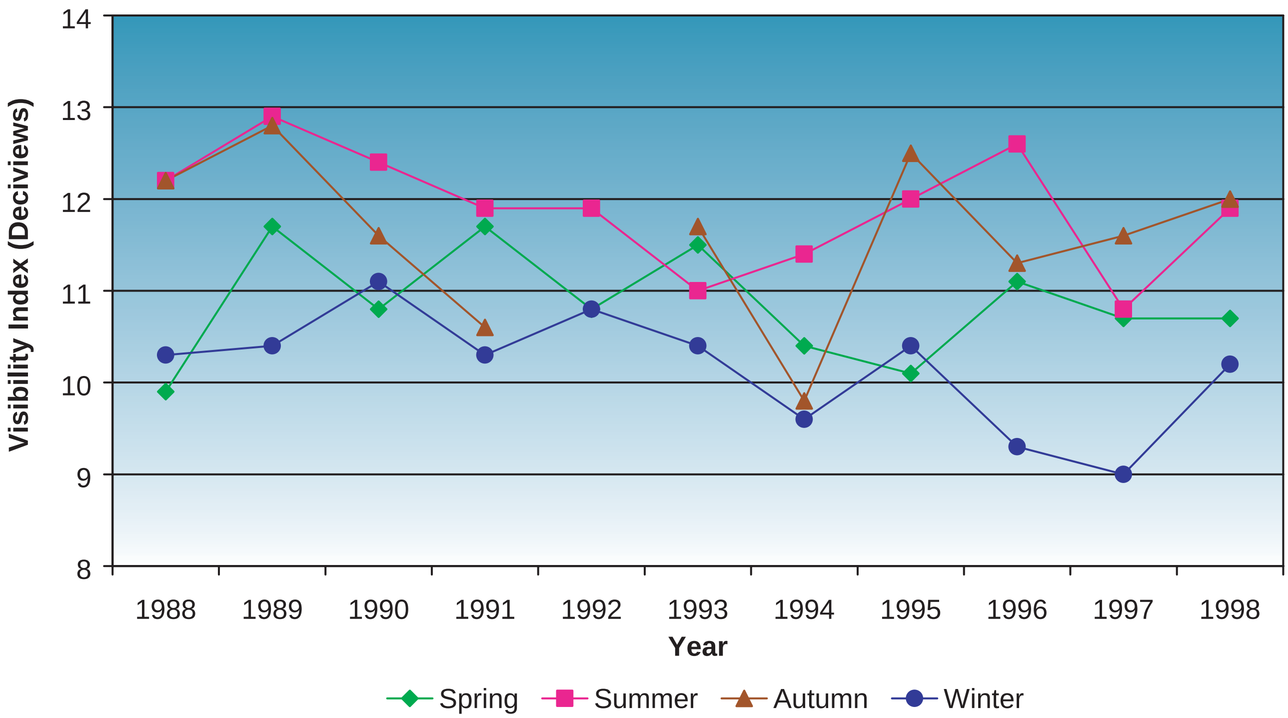

Figure AZ–23. Seasonal Deciview Averages from 1988–1998 for the Tonto IMPROVE Particulate Sampler

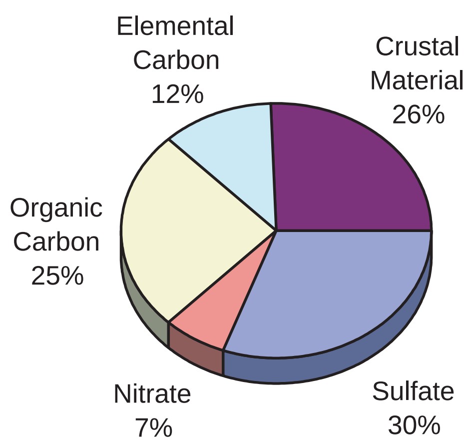

Figure AZ–24. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Tonto IMPROVE Particulate Sampler

Figure AZ–24 presents a chart showing the calculated fractional contribution to Tonto's light extinction by each aerosol component on an annual basis. Figure AZ–25 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 25 to 35 percent of the light extinction at the Tonto site, averaging 30 percent on an annual basis over a five-year period. The contributions from nitrates were near 6 percent in spring, summer, and autumn, but rose to 11 percent in the winter. The contributions from organic carbon remained relatively constant, between 23 and 28 percent in all four seasons. Elemental carbon measured at the Tonto National Monument site was responsible for 10 percent of the calculated aerosol light extinction in spring and summer, but rose to approximately 14 percent in the autumn and winter. The contributions from crustal material were near 32 percent in the spring but then dropped in the subsequent seasons to 26, 24, and 20 percent in summer, autumn, and winter.

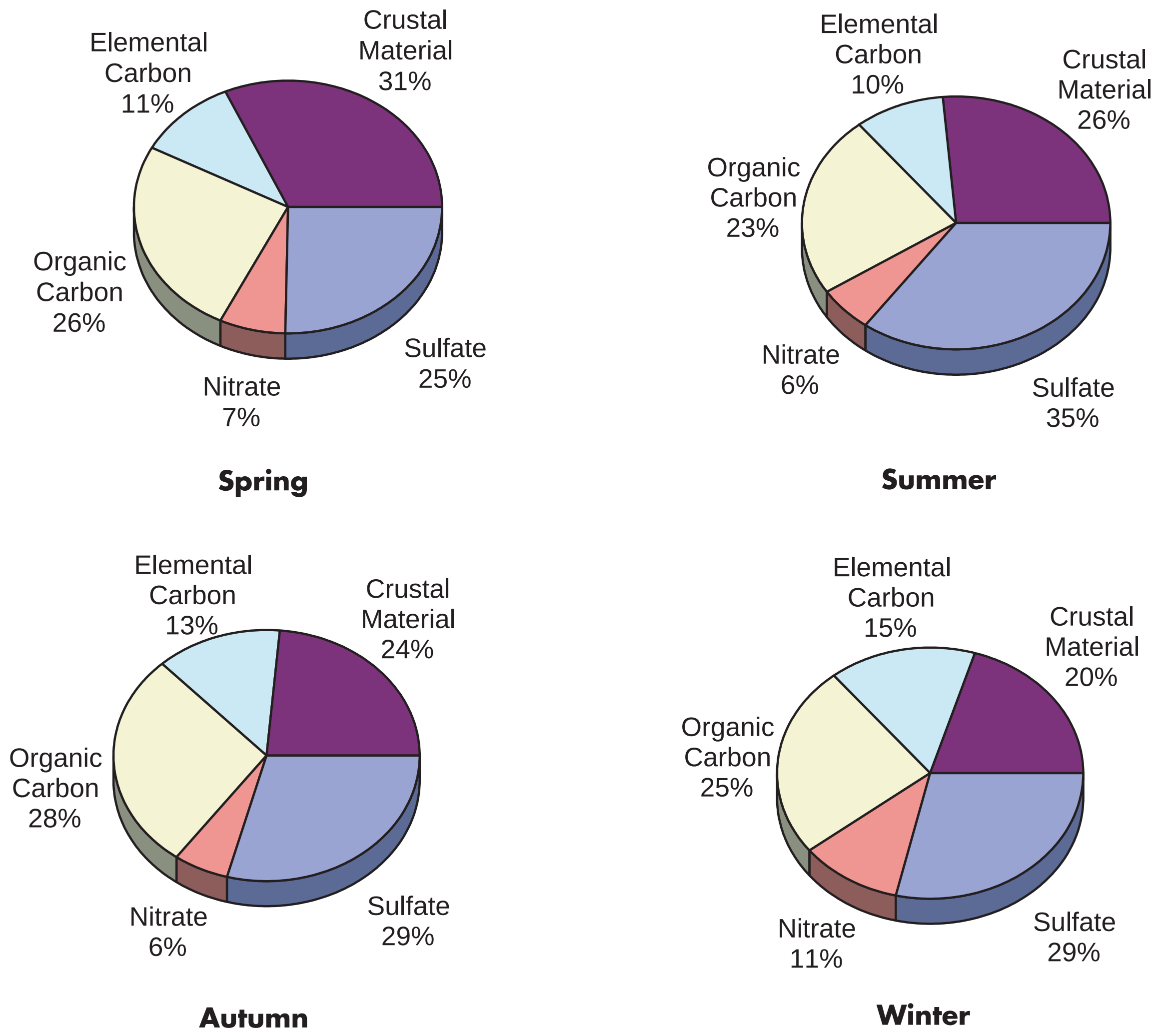

Figure AZ–25. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Tonto IMPROVE Particulate Sampler

Figure AZ–26 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Tonto National Monument site from 1988 to 1998. Over the eleven-year period, there was a statistically significant decreasing trend in the total annual aerosol light extinctions from approximately 22 to 20 Mm^{-1}, indicating improved visibility. No significant trends were noted in the annual light extinctions calculated for organic carbon, elemental carbon, or crustal material. However, the sulfates showed statistically significant decreases in their contribution to the light extinction coefficients, indicating lower ambient concentrations.

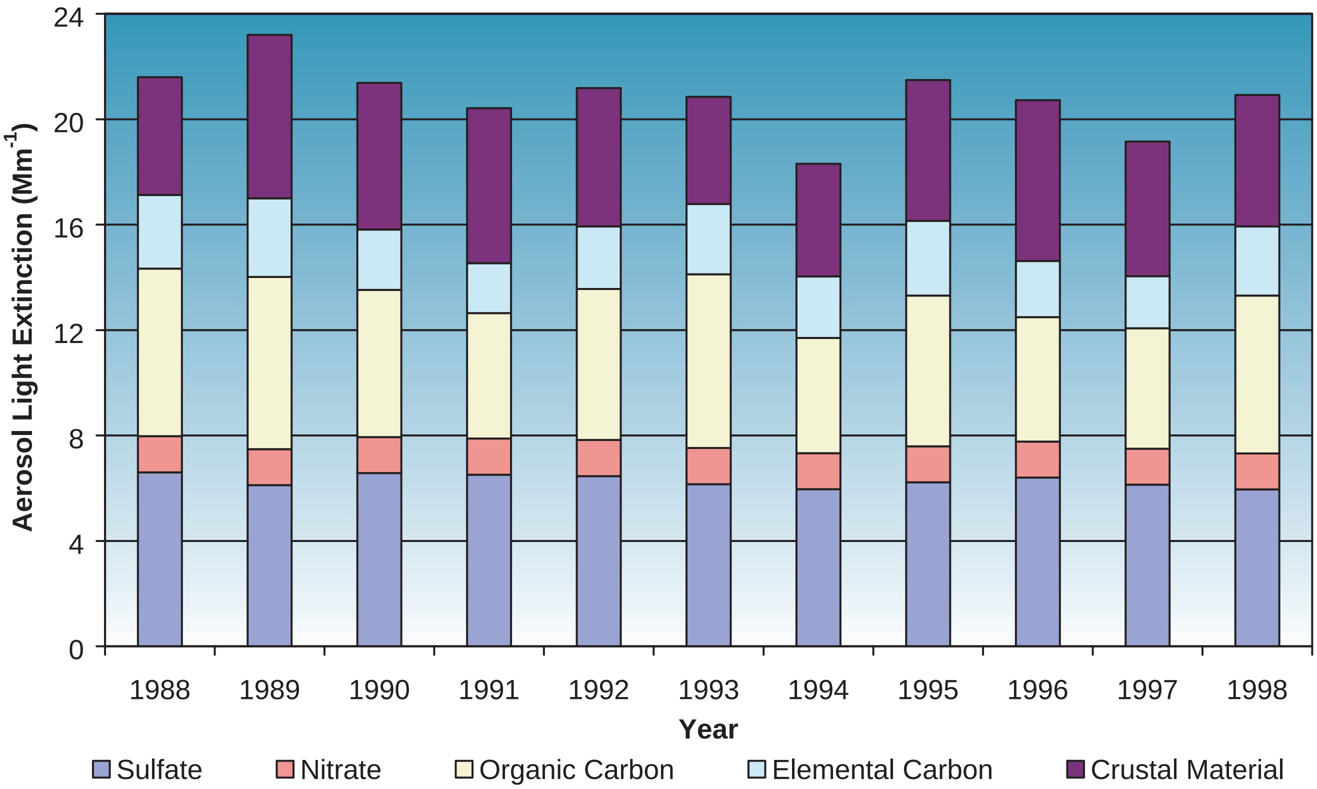

Figure AZ–26. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Tonto IMPROVE Particulate Sampler

Arizona State Summary

The calculated annual average aerosol extinction coefficients at Arizona's IMPROVE monitoring sites are presented in Table AZ–1. The calculated total aerosol extinction coefficients at all five sites were within 20 percent of the average (17.6 Mm^{-1}), indicating similar annual visibility conditions at all sites. The extinction coefficients for the individual species were also similar at the different sites. All five sites also showed similar rankings for contributions of the species to light extinction: sulfate, followed by organic carbon and crustal material, then elemental carbon, and lastly nitrate. The same rankings were observed for the Colorado, Texas, and Wyoming sites in Tables CO–1, TX–1, and WY–1.

Table AZ–1. Arizona Calculated Total Extinction Coefficients from 1994–1998

IMPROVE Site	Calculated Total Aerosol Extinction Coefficient (Mm^{-1})	Pollutant Extinction Coefficient (Mm^{-1})				
		Sulfate	Nitrate	Organic Carbon	Elemental Carbon	Crustal Material
Chiricahua NM	18.5	8.4	0.9	3.6	1.4	4.1
Grand Canyon NP (GRCA)	14.4	5.5	1.1	2.8	1.4	3.6
Grand Canyon NP (INGA)	18.3	5.6	1.1	4.8	1.8	5.1
Petrified Forest NP	16.6	6.1	1.1	4.1	2.3	3.1
Tonto NM	20.1	6.1	1.4	5.1	2.4	5.2
Average	17.6 ±2.2	6.3 ± 1.2	1.1 ± 0.2	4.1 ± 0.9	1.8 ± 0.5	4.2 ± 0.9

4. ARKANSAS

The only IMPROVE monitoring site in Arkansas that operated continuously from 1994 through 1998 was located near the Upper Buffalo Wilderness Area. Figure AR–1 shows the Upper Buffalo monitor location (35.83°N, 93.21°W, elevation 2360 feet) near the wilderness area in northern Arkansas. The Caney Creek Wilderness Area is also designated as a mandatory Federal Class I area covered by the Regional Haze Rule, but no IMPROVE particulate sampler has been installed at this site.

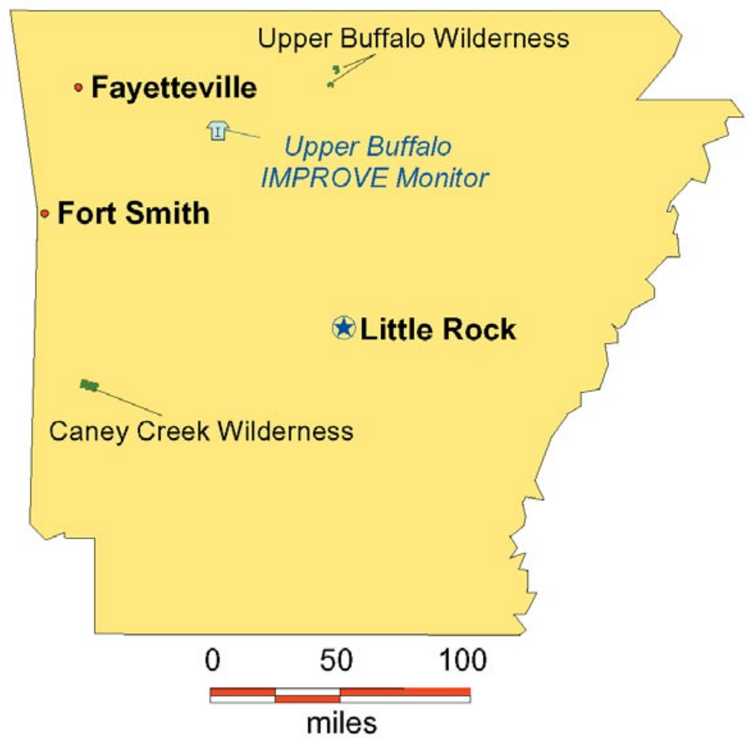

Figure AR–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in Arkansas

Upper Buffalo Wilderness Area

The Upper Buffalo IMPROVE particulate sampler started reporting in December of 1991. Figure AR–2 presents the calculated visibility indices for selected data sets in 1992 through 1998. The figure shows that from 1992 through 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained near 27 deciviews (VR 16 miles). From 1992 through 1998, there was no significant trend in the annual average of the visibility index for the mid-range days, which remained relatively constant near 20 deciviews (VR 33 miles). Similarly, the annual average of the visibility index for the least-impaired days showed no significant trend in the visibility index of 13.5 deciviews (VR 65 miles).

Figure AR–3 shows the seasonal averages for the calculated visibility index from 1992 through 1998. Coarse mass data for spring 1992 was not reported. Therefore, no spring 1992 value is reflected in Figure AR–3. Interested readers should consult http://improve.cnl.ucdavis.edu/cgi-bin/SSDisplay.cgi

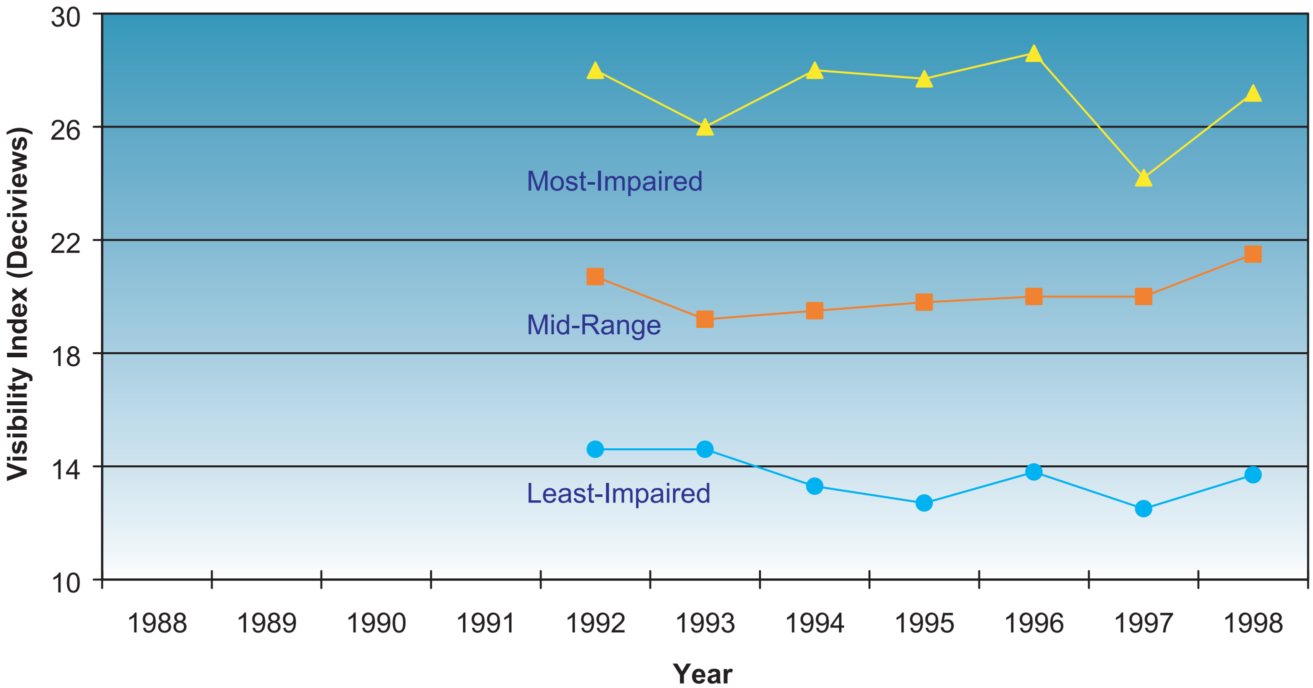

Figure AR–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1992–1998 for the Upper Buffalo IMPROVE Particulate Sampler

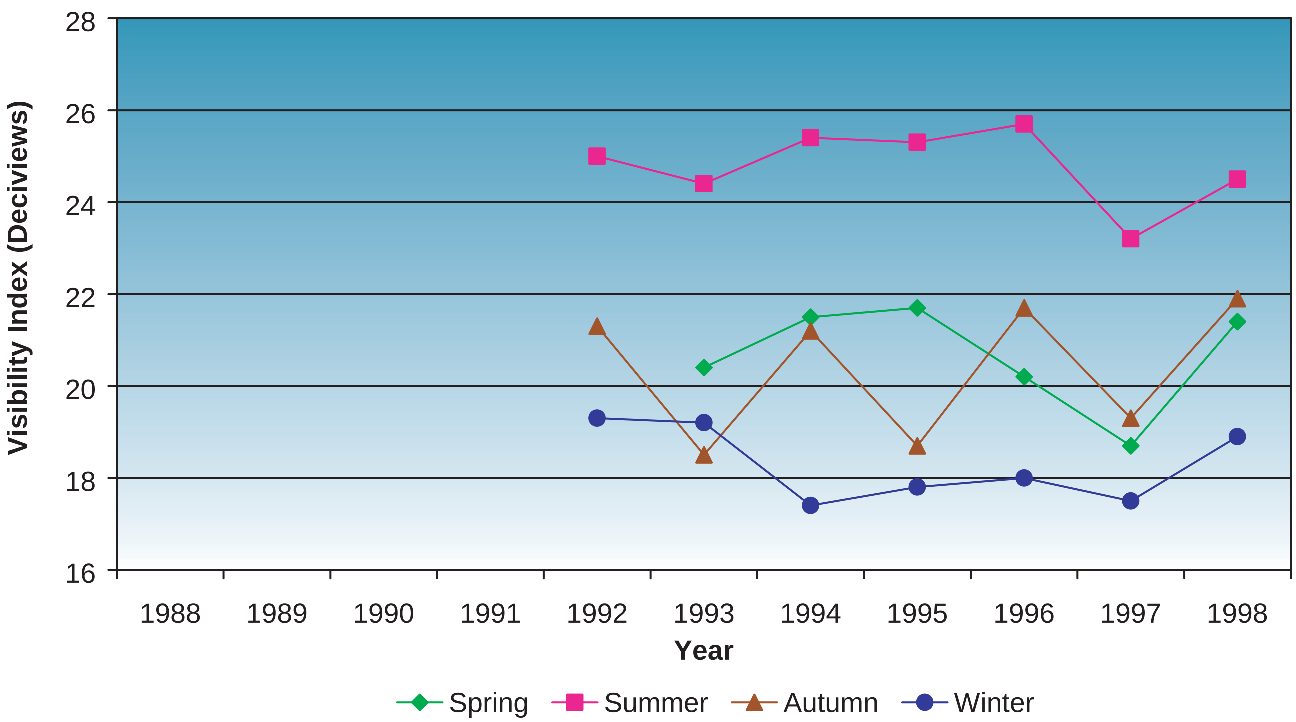

Figure AR–3. Seasonal Deciview Averages from 1992–1998 for the Upper Buffalo IMPROVE Particulate Sampler

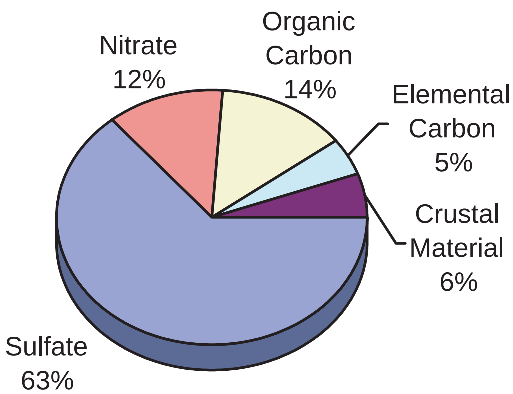

Figure AR–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Upper Buffalo IMPROVE Particulate Sampler

for additional data. The average visibility indices for summer were 3 to 8 deciviews higher than those during the autumn, winter, and spring. No statistically significant seasonal trends were observed in the calculated visibility indices over this time period for any of the seasons.

Figure AR–4 presents a chart showing the calculated fractional contribution to Upper Buffalo's light extinction by each aerosol component on an annual basis. Figure AR–5 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 55 to 70 percent of the light extinction at the Upper Buffalo site, averaging 63 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the summer and the lowest in the winter. The contributions from nitrates were 13, 9, 13, and 19 percent for the spring, summer, autumn, and winter, averaging just 12 percent

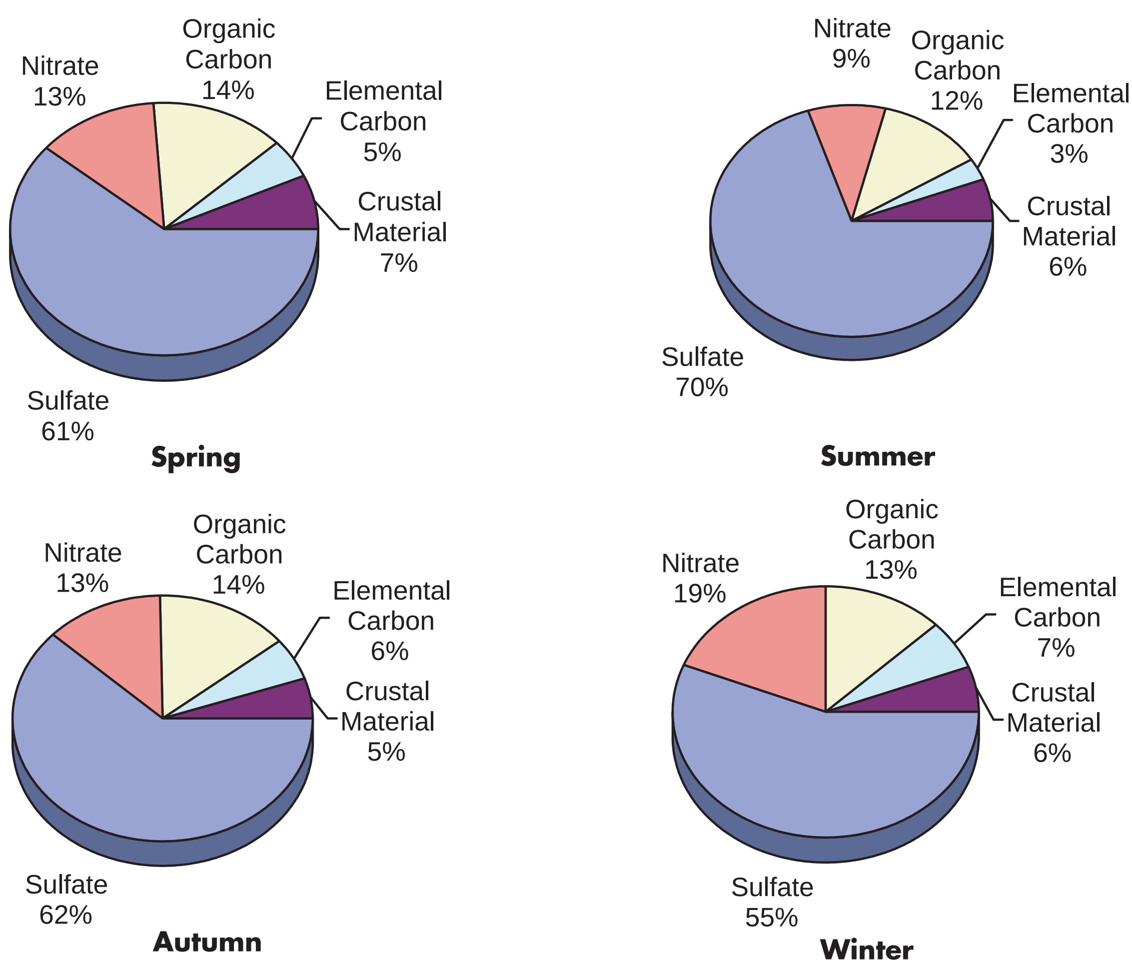

Figure AR–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Upper Buffalo IMPROVE Particulate Sampler

on an annual basis. The contributions from organic carbon ranged from 12 to 14 percent during the four seasons. Annually, elemental carbon and crustal material measured at the Upper Buffalo site were responsible for approximately 5 and 6 percent of the calculated aerosol light extinction.

Figure AR–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Upper Buffalo site from 1992 to 1998. Over the seven-year period, the total annual aerosol light extinctions remained between 63 and 80 Mm^{-1} (no significant trend). No significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, or elemental carbon. However, the crustal material showed statistically significant decreases in its annual contribution to the light extinction coefficients, indicating lower ambient concentrations.

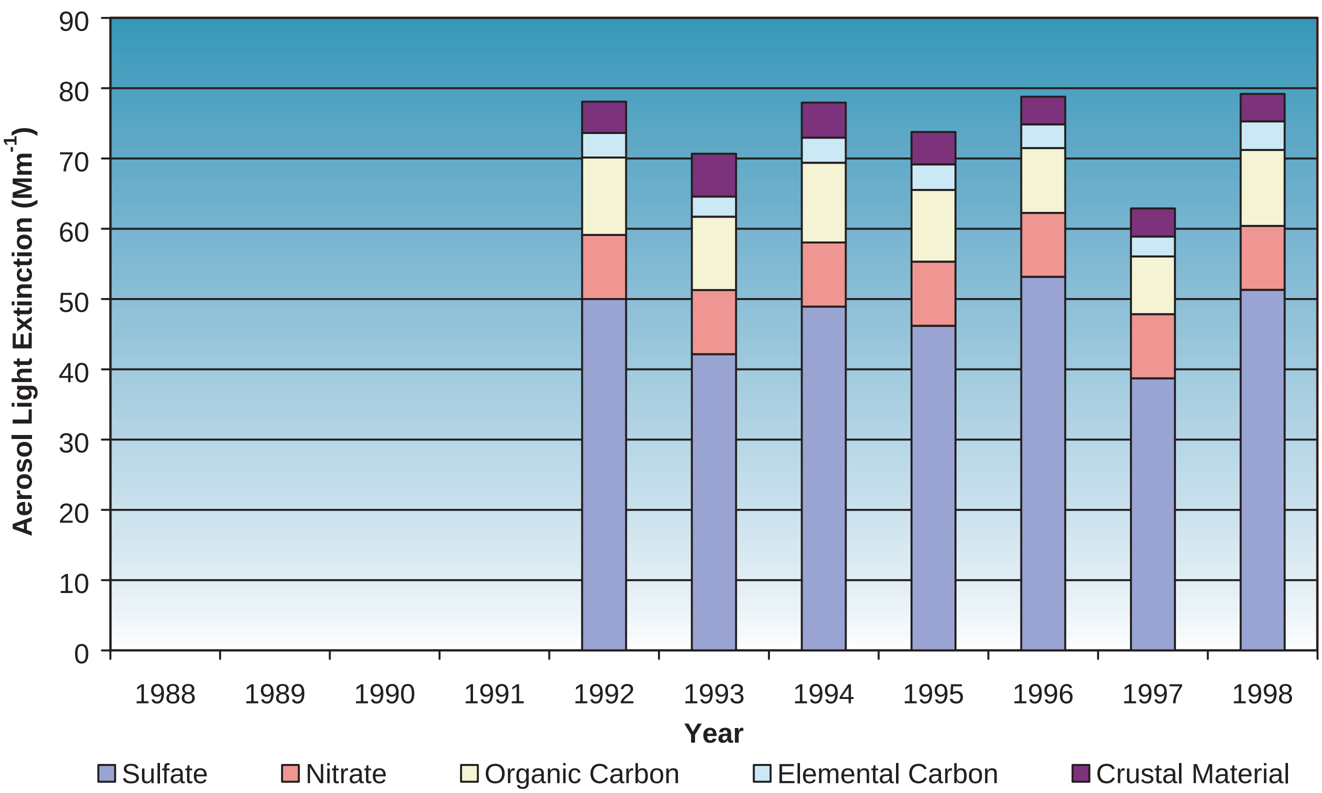

Figure AR–6. Contributions to Calculated Annual Aerosol Light Extinction from 1992–1998 for the Upper Buffalo IMPROVE Particulate Sampler

5. CALIFORNIA

The following seven IMPROVE particulate samplers in California operated continuously from 1994 through 1998:

Lassen Volcanic National Park (40.53°N, 121.57°W, elevation 5900 feet),
Pinnacles National Monument (36.49°N, 121.21°W, elevation 1040 feet),
Point Reyes Wilderness Area (38.12°N, 122.91°W, elevation 125 feet),
Redwood National Park (41.69°N, 124.09°W, elevation 760 feet),
San Gorgonio Wilderness Area (34.19°N, 116.91°W, elevation 5618 feet),
Sequoia National Park (36.52°N, 118.18°W, elevation 1800 feet), and
Yosemite National Park (37.71°N, 119.70°W, elevation 5300 feet).

The IMPROVE particulate sampler at Sequoia National Park began data collection on March 4, 1992, but no summary data was provided before 1995. Since the criteria for sites to be included in this report was a complete data set from 1994 through 1998, the data for Sequoia National Park will not be presented in this chapter of the report. However, this site is important when examining state, regional, and national trends so it will be included in discussions about groups of sites.

The National Park Service also operates a monitor in Death Valley under the IMPROVE protocol, but Death Valley National Monument is not a mandatory Federal Class I area and is not discussed in this report. Figure CA–1 shows the IMPROVE particulate sampler locations in the mandatory Federal Class I areas across the state. In addition, the following areas are designated as mandatory Federal Class I areas covered by the Regional Haze Rule but did not have an IMPROVE particulate sampler operating from 1994 through 1998:

Agua Tibia Wilderness Area,
Caribou Wilderness Area,
Cucamonga Wilderness Area,
Desolation Wilderness Area,
Dome Land Wilderness Area,
Emigrant Wilderness Area,
Hoover Wilderness Area,
John Muir Wilderness Area,
Joshua Tree Wilderness Area,
Kaiser Wilderness Area,
Kings Canyon National Park,
Lava Beds Wilderness Area,
Marble Mountain Wilderness Area,
Minarets Wilderness Area,
Mokelumne Wilderness Area,
San Gabriel Wilderness Area,
San Jacinto Wilderness Area,
San Rafael Wilderness Area,
South Warner Wilderness Area,
Thousand Lakes Wilderness Area,
Ventana Wilderness Area, and
Yolla Bolly–Middle Eel Wilderness Area.

Figure CA–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Sites in California

Lassen Volcanic National Park

The Lassen Volcanic IMPROVE particulate sampler started reporting in March of 1988. Figure CA–2 presents the calculated visibility indices at Lassen Volcanic National Park for selected data sets from 1988 through 1998. The figure shows that from 1988 through 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained between 12 and 15.3 deciviews (VR 75 to 55 miles). From 1988 through 1998 there was no statistically significant trend indicating improved visibility in the annual average of the visibility index for the mid-range days, which remained near 8 or 9 deciviews (VR 110 or 100 miles) through 1997 and then rose to 10 deciviews in 1998. The 1998 rise was attributed to an increase in organic carbon and elemental carbon concentrations, a common effect during fire episodes. For example, the total carbon concentration measured on October 10, 1998 rose over eight times its average value; Lassen Volcanic Park personnel (Arnold, 2000) confirmed prescribed burning activities a few miles from the monitor site during the first full week in October 1998. The annual average of the visibility index for the least-impaired days remained near 4.5 deciviews (VR 155 miles), indicating no statistically significant trend toward improved visibility on the least-impaired days.

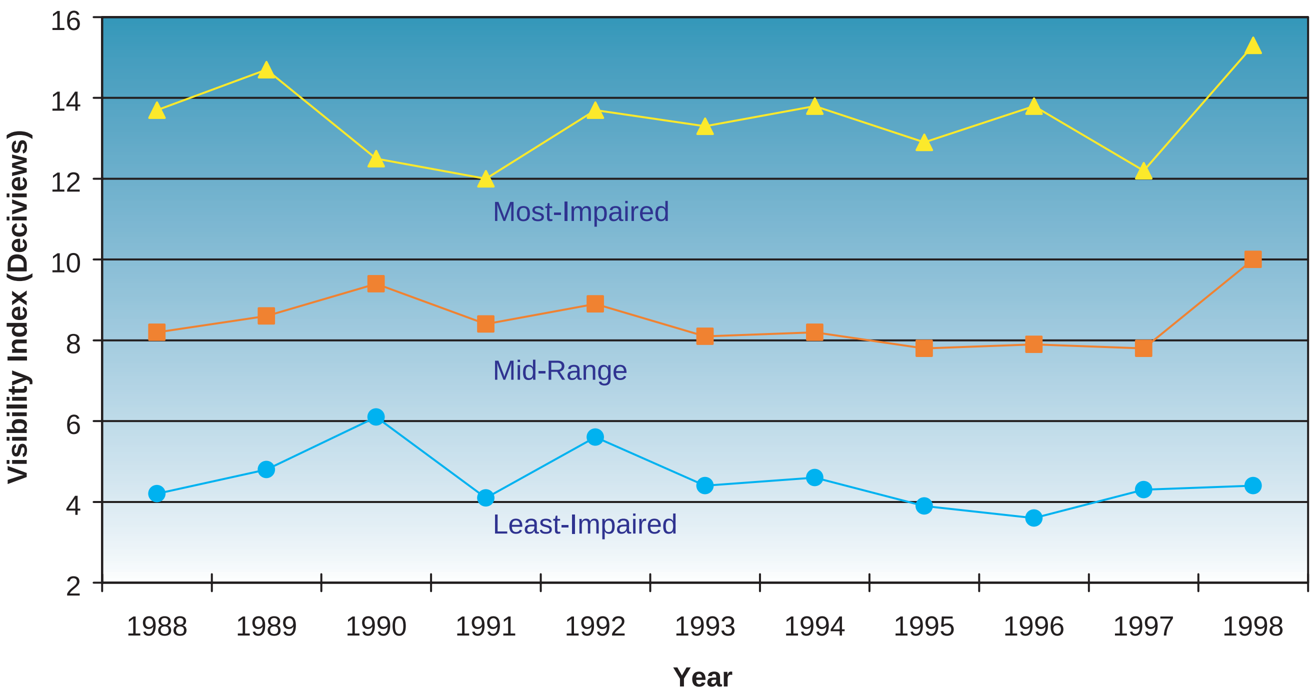

Figure CA–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Lassen Volcanic IMPROVE Particulate Sampler

Figure CA–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The average visibility indices for summer were 2 to 4 deciviews higher than those during the spring and autumn, and the visibility indices for the spring and autumn were 1 to 3 deciviews above the indices for winter. No significant seasonal trends were observed in the calculated visibility indices over this time period for the spring, summer, or autumn. However, the winter indices decreased 2 deciviews with a statistically significant trend, indicating improved visibility during that season.

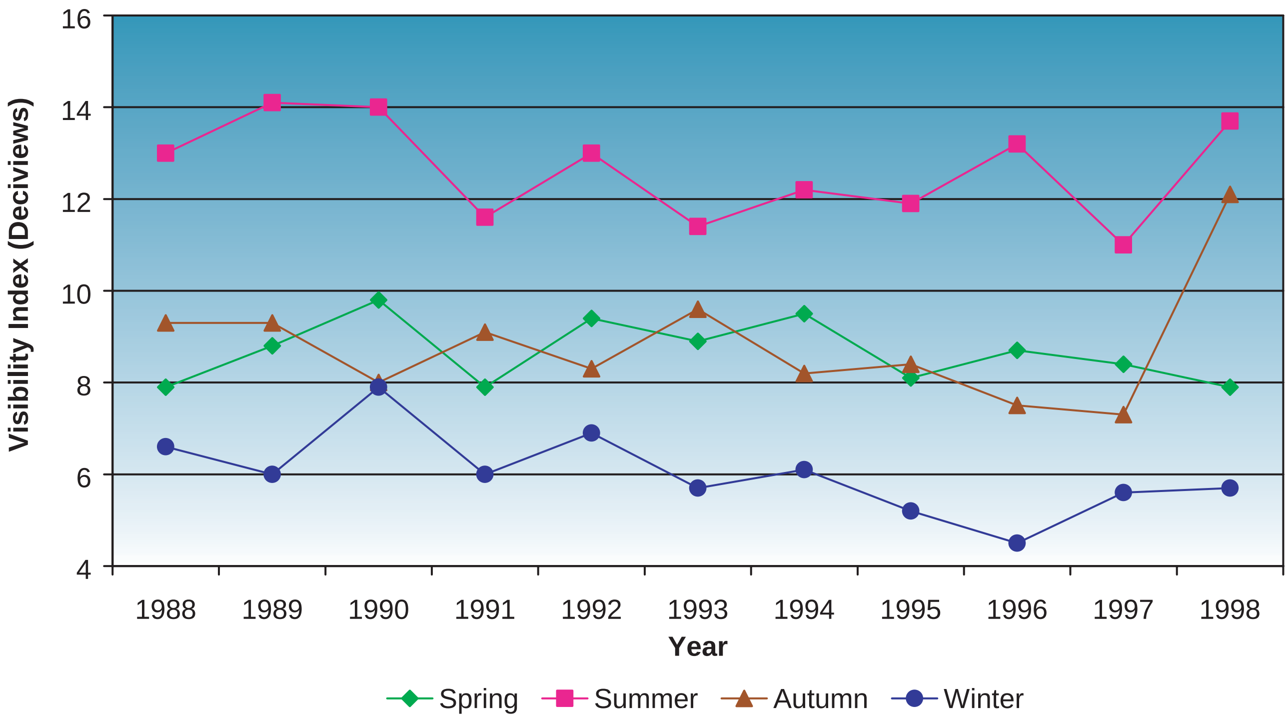

Figure CA–3. Seasonal Deciview Averages from 1988–1998 for the Lassen Volcanic IMPROVE Particulate Sampler

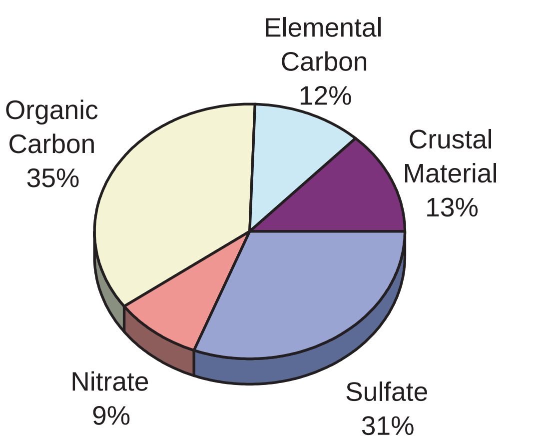

Figure CA–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Lassen Volcanic IMPROVE Particulate Sampler

Figure CA–4 presents a chart showing the calculated fractional contribution to Lassen Volcanic National Park's light extinction by each aerosol species on an annual basis. Figure CA–5 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 20 to 43 percent of the light extinction at the site, averaging 31 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the summer and the lowest in the winter. The contributions from nitrates were between 7 and 18 percent over the four seasons. The contributions from organic carbon ranged from 28 to 45 percent during the four seasons, with the highest percentages occurring in the autumn and winter. Annually, elemental carbon measured at the Lassen Volcanic site was responsible for 9 to 15 percent of the calculated aerosol light extinction. Crustal material contributions to the light extinction coefficient varied from 11 to 16 percent in the four seasons.

Figure CA–6 shows the calculated contributions of each of the aerosol mass components to the annual

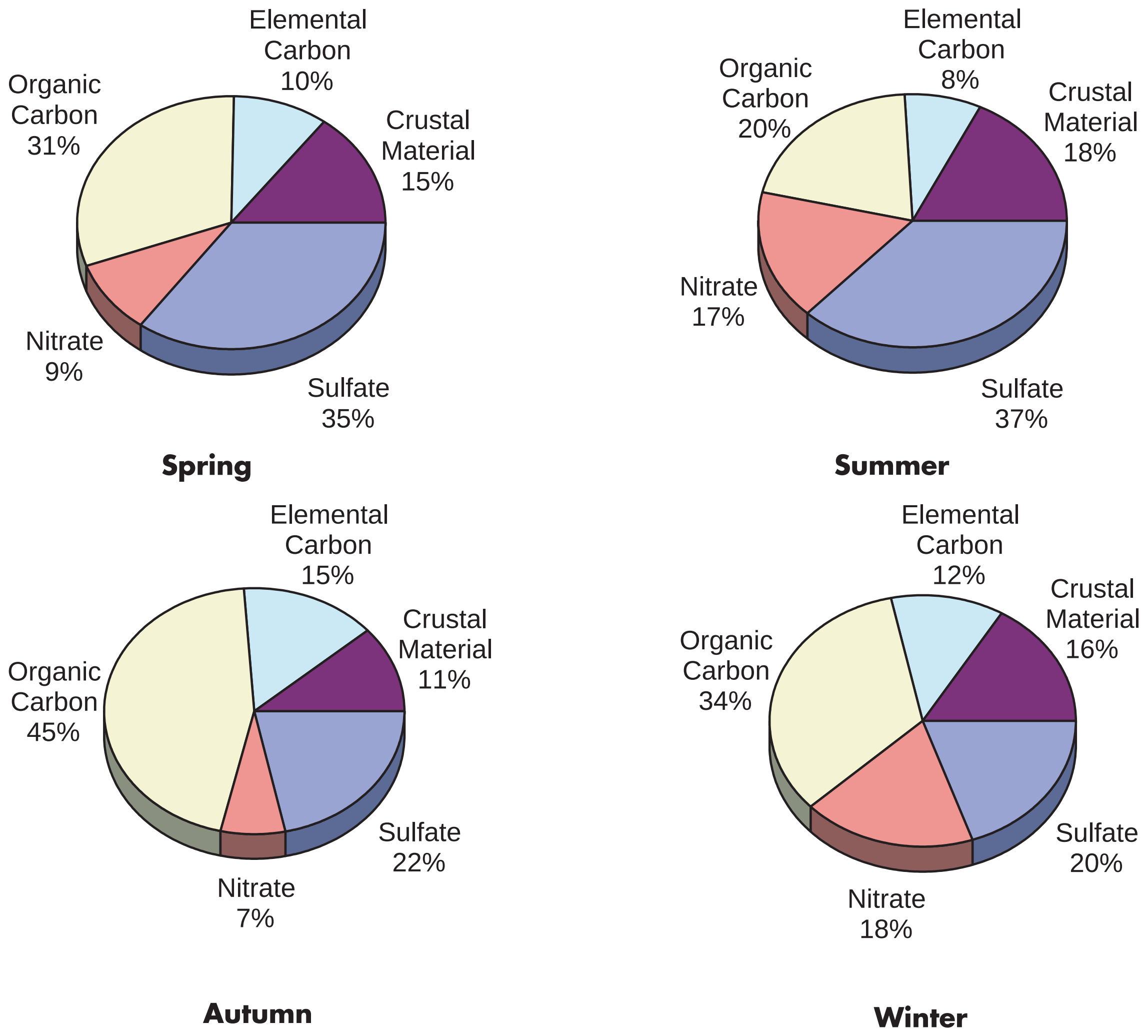

Figure CA–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Lassen Volcanic IMPROVE Particulate Sampler

average aerosol light extinctions at the Lassen Volcanic site from 1988 to 1998. Statistical analysis shows that over the eleven-year period there was no statistically significant trend in the total annual aerosol light extinctions. The extinction coefficients ranged from 12 to 18 Mm^{-1}. Ignoring the 1998 value (when nearby fires affected the visibility impairment in October), the total annual aerosol light extinction decreased from 17 to 13 Mm^{-1}, indicating a significant trend toward improved visibility. No significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, or elemental carbon. However, the crustal material showed statistically significant decreases in its annual contribution to the light extinction coefficients, indicating lower ambient concentrations.

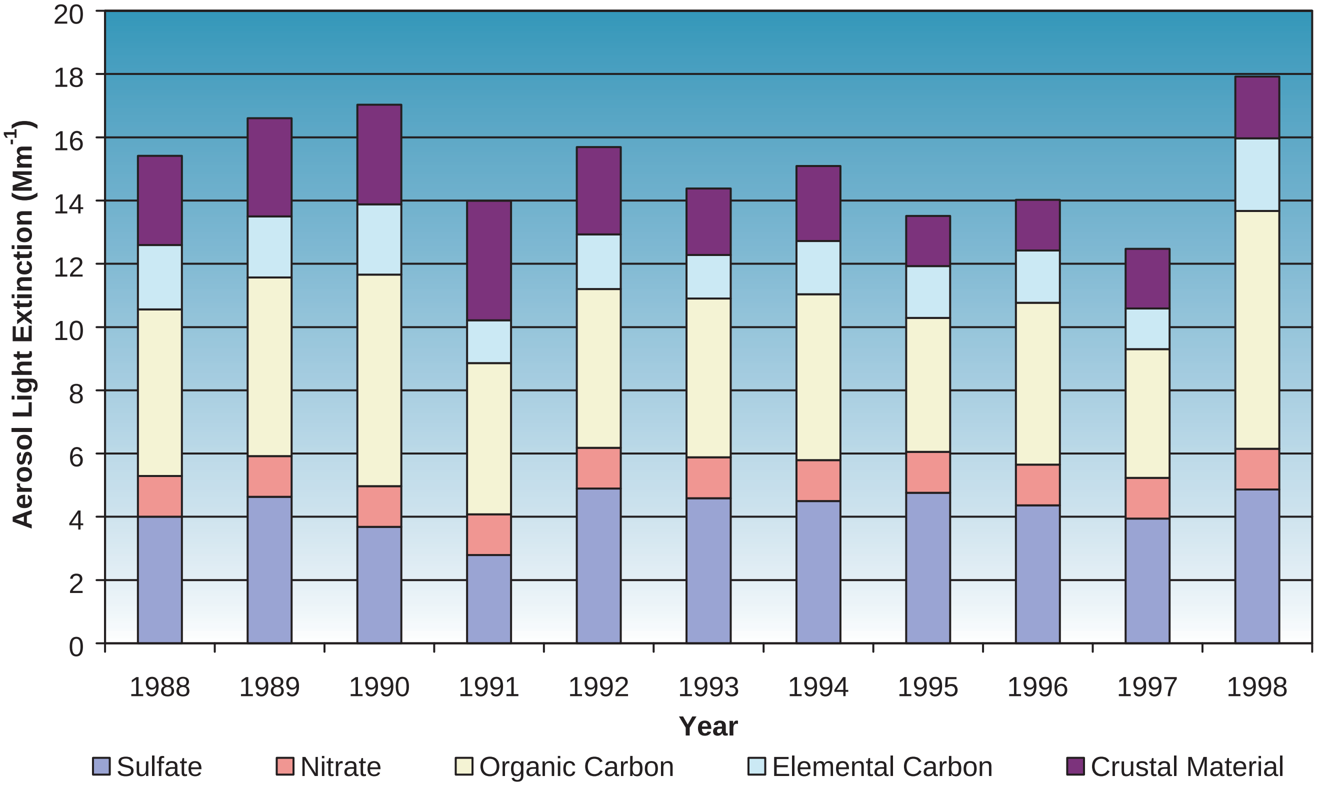

Figure CA–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Lassen Volcanic IMPROVE Particulate Sampler

Pinnacles National Monument

The Pinnacles IMPROVE particulate sampler started reporting in March of 1988. Figure CA–7 presents the calculated visibility indices at Pinnacles National Monument for selected data sets from 1988 through 1998. The figure shows that from 1988 through 1998 there was a significant trend indicating improved visibility in the annual average of the visibility index for the most-impaired days, which dropped from a high of 19.5 deciviews in 1989 to 17.5 deciviews in 1998 (VR from 35 to 40 miles). From 1988 through 1998 there was a significant trend indicating improved visibility in the annual average of the visibility index for the mid-range days, which decreased from 15 (VR 55 miles) to 13 deciviews (VR 65 miles). Similarly, the annual average of the visibility index for the least-impaired days decreased from 10 to 9 deciviews (VR from 90 to 100 miles), indicating a significant improvement in visibility on the least-impaired days.

Figure CA–8 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The average visibility indices were similar during all four seasons. The indices for winter dropped 3 deciviews. The statistically significant seasonal trend indicates significant improvements in visibility occurred. Even though the indices for spring, summer, and autumn decreased from 1 to 1.4 deciviews over all years, the drops were not uniform enough to be judged statistically significant trends.

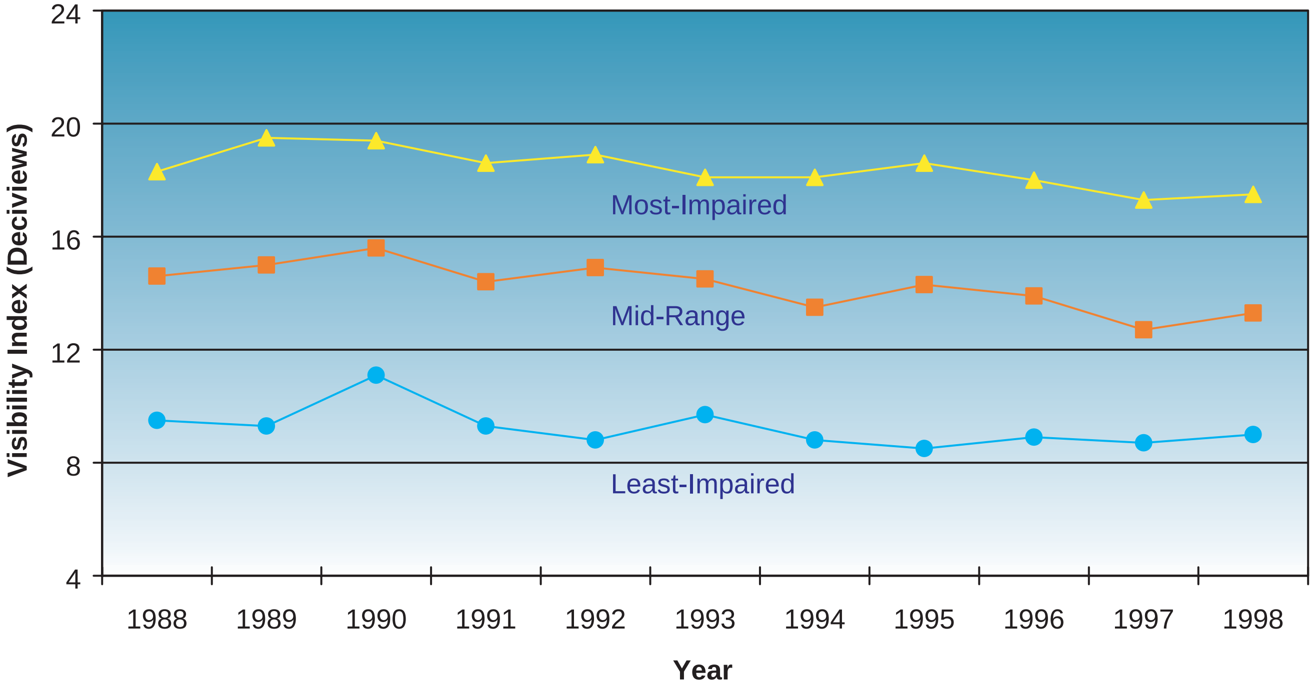

Figure CA–7. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988-1998 for the Pinnacles IMPROVE Particulate Sampler

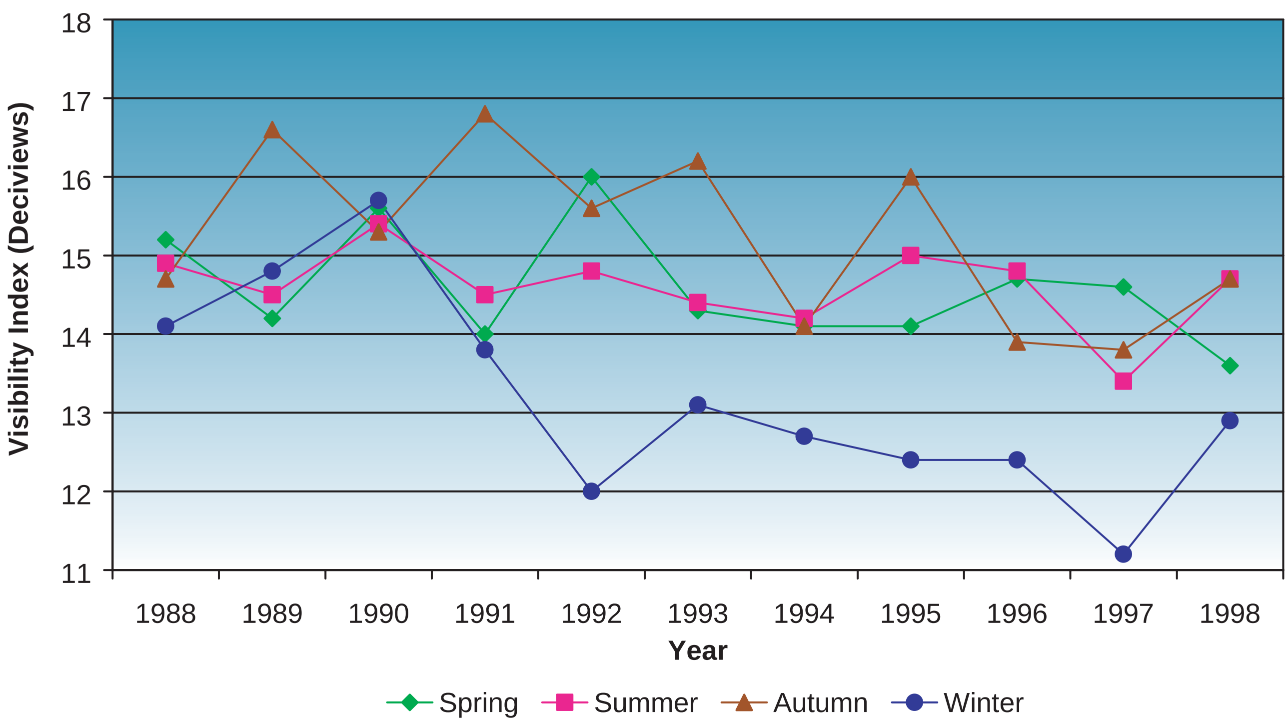

Figure CA–8. Seasonal Deciview Averages from 1988–1998 for the Pinnacles IMPROVE Particulate Sampler

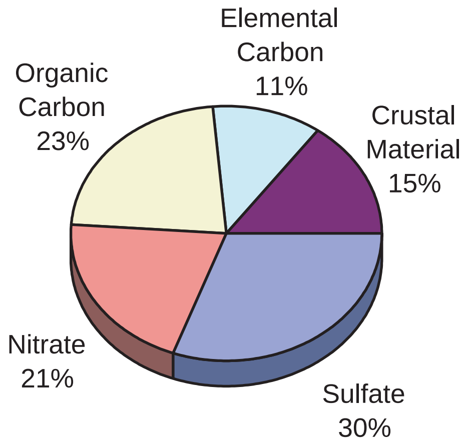

Figure CA–9. Contribution to Calculated Annual Aerosol Light Extinction Averaged from 1994–1998 for the Pinnacles IMPROVE Particulate Sampler

Figure CA–9 presents a chart showing the calculated fractional contribution to Pinnacle's light extinction by each aerosol component on an annual basis. Figure CA–10 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 22 to 37 percent of the light extinction at the site, averaging 30 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the summer and the lowest in the winter. The contributions from nitrates ranged between 17 and 30 percent, with the highest percentages observed in the winter. The contributions from organic carbon ranged from 20 to 26 percent during the four seasons, averaging 23 percent. Seasonally, elemental carbon measured at the Pinnacles site was responsible for 8 to 15 percent of the calculated aerosol light extinction. Crustal material contributions to the light extinction coefficient varied from 11 to 18 percent in the four seasons.

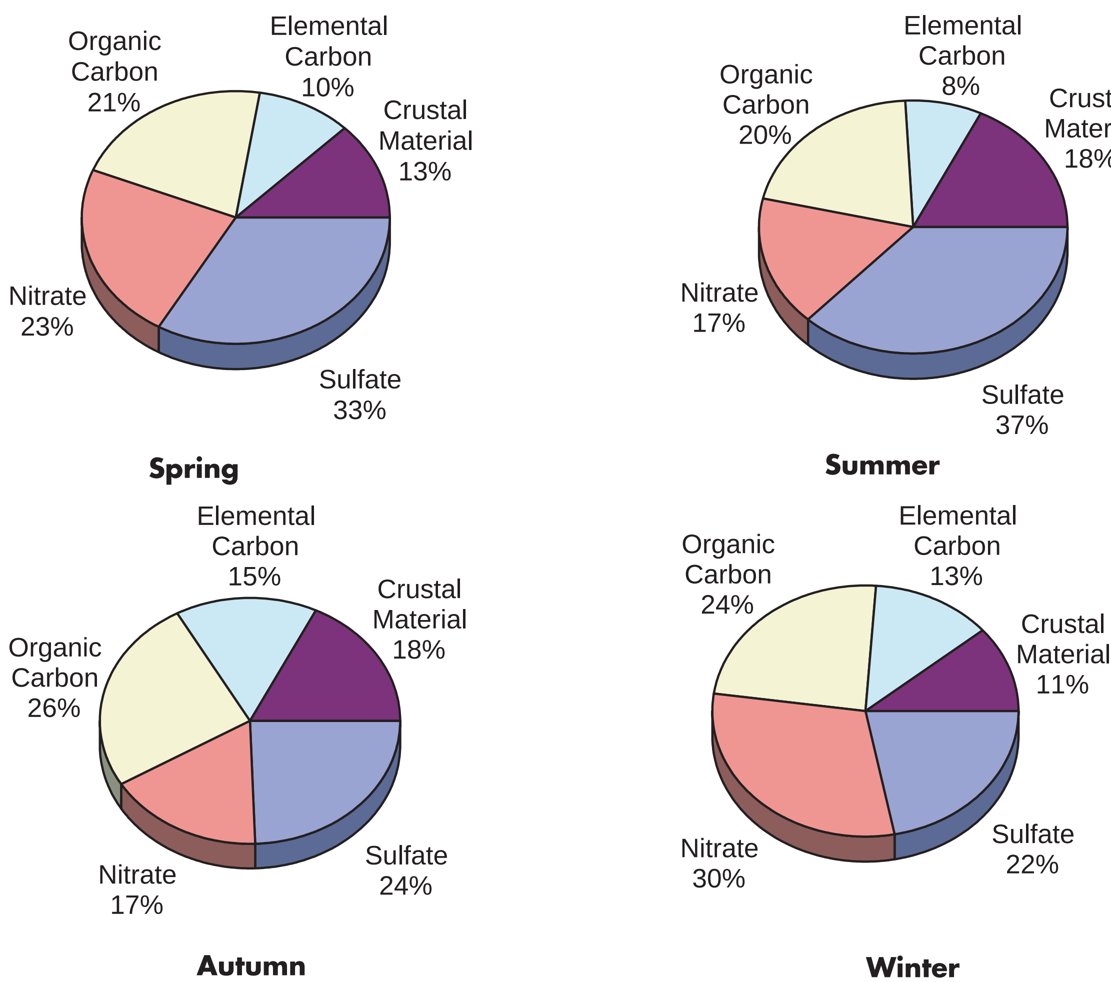

Figure CA–10. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Pinnacles IMPROVE Particulate Sampler

Figure CA–11 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Pinnacles site from 1988 to 1998. Over the eleven-year period, there was a statistically significant trend in the total annual aerosol light from approximately 36 to 30 Mm^{-1}, indicating improved visibility. The sulfate and crustal material aerosol species also showed significant decreases in their contributions to the annual light extinction coefficients. However, the decreases in organic and elemental carbon light extinction were not statistically significant.

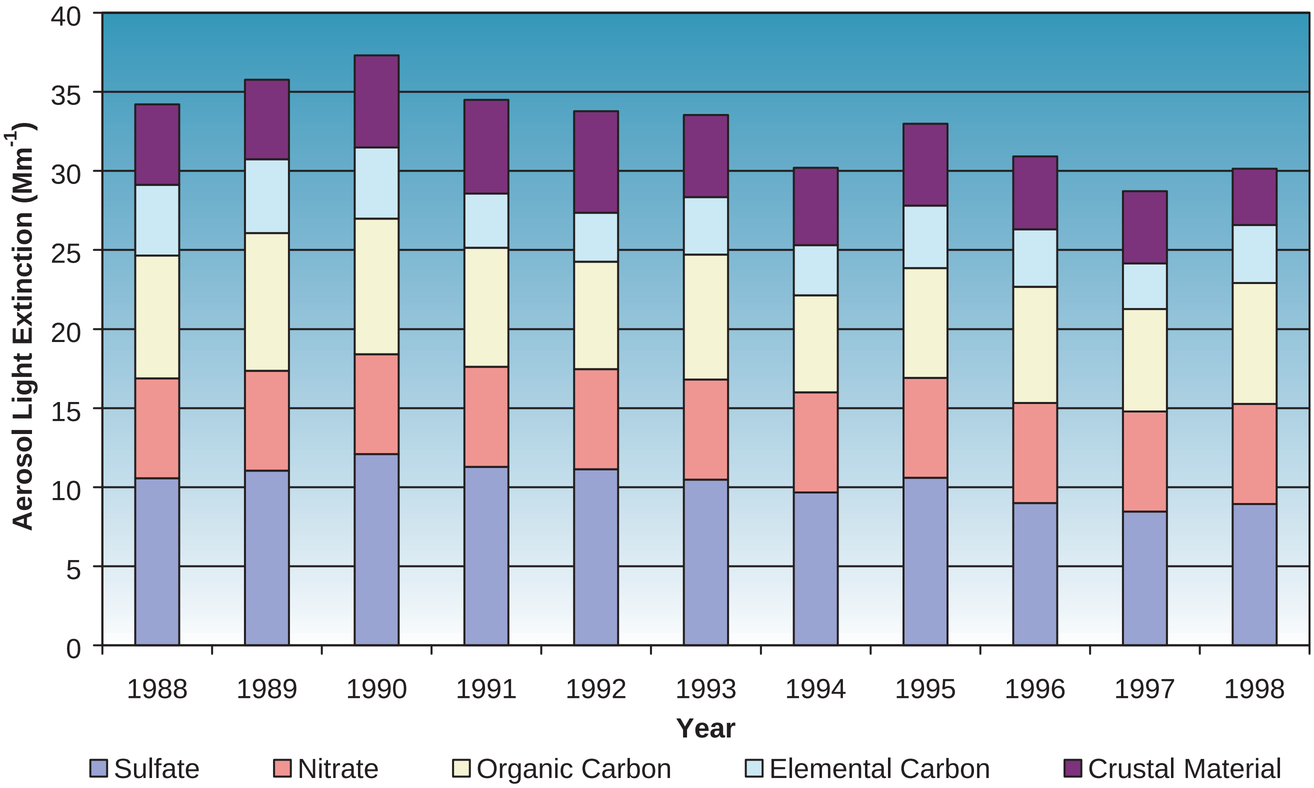

Figure CA–11. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Pinnacles IMPROVE Particulate Sampler

Point Reyes Wilderness

The Point Reyes IMPROVE particulate sampler started reporting in March of 1988. Figure CA–12 presents the calculated visibility indices at Point Reyes National Seashore for selected data sets in 1988 through 1998. The figure shows that from 1988 through 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained near 22 deciviews (VR 27 miles). From 1988 through 1998 there was no significant trend indicating improved visibility in the annual average of the visibility index for the mid-range days, despite the decrease from 16 (VR 50 miles) to 15 deciviews (VR 55 miles). The annual average of the visibility index for the least-impaired days remained near 12 deciviews (VR 75 miles) over the eleven-year period.

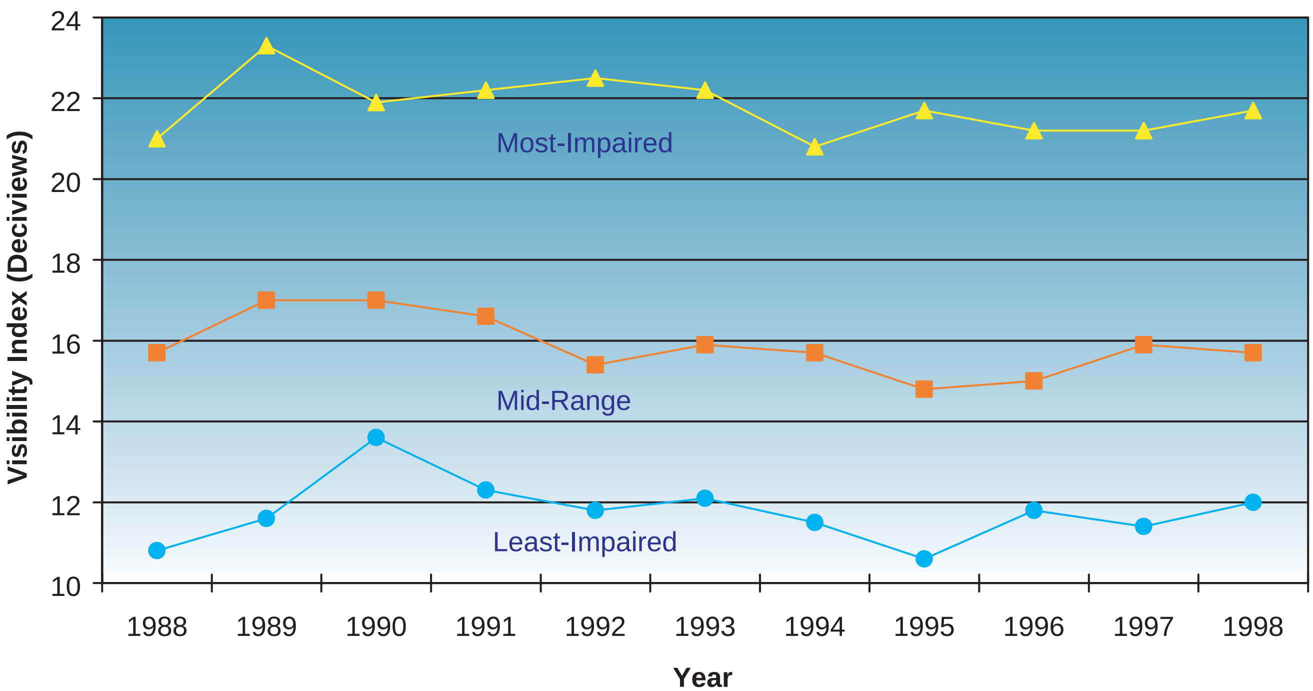

Figure CA–12. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Point Reyes IMPROVE Particulate Sampler

Figure CA–13 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The average visibility indices spanned similar ranges during spring, autumn, and winter, all the values typically 2 to 4 deciviews lower than summer values. The visibility indices for winter showed a statistically significant trend toward improved visibility (2.5-deciview improvement over 11 years). The visibility indices for spring, summer, and autumn showed no statistically significant trends over the eleven-year period, despite the decreases in the deciview indices for spring and autumn.

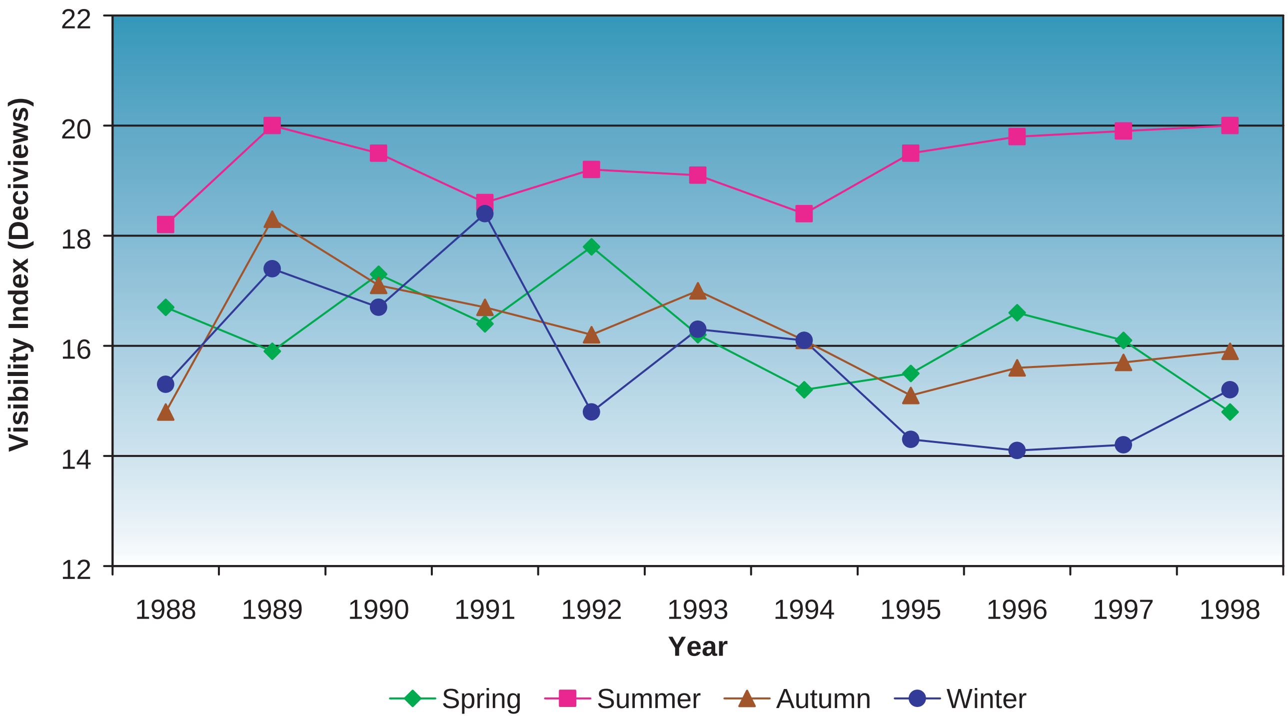

Figure CA–13. Seasonal Deciview Averages from 1988–1998 for the Point Reyes IMPROVE Particulate Sampler

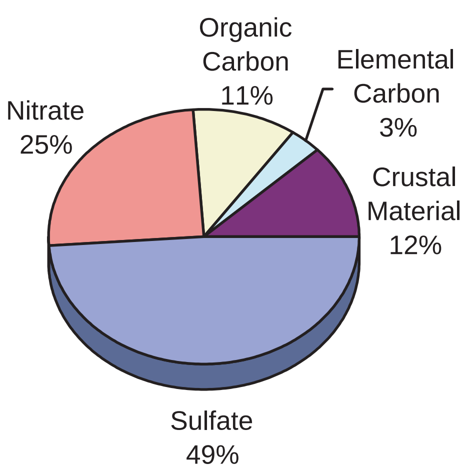

Figure CA–14. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Point Reyes IMPROVE Particulate Sampler

Figure CA–14 presents a chart showing the calculated fractional contribution to Point Reyes' light extinction by each aerosol species on an annual basis. Figure CA–15 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 35 to 63 percent of the light extinction at the site, averaging 49 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the summer and the lowest in the winter. The contributions from nitrates ranged between 23 and 27 percent. The contributions from organic carbon ranged from 5 to 18 percent during the four seasons, averaging 11 percent. Annually, elemental carbon measured at the Point Reyes site was responsible for just 1 to 7 percent of the calculated aerosol light extinction. Crustal material contributions to the light extinction coefficient varied from 8 to 15 percent in the four seasons.

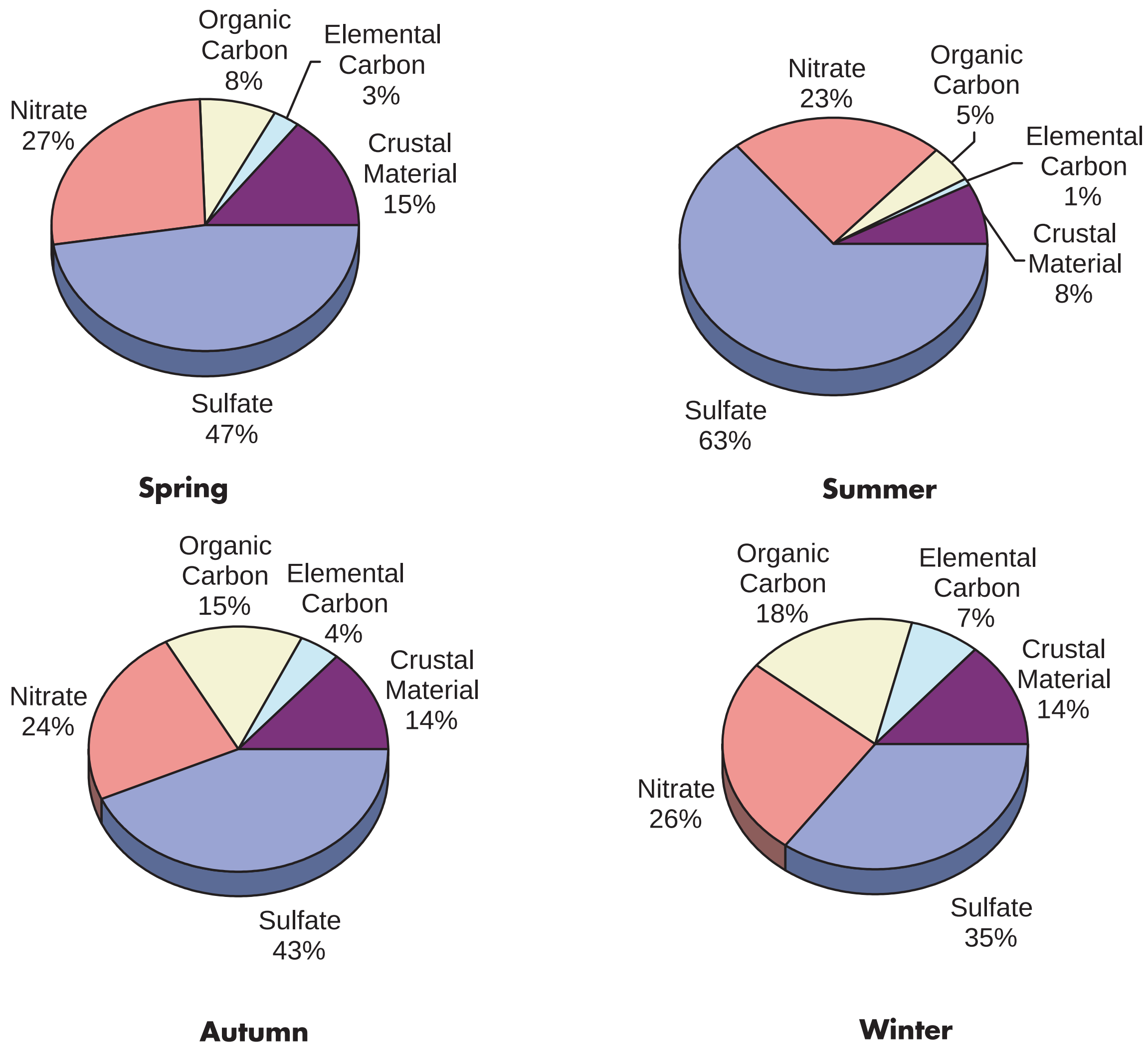

Figure CA–15. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Point Reyes IMPROVE Particulate Sampler

Figure CA–16 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Point Reyes site from 1988 to 1998. Over the eleven-year period, there was a significant trend in the total annual aerosol light extinctions, decreasing approximately 6 Mm^{-1}, indicating improved visibility. The sulfate and organic carbon light extinction coefficients did not change significantly during the eleven-year period. The other aerosol species (elemental carbon and crustal material) showed significant decreases in their contributions to the annual light extinction coefficients.

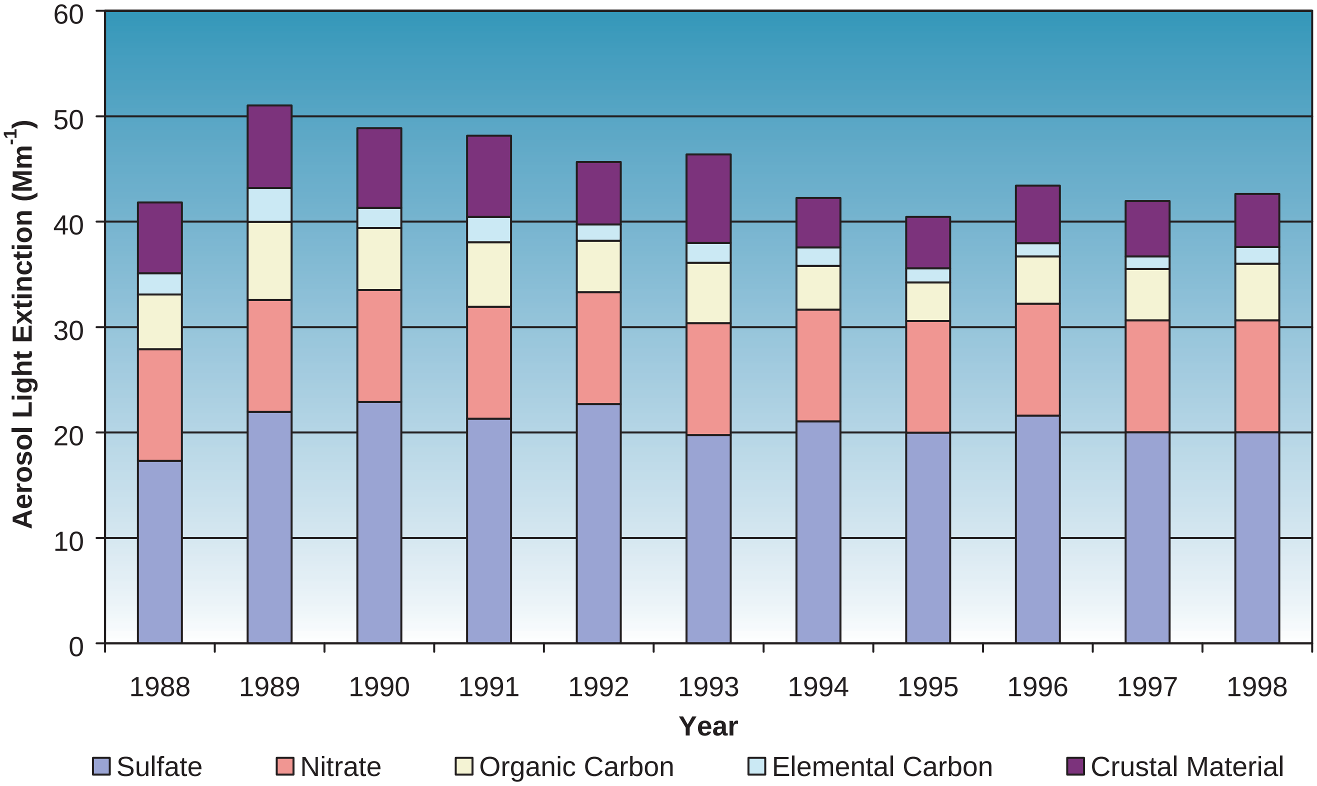

Figure CA–16. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Point Reyes IMPROVE Particulate Sampler

Redwood National Park

The Redwood IMPROVE particulate sampler started reporting in March of 1988. Figure CA–17 presents the calculated visibility indices at Redwood National Park for selected data sets from 1988 through 1998. The figure shows that from 1988 through 1998 there was a significant trend indicating improved visibility in the annual average of the visibility index for the most-impaired days, which decreased from approximately 23 to 21 deciviews (VR from 24 to 30 miles). From 1988 through 1998 there was no significant trend indicating improved visibility in the annual average of the visibility index for the mid-range days, which remained near 16 deciviews (VR 50 miles). Similarly, the annual average of the visibility index for the least-impaired days remained near 9 deciviews (VR from 100 miles), with no statistically significant trend.

Figure CA–18 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The average visibility indices are discernibly lower (better visibility) in winter than in the other three seasons. The indices for spring and summer remained relatively constant over the eleven-year period. The indices for autumn dropped 2 deciviews, with a statistically significant trend indicating improved visibility. The indices for winter dropped nearly 3 deciviews over this period and also represented a statistically significant trend toward improved visibility.

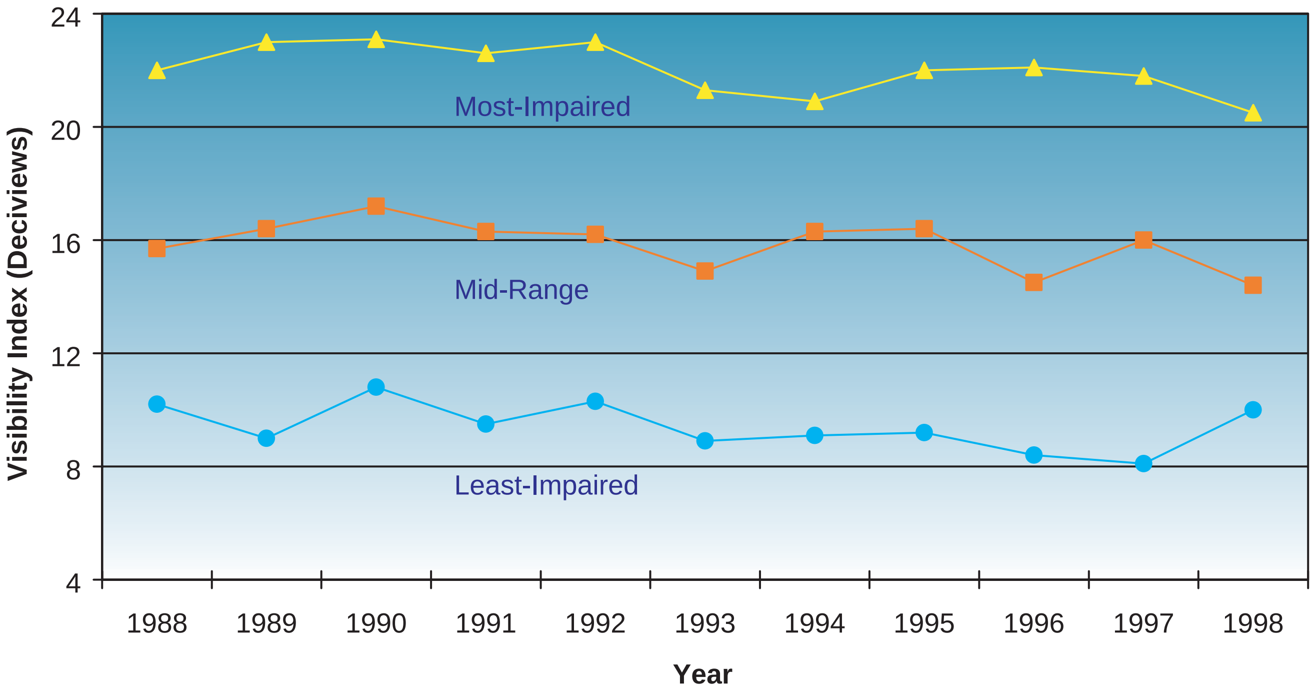

Figure CA–17. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Redwood IMPROVE Particulate Sampler

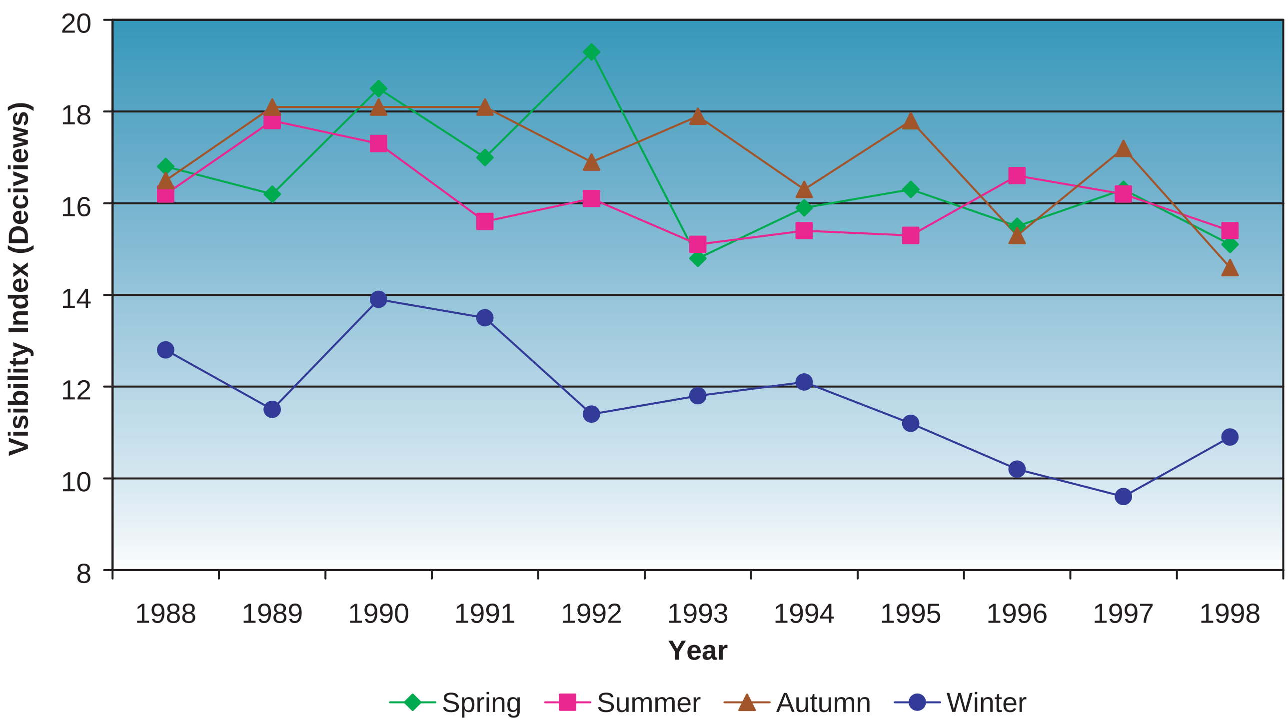

Figure CA–18. Seasonal Deciview Averages from 1988–1998 for the Redwood IMPROVE Particulate Sampler

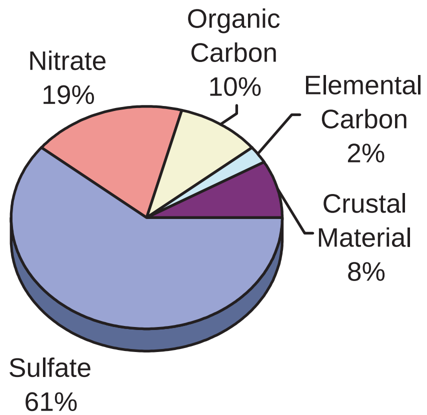

Figure CA–19. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Redwood IMPROVE Particulate Sampler

Figure CA–19 presents a chart showing the calculated fractional contribution to Redwood's light extinction by each aerosol species on an annual basis. Figure CA–20 shows the same information for the four seasons. Since the winter light extinction coefficients were less than half those in the other seasons, the annual averages presented in Figure CA–19 appear weighted to the spring, summer, and autumn readings shown in Figure CA–20. These five pie charts show that sulfate particles were responsible for 40 to 67 percent of the light extinction at the site, averaging 61 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the summer and the lowest in the winter. The contributions from nitrates ranged from 13 to 29 percent. The contributions from organic carbon ranged from 8 to 17 percent during the four seasons, averaging 10 percent. Seasonally, elemental carbon measured at the

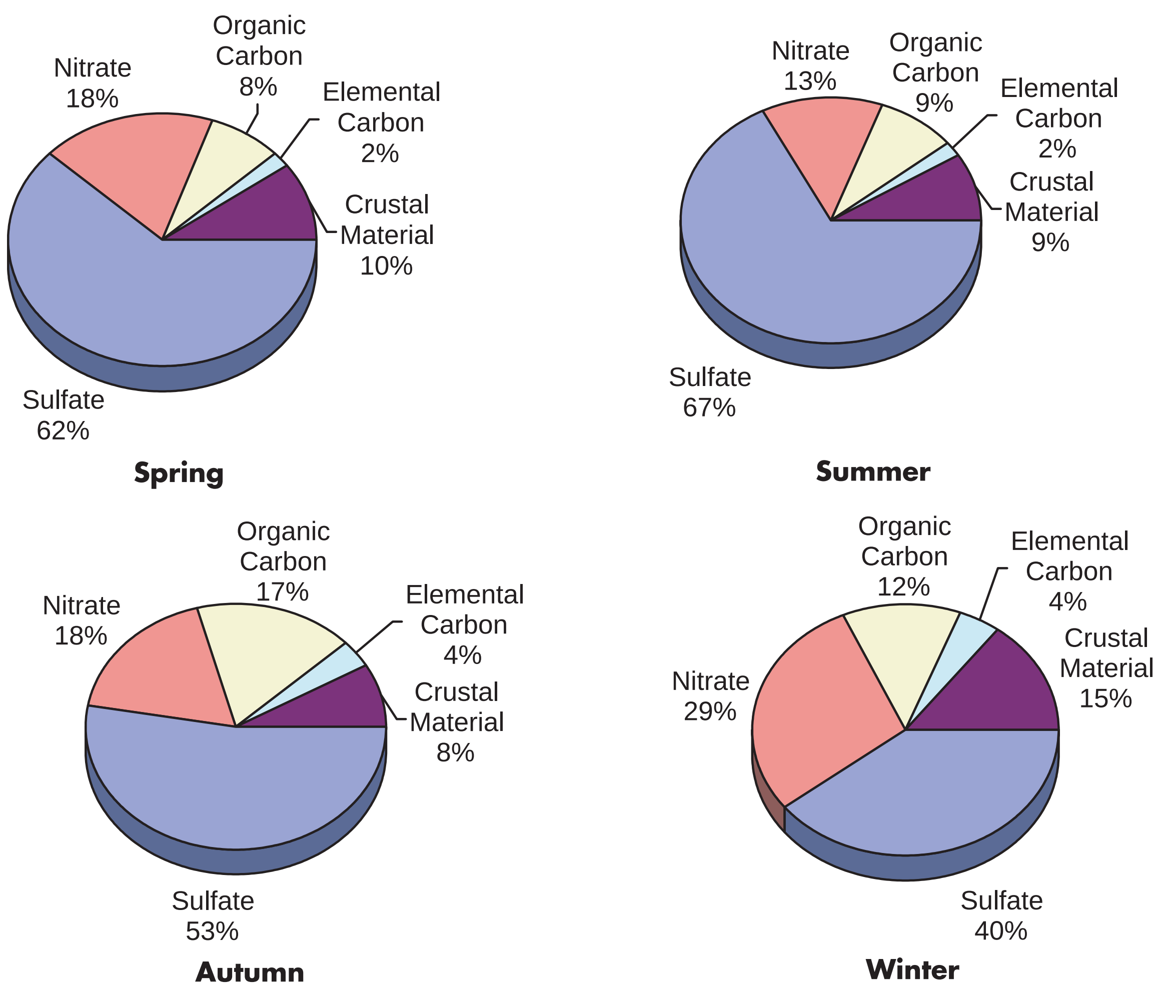

Figure CA–20. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Redwood IMPROVE Particulate Sampler

Redwood site was responsible for just 2 to 4 percent of the calculated aerosol light extinction. Crustal material contributions to the light extinction coefficient varied from 8 to 15 percent in the four seasons, with the winter contribution being the highest.

Figure CA–21 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Redwood site from 1988 to 1998. Over the eleven-year period, there was a significant trend in the total annual aerosol light extinctions from 48 to 39 Mm^{-1}, indicating improved visibility. The sulfates and crustal material extinction coefficients did not show significant trends over this time period. The organic and elemental carbon aerosol species showed significant decreases in their contributions to the annual light extinction coefficients.

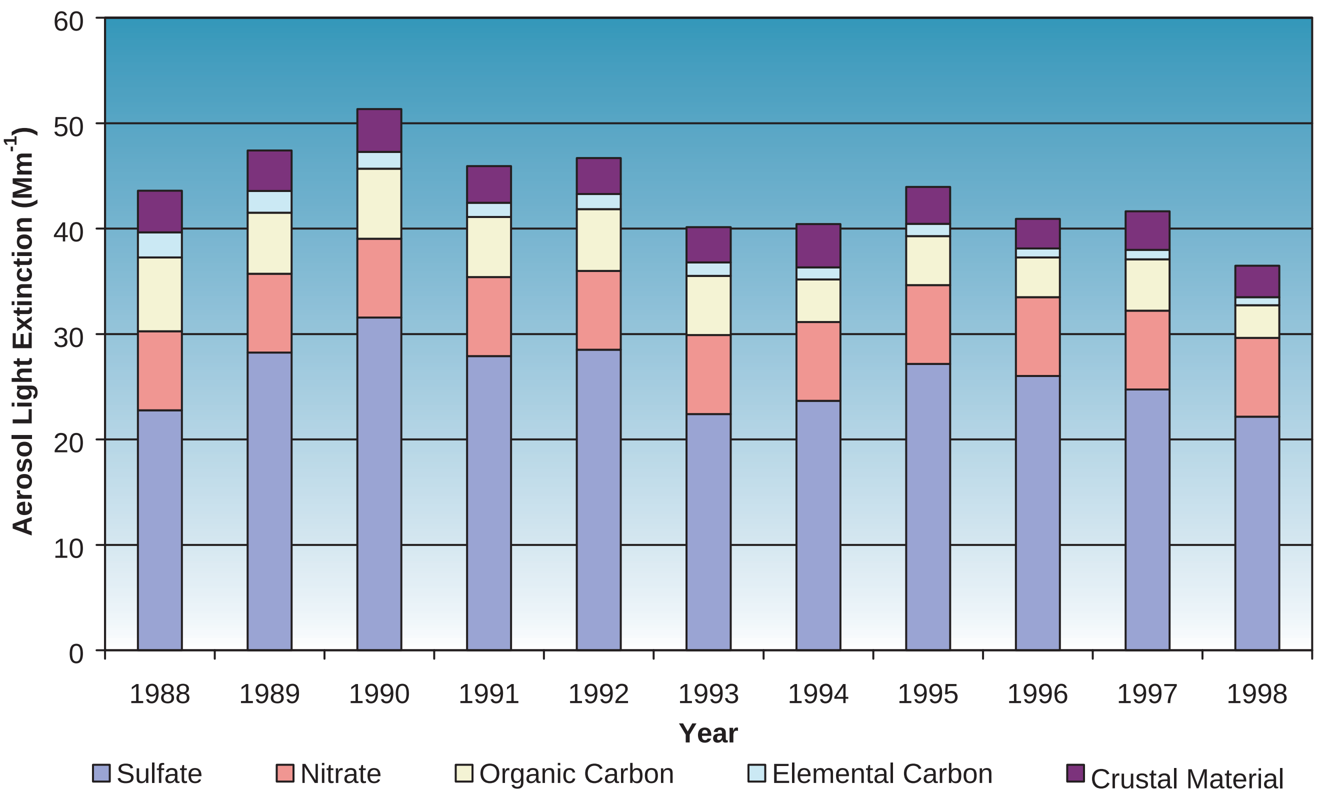

Figure CA–21. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Redwood IMPROVE Particulate Sampler

San Gorgonio Wilderness Area

The San Gorgonio IMPROVE particulate sampler started reporting in March of 1988. Figure CA–22 presents the calculated visibility indices at San Gorgonio Wilderness Area for selected data sets from 1988 through 1998. The figure shows that from 1988 through 1998 there was a significant trend indicating improved visibility in the annual average of the visibility index for the most-impaired days, which dropped from 24 to 22 deciviews (VR 22 to 27 miles). From 1988 through 1998, there was no significant trend in the annual average of the visibility index for the mid-range days, which mostly remained between 16 (VR 50 miles) and 19 deciviews (VR 36 miles). The annual average of the visi-

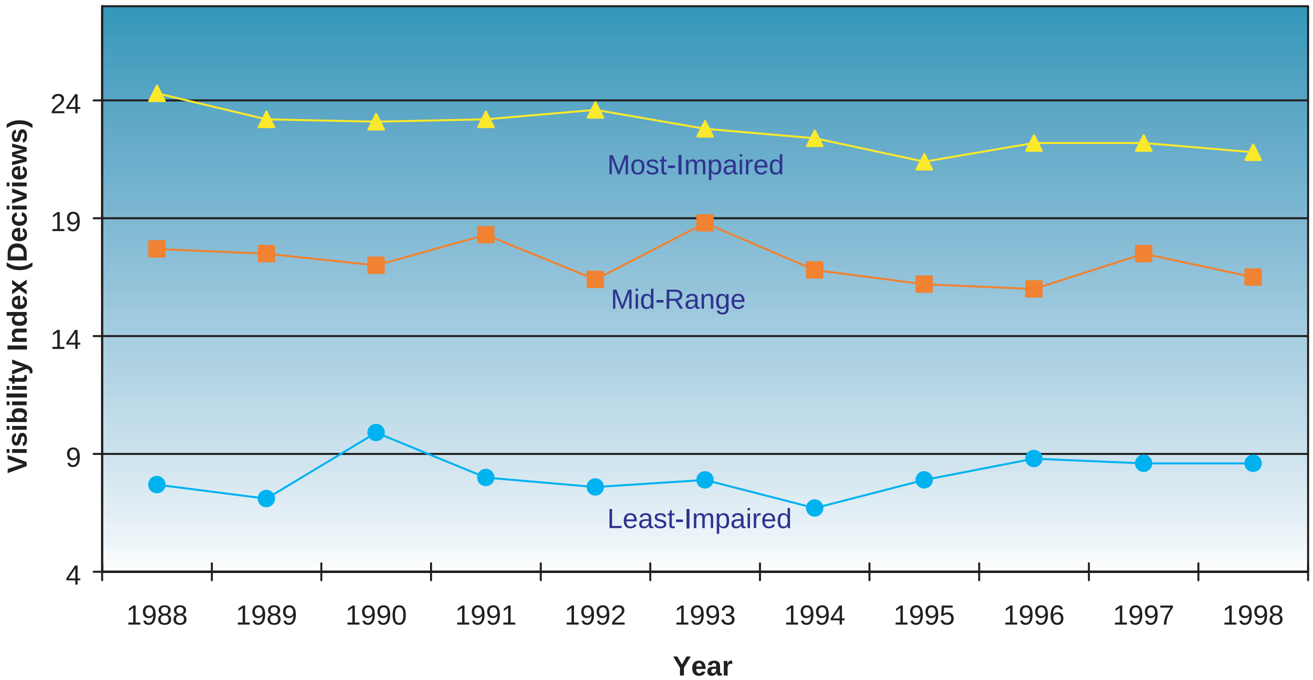

Figure CA–22. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the San Gorgonio IMPROVE Particulate Sampler

bility index for the least-impaired days remained near 8 deciviews (VR 110 miles), indicating no significant trend on the least-impaired days.

Figure CA–23 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The average visibility indices are discernibly lower (better visibility) in autumn and winter than in the spring and summer. The indices for the autumn and winter did not fluctuate greatly over the eleven-year period and no statistically significant trend was observed. Both the indices for spring and summer showed significant trends indicating improved visibility by an average decrease of 2.5 deciviews between 1988 and 1998.

Figure CA–24 presents a chart showing the calculated fractional contribution to San Gorgonio's light extinction by each aerosol species on an annual basis. Figure CA–25 shows the same information for the four seasons. Since the autumn and winter light extinction coefficients were much smaller than those in spring and summer, the annual averages presented in Figure CA-24 appear weighted to the spring and summer. These five pie charts show that sulfate particles were responsible for 13 to 25 percent of the light extinction at the site, averaging 23 percent on an annual basis over a five-year period. The contributions from nitrates ranged between 25 and 65 percent, with the highest percentages in winter. From all of the IMPROVE monitors, the San Gorgonio site has the highest annual nitrate concentrations and the highest fractional contributions to light extinction from nitrates. Nitrates represented 39 percent of the light extinction at this site on an annual basis over a five-year period. The contributions from organic carbon ranged from 10 to 26 percent during the four seasons, with the summer's percent contribution being the highest. Seasonally, elemental carbon measured at the San Gorgonio site was responsible for 6 to 11 percent of the calculated aerosol light extinction. Crustal material contributions to the light extinction coefficient varied from 6 to 15 percent in the four seasons, with the autumn contribution being the highest.

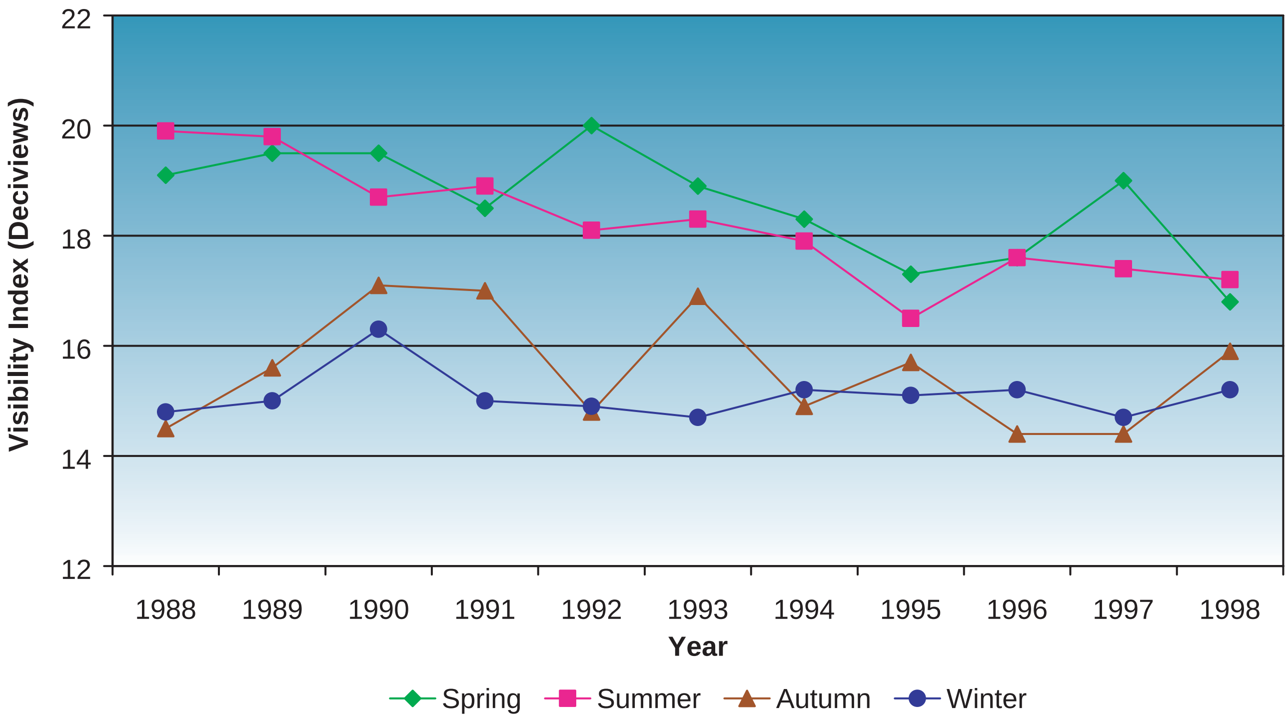

Figure CA–23. Seasonal Deciview Averages from 1988–1998 for the San Gorgonio IMPROVE Particulate Sampler

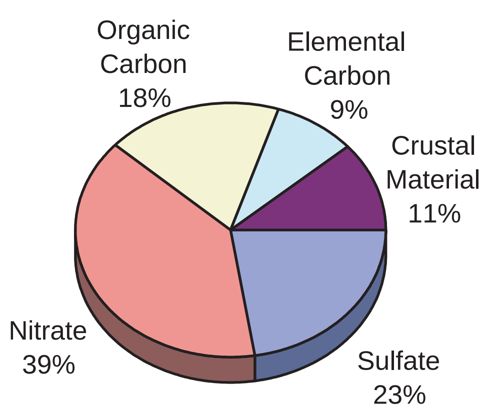

Figure CA–24. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the San Gorgonio IMPROVE Particulate Sampler

Figure CA–26 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the San Gorgonio site from 1988 to 1998. Over the eleven-year period, there was a significant trend in the total annual aerosol light extinctions from 50 to 42 Mm^{-1}, indicating improved visibility. The sulfate extinction coefficients did not show a significant trend over this time period. The other aerosol species (organic carbon, elemental carbon, and crustal material) showed significant decreases in their contributions to the annual light extinction coefficients.

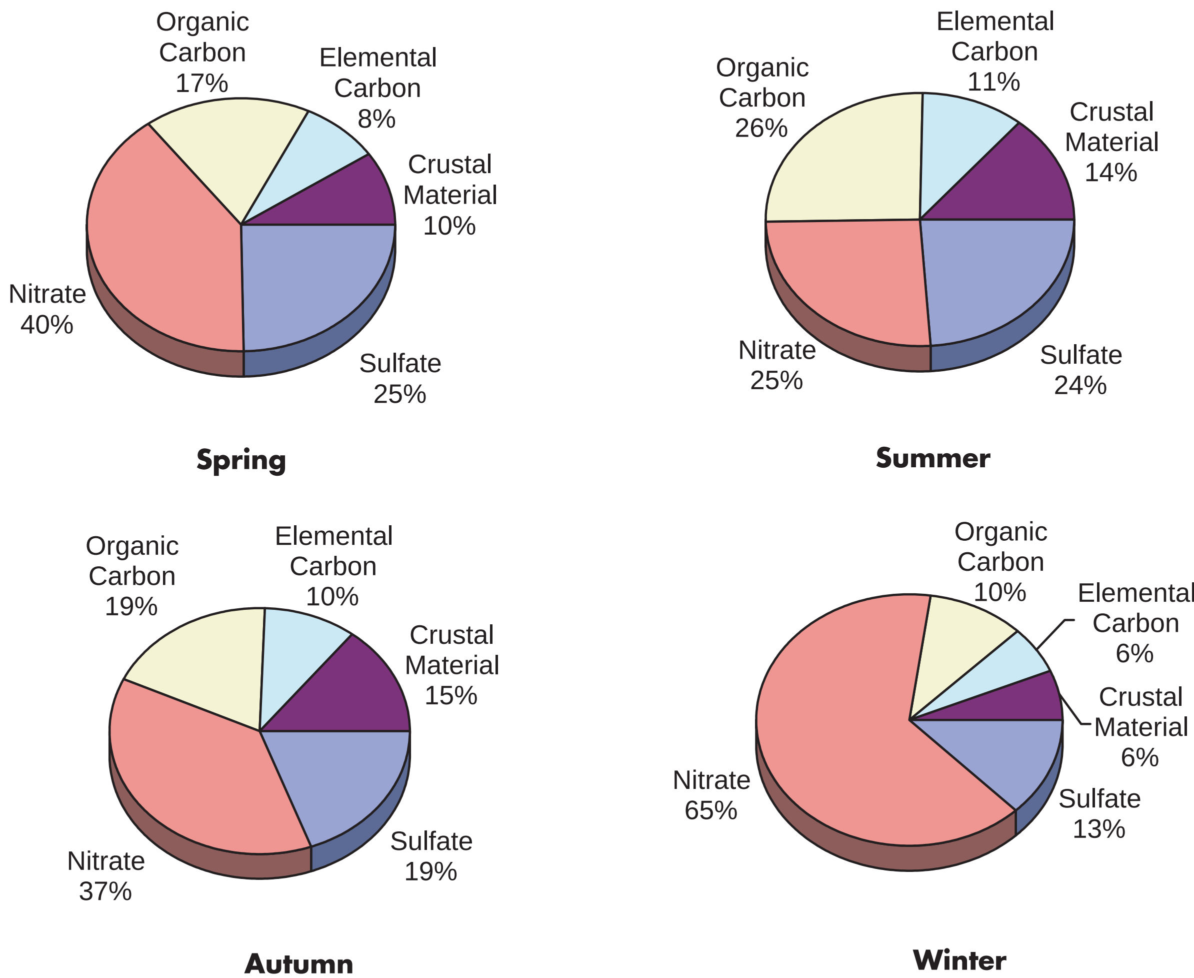

Figure CA–25. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the San Gorgonio IMPROVE Particulate Sampler

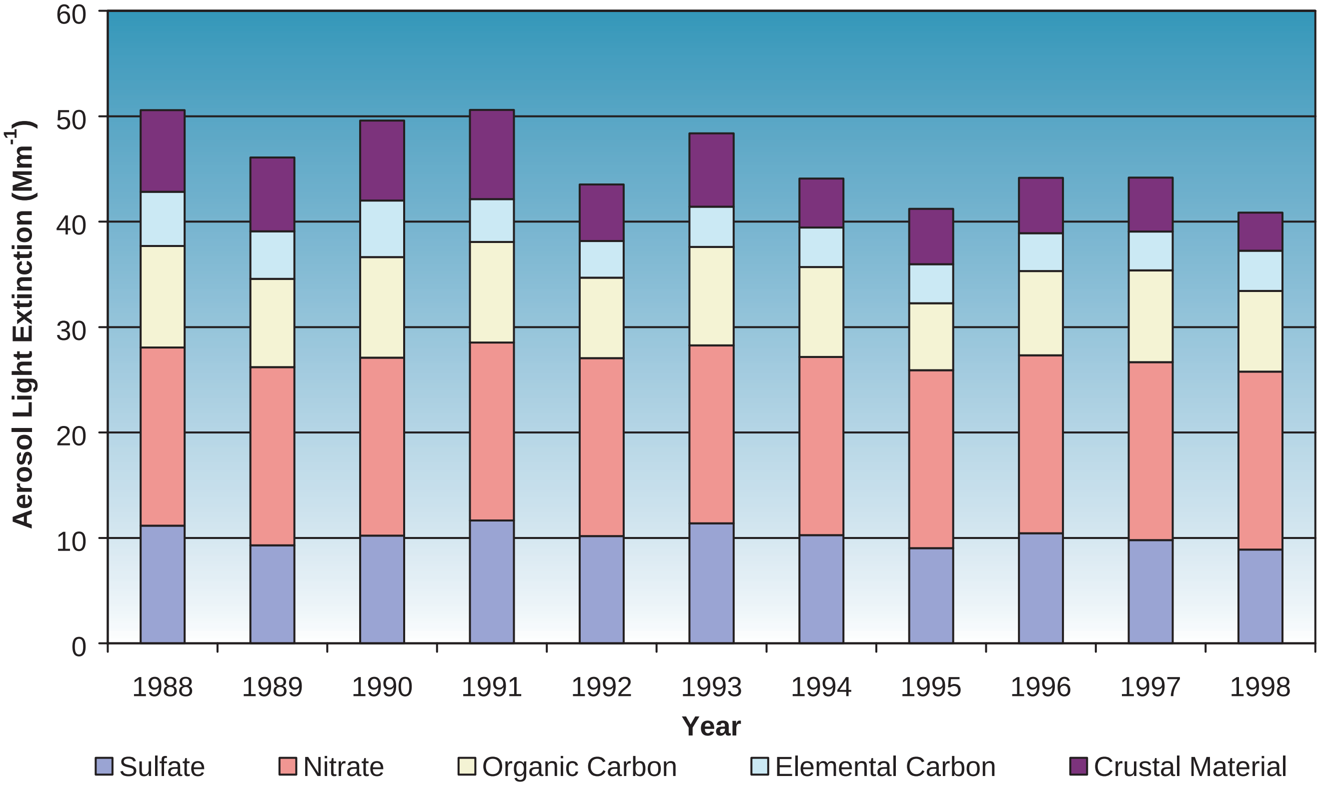

Figure CA–26. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the San Gorgonio IMPROVE Particulate Sampler

Yosemite National Park

The Yosemite IMPROVE particulate sampler started reporting in March of 1988. Figure CA–27 presents the calculated visibility indices at Yosemite National Park for selected data sets from 1988 through 1998. The figure shows from 1988 through 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained between 16 and 20 deciviews (VR 50 to 33 miles). From 1988 through 1998, there was no significant trend in the annual average of the visibility index for the mid-range days, which remained near 11 deciviews (VR 80 miles). Similarly, the annual average of the visibility index for the least-impaired days remained near 5 deciviews (VR 150 miles), indicating no significant trend on the least-impaired days.

Figure CA–28 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The average visibility indices are discernibly lower (better visibility) in winter than in the other three seasons. Statistical analysis shows that, over the eleven-year period, there was no significant trend in visibility in any of the four seasons.

Figure CA–29 presents a chart showing the calculated fractional contribution to Yosemite's light extinction by each aerosol component on an annual basis. Figure CA–30 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 18 to 33 percent of the light extinction at the site (highest percentage in the spring), averaging 26 percent on an

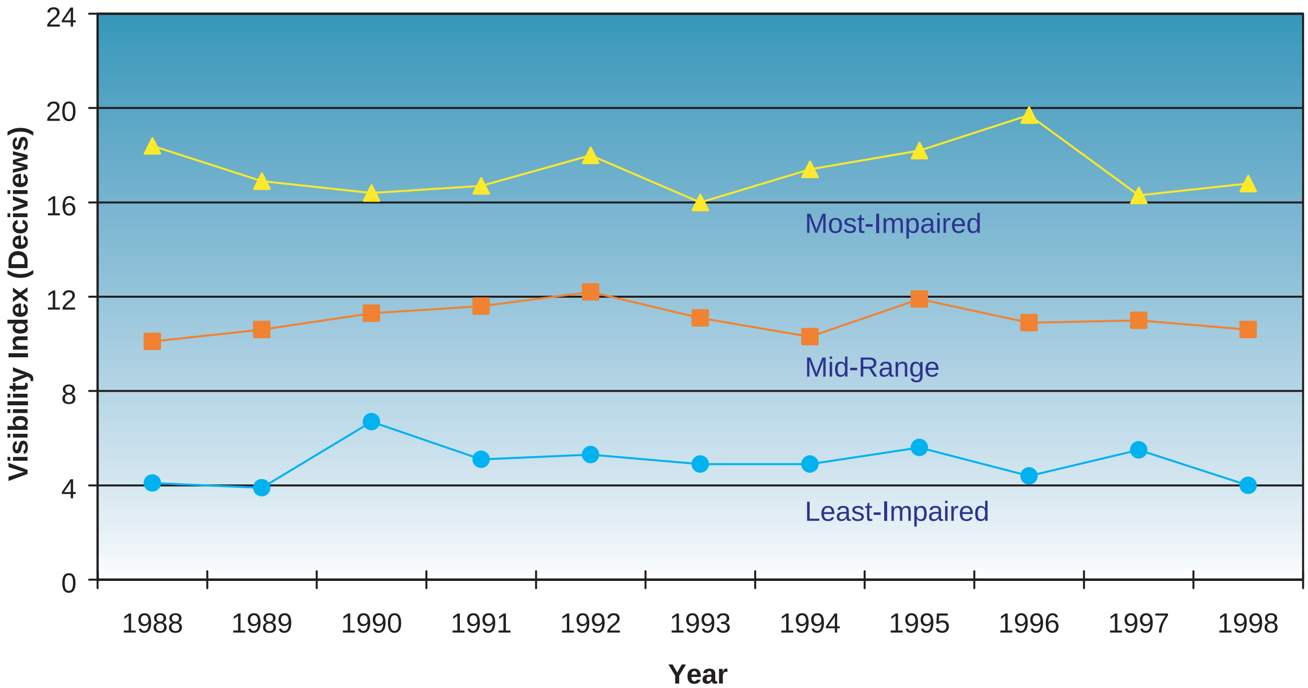

Figure CA–27. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Yosemite IMPROVE Particulate Sampler

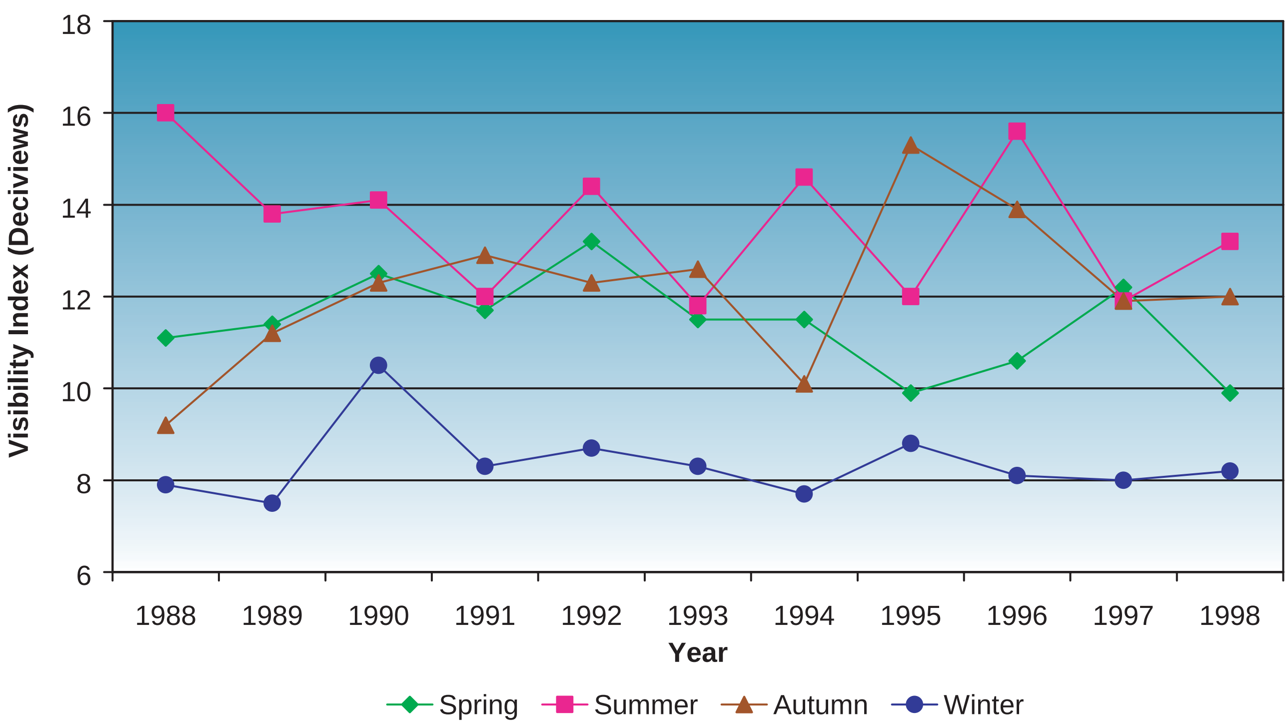

Figure CA–28. Seasonal Deciview Averages from 1988–1998 for the Yosemite IMPROVE Particulate Sampler

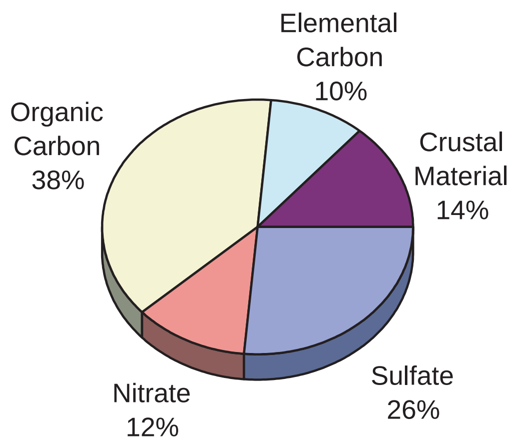

Figure CA–29. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Yosemite IMPROVE Particulate Sampler

annual basis over a five-year period. The contributions from nitrates ranged between 6 and 31 percent, with the highest percentage in winter. The contributions from organic carbon ranged from 26 to 46 percent during the four seasons, with the summer's and autumn's percent contributions being the highest. Elemental carbon measured at the Yosemite site was responsible for 8 to 12 percent of the calculated aerosol light extinction year-round. Crustal material contributions to the light extinction coefficient varied from 14 to 16 percent in the four seasons.

Figure CA–31 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Yosemite site from 1988 to 1998. Over the eleven-year period, the total annual aerosol light extinctions ranged between 21 and 27 Mm^{-1}. Statistical analysis determined that

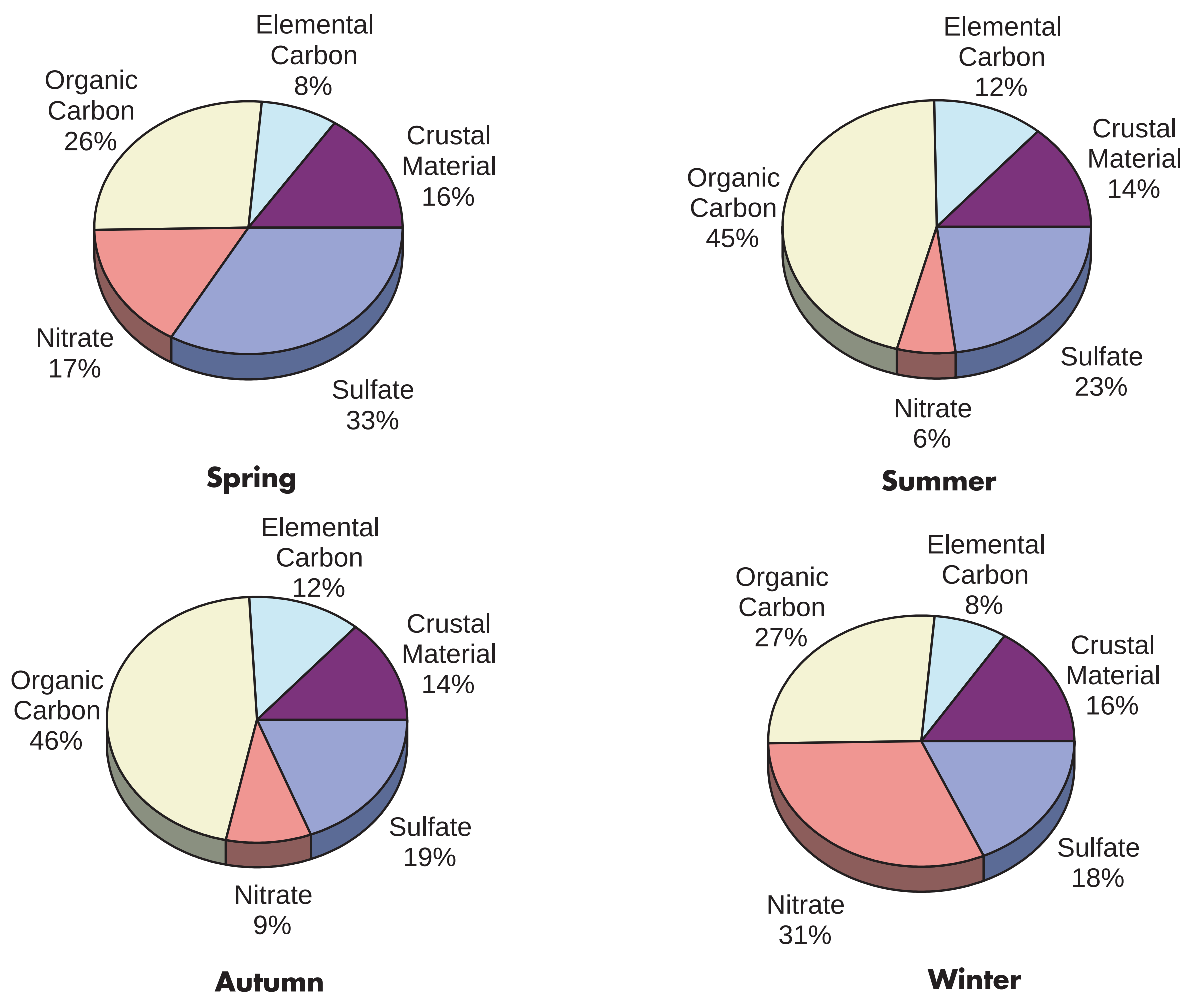

Figure CA–30. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Yosemite IMPROVE Particulate Sampler

no significant trend occurred. The sulfate, organic carbon, elemental carbon, and crustal material extinction coefficients did not show significant trend over this time period.

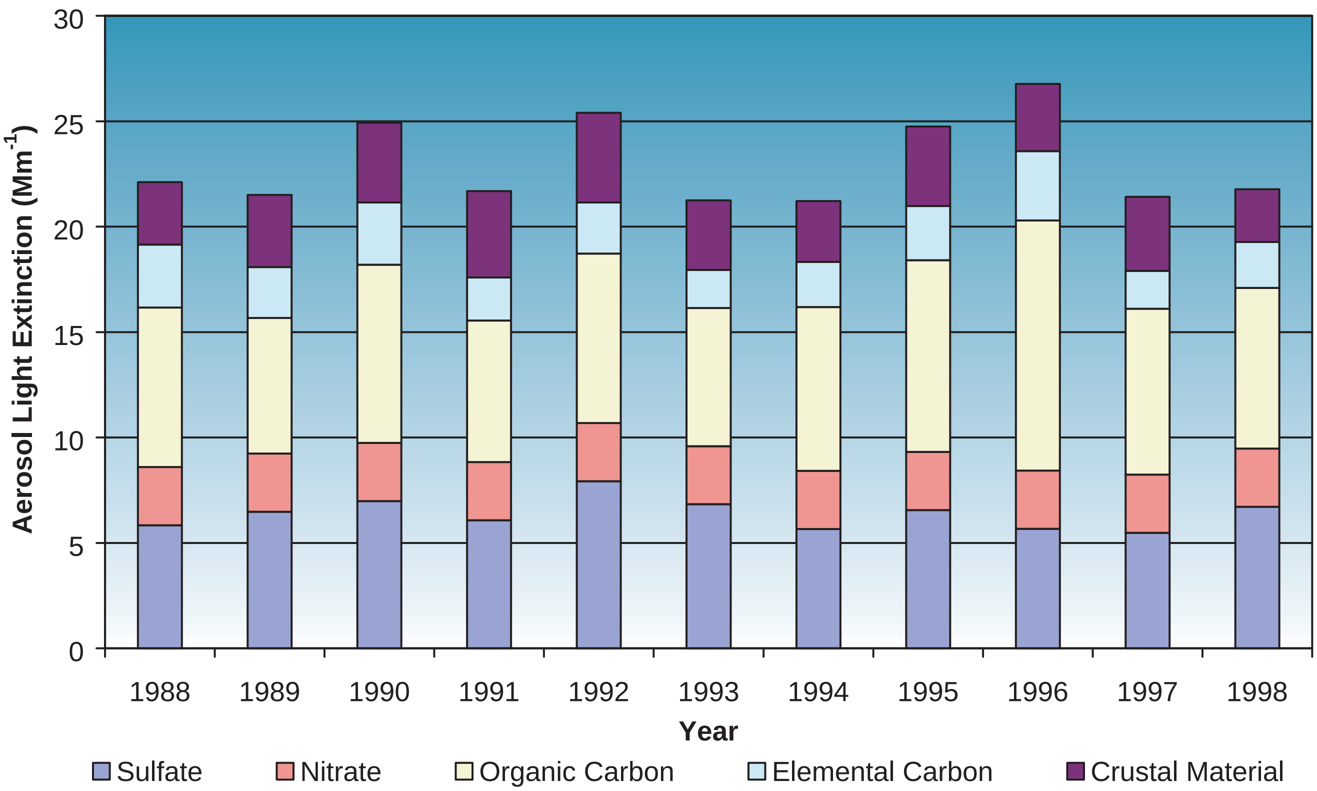

Figure CA–31. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Yosemite IMPROVE Particulate Sampler

California State Summary

The calculated annual average aerosol extinction coefficients at California's IMPROVE monitoring sites are presented in Table CA–1. The 1995-1998 data from Sequoia National Park also are included here. The coefficient at Lassen Volcanic National Park was less than half the average coefficient, and the coefficient from Sequoia National Park more than 40 percent higher than the average. These observations suggest that visibility across the state varies significantly on an annual basis. The annual average VR varied from 40 to 100 miles.

The pollutant species that contributed most to calculated light extinction also varied between monitoring sites. The coastal sites (Pinnacles, Point Reyes, and Redwood) showed high contributions from sulfates. Nitrates represented 39 percent of the calculated aerosol light extinction at the southern California site (San Gorgonio). The eastern sites (Lassen Volcanic, Sequoia, and Yosemite) showed high contributions from organic carbon.

Table CA–1. California Calculated Total Extinction Coefficients from 1994–1998

IMPROVE Site	Calculated Total Aerosol Extinction Coefficient (Mm^{-1})	Pollutant Extinction Coefficient (Mm^{-1})				
		Sulfate	Nitrate	Organic Carbon	Elemental Carbon	Crustal Material
Lassen Volcanic NP	14.6	4.5	1.3	5.2	1.7	1.9
Pinnacles NM	30.6	9.3	6.3	6.9	3.5	4.6
Point Reyes NS	42.1	20.5	10.6	4.5	1.4	5.1
Redwood NP	40.7	24.7	7.5	4.1	1.0	3.4
San Gorgonio Wilderness	42.9	9.7	16.9	7.8	3.7	4.8
Sequoia NP	50.5	11.4	11.2	14.5	5.3	8.1
Yosemite NP	23.2	6.0	2.8	8.8	2.4	3.2
Average	34.9 ± 12.7	12.3 ± 7.5	8.1 ± 5.3	7.4 ± 3.6	2.7 ± 1.5	4.4 ± 2.0

6. COLORADO

Twelve mandatory Federal Class I areas are located in Colorado. Four IMPROVE particulate samplers in Colorado operated continuously from 1994 through 1998. They were located at Great Sand Dunes National Monument (37.73°N, 105.51°W, elevation 8200 feet), Mesa Verde National Park (37.20°N, 108.48°W, elevation 7200 feet), Rocky Mountain National Park (40.36°N, 105.60°W, elevation 7900 feet), and Weminuche Wilderness Area (37.66°N, 107.80°W, elevation 9050 feet).

Figure CO–1 shows the Rocky Mountain monitoring location in the northern portion of the state and the other three locations in the south. An additional particulate sampler began collecting data near the Mount Zirkel Wilderness Area in July 1994; however, it is not discussed in this section since it did not have five full years of data between 1994 and 1998.

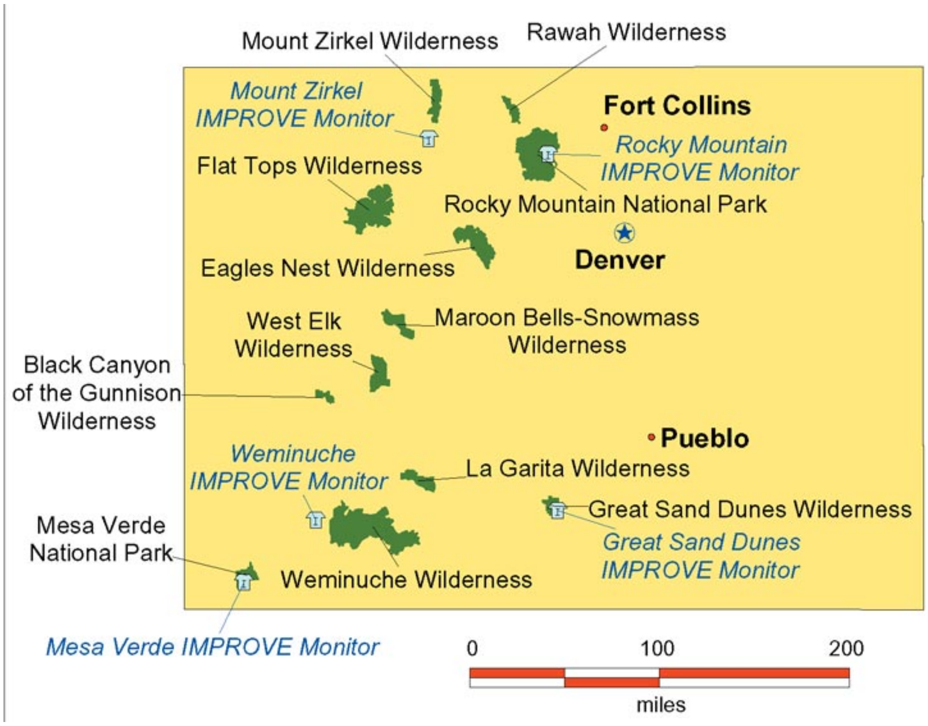

Figure CO–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Sites in Colorado

Other Colorado mandatory Federal Class I areas covered by the Regional Haze Rule (but not collecting IMPROVE data) include:

Rawah Wilderness Area,
Flat Tops Wilderness Area,
Eagles Nest Wilderness Area,
Black Canyon of the Gunnison Wilderness Area,
Maroon Bells-Snowmass Wilderness Area (data collected for the USDA Forest Service according to the IMPROVE protocol),
West Elk Wilderness Area, and
La Garita Wilderness Area.

Great Sand Dunes National Monument

The Great Sand Dunes IMPROVE particulate sampler started recording in May of 1988. Figure CO–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that from 1988 through 1998 there was no statistically significant trend in the annual average of the visibility index for the most-impaired days, which remained between approximately 11 and 14 deciviews (VR 80 to 60 miles). The coarse mass fraction was responsible for the spike in 1994 at Great Sand Dunes National Monument. The April 23, 1994 sample recorded 352 μg/m^3 total mass (PM_{10}), which is five standard deviations (s.d. = 67 μg/m^3) higher than the spring average of 24 μg/m^3. The next highest reading at the site over the eleven-year period was only 71 μg/m^3. Without this point recorded for April 23, 1994, the average total mass drops to 12 μg/m^3, and the 1994 numbers line up closer with other years.

From 1988 through 1998, Figure CO–2 shows a significant trend toward improved visibility in the annual average of the visibility index for the mid-range days, which decreased from 10 to 9 deciviews (VR 90 to 100 miles). Similarly, the annual average of the visibility indices for the least-impaired days decreased from 7 to 6 deciviews (VR 120 to 135 miles), indicating a statistically significant trend toward improved visibility.

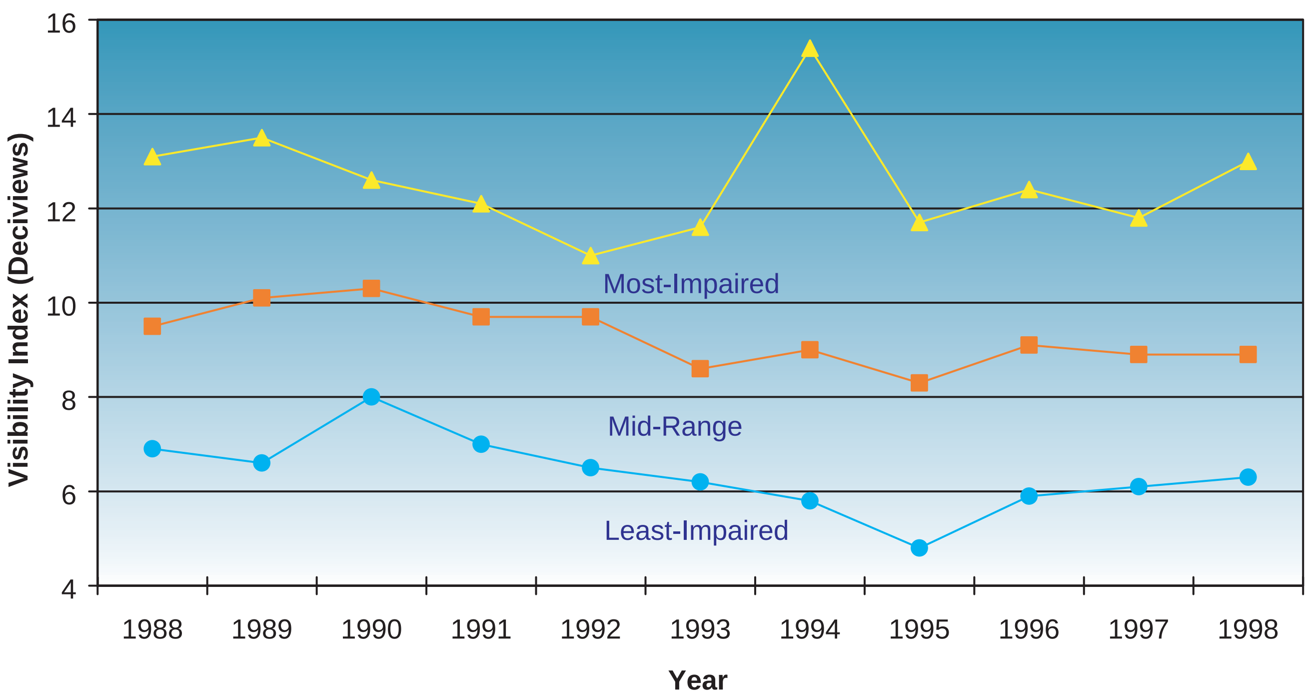

Figure CO–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Great Sand Dunes IMPROVE Particulate Sampler

Figure CO–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The average visibility indices for spring are on average 3 deciviews higher than those during the summer, autumn, and winter. The National Park Service indicated that wind events are more common in the spring than in other seasons at Great Sand Dunes (Bunch, 2000). Wind events can increase wind erosion and introduce substantial crustal material to the atmosphere. No significant seasonal trends were observed in the calculated visibility indices over this time period for any of the seasons. However, if the 1994 spring value was removed from Figure CO–3, the spring trend would be statistically significant toward improved visibility.

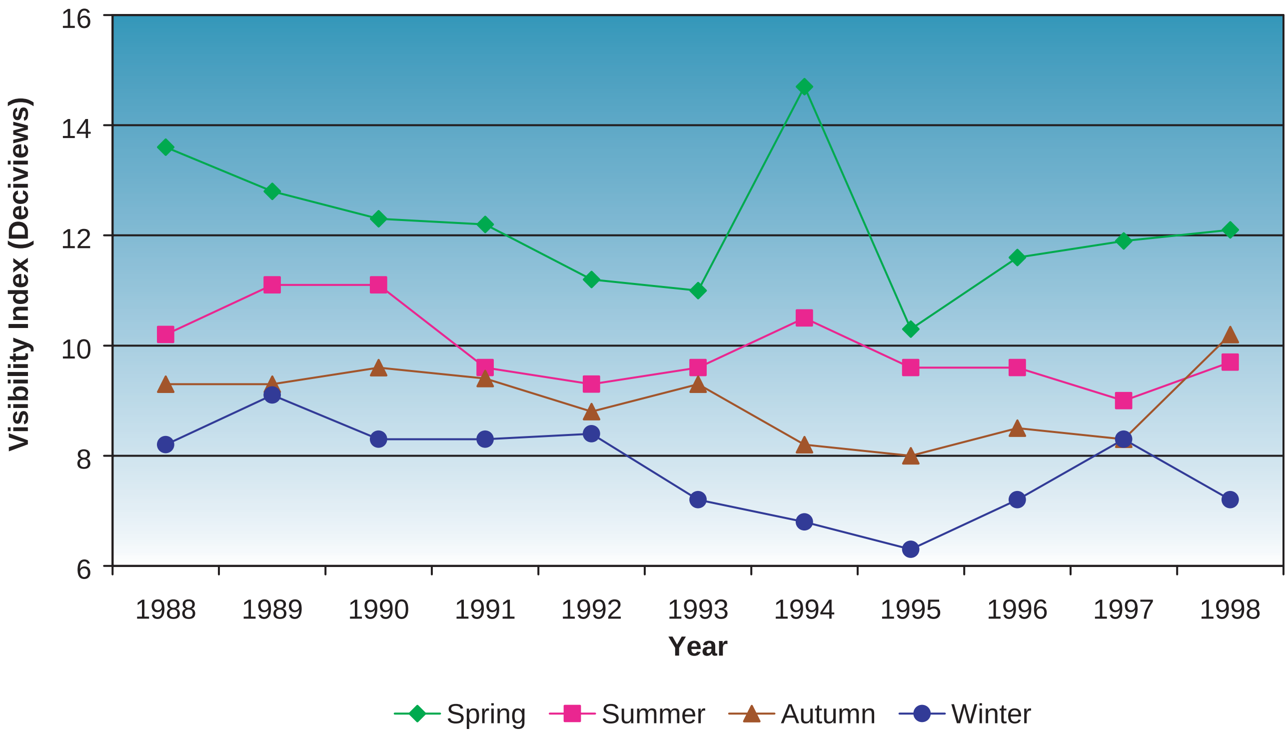

Figure CO–3. Seasonal Deciview Averages from 1988–1998 for the Great Sand Dunes IMPROVE Particulate Sampler

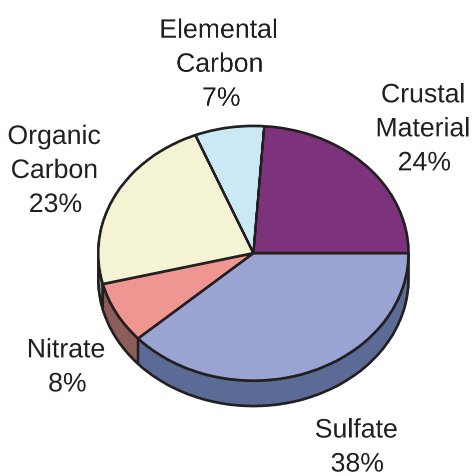

Figure CO–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Great Sand Dunes IMPROVE Particulate Sampler

Figure CO–4 presents a chart showing the calculated fractional contribution to Great Sand Dunes' light extinction by each aerosol species on an annual basis. Figure CO–5 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 34 to 48 percent of the light extinction at the site, averaging 38 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the spring and the lowest in the winter. The contributions from nitrates were 9, 5, 8, and 10 percent for the spring, summer, autumn, and winter, averaging just 8 percent on an annual basis. The contributions from organic carbon ranged from 13 percent in the spring up to 24 to 29 percent during the other three seasons. Annually, elemental carbon and crustal material measured at the Great Sand Dunes site were responsible for approximately 7 and 24 percent of the calculated aerosol light extinction.

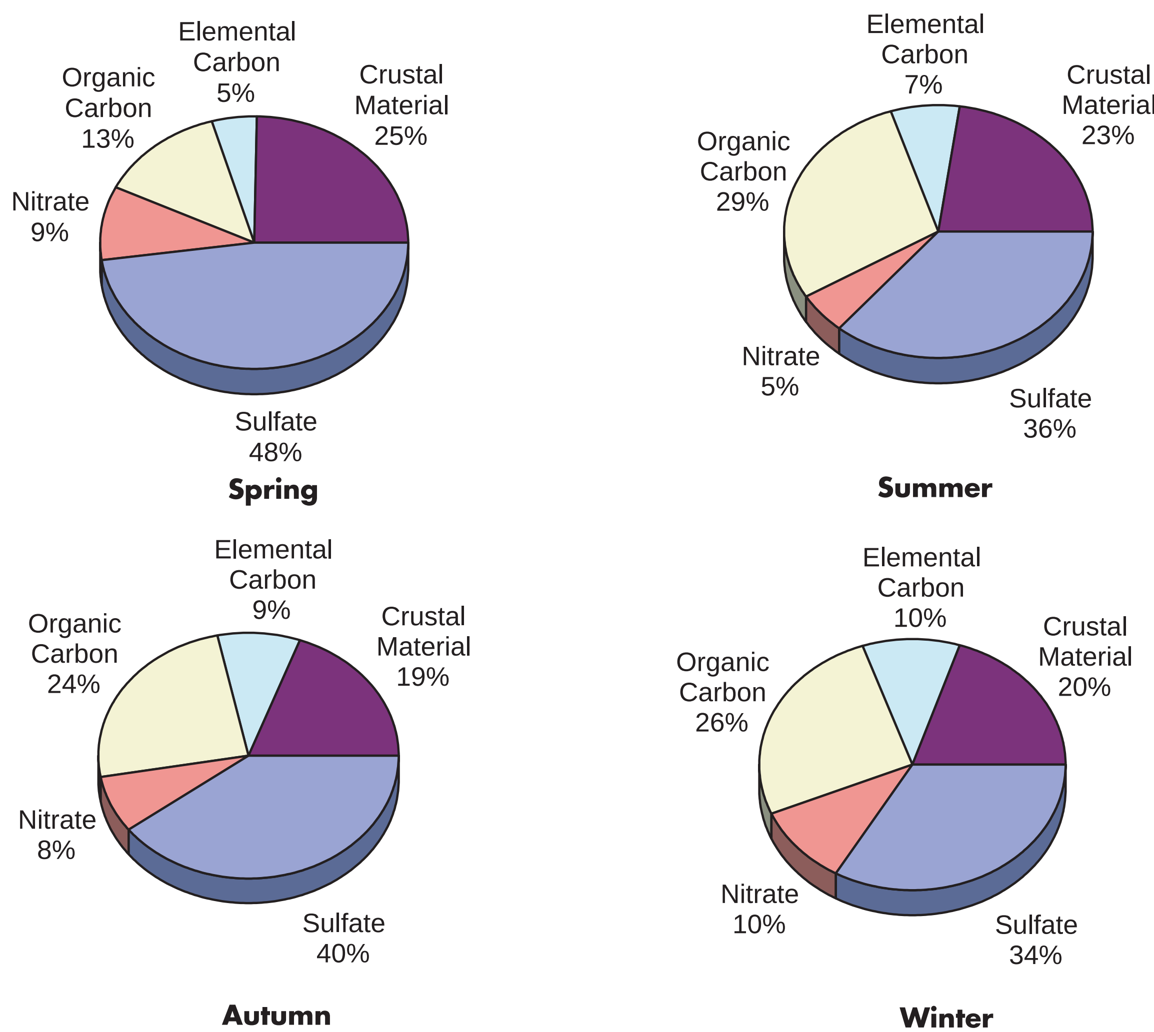

Figure CO–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Great Sand Dunes IMPROVE Particulate Sampler

Figure CO–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Great Sand Dunes site from 1988 to 1998. Over the eleven-year period, the total annual aerosol light extinctions decreased from approximately 17 to 15 Mm^{-1}, and the trend was statistically significant. No significant trends were noted in the annual light extinctions calculated for sulfates or elemental carbon. However, the organic carbon and crustal material showed statistically significant decreases in their annual contributions to the light extinction coefficients, indicating lower ambient concentrations.

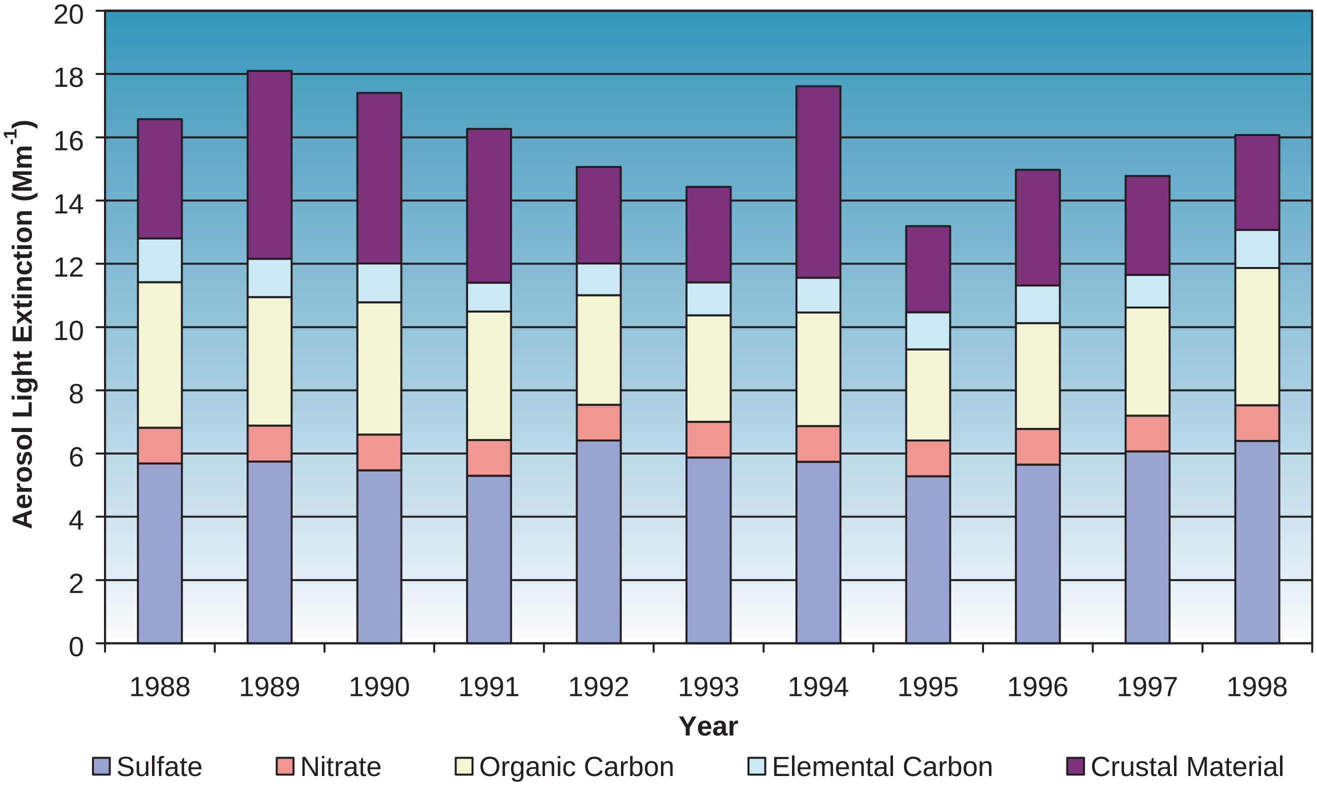

Figure CO–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Great Sand Dunes IMPROVE Particulate Sampler

Mesa Verde National Park

The Mesa Verde IMPROVE particulate sampler started reporting in March of 1988. Figure CO–7 presents the calculated visibility indices for selected data sets at Mesa Verde from 1988 through 1998. The figure shows that from 1988 through 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained near 11.5 deciviews (VR 80 miles). From 1988 through 1998, there was no significant trend in the annual average of the visibility index for the mid-range days, which remained relatively constant near 8.5 deciviews (VR 105 miles). The annual average of the visibility index for the least-impaired days remained near 6 deciviews (VR 135 miles) over the period and did not demonstrate a statistically significant trend in the visibility index.

Figure CO–8 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The average visibility indices for summer were generally 1 or 2 deciviews higher than those during the autumn, winter, and spring. No significant seasonal trends were observed in the calculated visibility indices over this time period for any of the seasons. The average indices for spring increased 1 deciview over the eleven-year period, but this trend toward decreased visibility was not statistically significant.

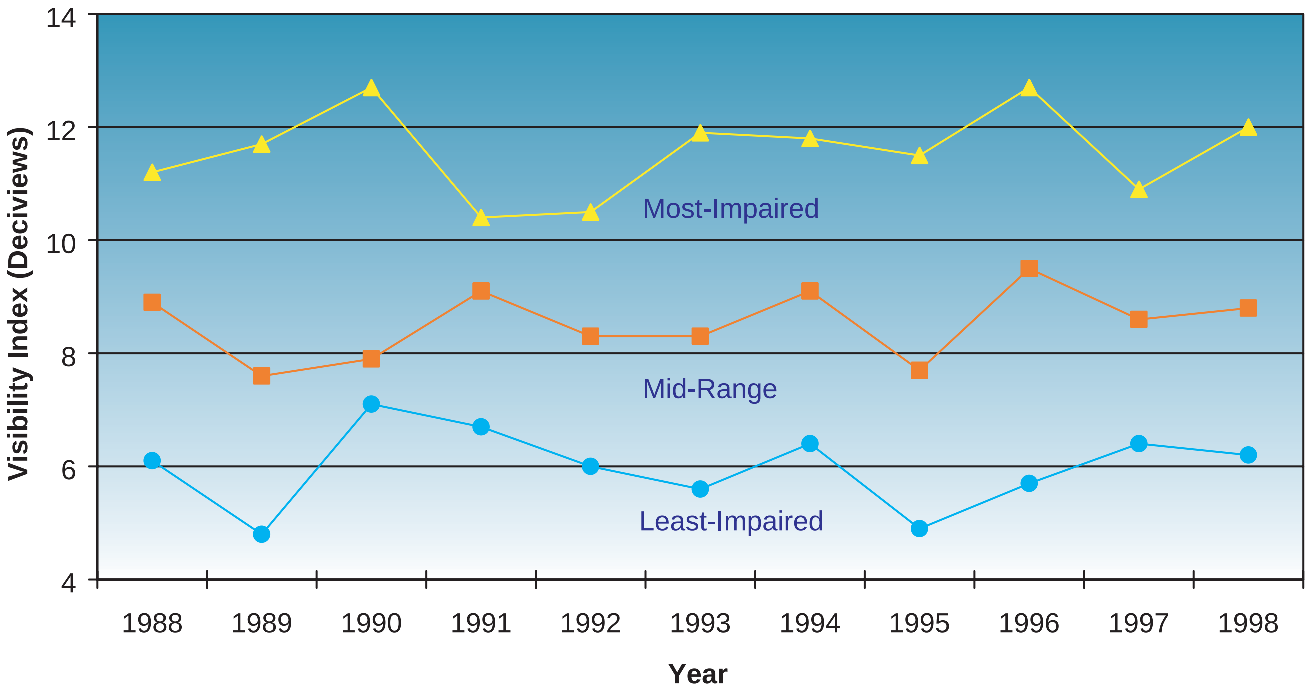

Figure CO–7. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Mesa Verde IMPROVE Particulate Sampler

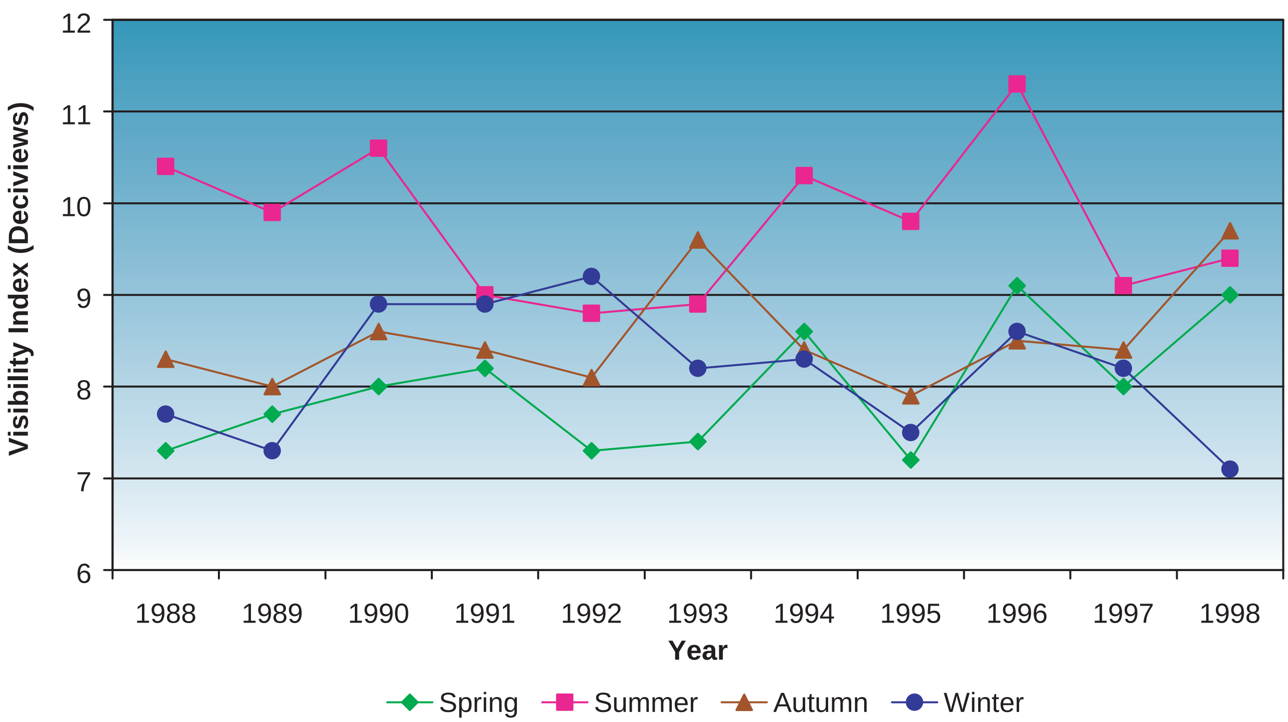

Figure CO–8. Seasonal Deciview Averages from 1988–1998 for the Mesa Verde IMPROVE Particulate Sampler

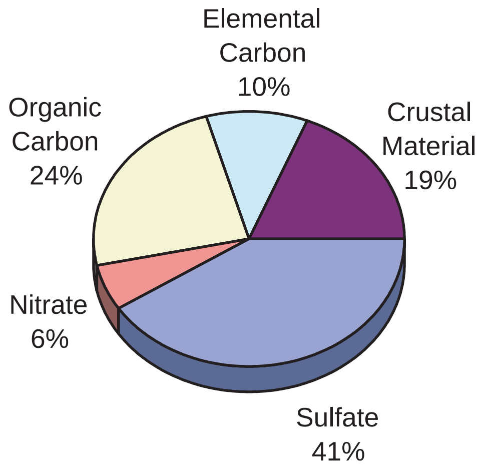

Figure CO–9. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Mesa Verde IMPROVE Particulate Sampler

Figure CO–9 presents a chart showing the calculated fractional contribution to Mesa Verde's light extinction by each aerosol species on an annual basis. Figure CO–10 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 34 to 43 percent of the light extinction at the Mesa Verde site, averaging 41 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the autumn and winter, but most other IMPROVE particulate samplers showed the lowest contributions from sulfates in the winter. The average contributions from nitrates ranged from 4 to 9 percent in the four seasons. The contributions from organic carbon ranged from 22 to 27 percent during the four seasons. Elemental carbon measured at the Mesa Verde site was responsible for 9 to 12 percent of the calculated

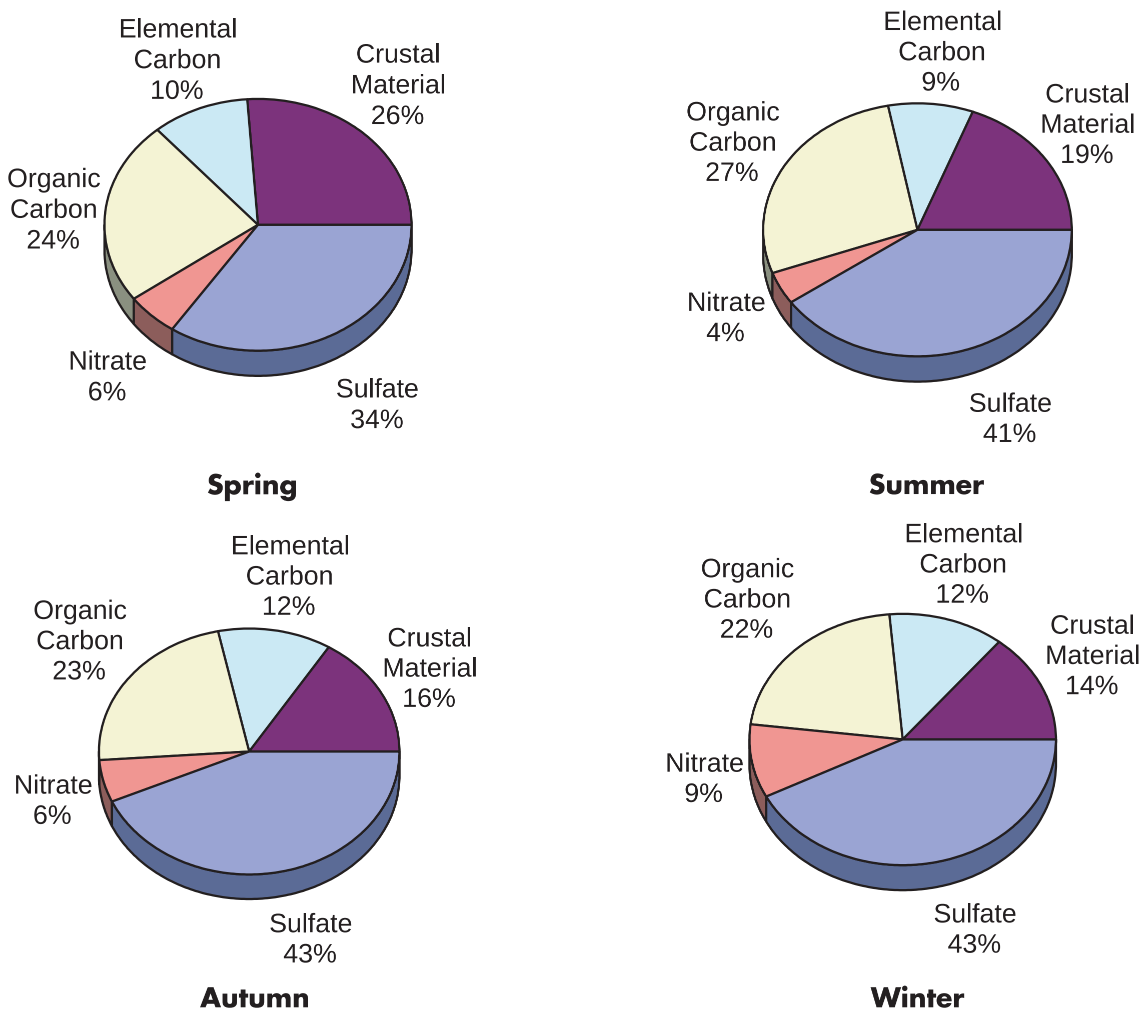

Figure CO–10. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Mesa Verde IMPROVE Particulate Sampler

aerosol light extinction. The crustal material contributions range from 14 to 26 percent, with the highest contributions during the spring season.

Figure CO–11 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Mesa Verde site from 1988 to 1998. Over the eleven-year period, the calculated total annual aerosol light extinctions remained near 14 Mm^{-1}. Statistical analysis determined that no significant trend occurred. In addition, no significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, or crustal material. However, the elemental carbon showed statistically significant increases in its annual contribution to the light extinction coefficients (from 0.9 to 1.6 Mm^{-1}), indicating higher ambient concentrations.

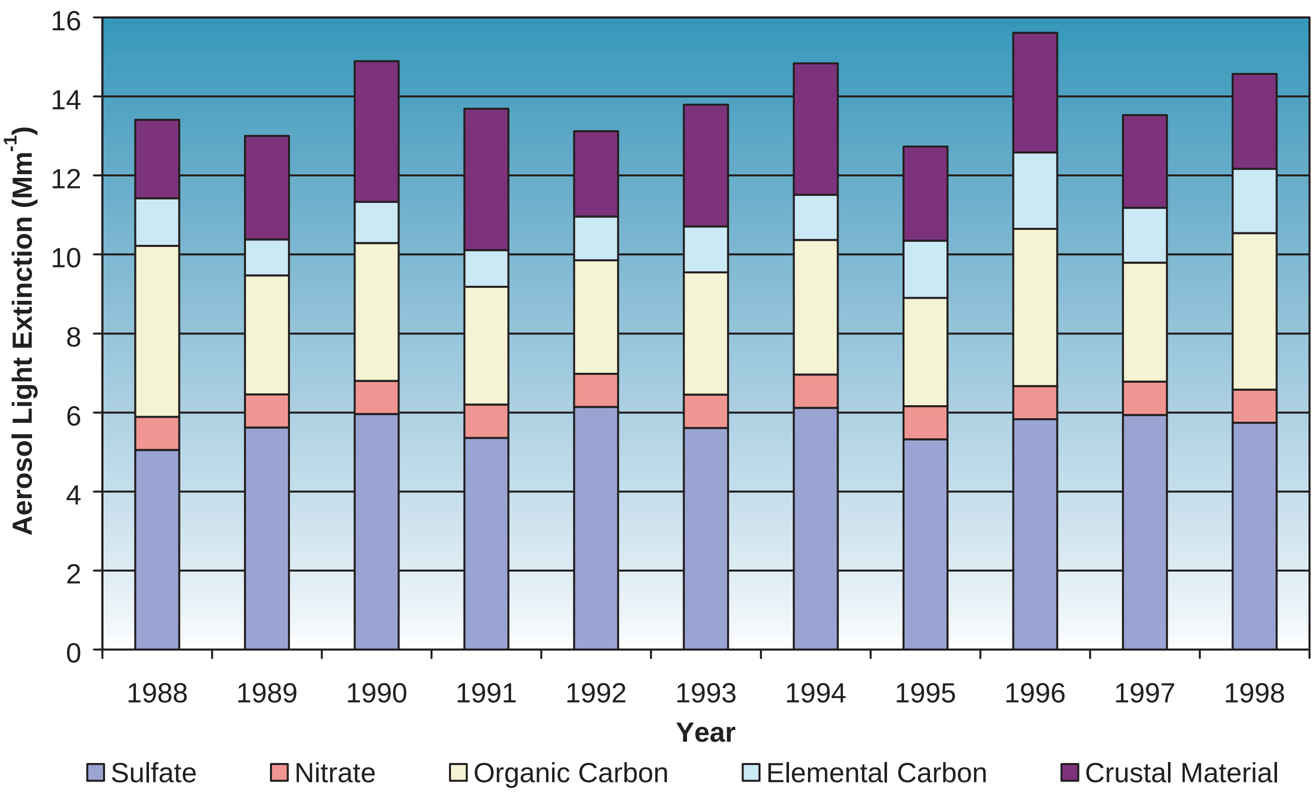

Figure CO–11. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Mesa Verde IMPROVE Particulate Sampler

Rocky Mountain National Park

The Rocky Mountain IMPROVE particulate sampler started reporting in March of 1988. Figure CO–12 presents the calculated visibility indices for selected data sets at Rocky Mountain National Park from 1988 through 1998. From 1988 through 1998, there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained near 13 deciviews (VR 65 miles). From 1988 through 1998, there was also no significant trend in the annual average of the visibility index for the mid-range days, which remained near 9 deciviews (VR 100 miles). The annual average of the visibility index for the least-impaired days remained near 5 deciviews (VR 150 miles).

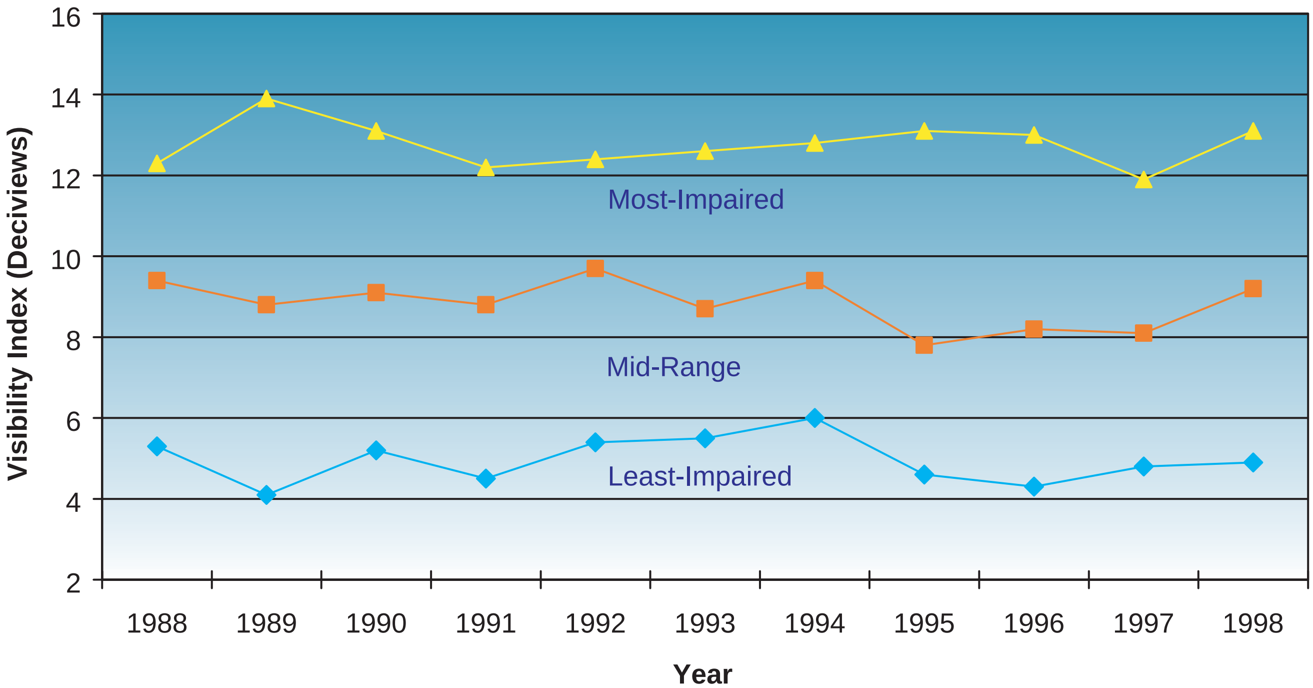

Figure CO–12. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Rocky Mountain IMPROVE Particulate Sampler

Figure CO–13 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The average visibility indices for summer were 1 to 4 deciviews higher than those during the spring and autumn. The visibility indices for the spring and autumn were generally 2 or 3 deciviews higher than the winter numbers. No significant seasonal trends were observed in the calculated visibility indices over this time period for the spring and autumn. The average indices for the summer and winter each declined 1 deciview unit over the eleven-year period (significant trend indicating improved visibility).

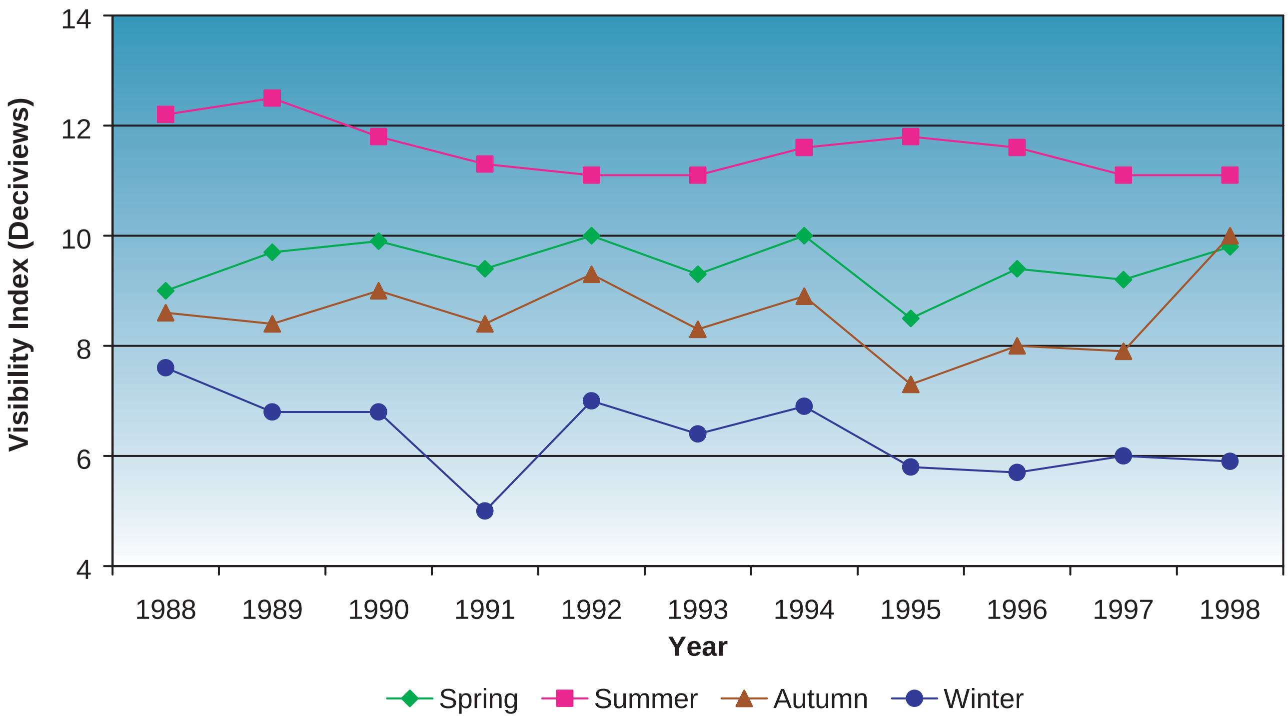

Figure CO–13. Seasonal Deciview Averages from 1988–1998 for the Rocky Mountain IMPROVE Particulate Sampler

Figure CO–14 presents a chart showing the calculated fractional contribution to Rocky Mountain's light extinction by each aerosol component on an annual basis. Figure CO–15 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 29 to 41 percent of the light extinction at the Rocky Mountain site, averaging 34 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the spring. This is different from most other sites, where sulfate contributions typically peaked in summer. The average contributions from nitrates ranged from 6 to 14 percent in the four seasons. The contributions from organic carbon ranged from 22 to 31 percent during the four seasons. Elemental carbon measured at the Rocky Mountain site was responsible for 9 to 13 percent of the calculated aerosol light extinction. The crustal material contributions ranged from 19 to 22 percent, with the highest contributions during the winter season.

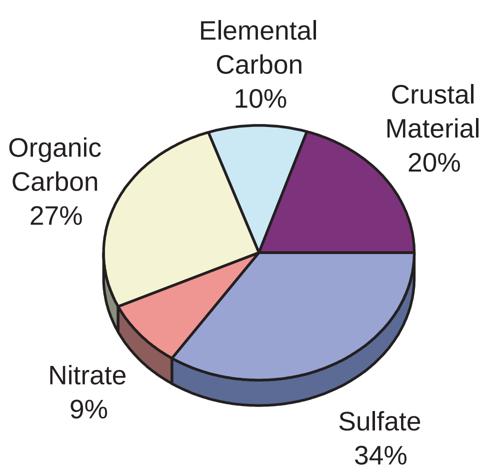

Figure CO–14. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Rocky Mountain IMPROVE Particulate Sampler

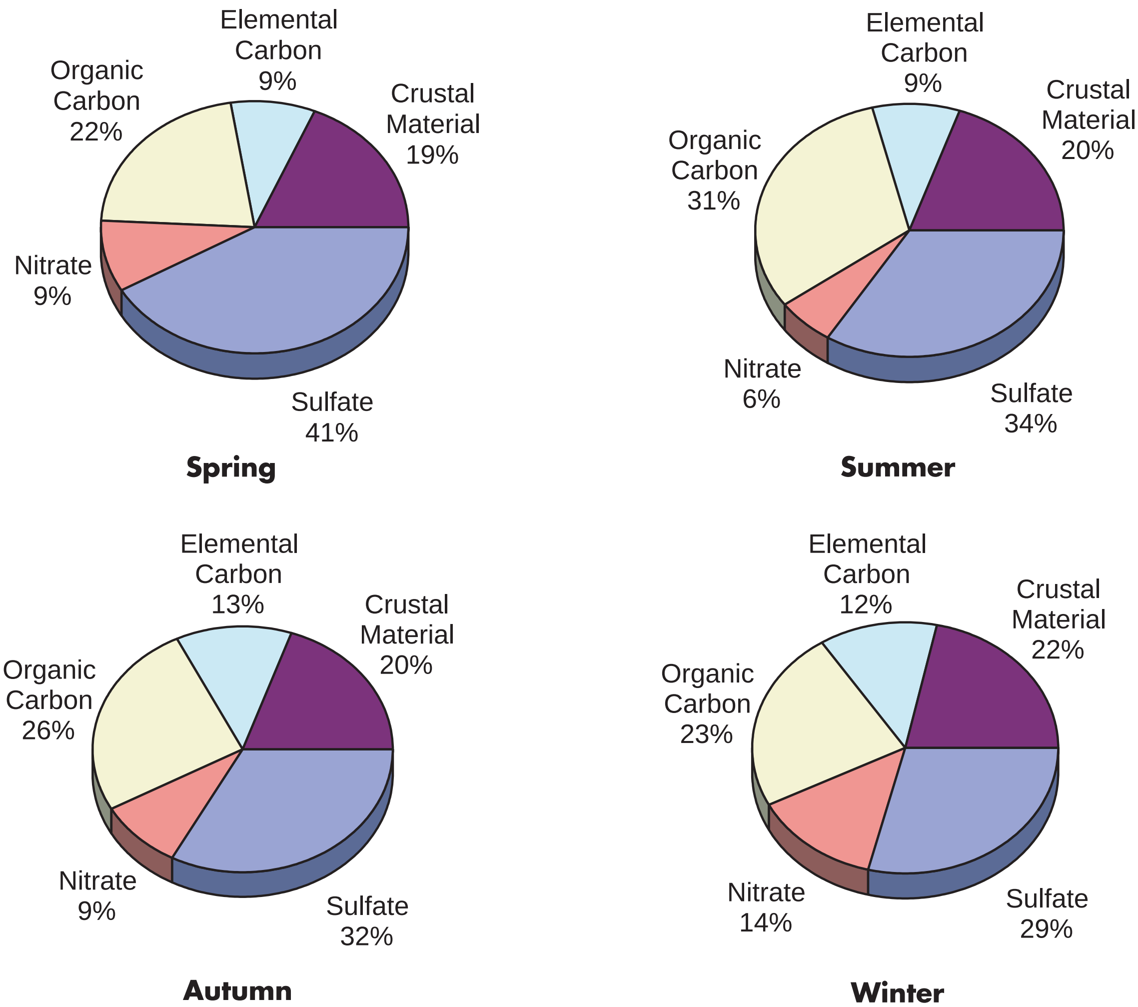

Figure CO–15. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Rocky Mountain IMPROVE Particulate Sampler

Figure CO–16 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Rocky Mountain site from 1988 to 1998. Over the eleven-year period, there was no significant trend in the total annual aerosol light extinctions which remained near 15 Mm^{-1}. No significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, elemental carbon, or crustal material.

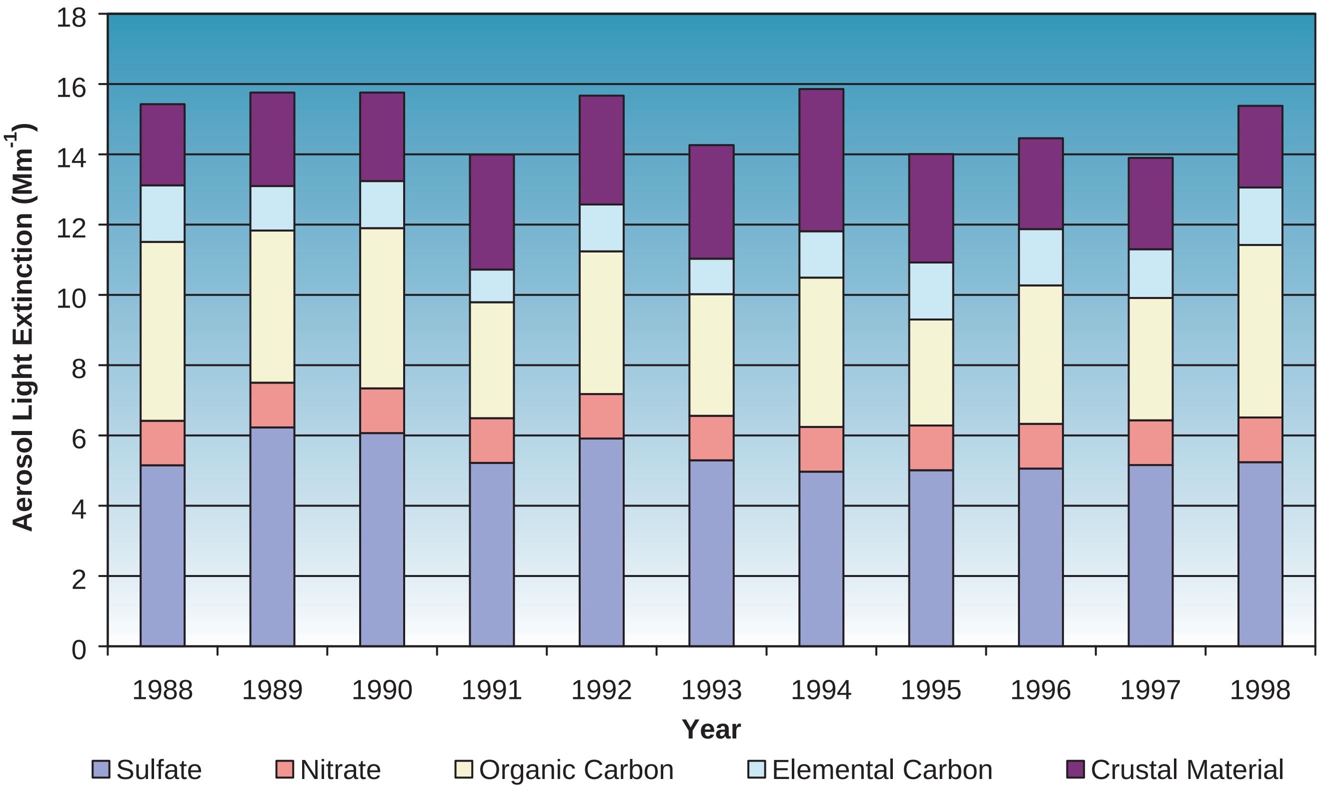

Figure CO–16. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Rocky Mountain IMPROVE Particulate Sampler

Weminuche Wilderness Area

The Weminuche IMPROVE particulate sampler started reporting in March of 1988. Figure CO–17 presents the calculated visibility indices for selected data sets at Weminuche Wilderness Area from 1988 through 1998. The figure shows that from 1988 through 1998 there was no statistically significant trend in the annual average of the visibility index for the most-impaired days, which remained near 12 deciviews (VR 75 miles). The annual average of the visibility index for the mid-range days remained near 9 deciviews (VR 100 miles) over the same time period, with no statistically significant improvement in visibility. From 1988 through 1998, there was no significant trend in the annual average of the visibility index for the least-impaired days, which remained near 5 deciviews (VR 150 miles).

Figure CO–18 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The average visibility indices for spring were 1 to 4 deciviews higher than those during the summer and autumn. The visibility indices for the summer and autumn were generally 2 or 3 deciviews higher than the winter numbers. No significant seasonal trends were observed in the calculated visibility indices over this time period for the spring, autumn, or winter. The average indices for the summer showed a significant trend indicating improved visibility as the indices declined 1 deciview unit over the eleven-year period.

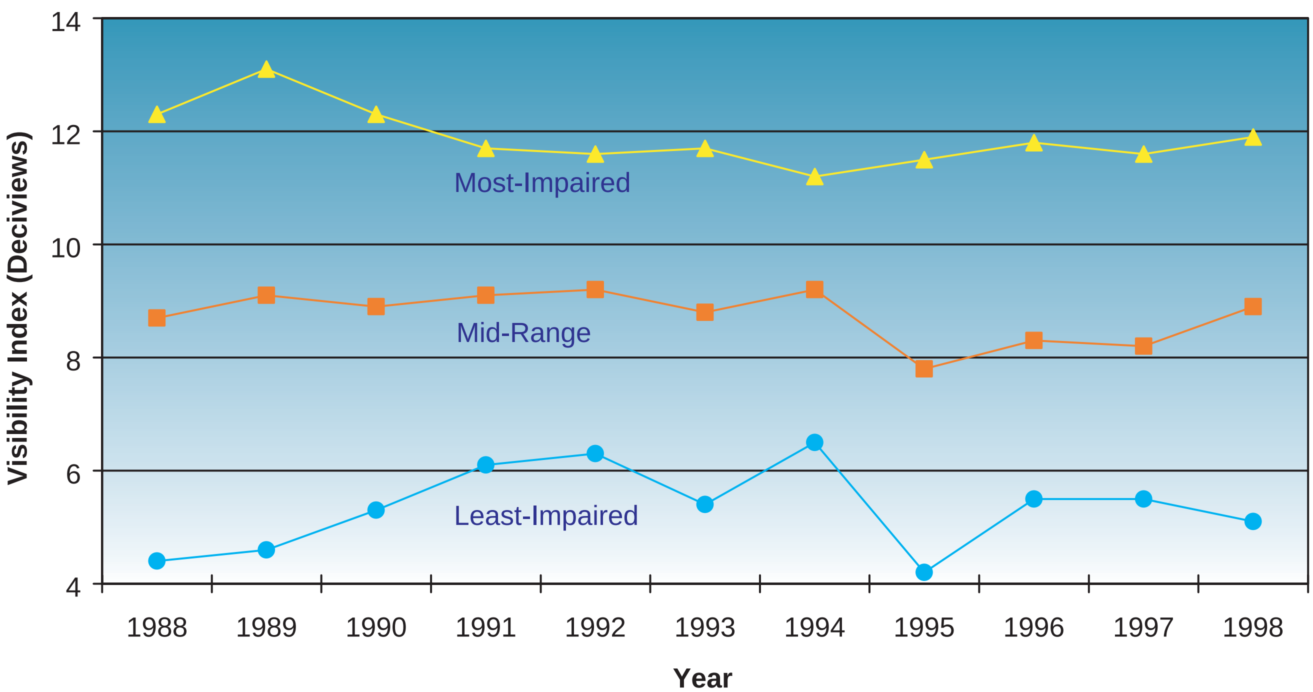

Figure CO–17. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Weminuche IMPROVE Particulate Sampler

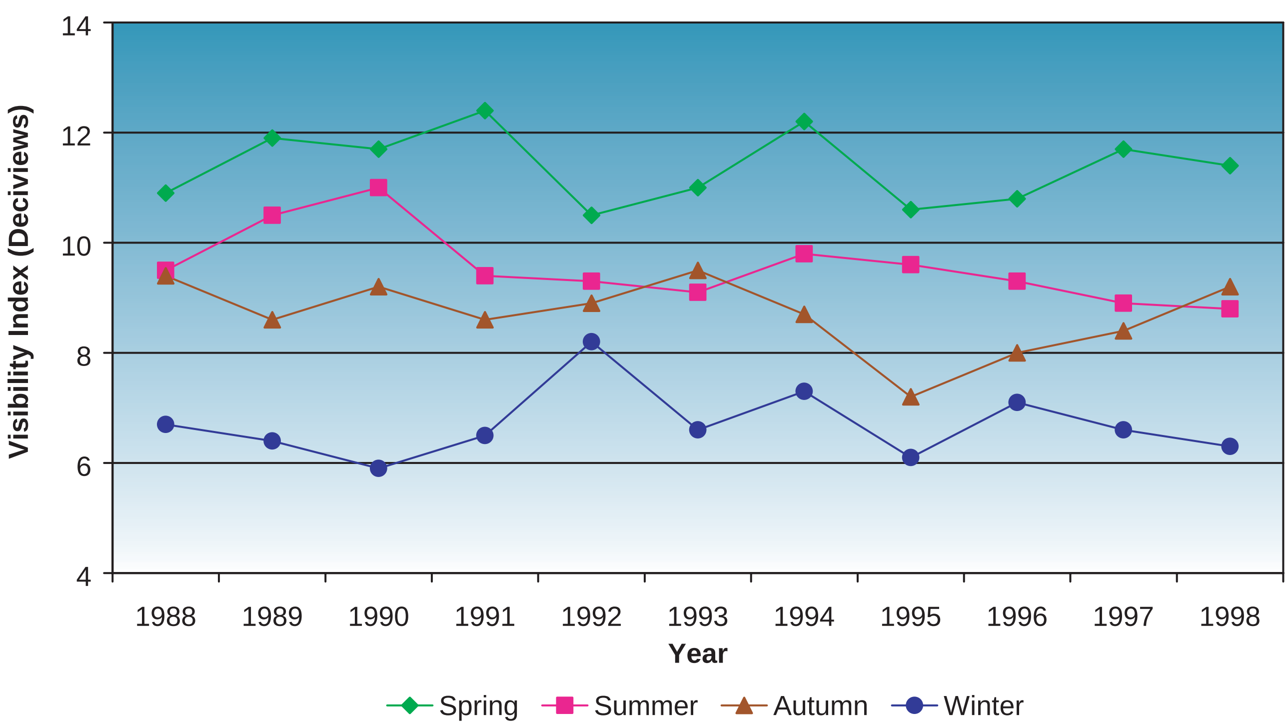

Figure CO–18. Seasonal Deciview Averages from 1988–1998 for the Weminuche IMPROVE Particulate Sampler

Figure CO–19 presents a chart showing the calculated fractional contribution to Weminuche's light extinction by each aerosol species on an annual basis. Figure CO–20 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 36 to 58 percent of the light extinction at the Weminuche site, averaging 42 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the spring, which is different from most other sites where sulfate typically peaked in summer. The average contributions from nitrates ranged from 4 to 8 percent in the four seasons. The contributions from organic carbon ranged from 13 to 29 percent during the four seasons. Elemental carbon measured at the Weminuche site was responsible for 6 to 15 percent of the calculated aerosol light extinction. The crustal material contributions ranged from 15 to 21 percent, with the highest contributions during the winter season.

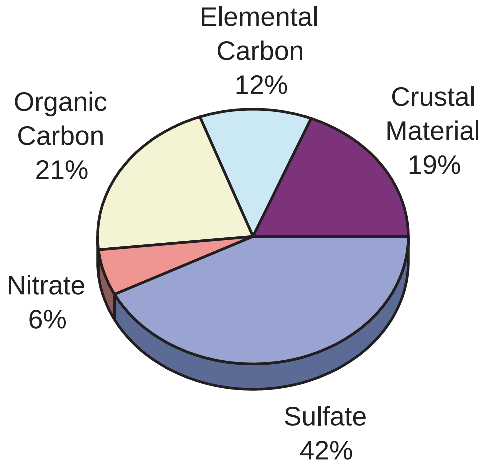

Figure CO–19. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Weminuche IMPROVE Particulate Sampler

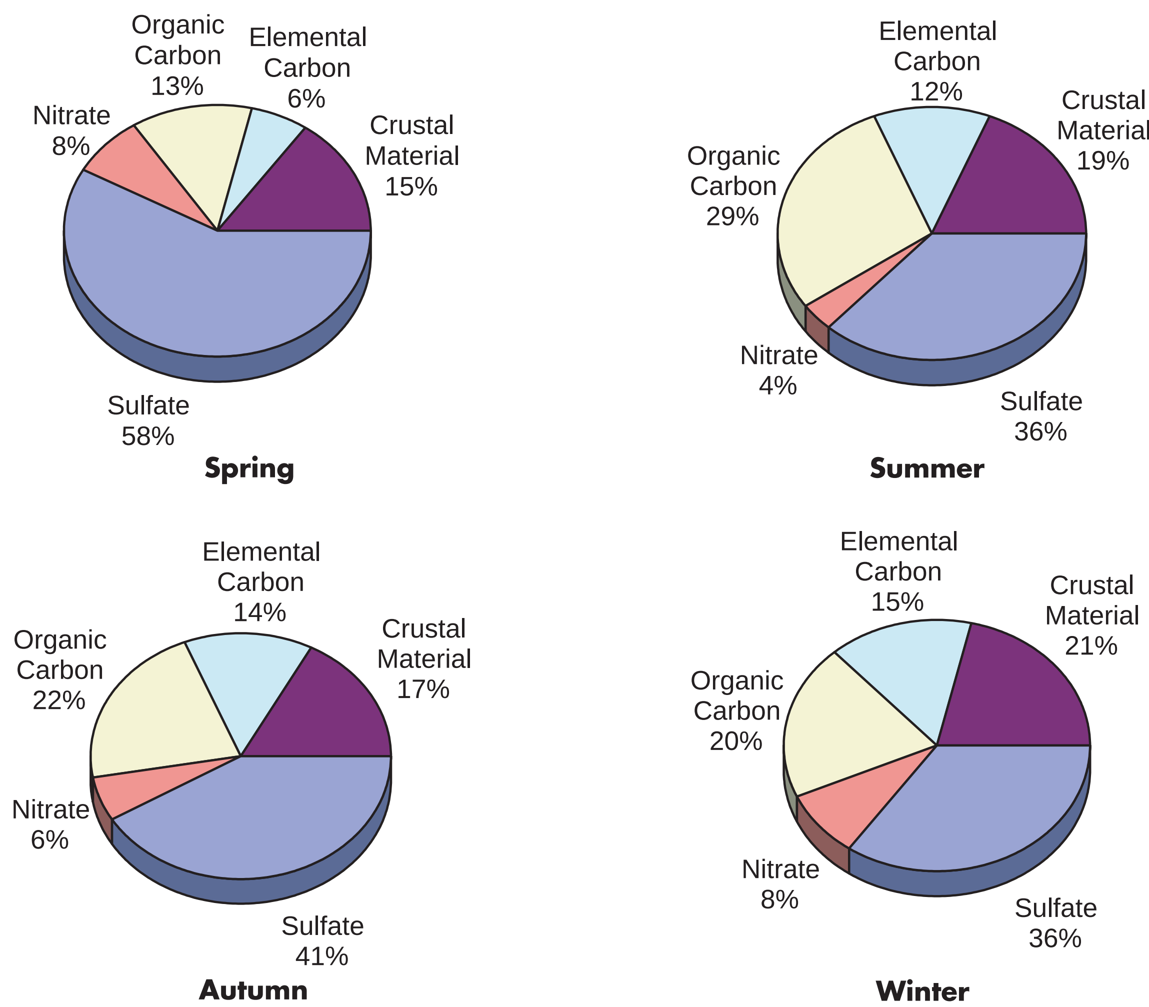

Figure CO–20. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Weminuche IMPROVE Particulate Sampler

Figure CO–21 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Weminuche site from 1988 to 1998. Over the eleven-year period, there was no statistically significant trend in the total annual aerosol light extinctions, which remained near 14 Mm^{-1}. No significant trends were noted in the annual light extinctions calculated for sulfates, elemental carbon, or crustal material. However, the organic carbon contributions showed statistically significant decreases in their annual contribution to the light extinction coefficients, indicating lower ambient concentrations.

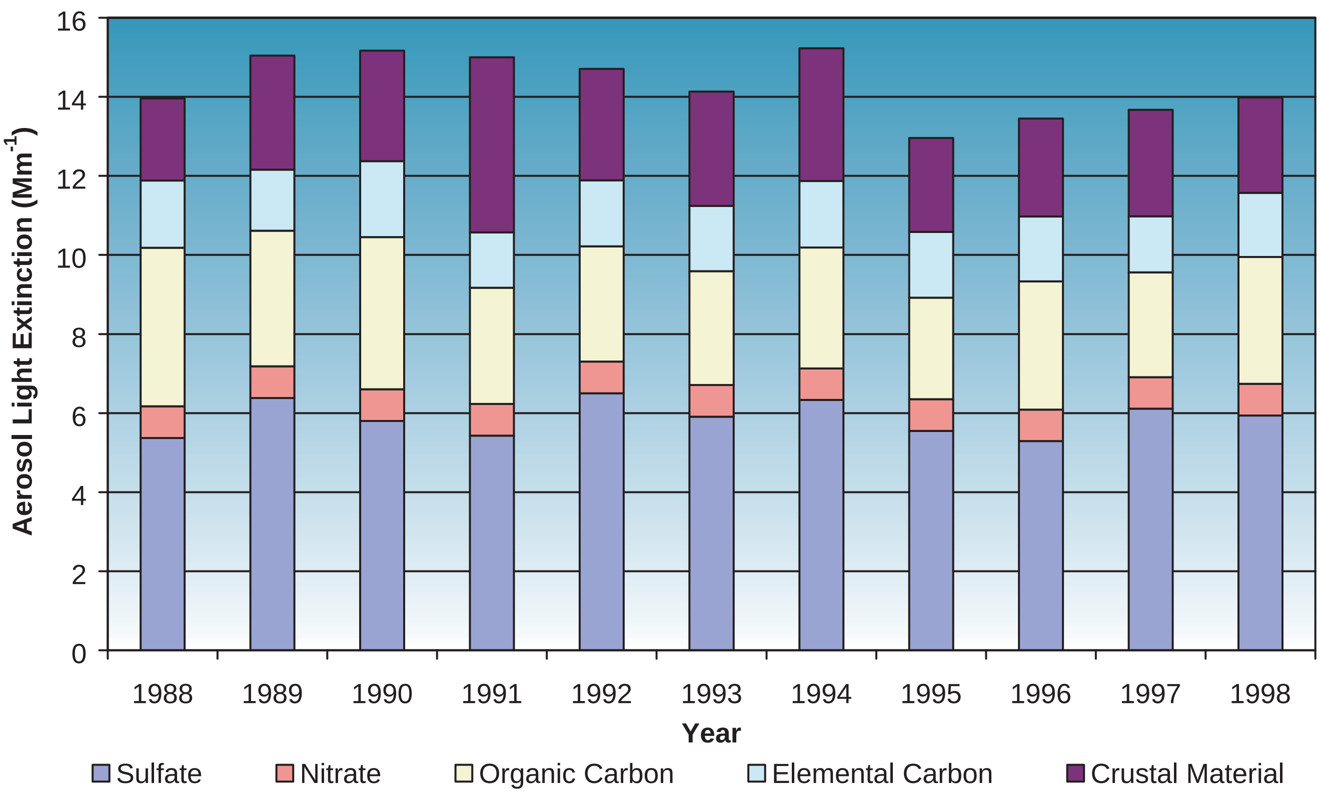

Figure CO–21. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Weminuche IMPROVE Particulate Sampler

Colorado State Summary

The calculated annual average aerosol extinction coefficients at Colorado's IMPROVE monitoring sites are presented in Table CO–1. The calculated total aerosol extinction coefficients at all four sites were within 5 percent of the average (14.5 Mm^{-1}), indicating similar annual visibility conditions at all sites. The extinction coefficients for the individual species were also similar at the different sites. All five sites also showed similar rankings for contributions of the species to light extinction: sulfate, followed by organic carbon and crustal material, then elemental carbon, and lastly nitrate. These rankings are identical to those presented for the Arizona, Texas, and Wyoming IMPROVE monitors in Tables AZ–1, TX–1, and WY–1.

Table CO–1. Colorado Calculated Total Extinction Coefficients from 1994–1998

IMPROVE Site	Calculated Total Aerosol Extinction Coefficient (Mm^{-1})	Pollutant Extinction Coefficient (Mm^{-1})				
		Sulfate	Nitrate	Organic Carbon	Elemental Carbon	Crustal Material
Great Sand Dunes NM	15.3	5.8	1.1	3.5	1.1	3.7
Mesa Verde NP	14.3	5.8	0.8	3.4	1.5	2.7
Rocky Mountain NP	14.7	5.1	1.3	3.9	1.5	2.9
Weminuche Wilderness	13.9	5.8	0.8	2.9	1.6	2.7
Average	14.5 ± 0.6	5.6 ± 0.4	1.0 ± 0.2	3.5 ± 0.4	1.4 ± 0.2	3.0 ± 0.5

7. FLORIDA

The only IMPROVE particulate sampler in Florida that operated continuously from 1994 through 1998 was the one located in the Chassahowitzka National Wildlife Refuge. Figure FL–1 shows the Chassahowitzka monitor location (28.75°N, 82.57°W, elevation 10 feet) near the Gulf of Mexico. An IMPROVE particulate sampler also collects data in the Everglades National Park. However, it was not operational for two months in 1998, so its data were not included in this report. The Saint Marks Wilderness Area is also a mandatory Federal Class I area covered by the Regional Haze Rule, but it does not have an operating IMPROVE particulate sampler. In 1980 the Bradwell Bay Wilderness Area was excluded as a mandatory Federal Class I area for purposes of visibility protection, so it is not covered by the Regional Haze Rule.

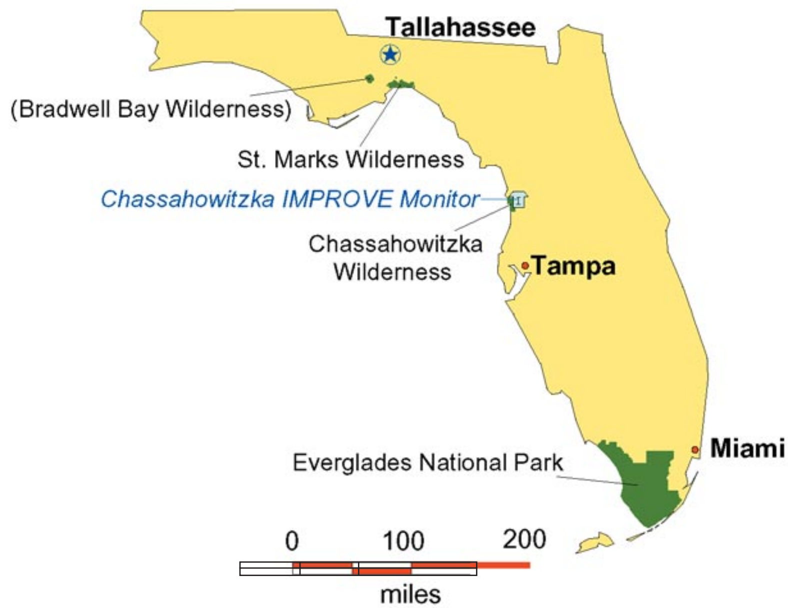

Figure FL–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in Florida

Chassahowitzka National Wildlife Refuge

The Chassahowitzka IMPROVE particulate sampler started recording in April of 1993. Figure FL–2 presents the calculated visibility indices for selected data sets from 1993 through 1998. The figure shows that from 1993 through 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained near 27 deciviews (VR 16 miles). From 1993 through 1998, there was no significant trend in the annual average of the visibility index for the mid-range days, which remained near 23 deciviews (VR 24 miles). The annual average of the visibility index for the least-impaired days remained near 18 deciviews (VR 40 miles), indicating no statistically significant trend in visibility.

Figure FL–3 shows the seasonal averages for the calculated visibility index from 1993 through 1998. The visibility indices for the four seasons all covered the nearly same range, from 21 to 24 deciviews. No significant seasonal trends were observed in the calculated visibility indices over this time period for any of the seasons.

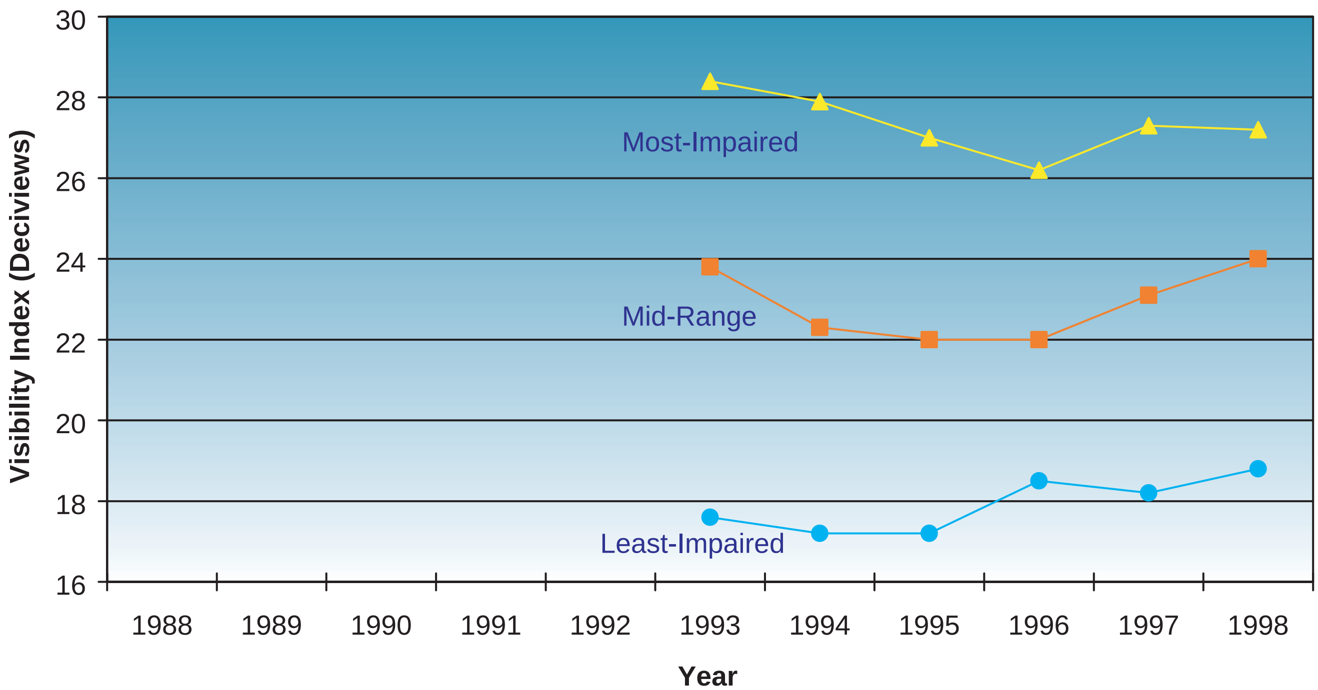

Figure FL–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1993–1998 for the Chassahowitzka IMPROVE Particulate Sampler

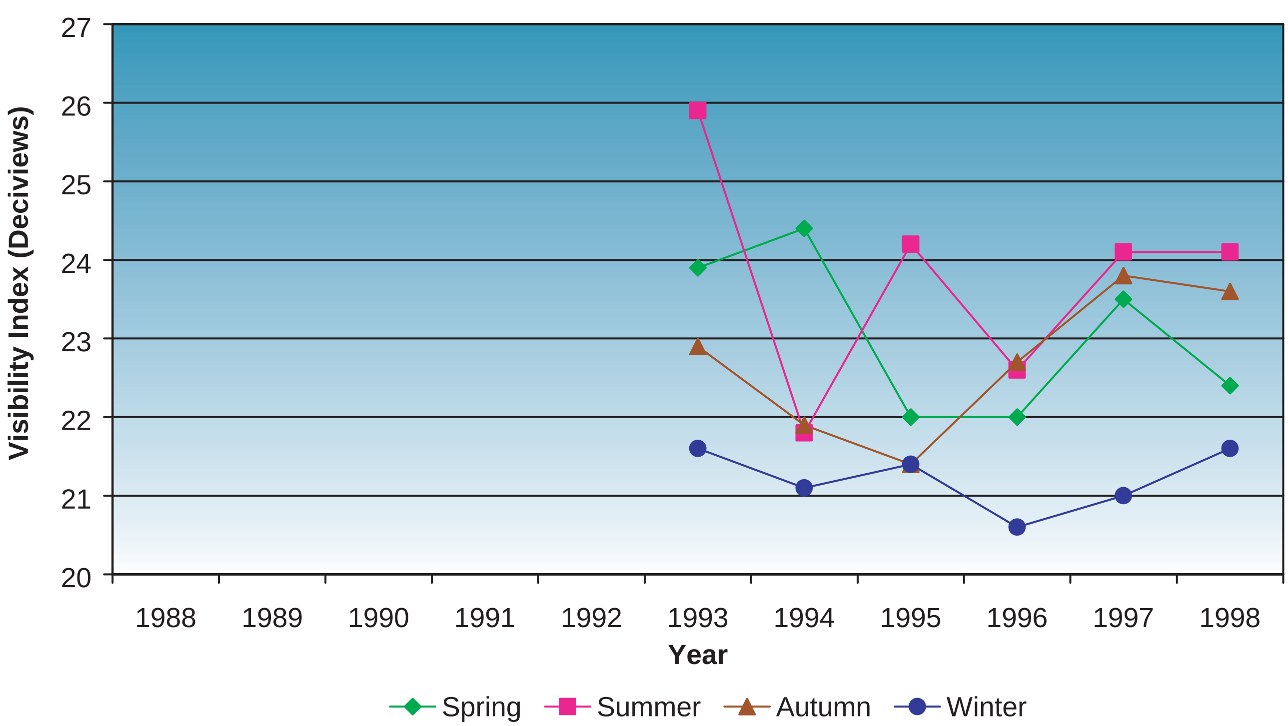

Figure FL–3. Seasonal Deciview Averages from 1993–1998 for the Chassahowitzka IMPROVE Particulate Sampler

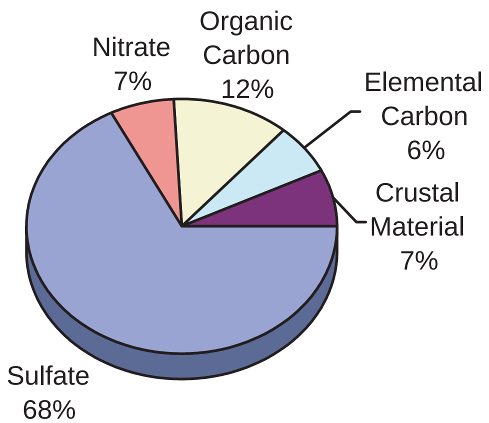

Figure FL–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Chassahowitzka IMPROVE Particulate Sampler

Figure FL–4 presents a chart showing the calculated fractional contribution to Chassahowitzka's light extinction by each aerosol species on an annual basis. Figure FL–5 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 59 to 69 percent of the light extinction at the Chassahowitzka site, averaging 68 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the summer and the lowest in the winter. The contributions from organic carbon ranged from 10 to 16 percent during the four seasons, with winter showing the highest values. Nitrate, elemental carbon, and crustal material measured at the Chassahowitzka site were each responsible for approximately 7 percent of the calculated aerosol light extinction year-round.

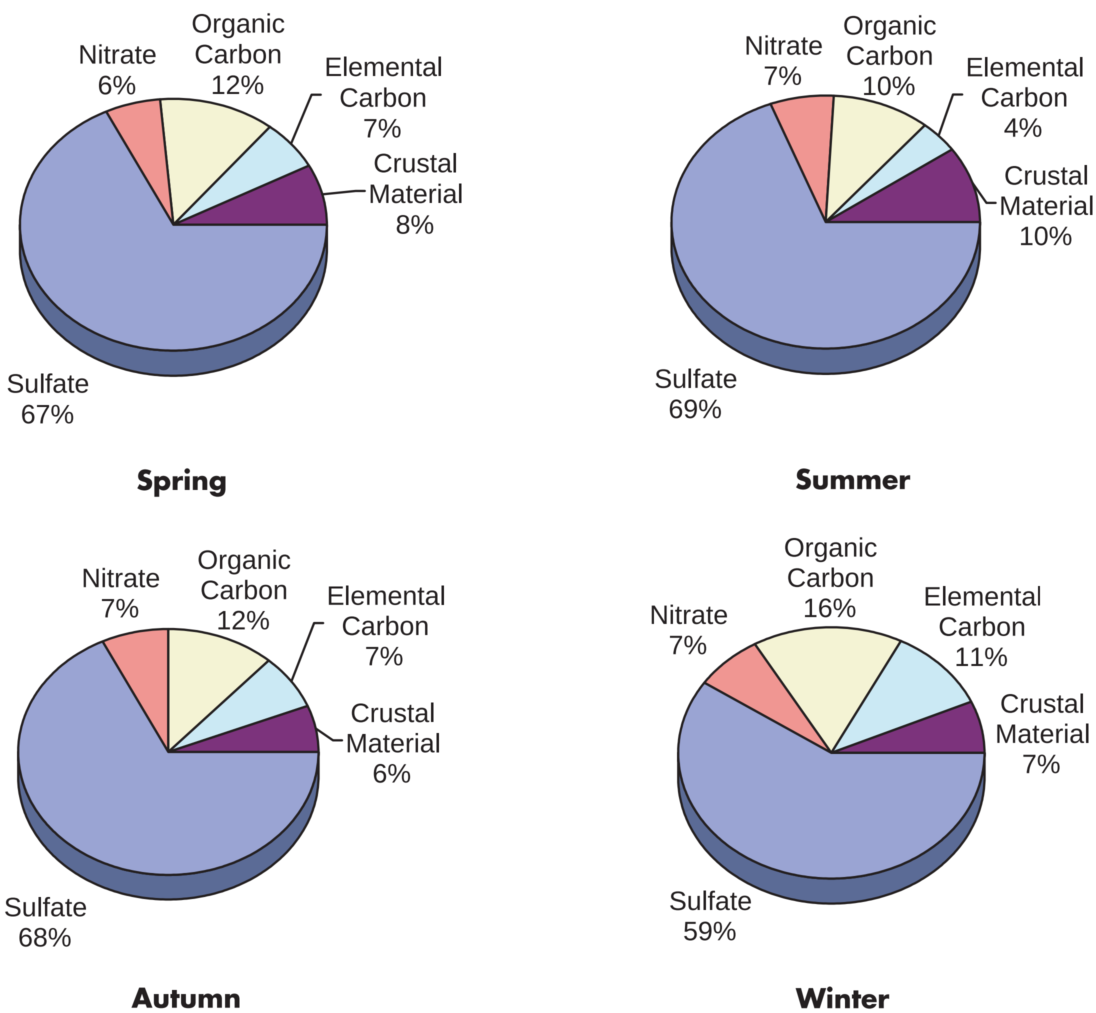

Figure FL–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Chassahowitzka IMPROVE Particulate Sampler

Figure FL–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Chassahowitzka site from 1993 to 1998. Over the six-year period, the total annual aerosol light extinctions remained near 90 Mm^{-1} (no statistically significant trend). Similarly, no significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, elemental carbon, or crustal material.

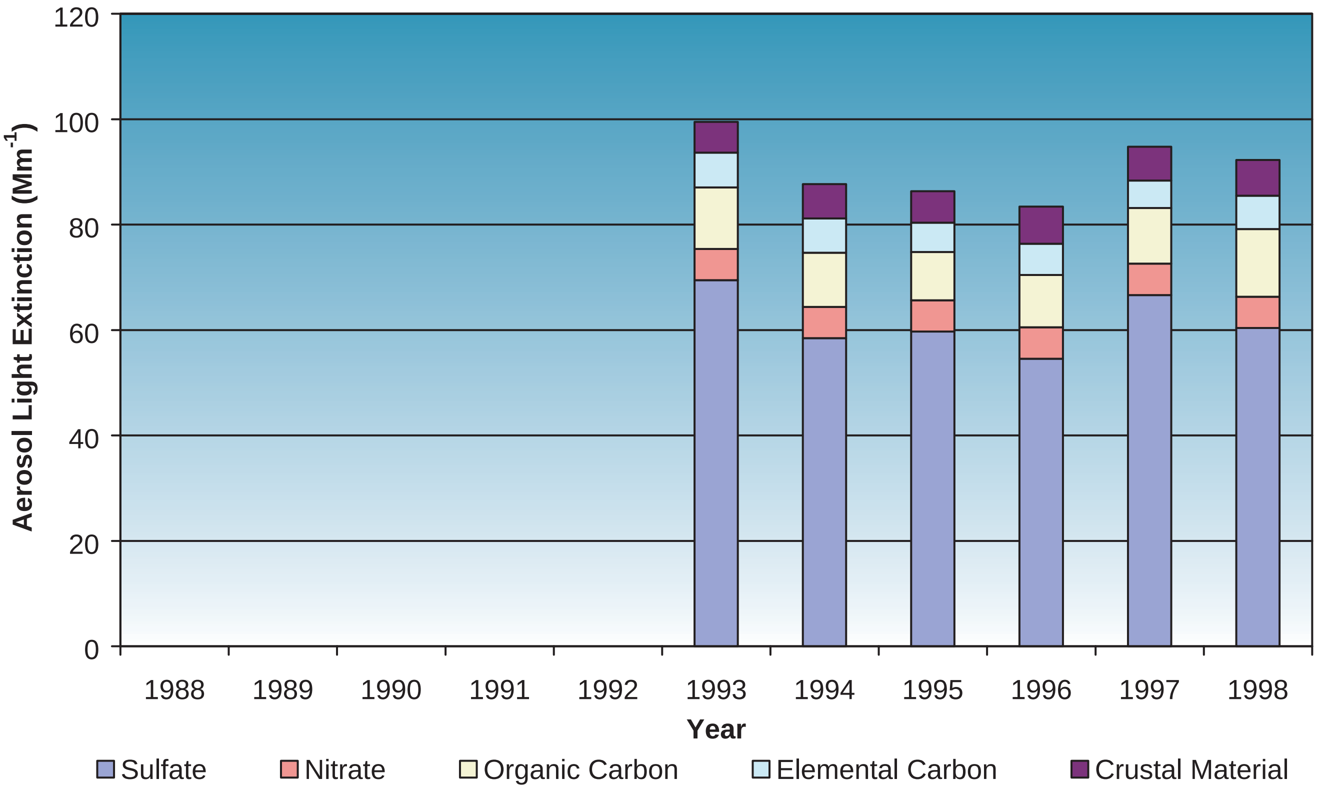

Figure FL–6. Contributions to Calculated Annual Aerosol Light Extinction from 1993–1998 for the Chassahowitzka IMPROVE Particulate Sampler

8. GEORGIA

The only IMPROVE particulate sampler in Georgia that operated continuously from 1994 through 1998 was the one located in the Okefenokee National Wildlife Refuge. Figure GA–1 shows the Okefenokee monitor location (30.74°N, 82.12°W, elevation 50 feet) in the southeast corner of the state. The Cohutta and Wolf Island Wilderness Areas are additional Class I areas covered by the Regional Haze Rule, but they do not have operating IMPROVE particulate samplers.

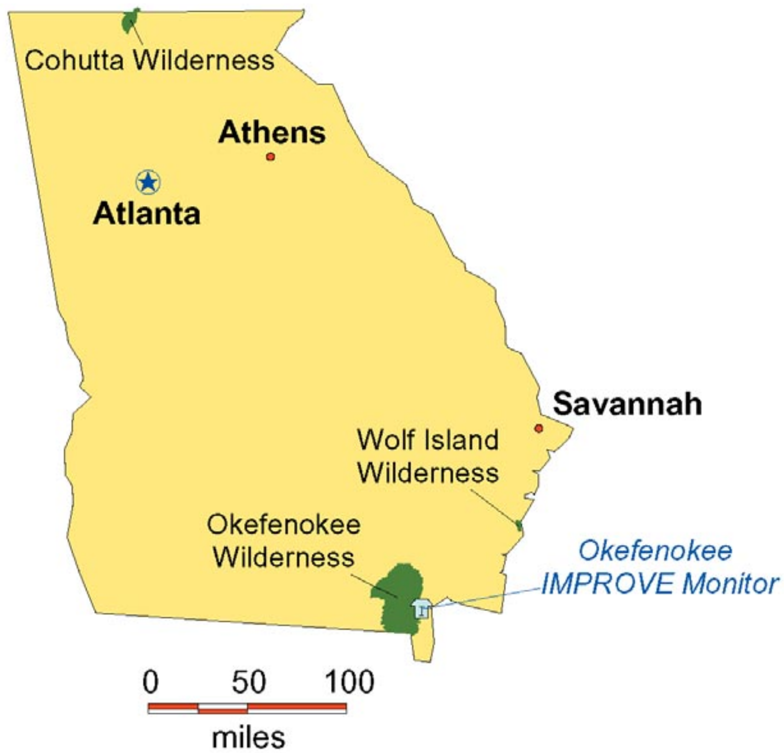

Figure GA–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in Georgia

Okefenokee National Wildlife Refuge

The Okefenokee IMPROVE particulate sampler started reporting in September of 1991. Figure GA–2 presents the calculated visibility indices for selected data sets from 1992 through 1998. The figure shows that from 1992 through 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained near 29 deciviews (VR 13 miles). From 1992 through 1998 there was no significant trend in the annual average of the visibility index for the mid-range days, which remained near 23 deciviews (VR 24 miles). The annual average of the visibility index for the least-impaired days remained near 18 deciviews (VR 40 miles) for most years, with no statistically significant trend in visibility.

Figure GA–3 shows the seasonal averages for the calculated visibility index from 1992 through 1998. The visibility indices for the four seasons ranged from 21 to 27 deciviews. Summer indices were higher than all other seasons in four of the seven years, and winter indices were lowest in six of the

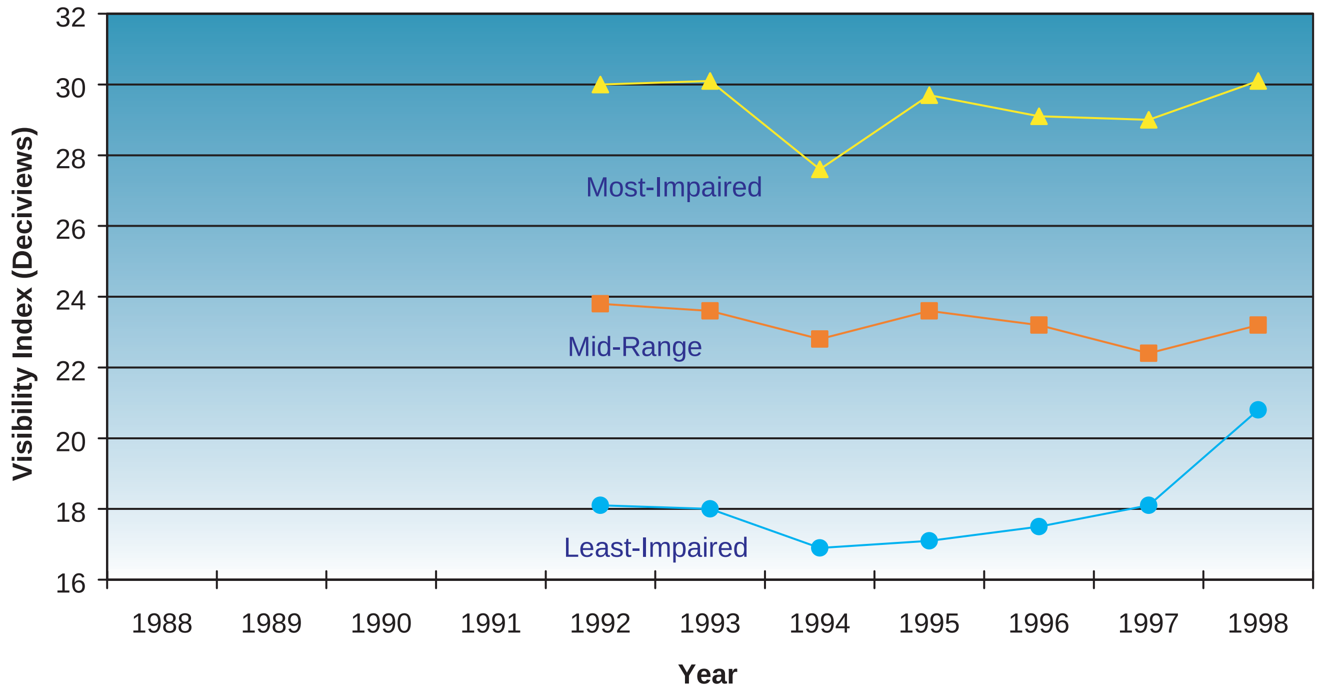

Figure GA–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1992–1998 for the Okefenokee IMPROVE Particulate Sampler

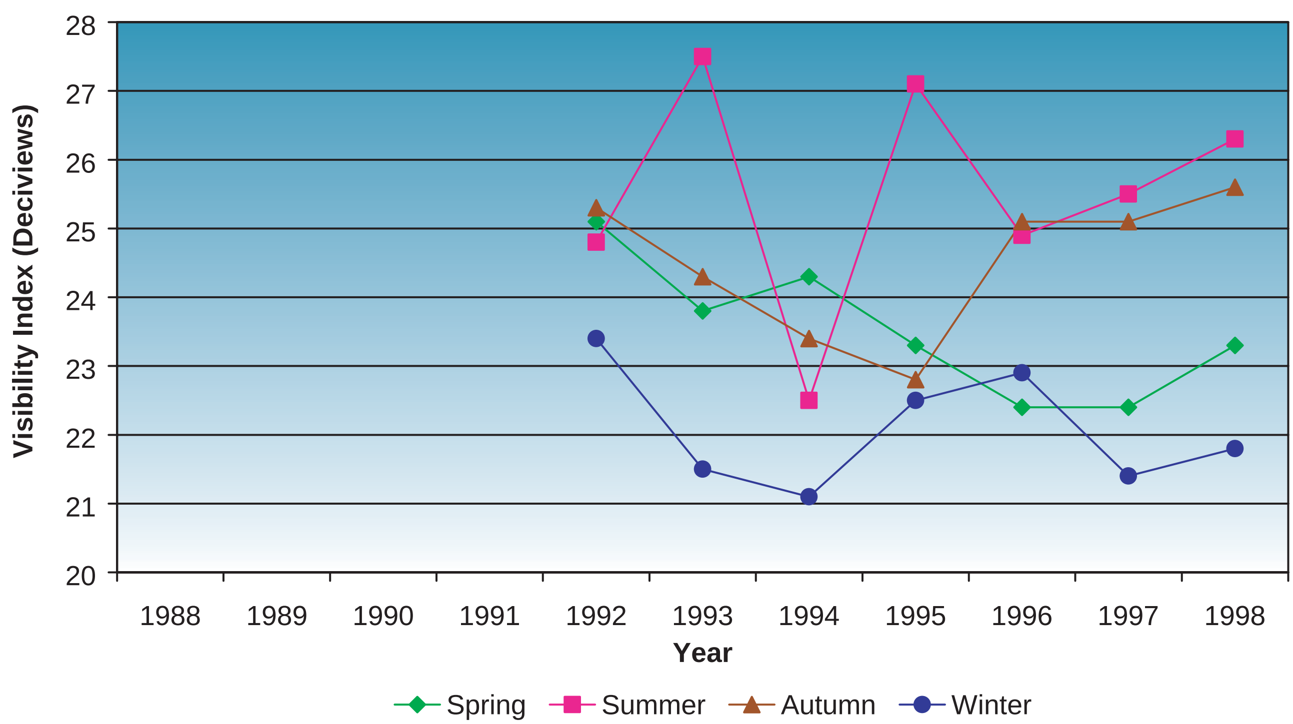

Figure GA–3. Seasonal Deciview Averages from 1992–1998 for the Okefenokee IMPROVE Particulate Sampler

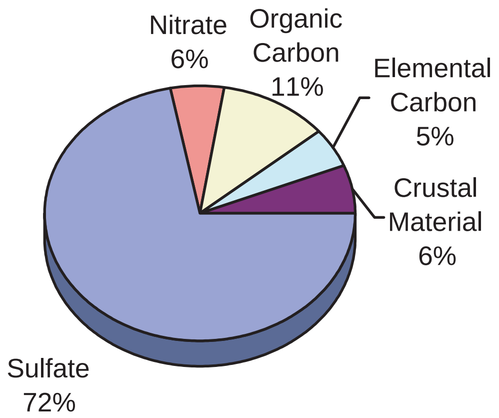

Figure GA–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Okefenokee IMPROVE Particulate Sampler

seven years. No significant seasonal trends were observed in the calculated visibility indices over this time period for summer, autumn, or winter. However, the spring indices showed a statistically significant decrease, indicating a 2 deciview improvement over seven years.

Figure GA–4 presents a chart showing the calculated fractional contribution to Okefenokee's light extinction by each aerosol species on an annual basis. Figure GA–5 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 64 to 76 percent of the light extinction at the Okefenokee site, averaging 72 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the summer and autumn and the lowest in the winter. The contributions from organic carbon ranged from 9 to 16 percent during the four seasons, with winter showing the

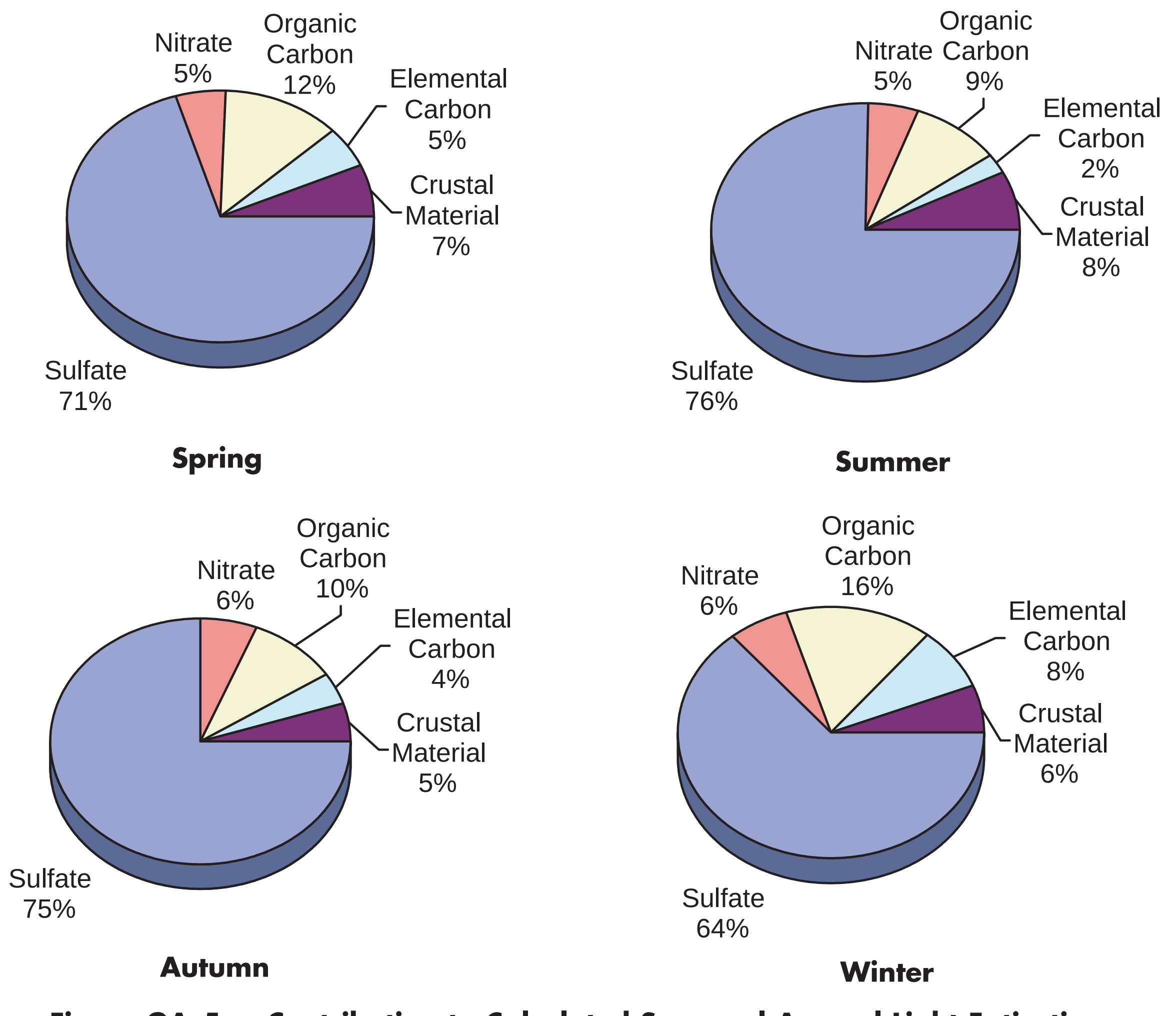

Figure GA–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Okefenokee IMPROVE Particulate Sampler

highest values. Nitrate, elemental carbon, and crustal material measured at the Okefenokee site were each responsible for approximately 6, 5, and 6 percent of the calculated aerosol light extinction year-round.

Figure GA–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Okefenokee site from 1992 to 1998. Over the seven-year period, the total annual aerosol light extinctions remained near 100 Mm^{-1} (no significant trend). Similarly, no significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, elemental carbon, or crustal material.

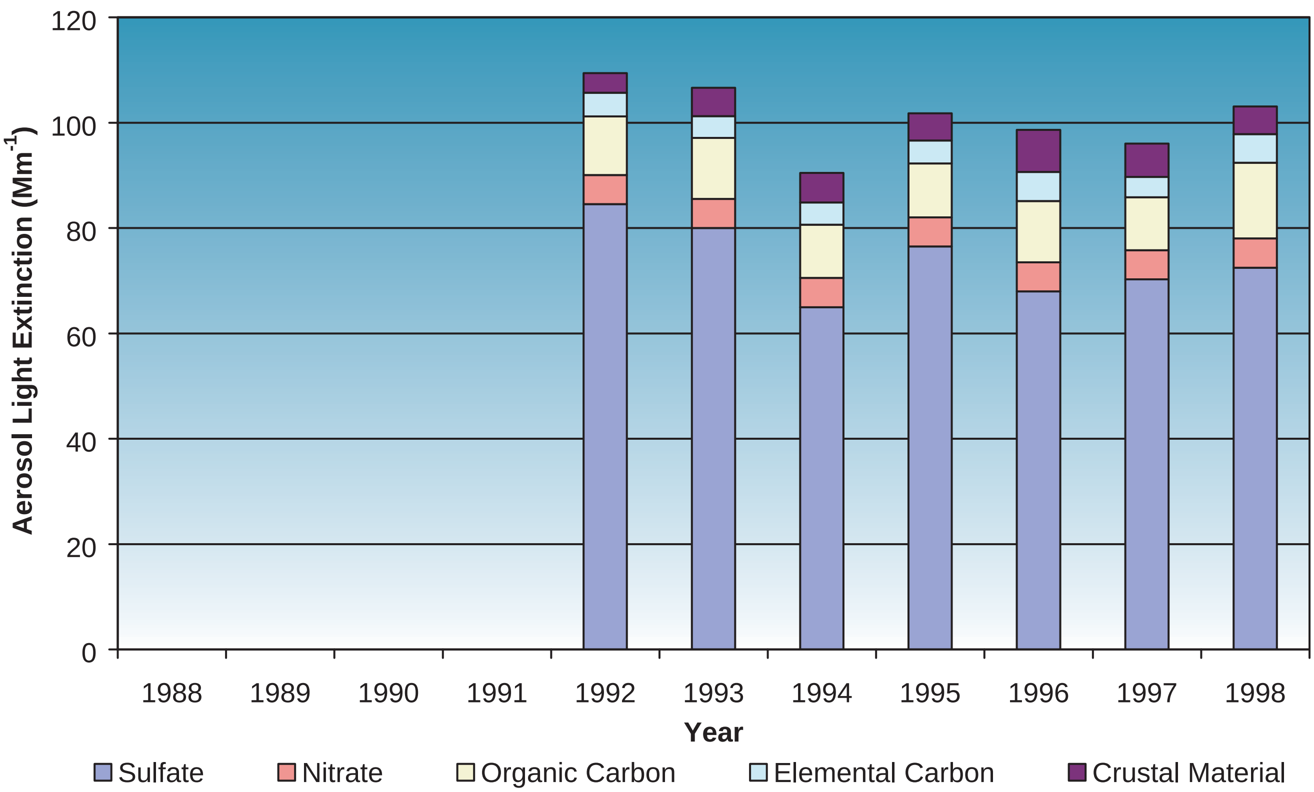

Figure GA–6. Contributions to Calculated Annual Aerosol Light Extinction from 1992–1998 for the Okefenokee IMPROVE Particulate Sampler

9. KENTUCKY

The only IMPROVE monitoring site in Kentucky that operated continuously from 1994 through 1998 was the one located in the Mammoth Cave National Park. Figure KY–1 shows the Mammoth Cave particulate sampler location (37.21°N, 86.07°W, elevation 750 feet) in central Kentucky. There are no additional mandatory Federal Class I areas in Kentucky covered by the Regional Haze Rule.

Figure KY–1. Mandatory Federal Class I Area and IMPROVE Monitoring Site in Kentucky

Mammoth Cave National Park

The Mammoth Cave IMPROVE particulate sampler started recording in September of 1991. Figure KY–2 presents the calculated visibility indices for selected data sets from 1992 through 1998. The figure shows that from 1992 through 1998 there was a statistically significant trend in the annual average of the visibility index for the most-impaired days, which decreased from 33 to 32 deciviews (VR from 9 to 10 miles). From 1992 through 1998, there was no significant trend in the annual average of the visibility index for the mid-range days, which remained near 26 deciviews (VR 18 miles). The annual average of the visibility index for the least-impaired days remained near 19 deciviews (VR 36 miles) for most years, with no statistically significant trend in visibility.

Figure KY–3 shows the seasonal averages for the calculated visibility index from 1992 through 1998. The visibility indices for the summer were at least 5 deciviews higher than the other seasons; visual range was 21 miles for spring 1992, but only 9 miles in the summer of the same year. The lowest

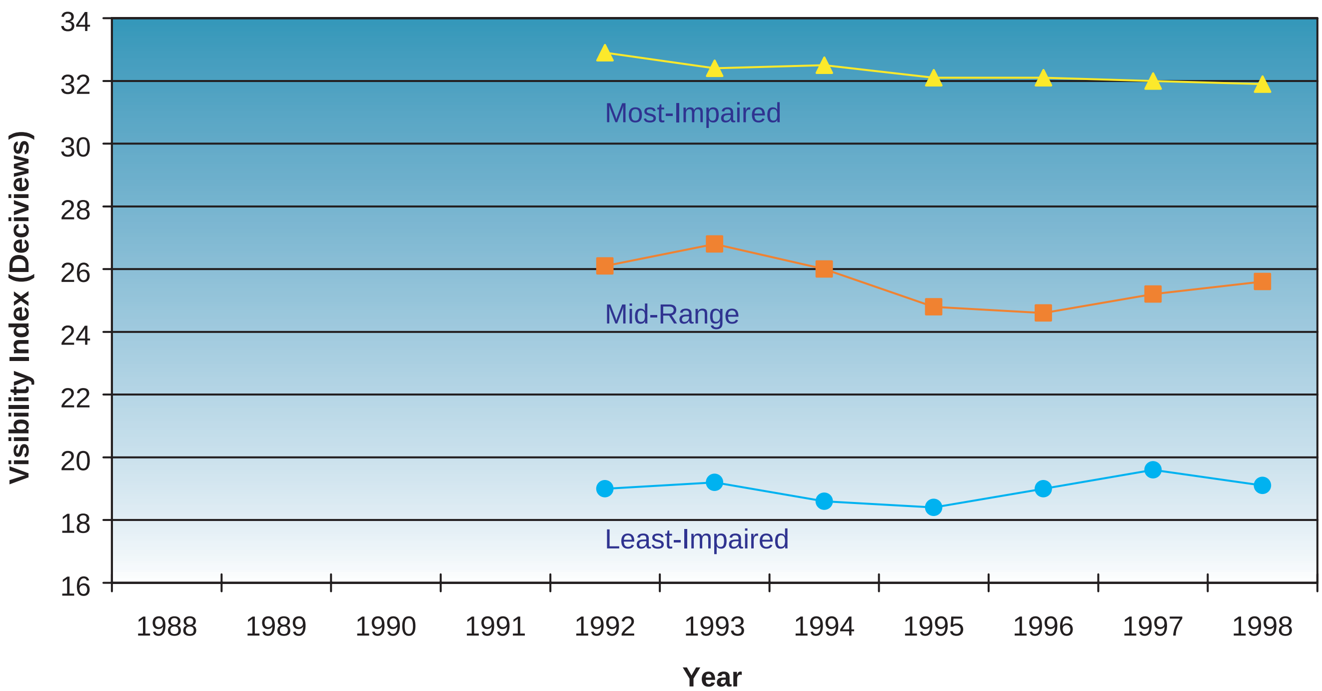

Figure KY–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1992–1998 for the Mammoth Cave IMPROVE Particulate Sampler

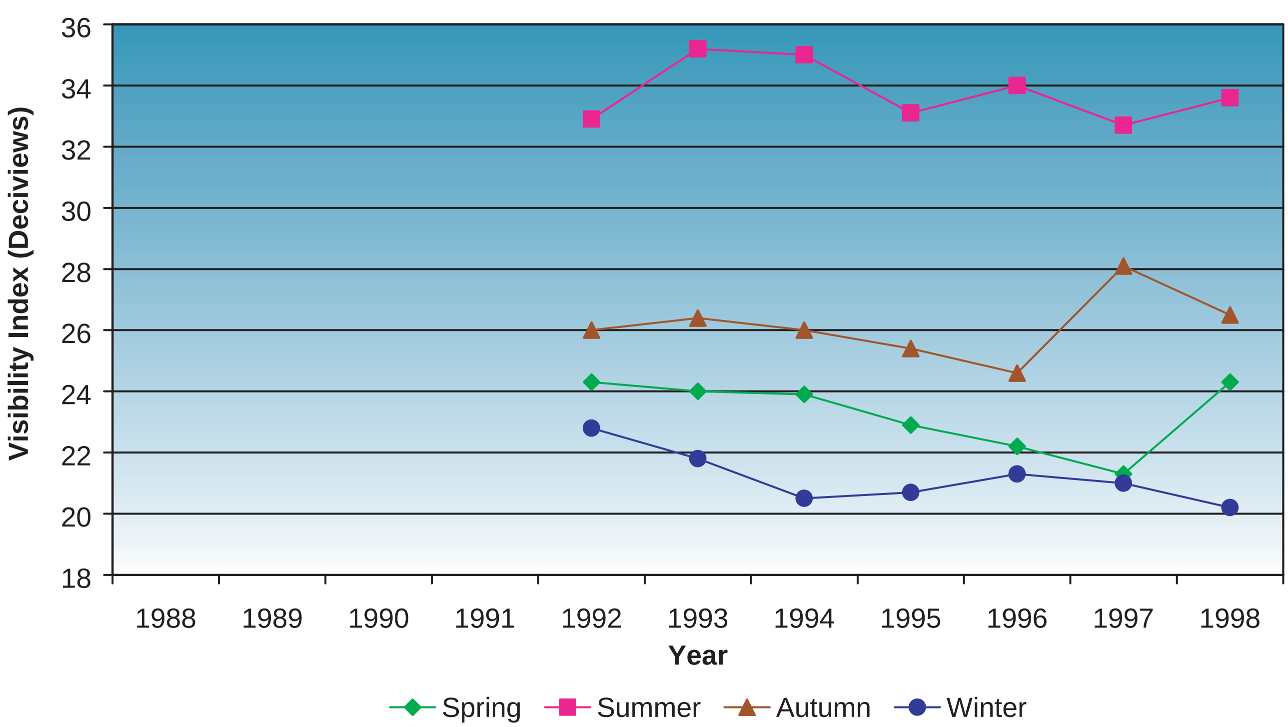

Figure KY–3. Seasonal Deciview Averages from 1992–1998 for the Mammoth Cave IMPROVE Particulate Sampler

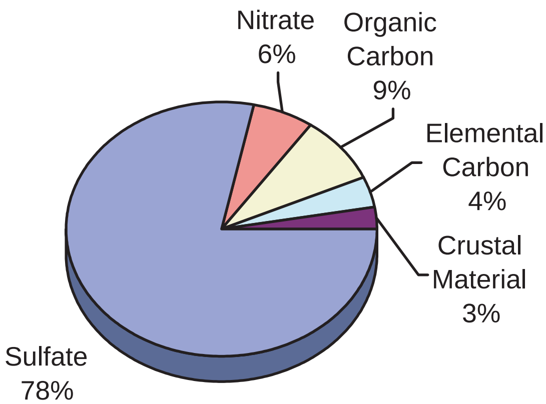

Figure KY–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Mammoth Cave IMPROVE Particulate Sampler

visibility indices (best visibility) were observed during the winter seasons. No significant seasonal trends were observed in the calculated visibility indices over this time period for any of the seasons.

Figure KY–4 presents a chart showing the calculated fractional contribution to Mammoth Cave's light extinction by each aerosol species on an annual basis. Figure KY– 5 shows the same information for the four seasons. These five pie charts show that sulfate particles were responsible for 67 to 87 percent of the light extinction at the Mammoth Cave site, averaging 78 percent on an annual basis over a five-year period. The highest sulfate contributions occured in the summer and the lowest in the winter. During the summer season, the other four components combined (nitrates, organic and elemental carbon, and crustal material) represented only 13 percent of the light extinction. The contributions from nitrate ranged from 4 to 9

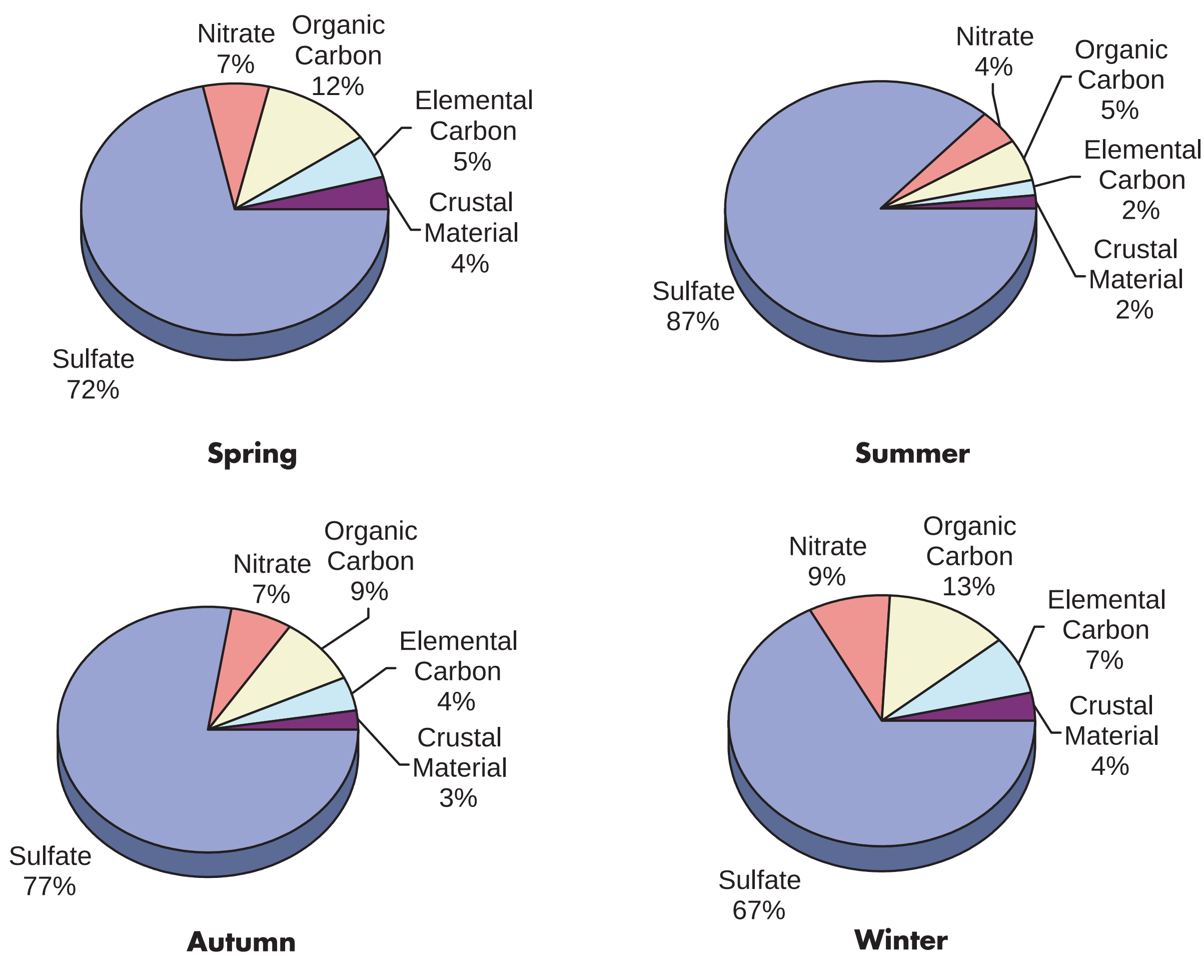

Figure KY–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Mammoth Cave IMPROVE Particulate Sampler

percent during the four seasons, with winter showing the highest values. Organic carbon percentages varied from 5 to 13 percent for the seasons. Elemental carbon and crustal material measured at the Mammoth Cave site were responsible for approximately 4 and 3 percent of the calculated aerosol light extinction year-round.

Figure KY–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Mammoth Cave site from 1992 to 1998. Over the seven-year period, the total annual aerosol light extinctions remained near 130 Mm^{-1} (no significant trend). Similarly, no significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, elemental carbon, or crustal material.

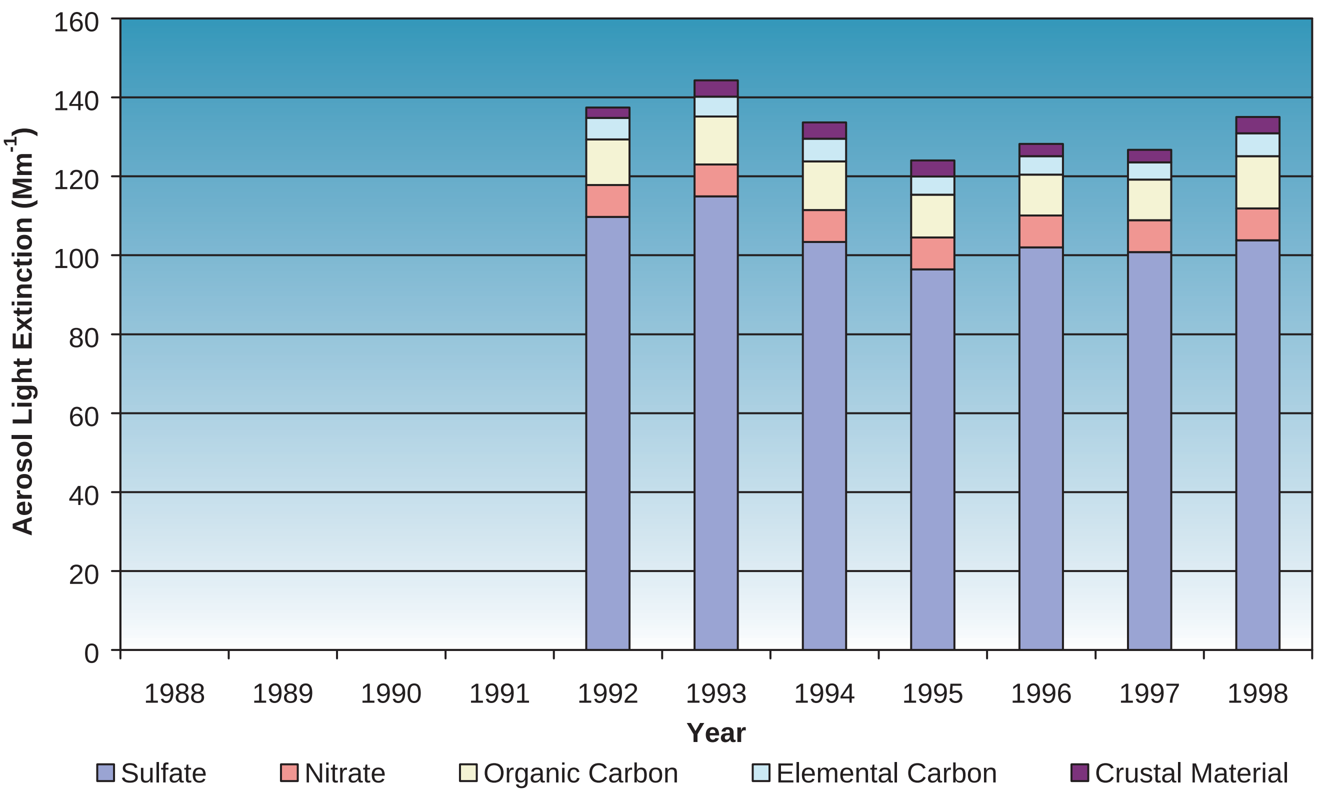

Figure KY–6. Contributions to Calculated Annual Aerosol Light Extinction from 1992–1998 for the Mammoth Cave IMPROVE Particulate Sampler

10. MAINE

The only IMPROVE particulate sampler in Maine that operated continuously from 1994 through 1998 was the one located in Acadia National Park. Figure ME–1 shows the Acadia particulate sampler location (44.37°N, 68.26°W, elevation 400 feet) near the Maine coast. The Moosehorn Wilderness Area is an additional Class I area covered by the Regional Haze Rule, but its IMPROVE monitor did not begin operation until July 1994. Since the Moosehorn sampler did not have five continuous years of data from 1994 to 1998, it was not included in this report. Roosevelt Campobello International Park is another mandatory Federal Class I area located just outside Maine in New Brunswick, Canada, but it does not have an operating IMPROVE particulate sampler.

Figure ME–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in Maine

Acadia National Park

The Acadia IMPROVE particulate sampler started reporting in March of 1988. Figure ME–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most-impaired days varied from 23 to 27 deciviews (VR from 24 to 16 miles), but there was no statistically significant trend. The visibility indices on the mid-range days improved from 17 to 15 deciviews (VR from 45 to 55 miles), and the indices on the least-impaired days improved from 12 to 10 deciviews (VR from 76 to 90 miles). The visibility trends were statistically significant improvements for the mid-range and least-impaired days over the time period examined.

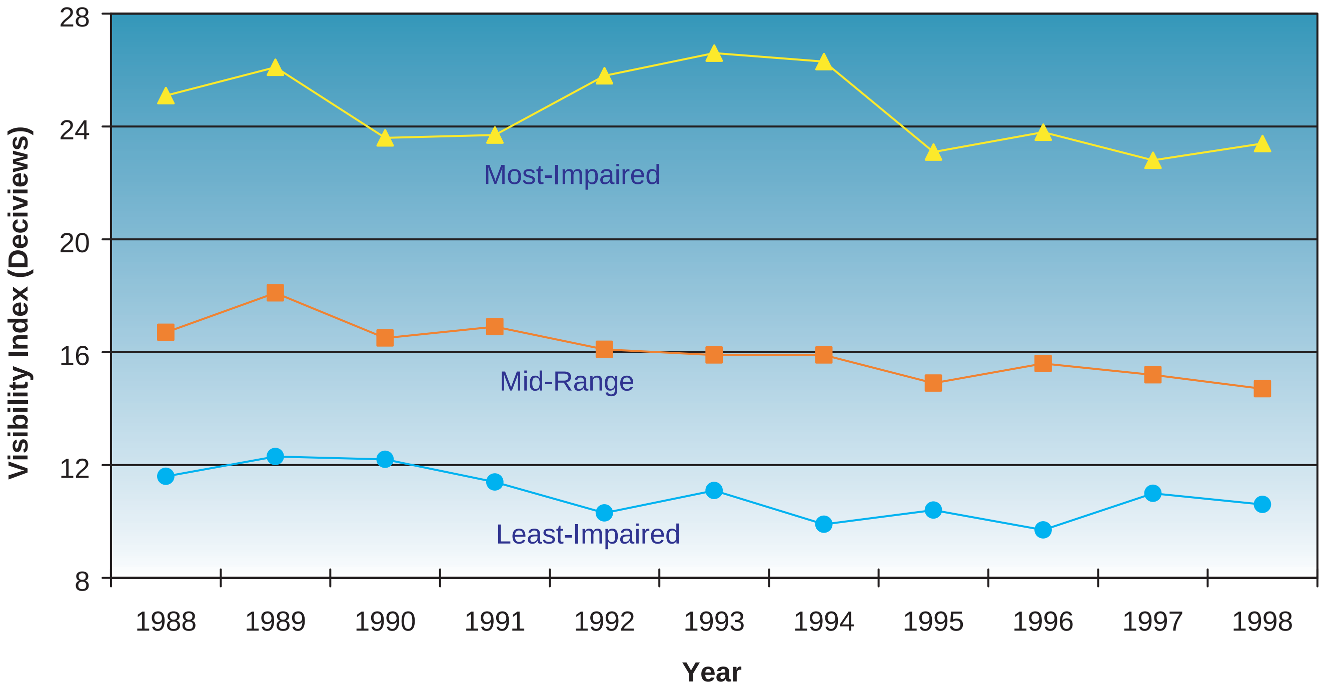

Figure ME–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Acadia IMPROVE Particulate Sampler

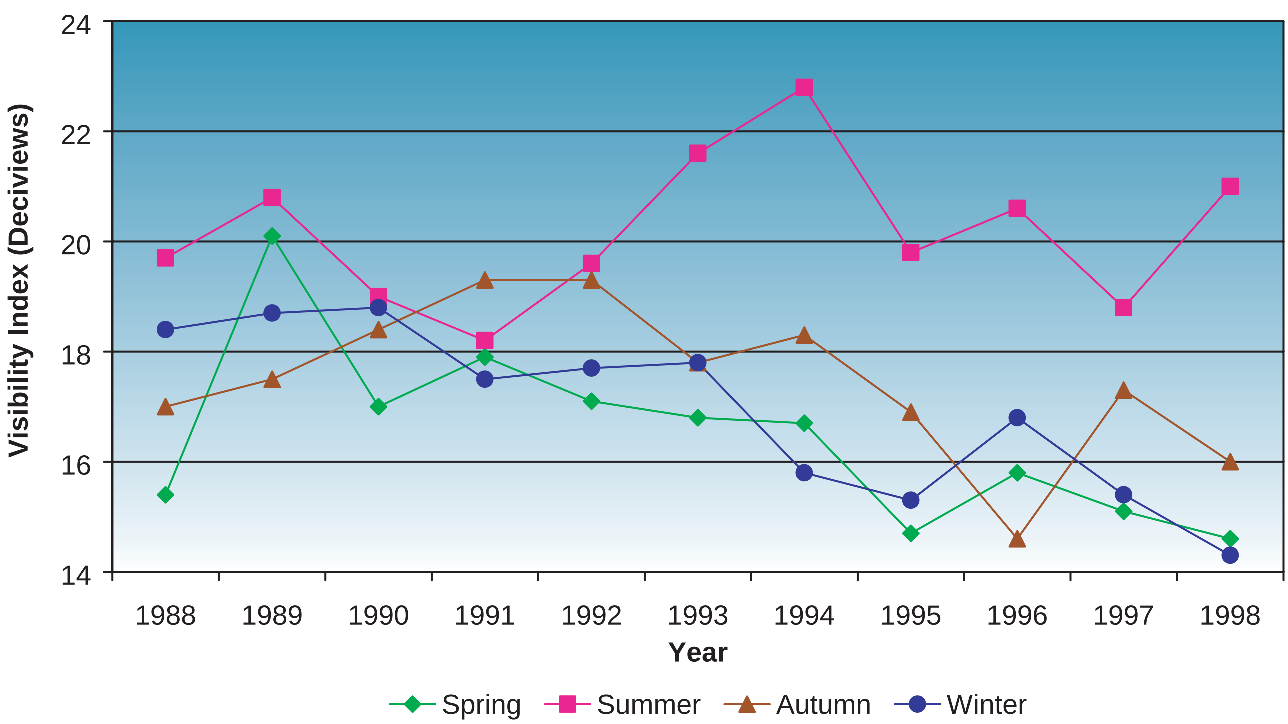

Figure ME–3. Seasonal Deciview Averages from 1988–1998 for the Acadia IMPROVE Particulate Sampler

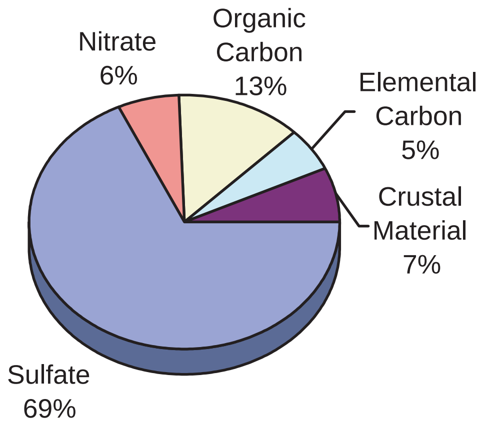

Figure ME–4. Contribution to Calculated Annual Aerosol Light Extinction Averaged from 1994–1998 for the Acadia IMPROVE Particulate Sampler

Figure ME–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. After 1992, the visibility indices for summer were at least 2 deciviews higher than those during the other three seasons. The visibility indices for summer and autumn showed no significant trend over the eleven-year period, but the indices for winter and spring showed significant trends toward increased visibility (with decreases of 4 and 3 deciviews over the eleven-year period for the winter and spring seasons).

Figure ME–4 presents a chart showing the calculated fractional contribution to Acadia's light extinction by each aerosol species on an annual basis. Figure ME–5 shows the same information for four seasons. These five pie charts show that sulfate particles were responsible for 65 to 70 percent of the light

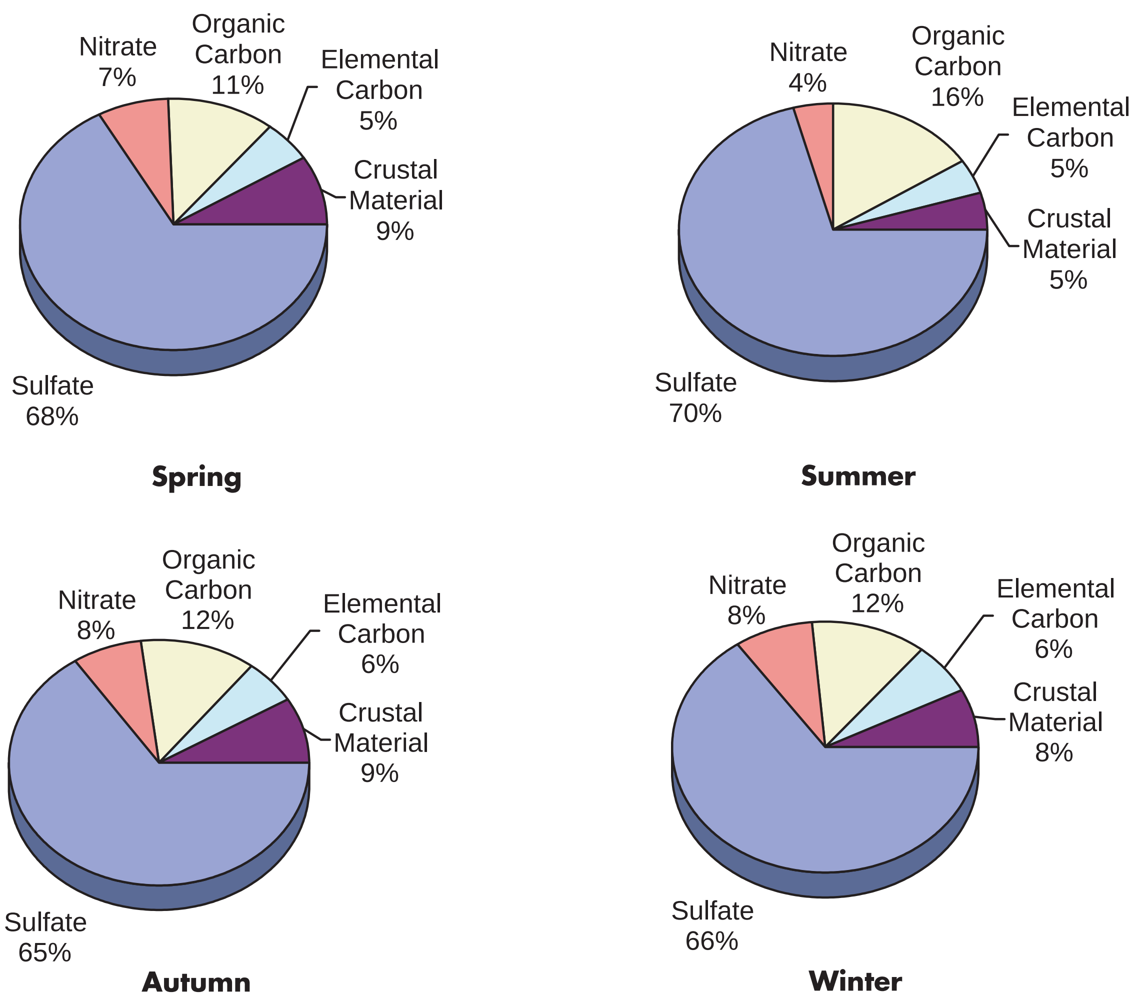

Figure ME–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Acadia IMPROVE Particulate Sampler

extinction at the Acadia site, averaging 69 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the summer the lowest in the autumn and winter. The contributions from nitrate ranged from 4 to 8 percent during the four seasons. Organic carbon percentages varied from 11 to 16 percent for the seasons. Elemental carbon and crustal material measured at the Acadia site were responsible for approximately 5 and 7 percent of the calculated aerosol light extinction year-round.

Figure ME–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Acadia site from 1988 to 1998. During the first seven years and the last four years, the aerosol light extinctions averaged 54 and 45 Mm^{-1} , but no statistically significant trend was observed by the Thiel test method. The large drop occurred between 1994 and 1995 and can be attributed to the decrease in sulfate contributions during the same time frame. Phase I of the EPA Acid Rain Program was instituted in 1995 and targeted emission reductions of sulfate particle precursors. The organic and elemental contributions indicated a significant trend toward improved visibility. However, no significant trends were noted in the annual light extinctions calculated for sulfates or crustal material.

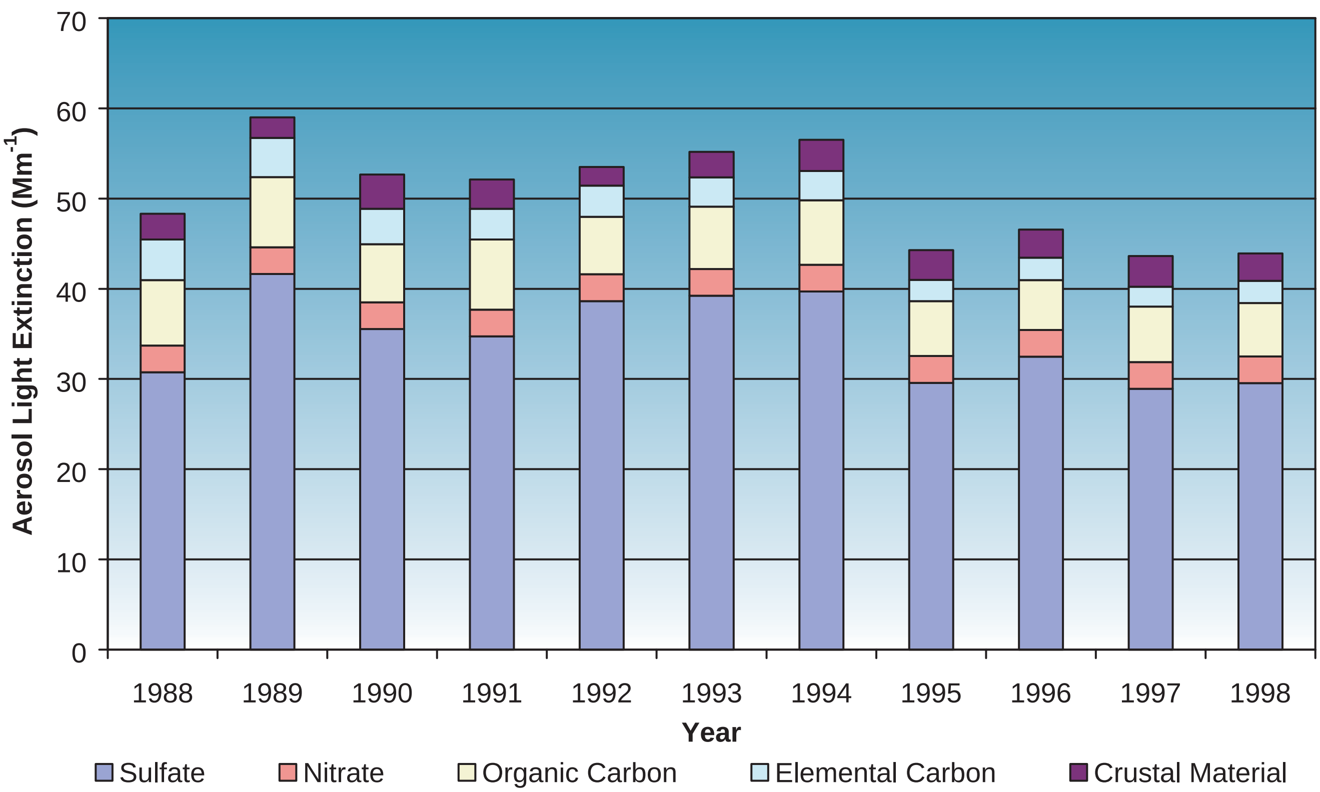

Figure ME–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Acadia IMPROVE Particulate Sampler

11. MINNESOTA

The only IMPROVE particulate sampler in Minnesota that operated continuously from 1994 through 1998 was the one located in the Boundary Waters Canoe Area. Figure MN–1 shows the Boundary Waters particulate sampler location (47.95°N, 91.95°W, elevation 1700 feet) near the Canadian border. Voyageurs National Park is an additional Class I area covered by the Regional Haze Rule, but the IMPROVE particualte sampler at this location stopped collecting data in August 1993. Therefore, only data from the Boundary Waters Canoe Area monitor is included in this report.

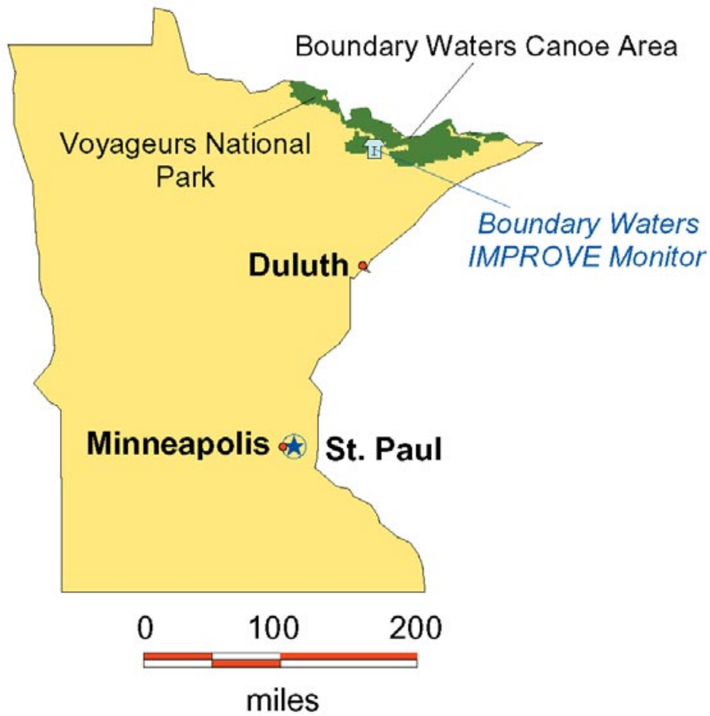

Figure MN–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in Minnesota

Boundary Waters Canoe Area

The Boundary Waters IMPROVE particulate sampler started reporting in August of 1991. Figure MN–2 presents the calculated visibility indices for selected data sets from 1992 through 1998. The figure shows that the visibility index for the most-impaired days remained near 21 deciviews (VR 30 miles). The visibility indices on the mid-range days remained near 13 deciviews (VR 65 miles), and the indices on the least-impaired days stayed close to 8 deciviews (VR 110 miles). The visibility indices for the most-impaired, mid-range, and least-impaired days showed no statistically significant trends over the time period examined.

Figure MN–3 shows the seasonal averages for the calculated visibility index from 1992 through 1998. A summary value for summer 1996 was not reported because carbon measurements were not col-

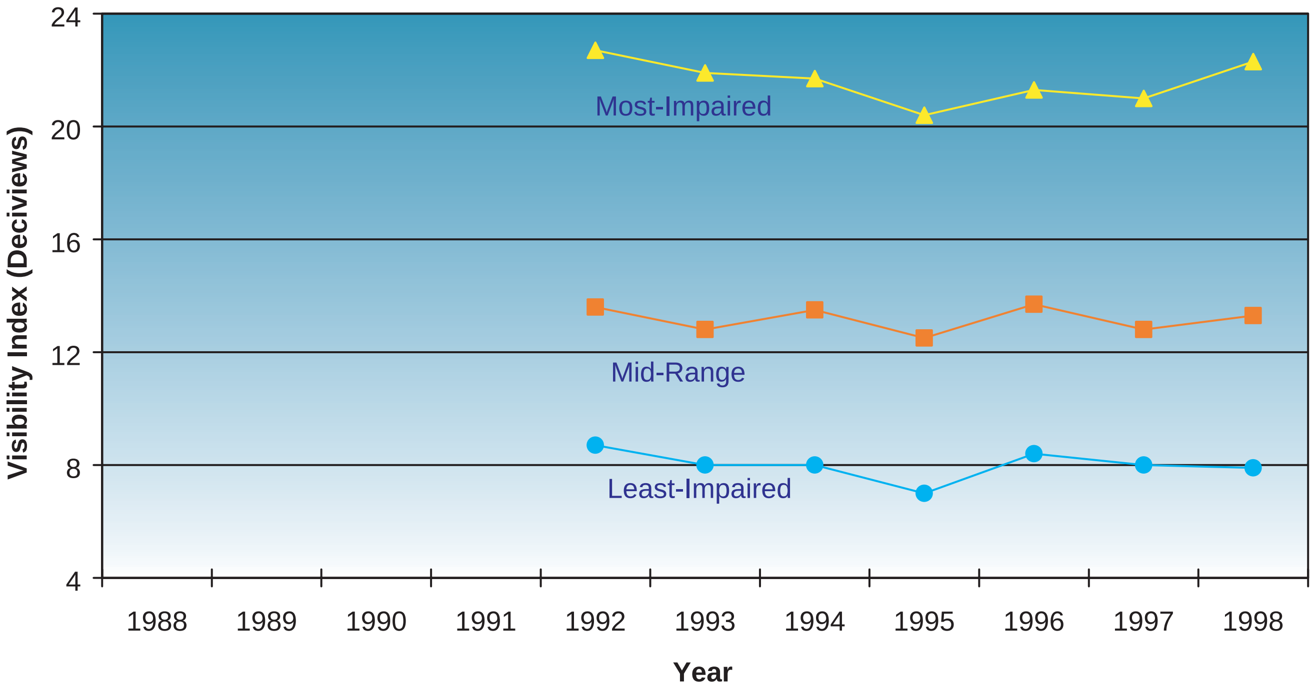

Figure MN–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1992–1998 for the Boundary Waters IMPROVE Particulate Sampler

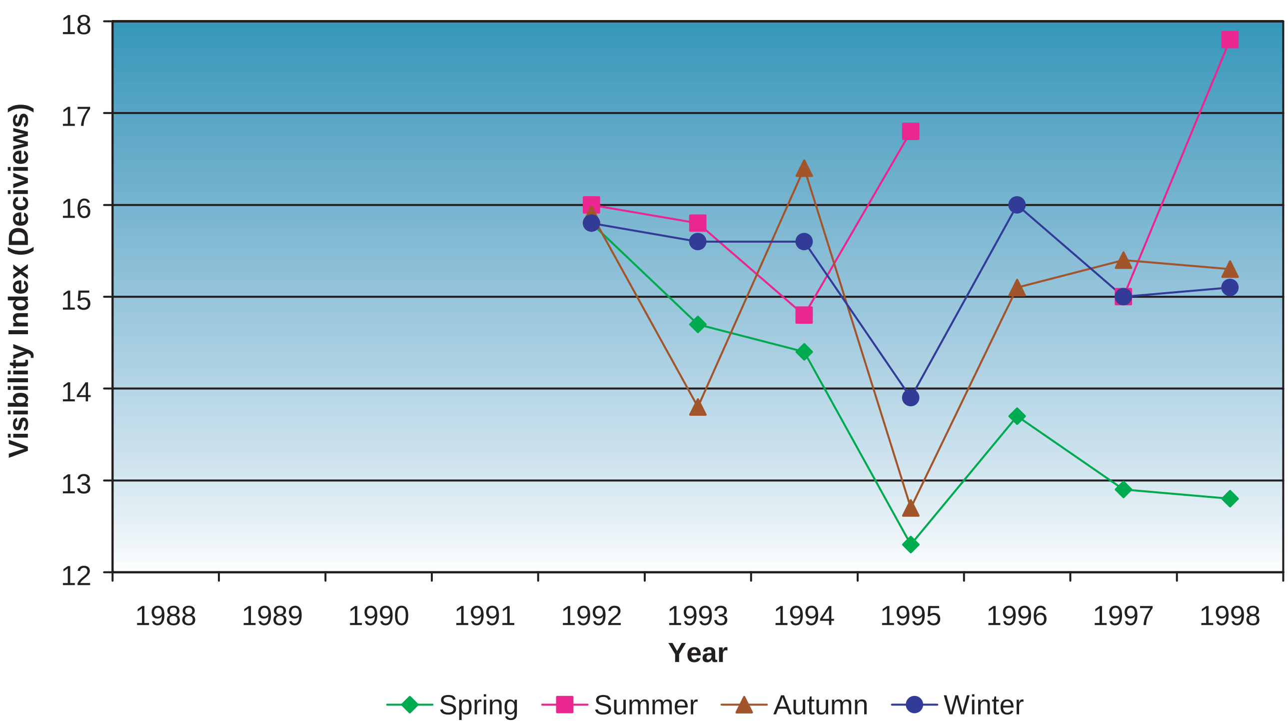

Figure MN–3. Seasonal Deciview Averages from 1992–1998 for the Boundary Waters IMPROVE Particulate Sampler

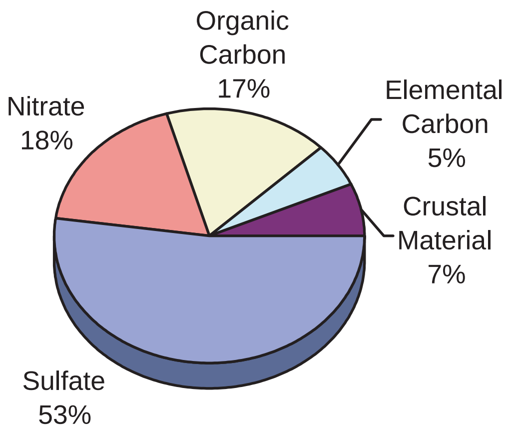

Figure MN–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Boundary Waters IMPROVE Particulate Sampler

lected. This is reflected in Figure MN–3. Interested readers can view the data for other species at http://improve.cnl.ucdavis.edu/cgi-bin/SSDisplay.cgi. All four seasons showed similar visibility indices through 1994, but the spring indices dropped considerably in later years. The statistically significant decrease in spring indices corresponds to a drop in spring sulfate concentrations and may be correlated to Phase 1 of the EPA's Acid Rain Program. The other seasonal visibility indices showed no statistically significant trends over the seven-year period.

Figure MN–4 presents a chart showing the calculated fractional contribution to Boundary Water's light extinction that each aerosol species is calculated to contribute on an annual basis. Figure MN–5 shows the

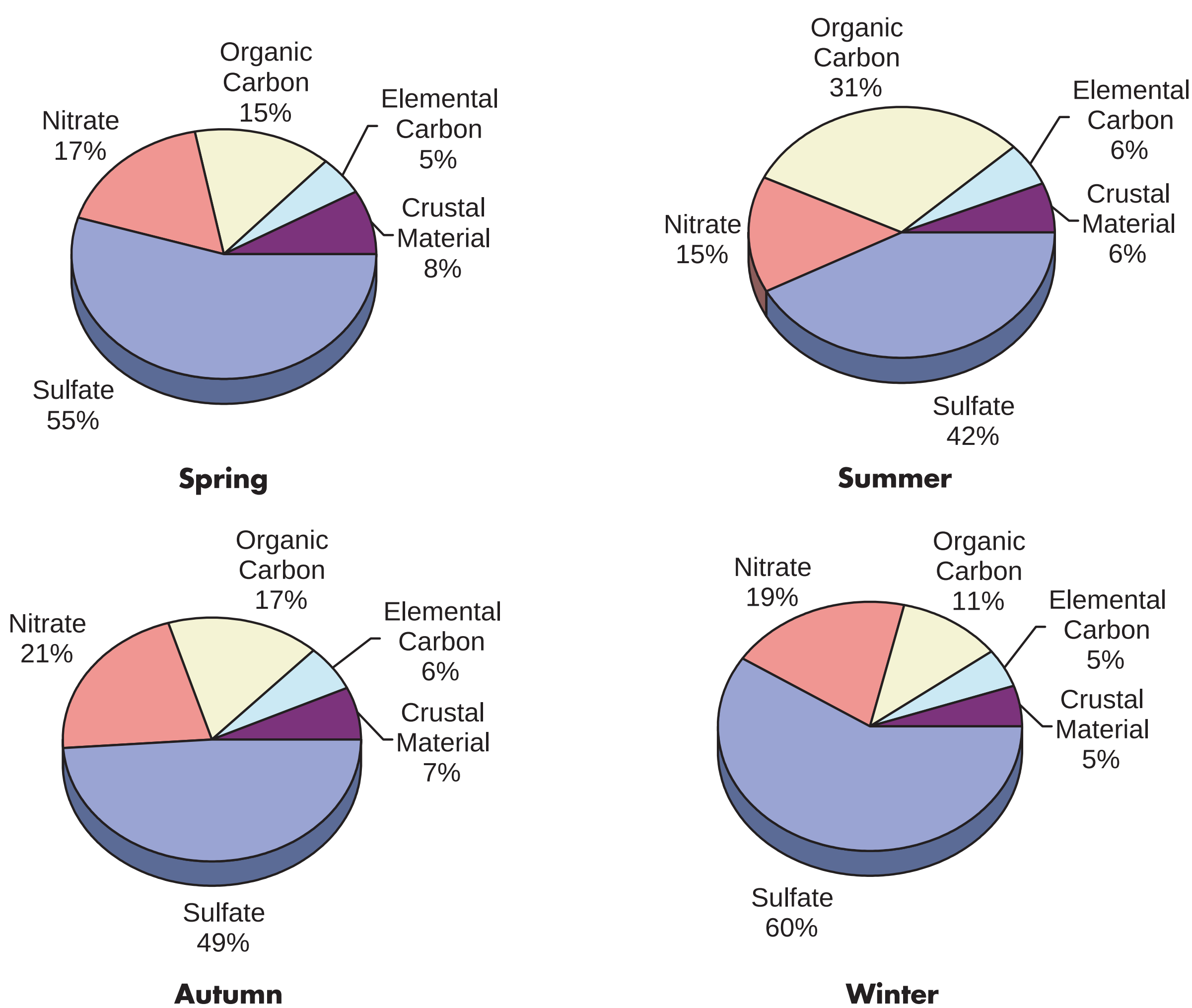

Figure MN–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Boundary Waters IMPROVE Particulate Sampler

same information for the four seasons. These five pie charts show that sulfate particles were responsible for 42 to 60 percent of the light extinction at the Boundary Waters site, averaging 53 percent on an annual basis over a five-year period. The highest sulfate contributions occurred in the winter, and the lowest in the summer. The contributions from nitrate ranged from 15 to 21 percent during the four seasons, with winter showing the highest values. Organic carbon percentages varied from 11 to 31 percent for the seasons, with the summer percent contributions being double those during other seasons. Elemental carbon and crustal material measured at the Boundary Waters site were responsible for approximately 5 and 7 percent of the calculated aerosol light extinction year-round.

Figure MN–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Boundary Waters site from 1992 to 1998. Over the seven-year period, the total annual aerosol light extinctions ranged from 30 to 40 $Mm^{-1.}$ No statistically significant trends indicated long-term changes in visibility. Also, no significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, elemental carbon, or crustal material. Since the Boundary Waters site collected only about one half of the scheduled measurements during summer 1995, summer 1996, autumn 1998, and winter 1998, the reader should be cautioned that the annual values reported in Figure MN–6 may not be representative of the true annual averages.

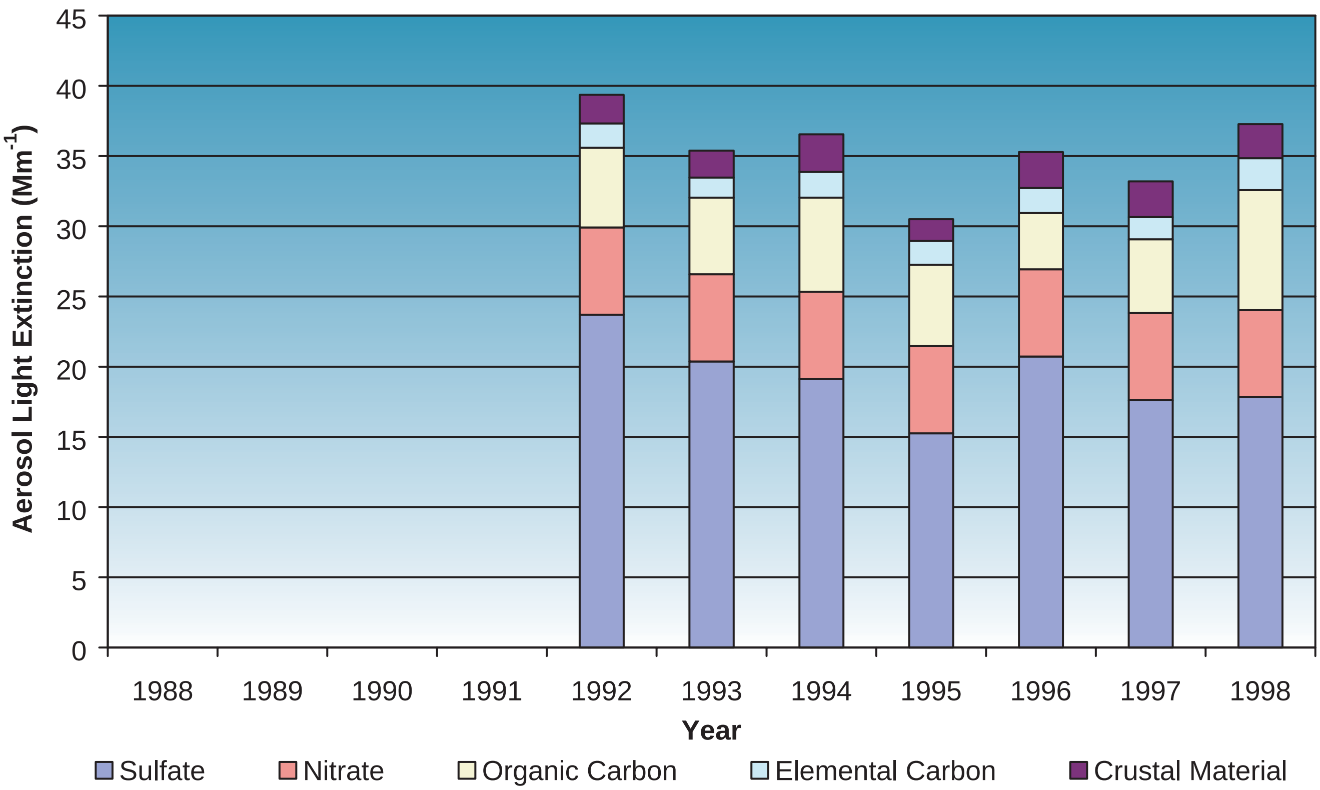

Figure MN–6. Contributions to Calculated Annual Aerosol Light Extinction from 1992–1998 for the Boundary Waters IMPROVE Particulate Sampler

12. MONTANA

The only IMPROVE particulate sampler site in Montana that operated continuously from 1994 through 1998 was the one located in Glacier National Park. Figure MT–1 shows the Glacier Park particulate sampler location (48.51°N, 113.99°W, elevation 4500 feet) near the Canadian border. Sula Peak (near the Selway-Bitterroot Wilderness Area) began operation of an IMPROVE particulate sampler in August 1994 and therefore did not have five complete years of data collected for this report. Additional mandatory Federal Class I areas include Cabinet Mountains Wilderness, Bob Marshall Wilderness, Scapegoat Wilderness, U.L. Bend Wilderness, Medicine Lake Wilderness, Gates of the Mountains Wilderness, Anaconda-Pintlar Wilderness, and Red Rock Lakes Wilderness, but IMPROVE particulate samplers have not been established at these sites. The northeastern border of the Selway-Bitterroot Wilderness is located in Montana, and the western and northern borders of Yellowstone National Park are located in Montana. The Flathead Fort Peak and Northern Cheyenne Tribal Governments have redesignated their lands as Class I, but these areas are not covered by the Regional Haze Rule.

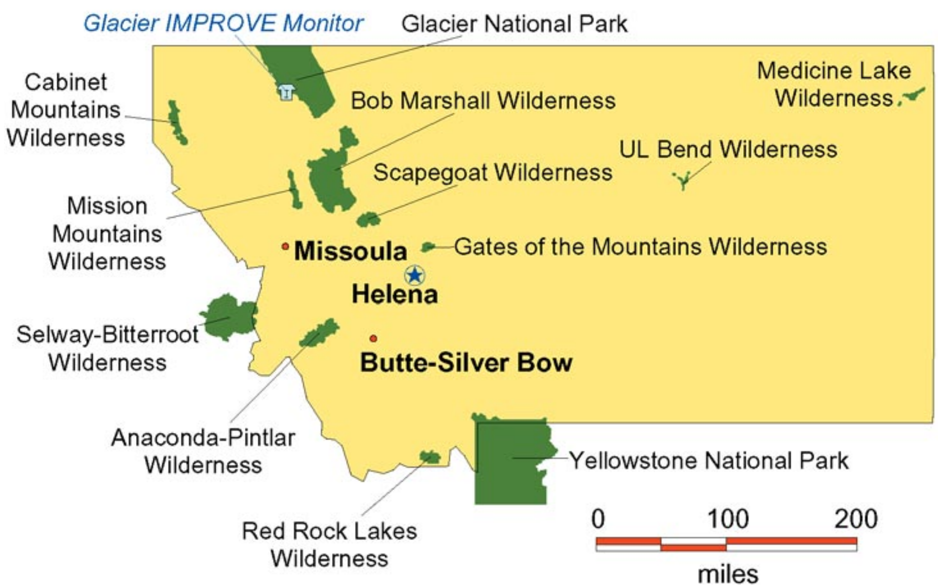

Figure MT–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in Montana

Glacier National Park

The Glacier IMPROVE particulate sampler started reporting in March of 1988. Figure MT–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most-impaired days remained near 19 deciviews (VR 36 miles). No statistically significant trend in visibility occurred. Similarly, statistical analysis indicated no significant trend when examining the visibility indices on the mid-range days; the index values remained near 14 deciviews (VR 60 miles). The indices on the least-impaired days remained near 9 deciviews (VR 100 miles) and showed no significant trend in visibility.

Figure MT–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The visibility indices for all four seasons generally covered the same range of values. The visibil-

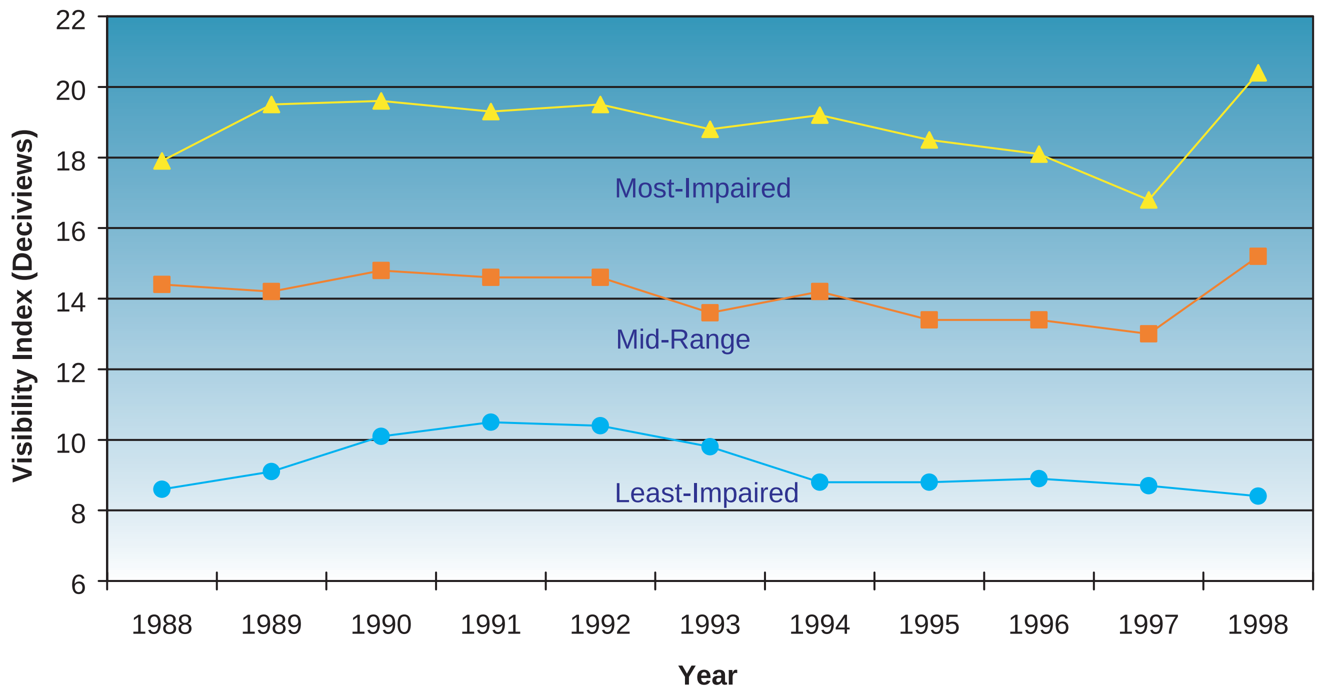

Figure MT–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Glacier IMPROVE Particulate Sampler

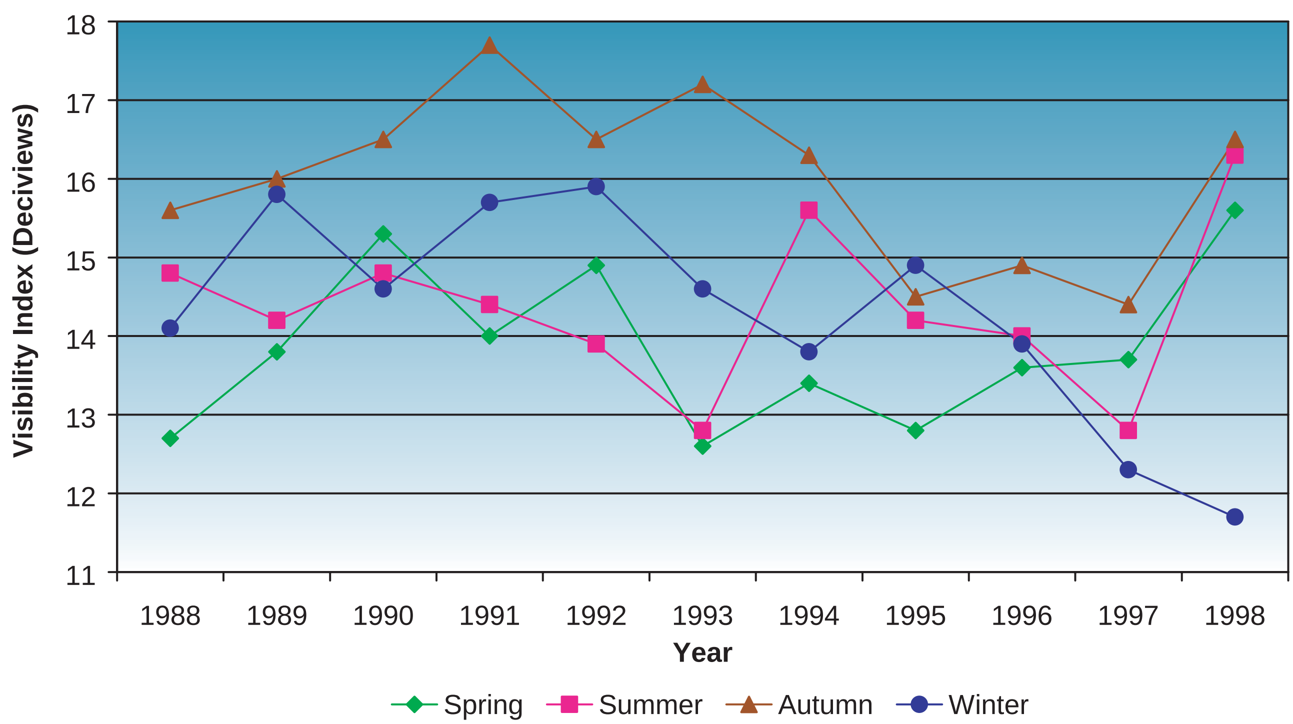

Figure MT–3. Seasonal Deciview Averages from 1988–1998 for the Glacier IMPROVE Particulate Sampler

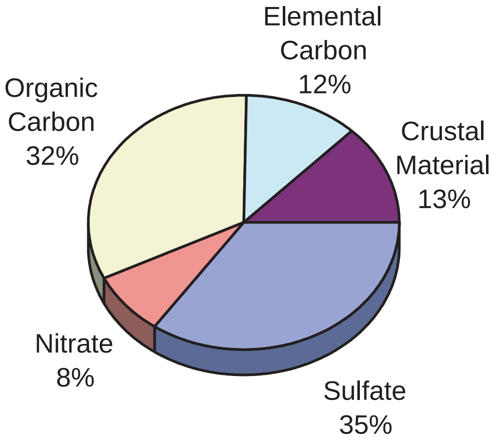

Figure MT–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Glacier IMPROVE Particulate Sampler

ity indices for winter showed a statistically significant trend, indicating an improvement in winter visibility at the Glacier Park site. The seasonal visibility indices for the other seasons showed no statistically significant trends over the eleven-year period. The spring, summer, and autumn seasons all showed sharp increases in the visibility indices in 1998 (marked by a fifty percent increase in organic carbon concentrations from 1997 to 1998), but no statistically significant trends were observed even when the 1998 values were ignored

Figure MT–4 presents a chart showing the calculated fractional contribution to Glacier Park's light extinction by each aerosol species on an annual basis. Figure MT–5 shows the same information for the four seasons. These five pie charts show the two largest contributors to light extinction were sulfate particles and organic carbon. The sulfate particles were responsible for 29 to 43

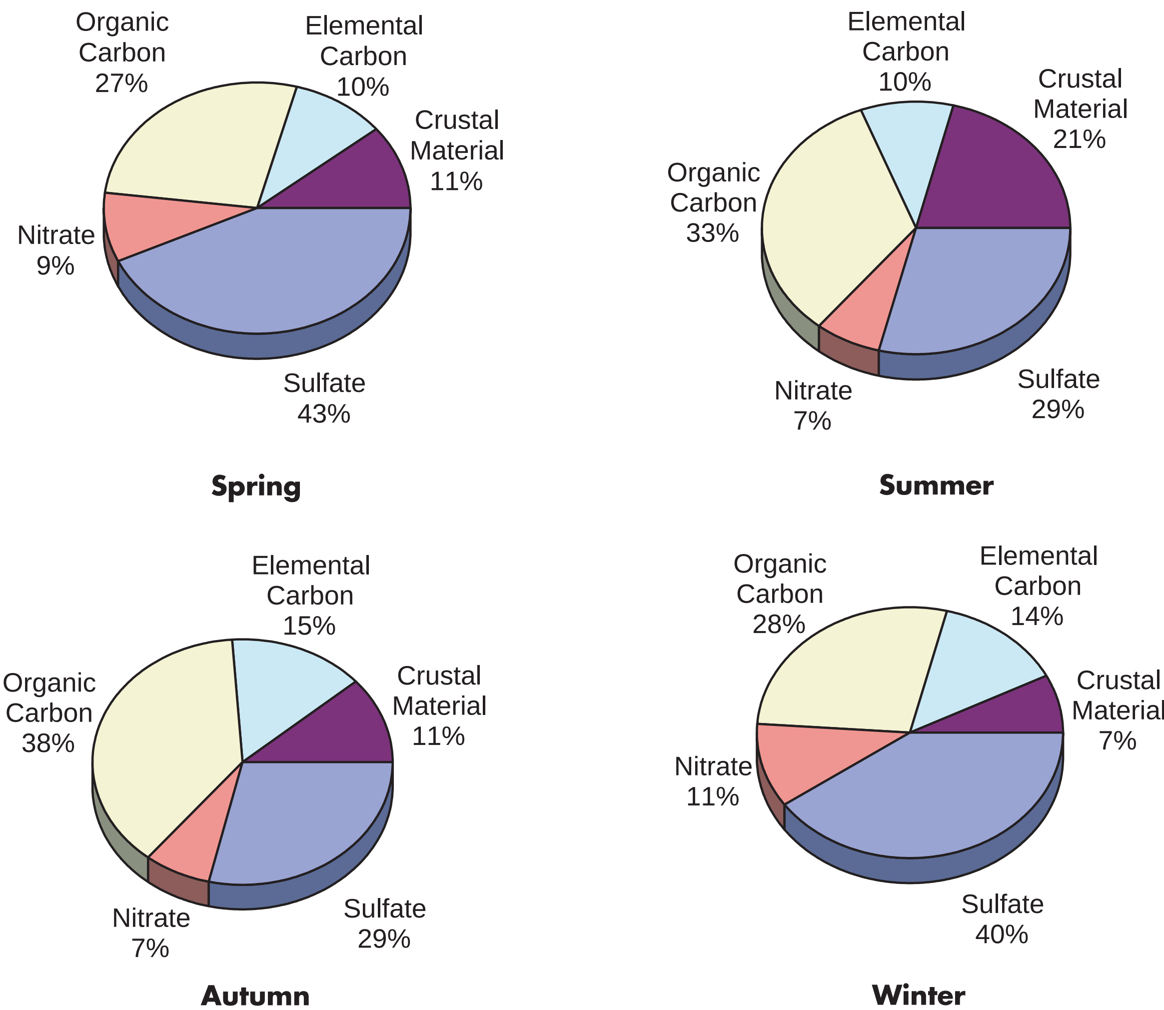

Figure MT–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Glacier IMPROVE Particulate Sampler

percent of the light extinction at the Glacier Park site, averaging 35 percent on an annual basis over a five-year period. The highest sulfate contributions occured in the spring, and the lowest in the summer and autumn. Organic carbon percentages varied from 27 to 38 percent for the seasons, with the autumn contributions 10 percent higher than winter and spring. The contributions from nitrate ranged from 7 to 11 percent during the four seasons, with winter showing the highest percentage. Elemental carbon measured at the Glacier Park site was responsible for approximately 12 percent of the calculated aerosol light extinction year-round. The percent contributions from crustal material ranged from 7 to 21 percent.

Figure MT–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Glacier Park site from 1988 to 1998. Over the eleven-year period, the total annual aerosol light extinctions ranged from 28 to 37 Mm^{-1} with no statistically significant trend toward improved visibility. No significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, elemental carbon, or crustal material. The abrupt increase in the light extinction coefficient from 1997 to 1998 was caused by marked jumps in the ambient organic carbon and crustal material concentrations during spring, summer, and autumn.

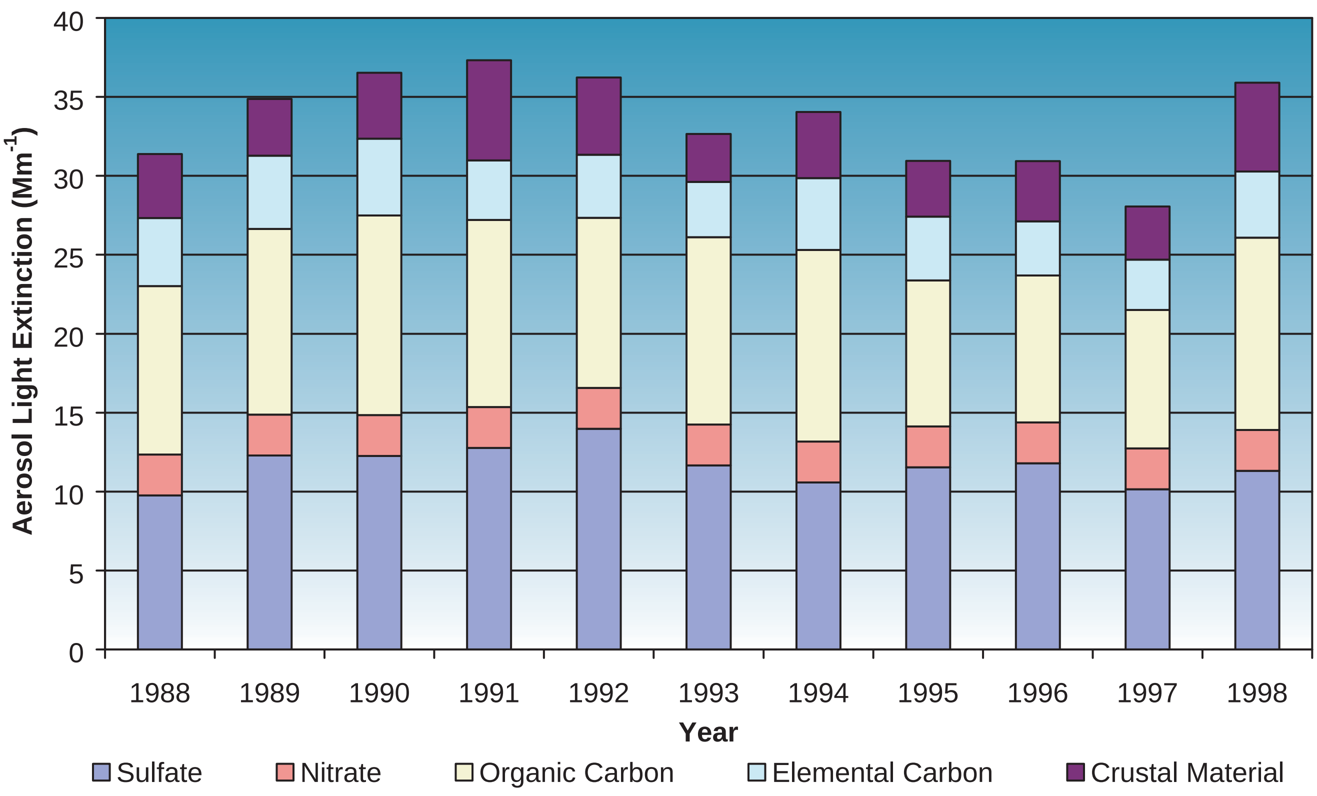

Figure MT–6. Contributions to Calculated Annual Aerosol Light Extinction From 1988–1998 for Glacier IMPROVE Particulate Sampler

13. NEVADA

An IMPROVE particulate sampler in Nevada's Jarbidge Wilderness Area operated continuously from 1988 through 1998. Figure NV–1 shows the Jarbidge monitoring location (41.89°N, 115.43°W, elevation 6300 feet) in northern Nevada. The Jarbidge Wilderness Area is Nevada's only mandatory Federal Class I area. An IMPROVE monitor (39.00°N, 114.22°W, elevation 6800 feet) operates in Great Basin National Park, but Great Basin is not a mandatory Federal Class I area. Therefore, the results from the Great Basin monitor site will not be detailed in this section. However, data from the Great Basin IMPROVE particulate sampler are included in the national and regional analyses discussed in Chapter 3.

Figure NV–1. Mandatory Federal Class I Area and IMPROVE Monitoring Sites in Nevada

Jarbidge Wilderness Area

The Jarbidge IMPROVE particulate sampler started reporting in March of 1988. Figure NV–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most-impaired days remained near 12 deciviews (VR 75 miles). There was no statistically significant trend in visibility. The visibility indices on the mid-range days remained near 7 deciviews (VR 120 miles), with no significant trend in visibility. The indices on the least-impaired days remained near 4 deciviews (VR 165 miles), with no significant trend in visibility. Jarbidge's annual visibility indices for the least-impaired days were among the lowest index sets calculated at IMPROVE stations across the United States. No data samples were collected between October 12, 1996 and April 30, 1997 (the time of year with the lowest readings), so the 1996 average visibility indices for the most-impaired, mid-range, and least-impaired days rose markedly.

Figure NV–3 shows the seasonal averages for the calculated visibility indices from 1988 through 1998. A summary value for winter 1996 was not reported because the site did not collect data between

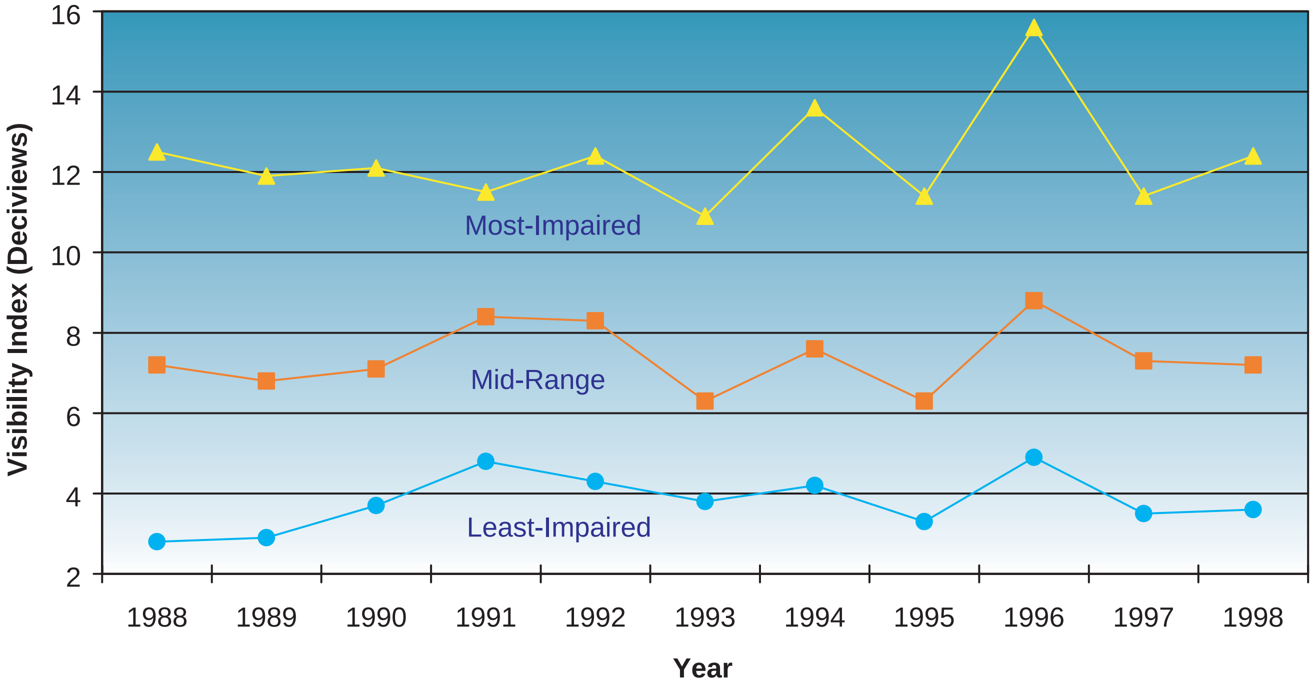

Figure NV–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Jarbidge IMPROVE Particulate Sampler

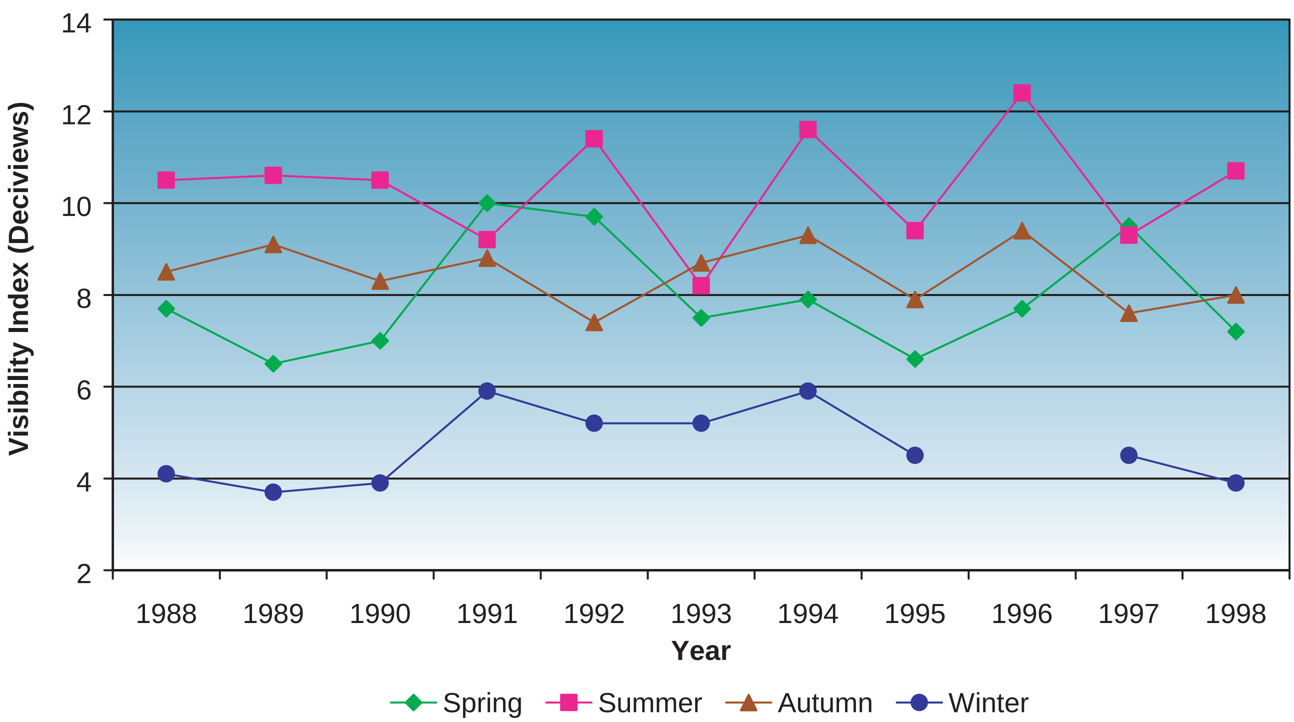

Figure NV–3. Seasonal Decivew Averages from 1988–1998 for the Jarbidge IMPROVE Particulate Sampler

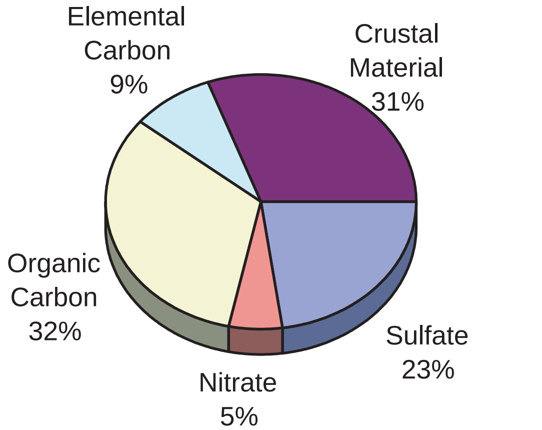

Figure NV–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Jarbidge IMPROVE Particulate Sampler

October 12, 1996 and April 30, 1997. This is reflected in Figure NV–3. The visibility indices for the winter season were generally at least 2 deciviews lower than those for the other three seasons (indicating better visibility during the winter). None of the seasonal visibility indices (spring, summer, autumn, and winter) showed statistically significant trends over the eleven year period.

Figure NV–4 presents a chart showing the calculated fractional contribution to Jarbidge's light extinction by each aerosol species on an annual basis. Figure NV–5 shows the same information for the four seasons. These five pie charts show that the three largest contributors to light extinction were sulfate particles, organic carbon, and crustal material. The sulfate particles were responsible for 18 to 33 percent of the light extinction at the

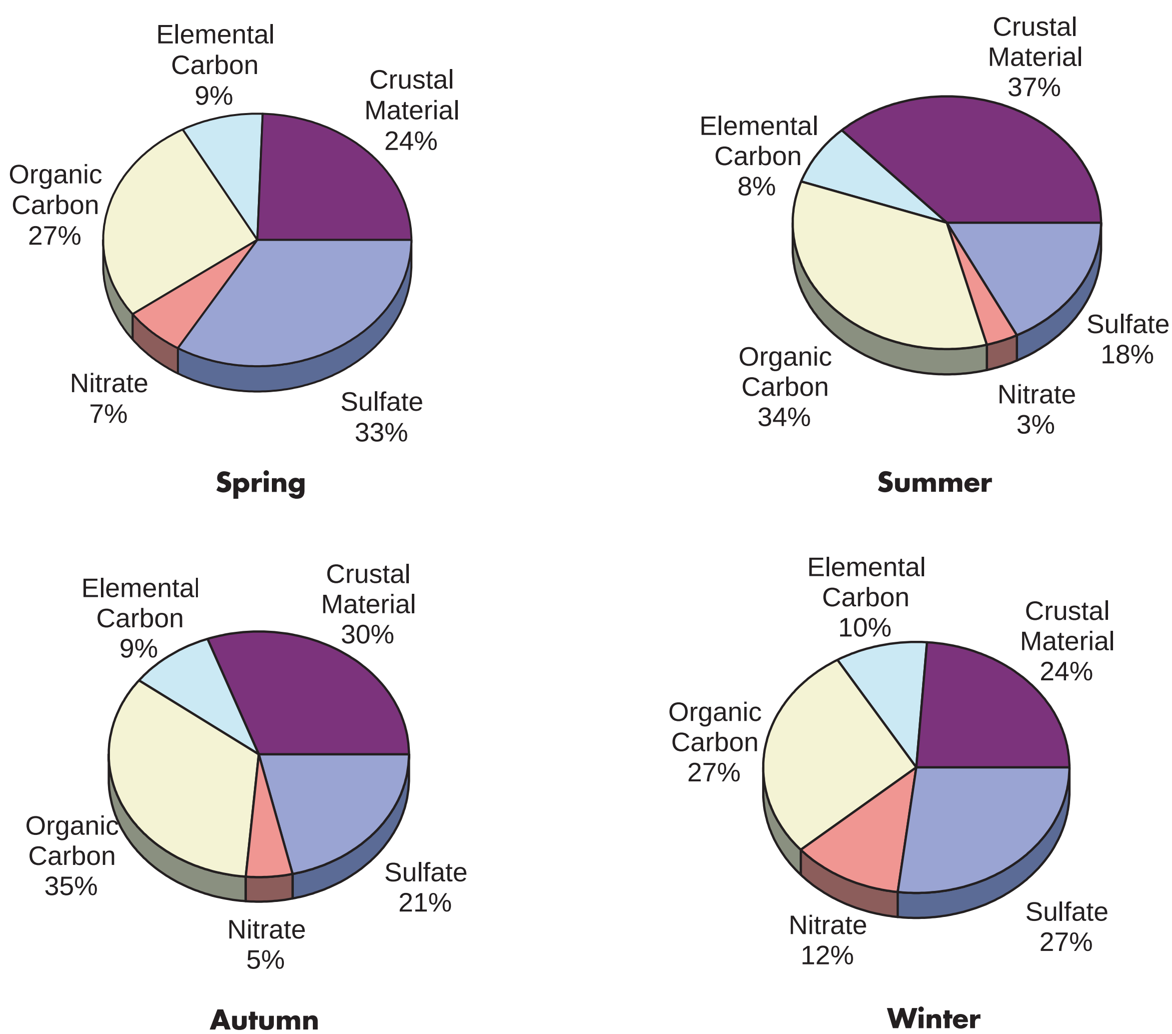

Figure NV–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Jarbidge IMPROVE Particulate Sampler

Jarbidge site, averaging 23 percent on an annual basis over a five-year period. Organic carbon percentages varied from 27 to 35 percent for the seasons, with summer and autumn percent contributions 8 percent higher than winter and spring. Crustal material represented between 24 and 37 percent of the calculated light extinction, with its highest contributions in the summer seasons. The contributions from nitrate ranged from 3 to 12 percent during the four seasons, with winter showing the highest percentages. Elemental carbon measured at the Jarbidge site was responsible for approximately 9 percent of the calculated aerosol light extinction year-round.

Figure NV–6 shows the calculated contributions of each of the aerosol mass components to the annual averaged aerosol light extinctions at the Jarbidge site from 1988 to 1998. Over the eleven-year period, the total annual aerosol light extinctions ranged from 11 to 14 Mm^{-1} (except for 1996 when more than four months of autumn and winter data were missing) with no statistically significant trend in visibility. No significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, or crustal material. However, the annual light extinctions for elemental carbon showed a statistically increasing trend over the eleven-year period, indicating an increase in the ambient concentrations of elemental carbon.

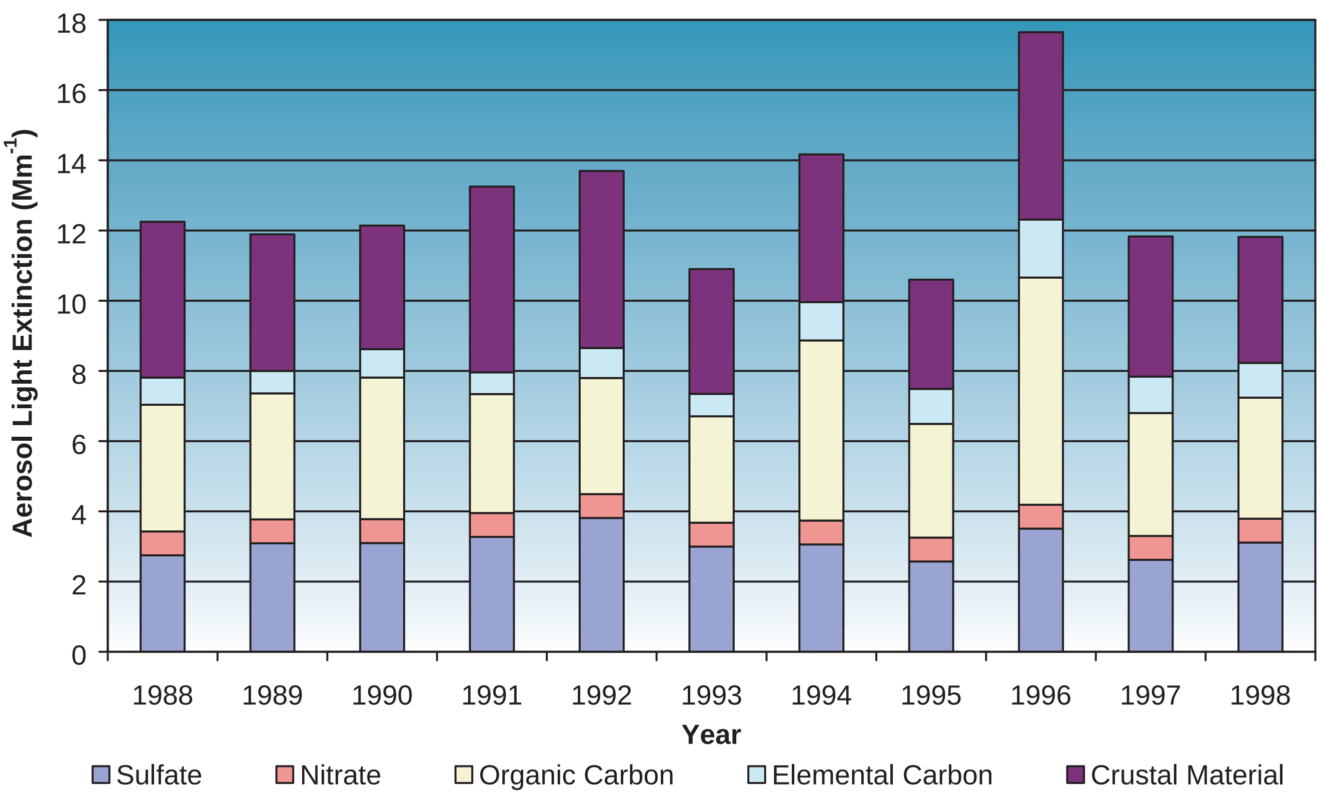

Figure NV–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Jarbidge IMPROVE Particulate Sampler

14. NEW JERSEY

The only IMPROVE particulate sampler site in New Jersey is near the Brigantine Wilderness, located within the Edwin B. Forsythe National Wildlife Refuge. Figure NJ–1 shows the Brigantine particulate sampler location (39.47°N, 74.45°W, elevation 50 feet) near the Atlantic Coast. The Brigantine Wilderness Area is New Jersey's only mandatory Federal Class I area covered under the Regional Haze Rule.

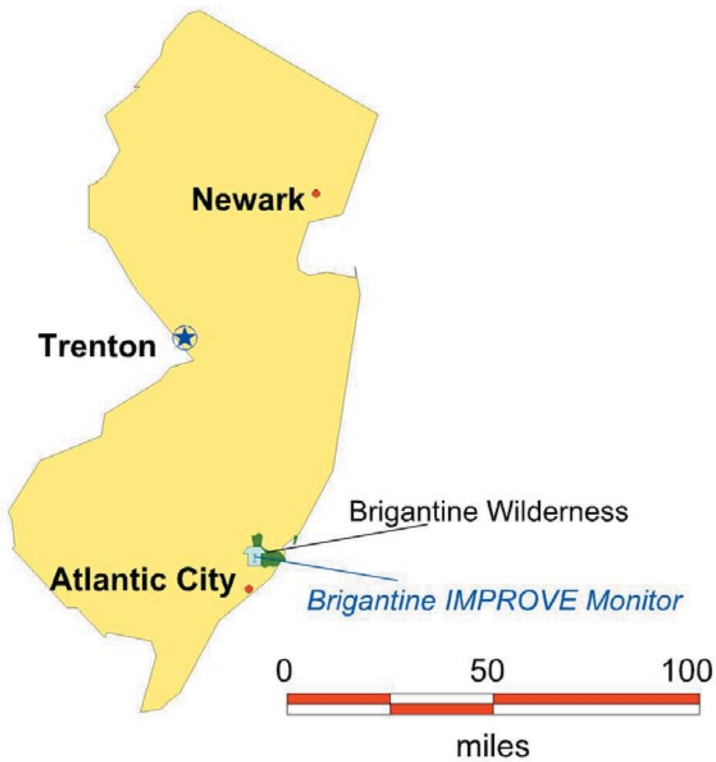

Figure NJ–1. Mandatory Federal Class I Area and IMPROVE Monitoring Site in New Jersey

Brigantine Wilderness Area, Edwin B. Forsythe National Wildlife Refuge

The Brigantine IMPROVE particulate sampler started collecting data in September of 1991. Figure NJ–2 presents the calculated visibility indices for selected data sets from 1992 through 1998. The figure shows that the visibility index for the most-impaired days remained near 30 deciviews (VR 12 miles). There was no statistically significant trend in visibility. The visibility indices on the mid-range days remained between 21 and 23 deciviews (VR from 30 to 24 miles), with no significant trend in visibility. The indices on the least-impaired days remained near 17 deciviews (VR 45 miles), with no significant trend in visibility.

Figure NJ–3 shows the seasonal averages for the calculated visibility index from 1992 through 1998. The visibility indices for the summer season were generally 3 deciviews higher than those for the spring season, and the spring values were 1 or 2 deciviews higher than autumn and winter. The seasonal visibility indices for spring, autumn, and winter showed no statistically significant trends over the

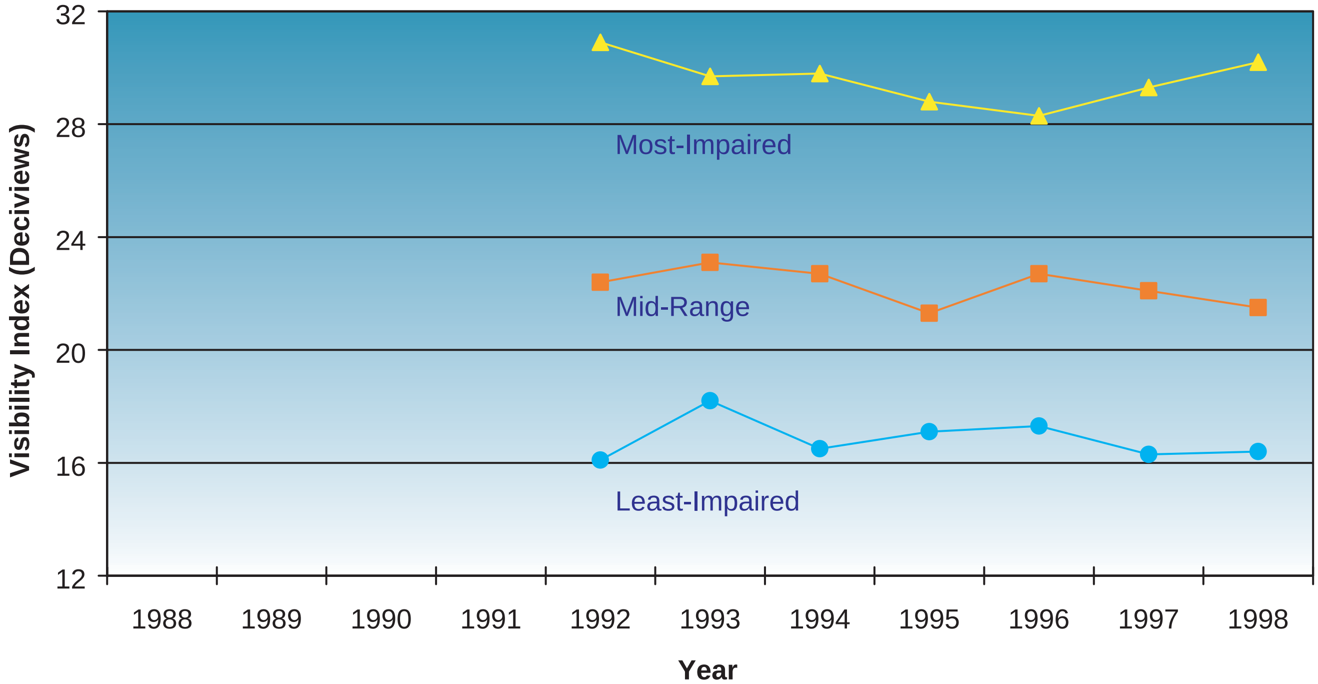

Figure NJ–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1992–1998 for the Brigantine IMPROVE Particulate Sampler

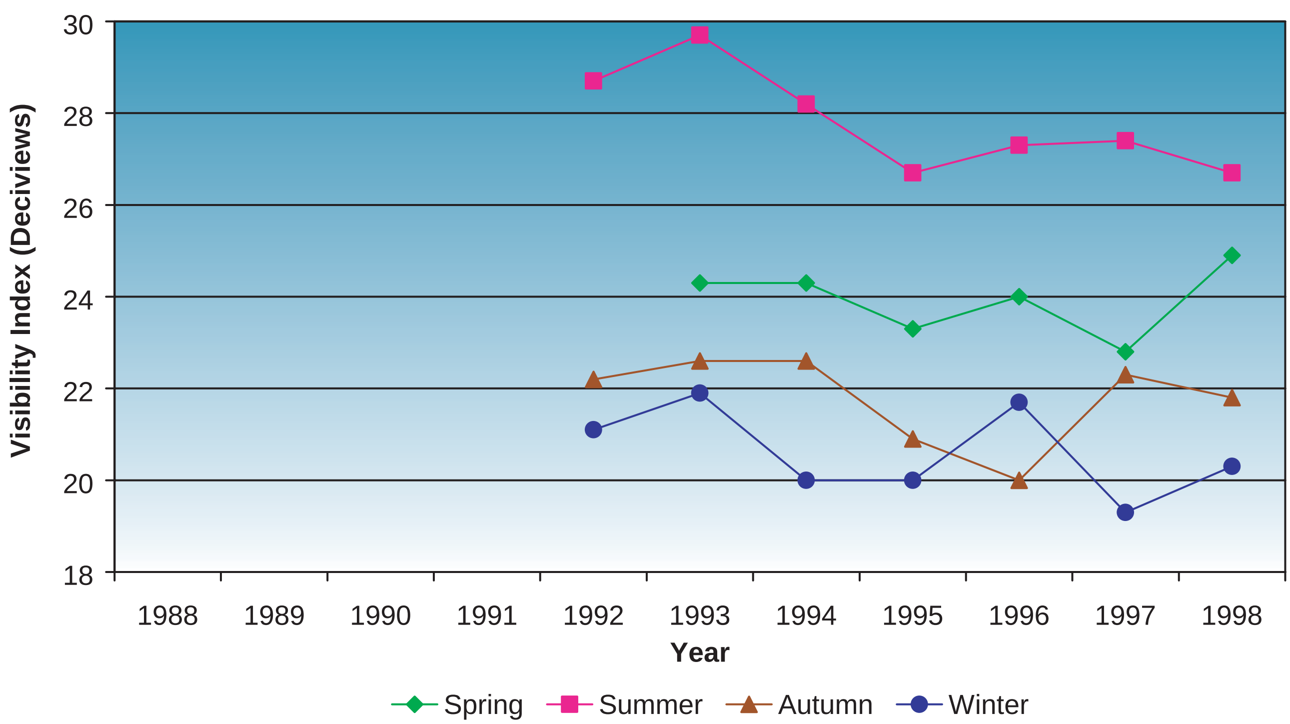

Figure NJ–3. Seasonal Deciview Averages from 1992–1998 for the Brigantine IMPROVE Particulate Sampler

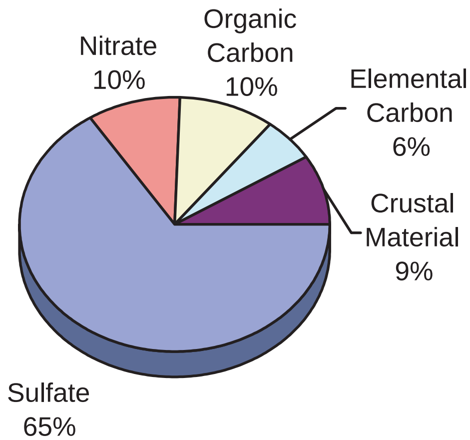

Figure NJ–4. Contribution to Calculated Annual Aerosol Light Extinction Averaged from 1994–1998 for the the Brigantine IMPROVE Particulate Sampler

seven-year period, but the summer indices dropped 2 deciviews with a statistically significant decrease.

Figure NJ–4 presents a chart showing the calculated fractional contribution to Brigantine's light extinction of each aerosol species on an annual basis. Figure NJ–5 shows the same information for the four seasons. These five pie charts show the largest contributors to light extinction were sulfate particles. The sulfate particles were responsible for 55 to 76 percent of the light extinction at the Brigantine site, averaging 65 percent on an annual basis over a five-year period. The contributions from sulfates were highest in the summer and lowest during the winter season. The contributions from nitrate ranged from 7 to 11 percent during the four seasons, with autumn and winter showing the highest percentages.

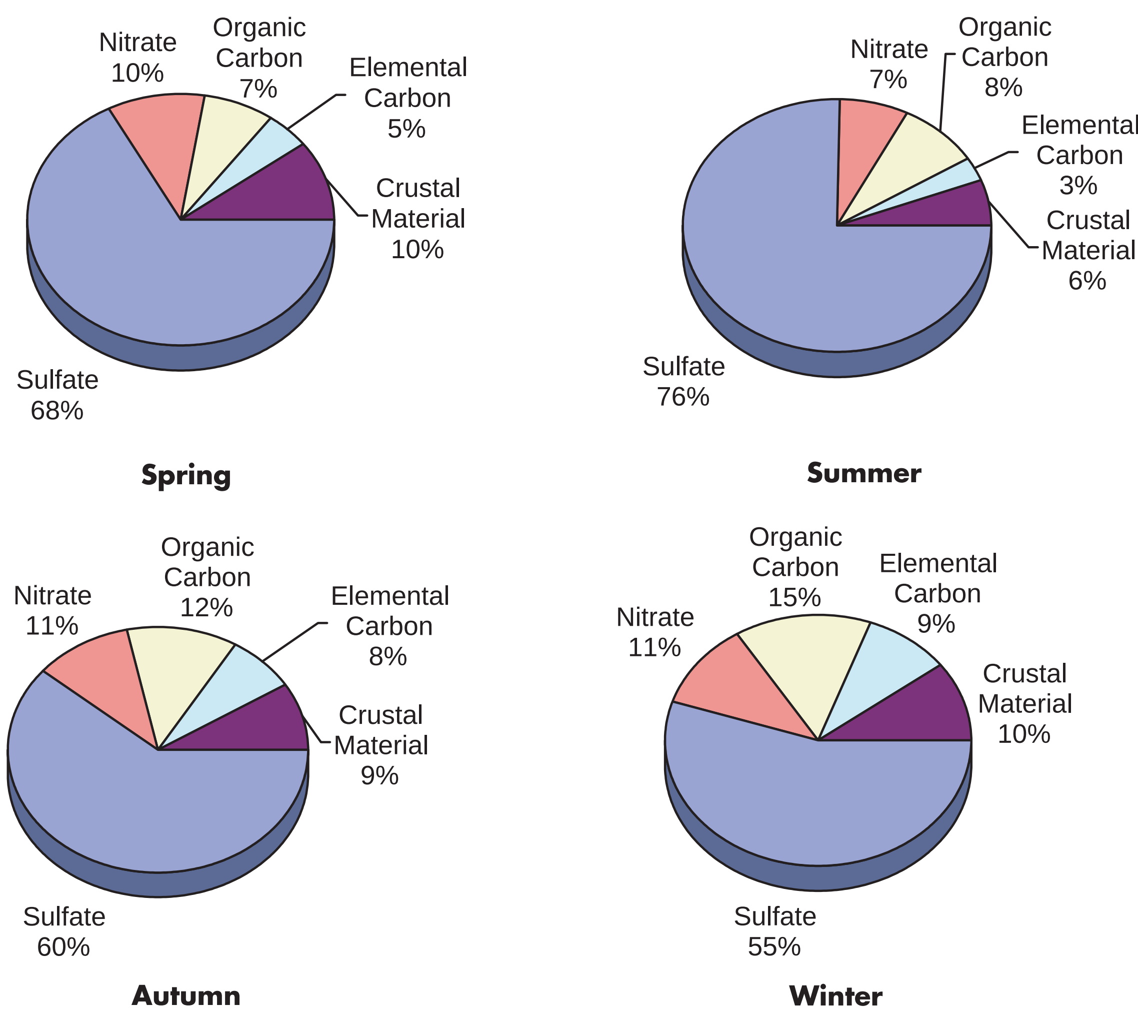

Figure NJ–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Brigantine IMPROVE Particulate Sampler

Organic carbon percentages remained between 7 and 15 percent for the seasons. Elemental carbon and crustal material measured at the Brigantine site were responsible for 6 and 9 percent of the calculated aerosol light extinction year-round.

Figure NJ–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Brigantine site from 1992 to 1998. Over the seven-year period, the total annual aerosol light extinctions ranged from 89 to 110 Mm^{-1} with no statistically significant trend in visibility. Similarly, no significant trends were noted in the annual light extinctions calculated for sulfates, organic carbon, or elemental carbon. The light extinction from sulfate aerosols dropped 16 percent between the first three and last four years, coinciding with the emission reductions of Phase I of the Acid Rain Program. However, the decrease was not statistically significant according to the Theil test method. The annual light extinctions for crustal material increased approximately 4 Mm^{-1} over the same period, a statistically significant trend indicating higher crustal material concentrations in the ambient air.

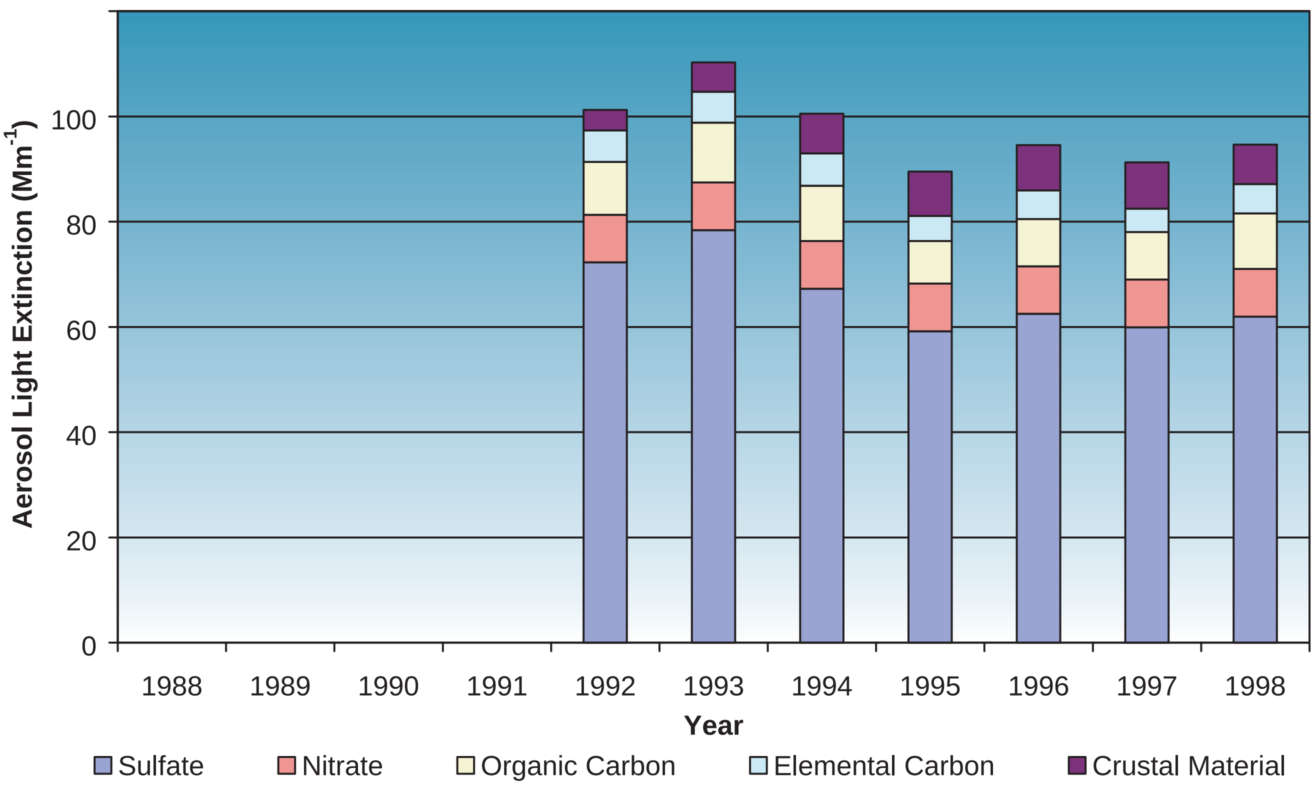

Figure NJ–6. Contributions to Calculated Annual Aerosol Light Extinction from 1992–1998 for the Brigantine IMPROVE Particulate Sampler

15. NEW MEXICO

Nine mandatory Federal Class I areas are located in New Mexico. The only IMPROVE particulate sampler in New Mexico that operated continuously from 1994 through 1998 is located at Bandelier Wilderness Area. Figure NM–1 shows the Bandelier particulate sampler location (35.79°N, 106.26°W, elevation 6500 feet) west of Santa Fe. Additional mandatory Federal Class I areas in New Mexico include Carlsbad Caverns National Park and the following wilderness areas: Wheeler Peak, San Pedro Parks, Pecos, Bosque del Apache, Gila, White Mountain, and Salt Creek. An IMPROVE particulate sampler in the Gila Cliff Dwellings National Monument near the Gila Wilderness Area began reporting data in June 1994, so five complete years of data were not available for its inclusion in this report. The other mandatory Federal Class I areas do not have IMPROVE monitoring data for the years prior to 1999.

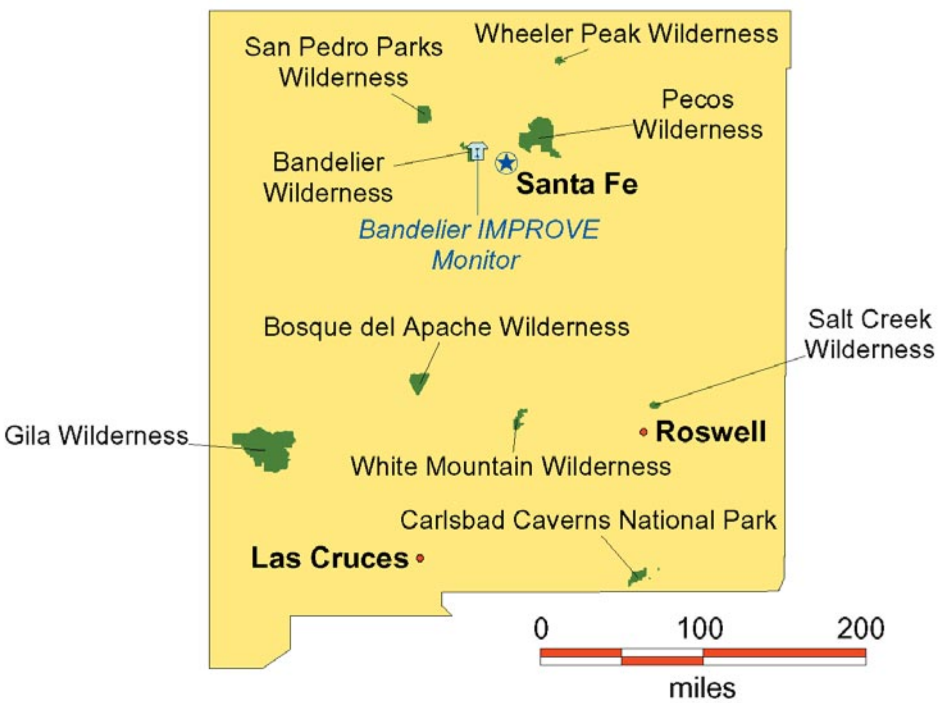

Figure NM–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in New Mexico

Bandelier Wilderness Area

The Bandelier IMPROVE particulate sampler started reporting in March of 1988. Figure NM–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most-impaired days remained between 10 and 14 deciviews (VR 90 to 60 miles). There was no statistically significant trend in visibility. However, the visibility indices on the mid-range days decreased from 10 to 9 deciviews (VR 90 to 100 miles), with a significant trend toward improved visibility. The indices on the least-impaired days remained near 7 deciviews (VR 120 miles), with no significant trend in the visibility indices. Readers may note that the 1990 most-impared average deciview index was lower than the mid-range index; this crossover occurred because the data were sorted based on mass, not based on visibility impairment.

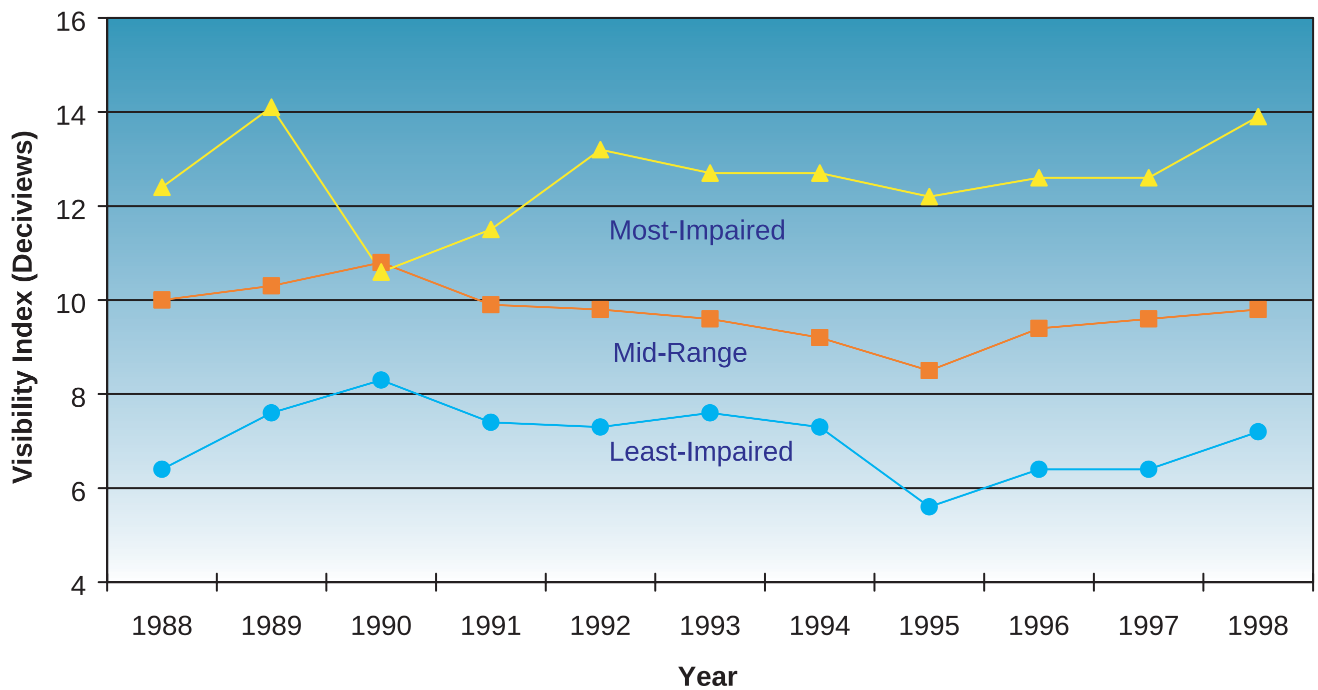

Figure NM–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Bandelier IMPROVE Particulate Sampler

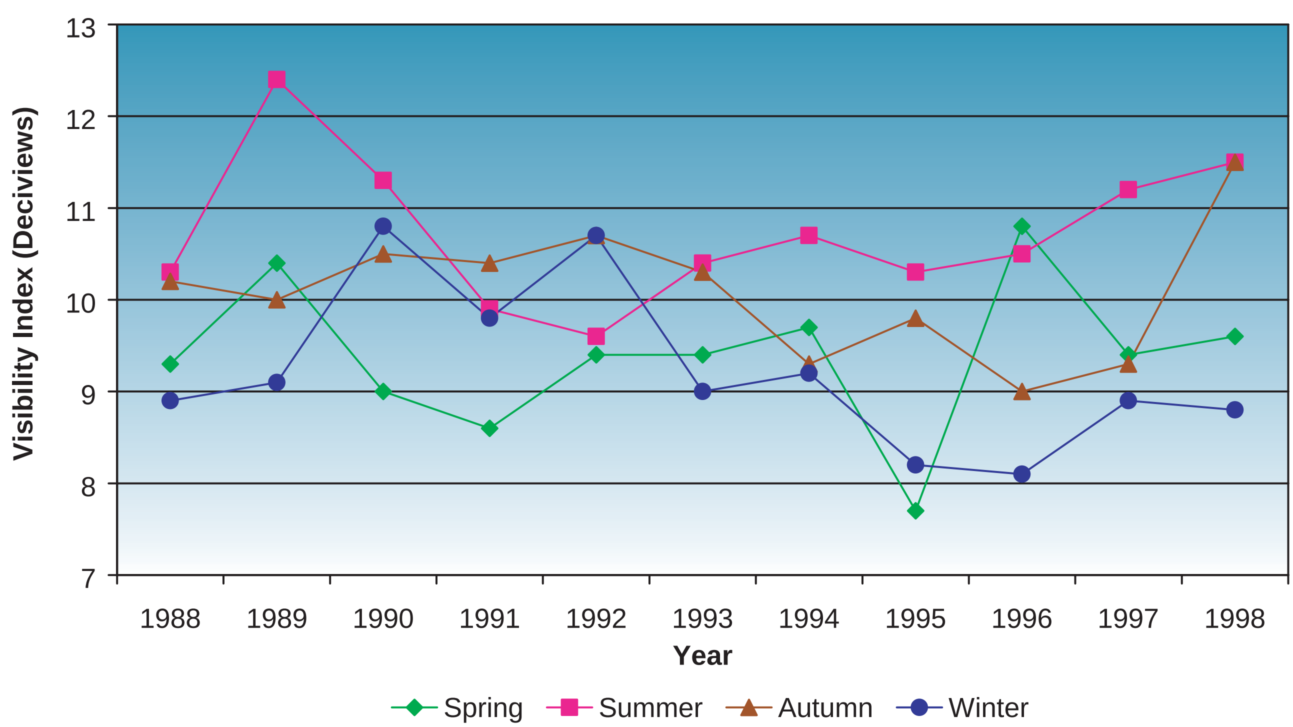

Figure NM–3. Seasonal Deciview Averages from 1988–1998 for the Bandelier IMPROVE Particulate Sampler

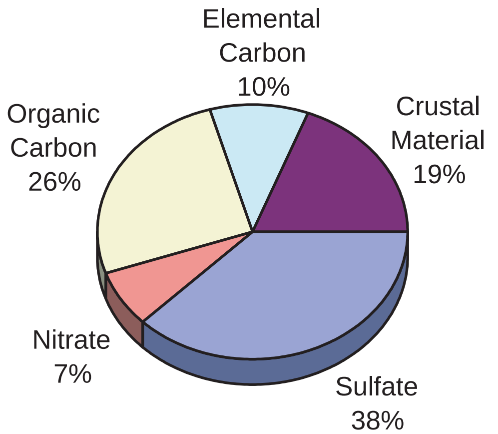

Figure NM–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Bandelier IMPROVE Particulate Sampler

Figure NM–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The visibility indices for all four seasons were generally between 8 and 12 deciviews. The visibility indices for spring, summer, and autumn showed no statistically significant trends over the eleven-year period. However, the winter indicies decreased more than 1 deciview within a statistically significant trend.

Figure NM–4 presents a chart showing the calculated fractional contribution to Bandelier's light extinction by each aerosol species on an annual basis. Figure NM–5 shows the same information for the four seasons. These five pie charts show the largest contributors to light extinction were sulfate particles and organic carbon. The sulfate particles were responsible for 33 to 41 percent of the light extinction at the Bandelier site, averaging 38 percent on an annual basis over a five-year period. The contributions from sulfates were highest in the summer and lowest during the

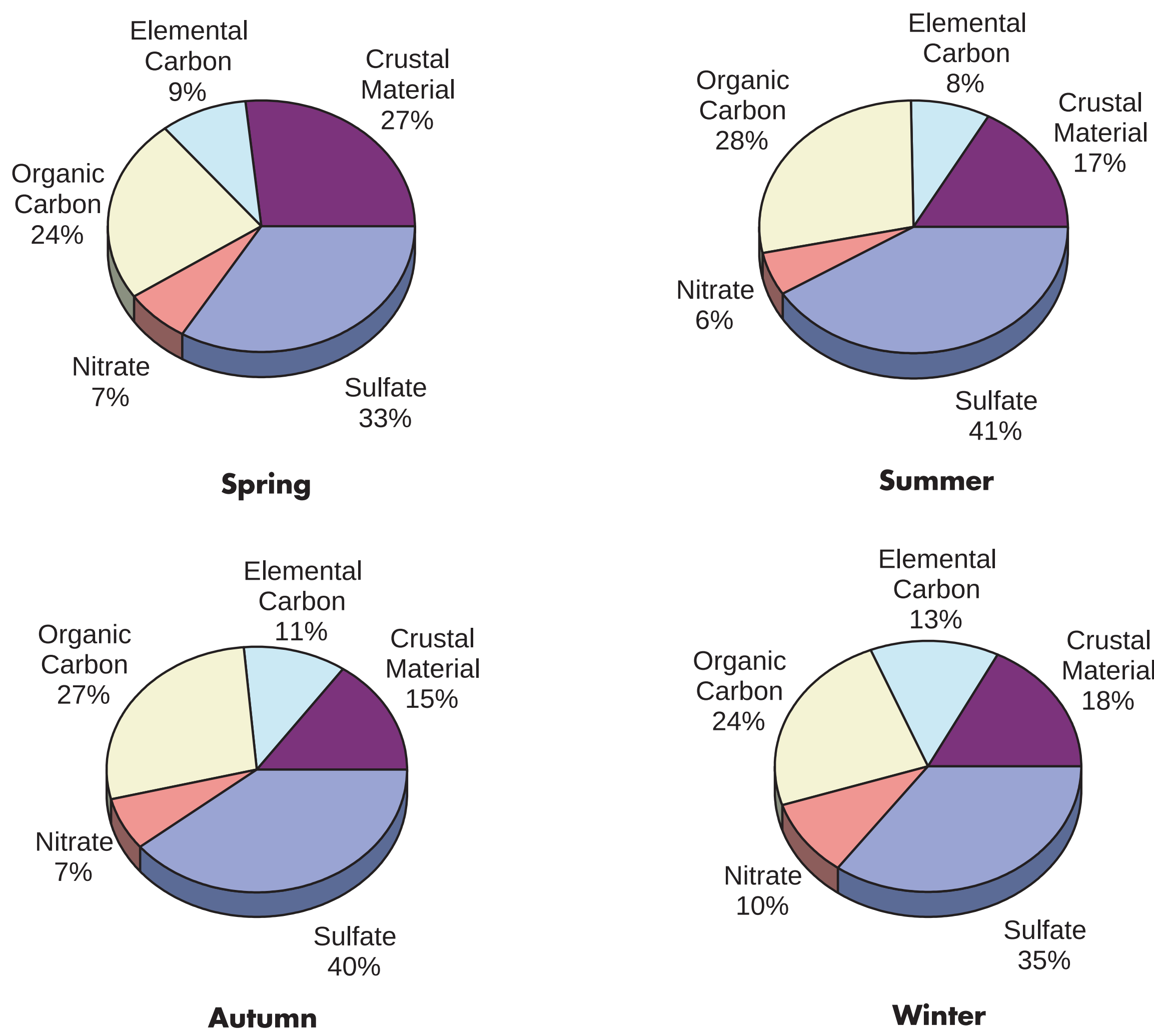

Figure NM–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Bandelier IMPROVE Particulate Sampler

spring season. Organic carbon percentages remained between 24 and 28 percent for the seasons. The contributions from nitrate ranged from 6 to 10 percent during the four seasons, with winter showing the highest percentages. Elemental carbon measured at the Bandelier site was responsible for approximately 10 percent of the calculated aerosol light extinction year-round. Crustal material represented 27 percent of the light extinction at the monitor in the spring but only approximately17 percent during the remaining three seasons.

Figure NM–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Bandelier site from 1988 to 1998. Over the eleven-year period, the total annual aerosol light extinctions remained near 17 Mm^{-1} with no statistically significant trend in visibility. Similarly, the annual light extinctions for sulfates, organic carbon, elemental carbon, and crustal material showed no significant trends in their values.

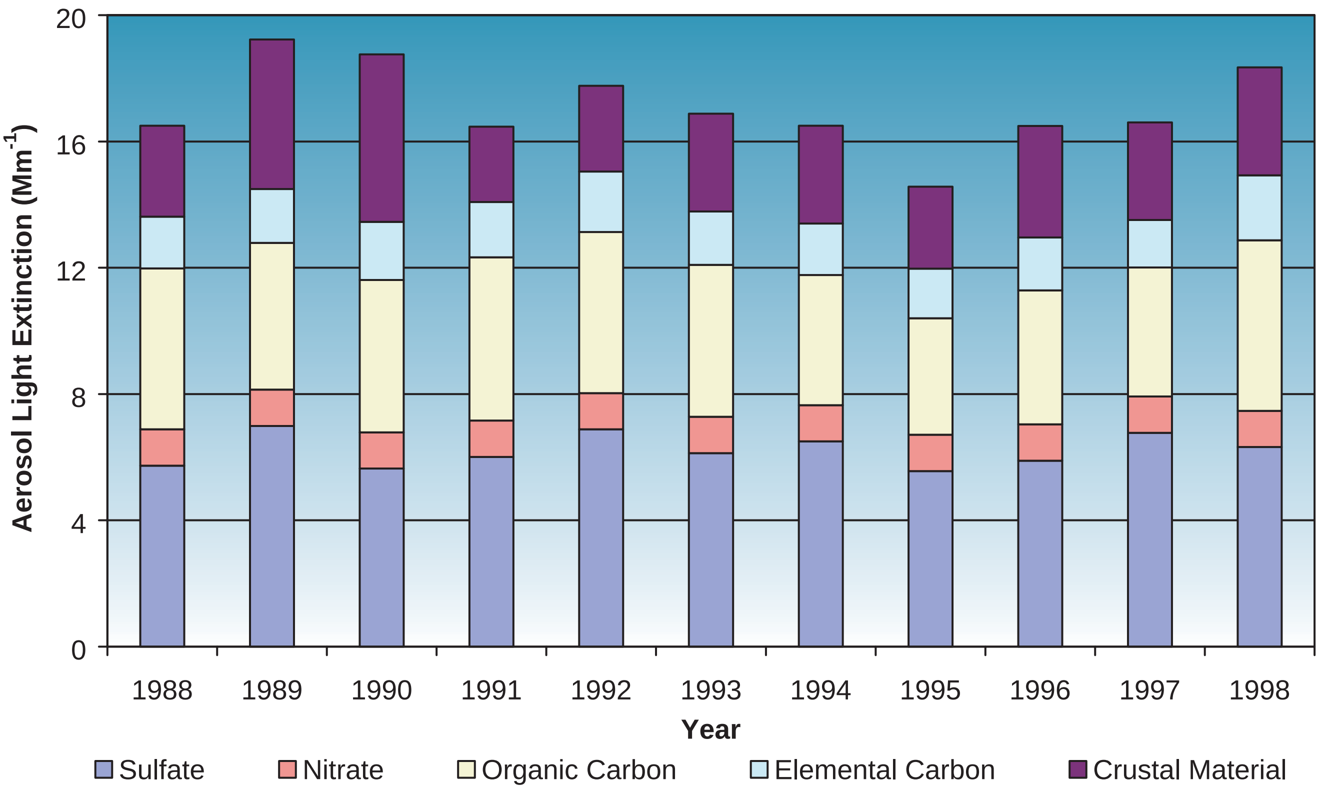

Figure NM–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Bandelier IMPROVE Particulate Sampler

16. OREGON

Two IMPROVE particulate samplers in Oregon operated continuously from 1994 through 1998 and are located at the Three Sisters Wilderness Area (monitor at 44.28°N, 122.05°W, elevation 2850 feet) and Crater Lake National Park (42.88°N, 122.13°W, elevation 6500 feet). Figure OR–1 shows the Three Sisters and Crater Lake particulate sampler locations east and southeast of Eugene. Additional mandatory Federal Class I areas in Oregon covered under the Regional Haze Rule include the following wilderness areas: Mount Hood, Eagle Cap, Hells Canyon, Mount Jefferson, Mount Washington, Strawberry Mountain, Diamond Peak, Kalmiopsis, Mountain Lakes, and Gearhart Mountains. These Class I areas do not have IMPROVE particulate sampler data for the years prior to 1999.

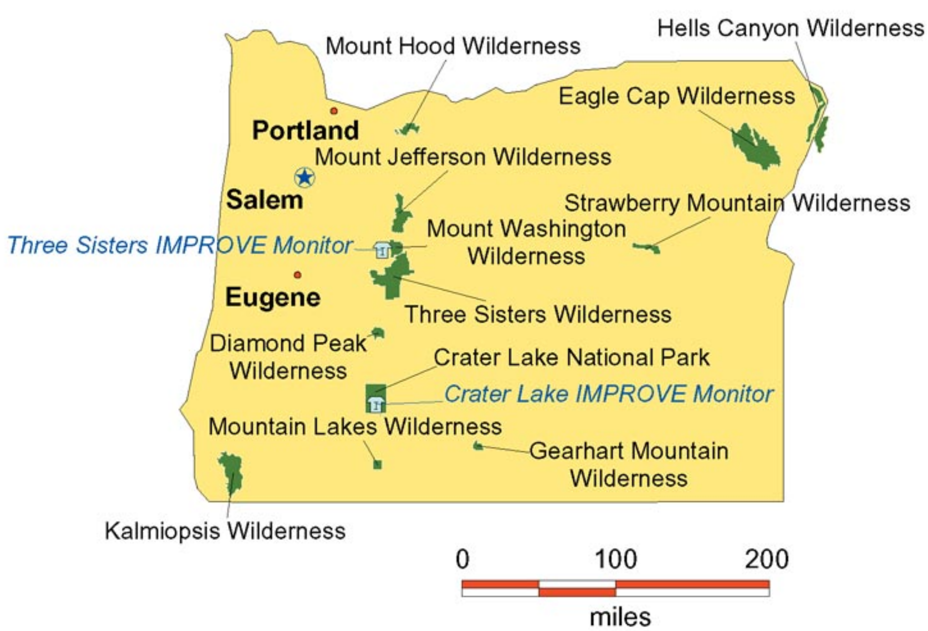

Figure OR–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Sites in Oregon

Crater Lake National Park

The Crater Lake IMPROVE particulate sampler started operating in March of 1988. Figure OR–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most-impaired days generally remained near 13 deciviews (VR 65 miles). There was no statistically significant trend in visibility for the most-impaired days. The visibility indices on the mid-range days remained near 8 deciviews (VR 110 miles), with no significant trend in visibility. The indices on the least-impaired days remained near 4.5 deciviews (VR 155 miles), with no significant trend in visibility.

Figure OR–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The visibility indices for all four seasons were generally between 5 and 11 deciviews. The indices

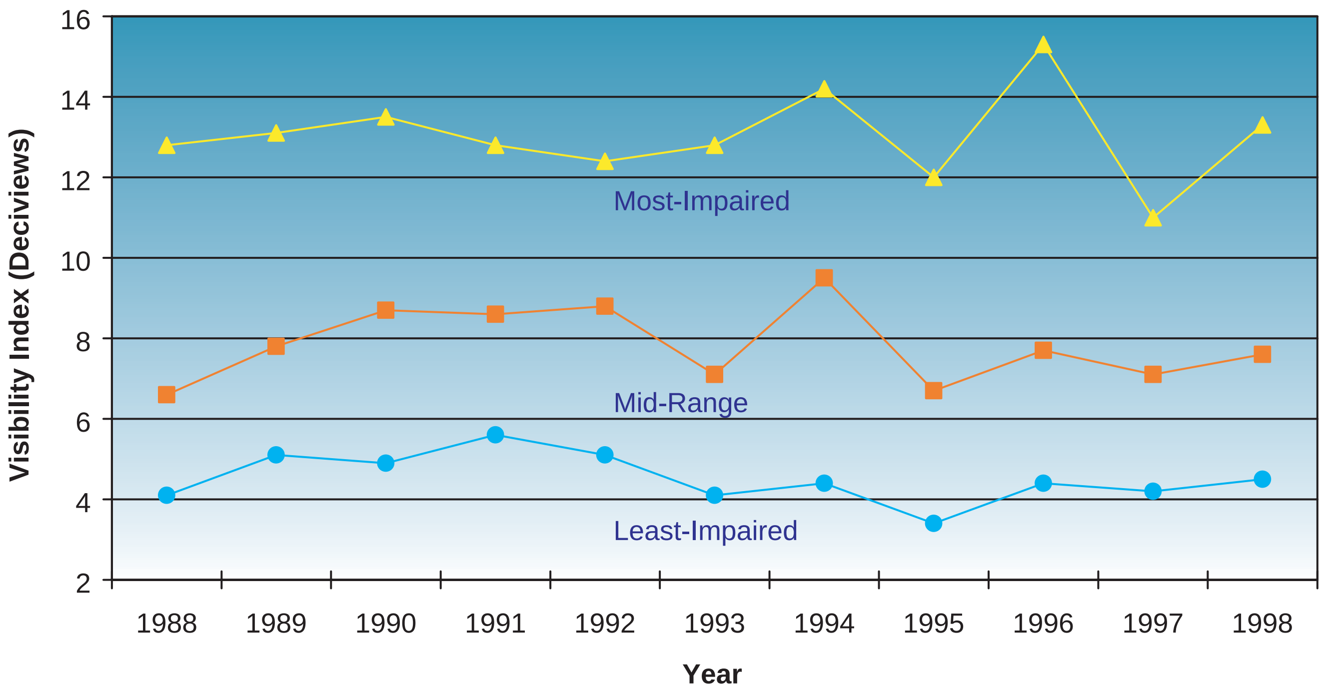

Figure OR–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Crater Lake IMPROVE Particulate Sampler

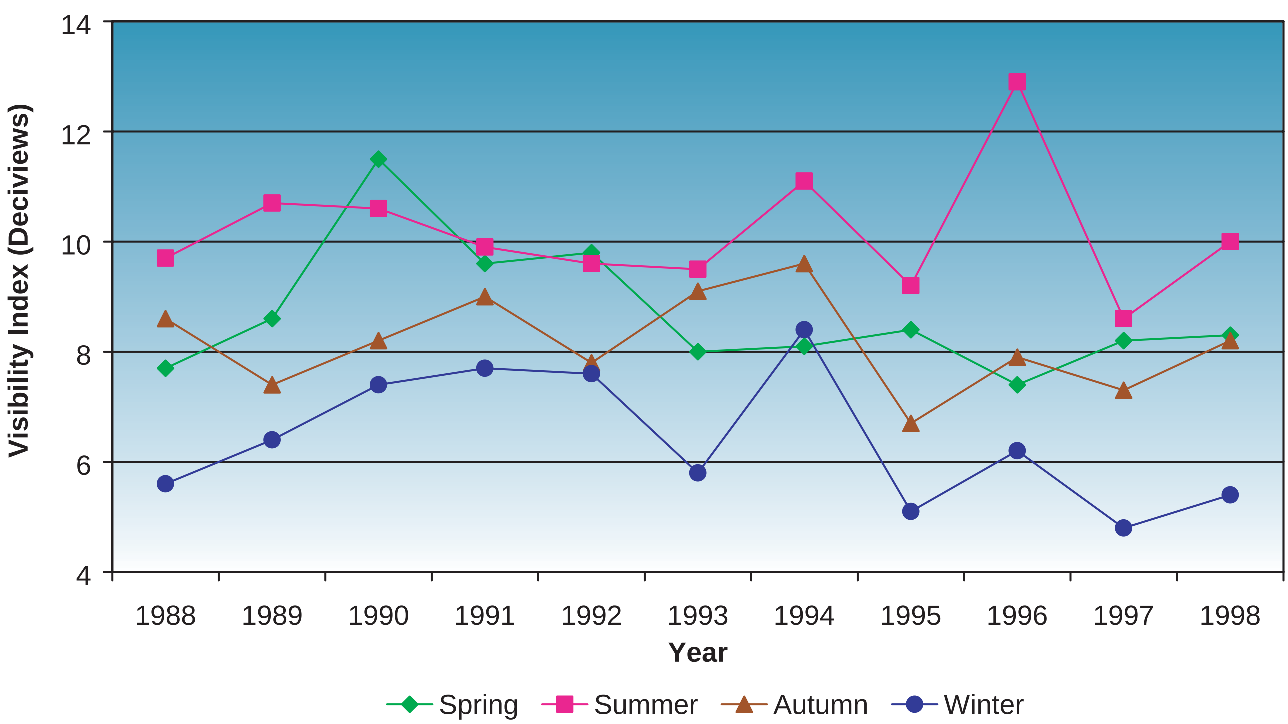

Figure OR–3. Seasonal Deciview Averages from 1988–1998 for the Crater Lake IMPROVE Particulate Sampler

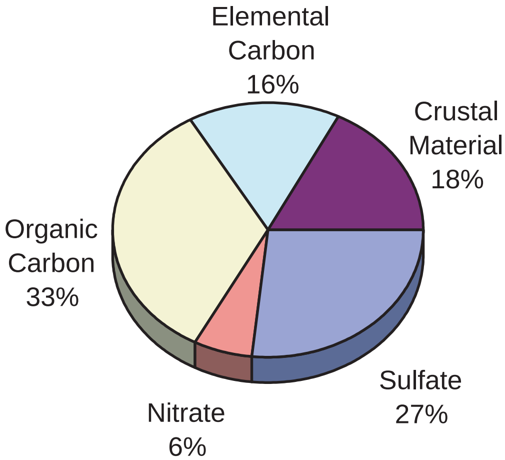

Figure OR–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Crater Lake IMPROVE Particulate Sampler

for summer were most frequently the highest, and the indices for winter the lowest. The visibility indices for each of the seasons showed no statistically significant trends over the eleven-year period.

Figure OR–4 presents a chart showing the calculated fractional contribution to Crater Lake's light extinction by each aerosol species on an annual basis. Figure OR–5 shows the same information for the four seasons. These five pie charts show that the largest contributor to light extinction was organic carbon. Organic carbon percentages ranged from 20 to 41 percent for the seasons, averaging 33 percent over a five-year period. The summer and autumn percent contributions from organic carbon were double those of winter. Sulfate particles were responsible for 20 to 36 percent of the light extinction at the Crater Lake site, averaging 27 percent on an annual

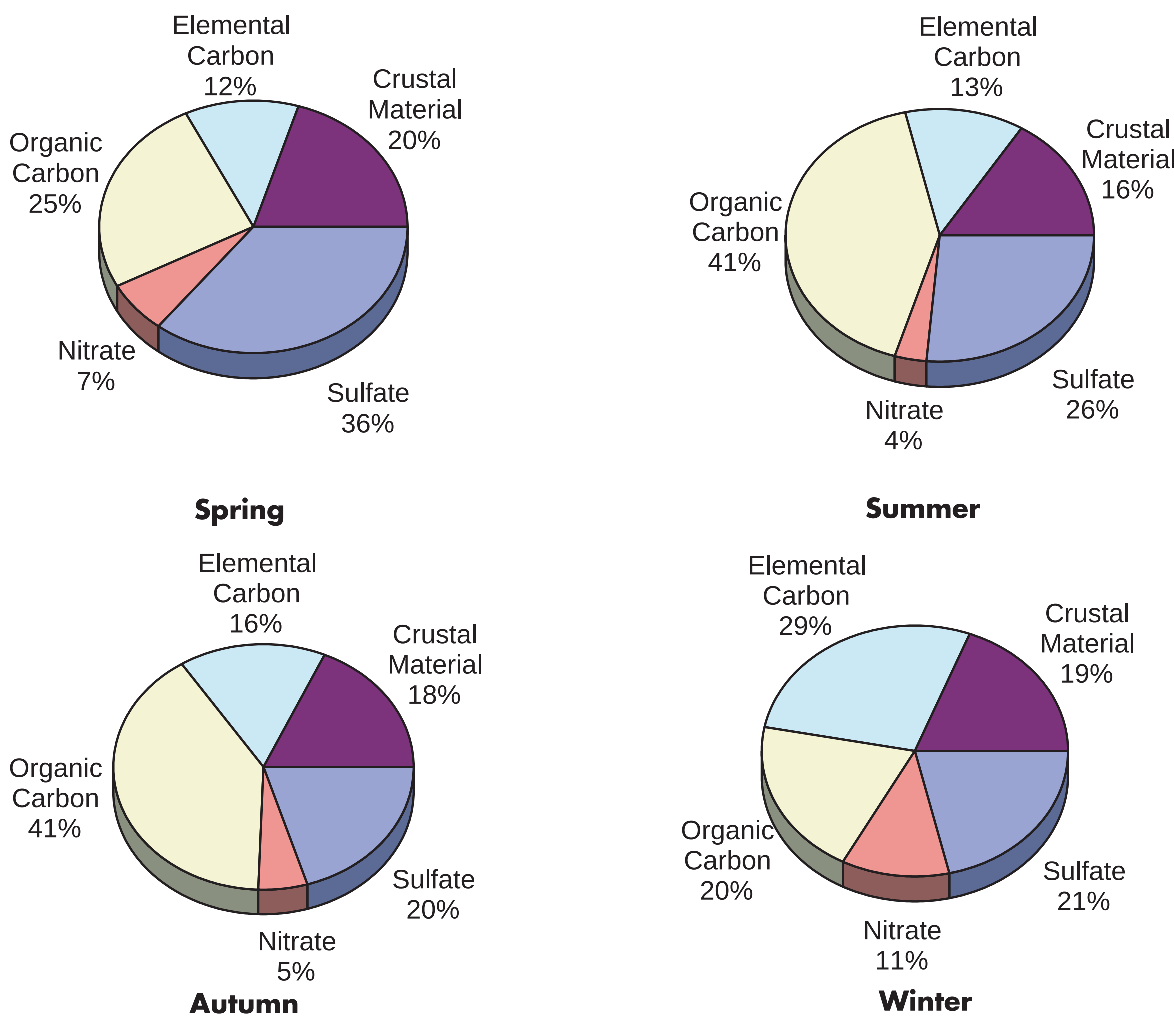

Figure OR–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Crater Lake IMPROVE Particulate Sampler

basis over a five-year period. The contributions from sulfates were highest in the spring and lowest during the autumn. The contributions from nitrate and crustal material were near 6 and 18 percent year-round. Elemental carbon measured at the Crater Lake site was responsible for 12 to 29 percent of the calculated aerosol light extinction, with the highest contributions occurring during the winter.

Figure OR–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Crater Lake site from 1988 to 1998. Over the eleven-year period, the total annual aerosol light extinctions remained near 14 Mm^{-1} with no statistically significant trend toward improved visibility. Similarly, the annual light extinctions for sulfates, organic carbon, elemental carbon, and crustal material showed no significant trends in their values.

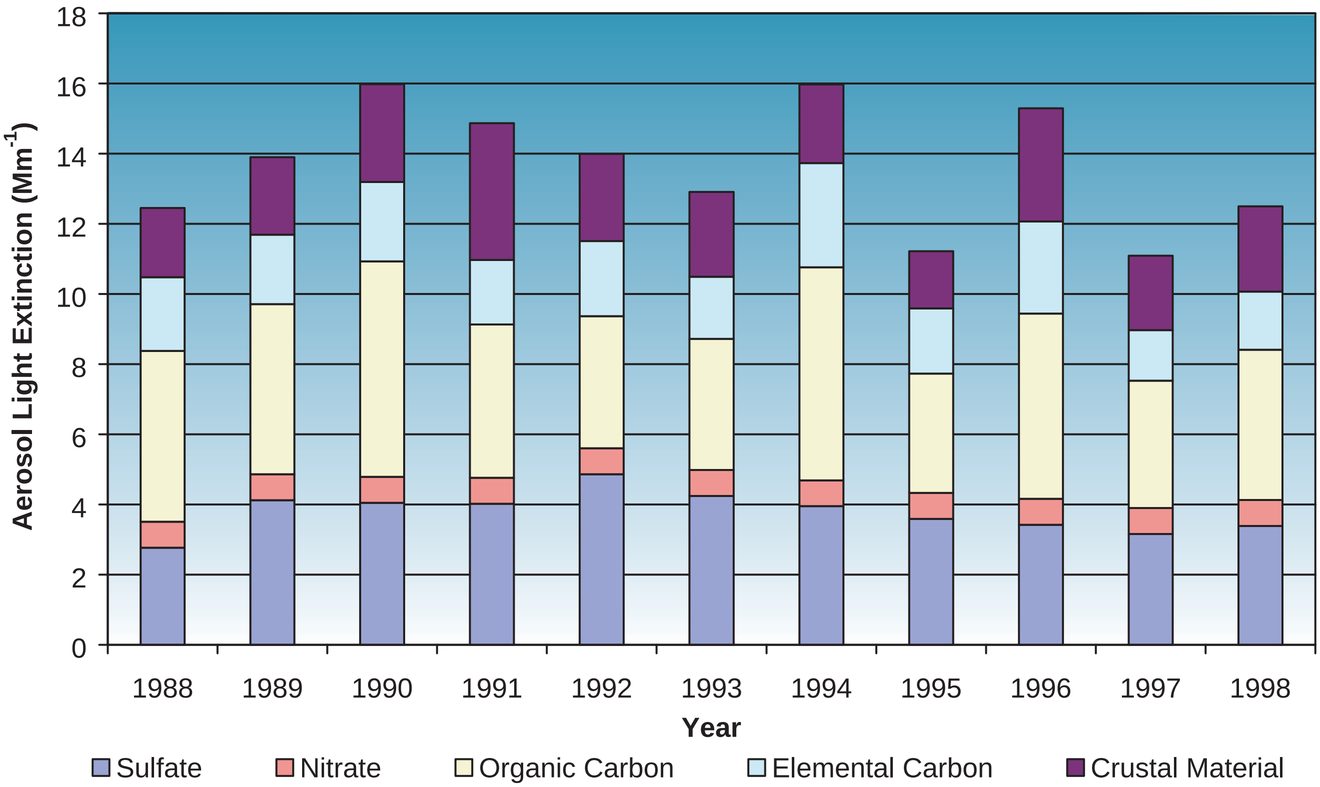

Figure OR–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Crater Lake IMPROVE Particulate Sampler

Three Sisters Wilderness Area

The Three Sisters IMPROVE particulate sampler started reporting data in July of 1993. Figure OR–7 presents the calculated visibility indices for selected data sets from 1994 through 1998. The figure shows that the visibility index for the most-impaired days remained near 18 deciviews (VR 40 miles). There was no statistically significant trend in visibility. The visibility indices on the mid-range and least-impaired days remained near 10 and 4.5 deciviews (VR 90 and 155 miles), respectively, with no significant trend in visibility.

Figure OR–8 shows the seasonal averages for the calculated visibility index from 1994 through 1998. Because coarse mass measurements were not available for spring 1994, no visibility index was

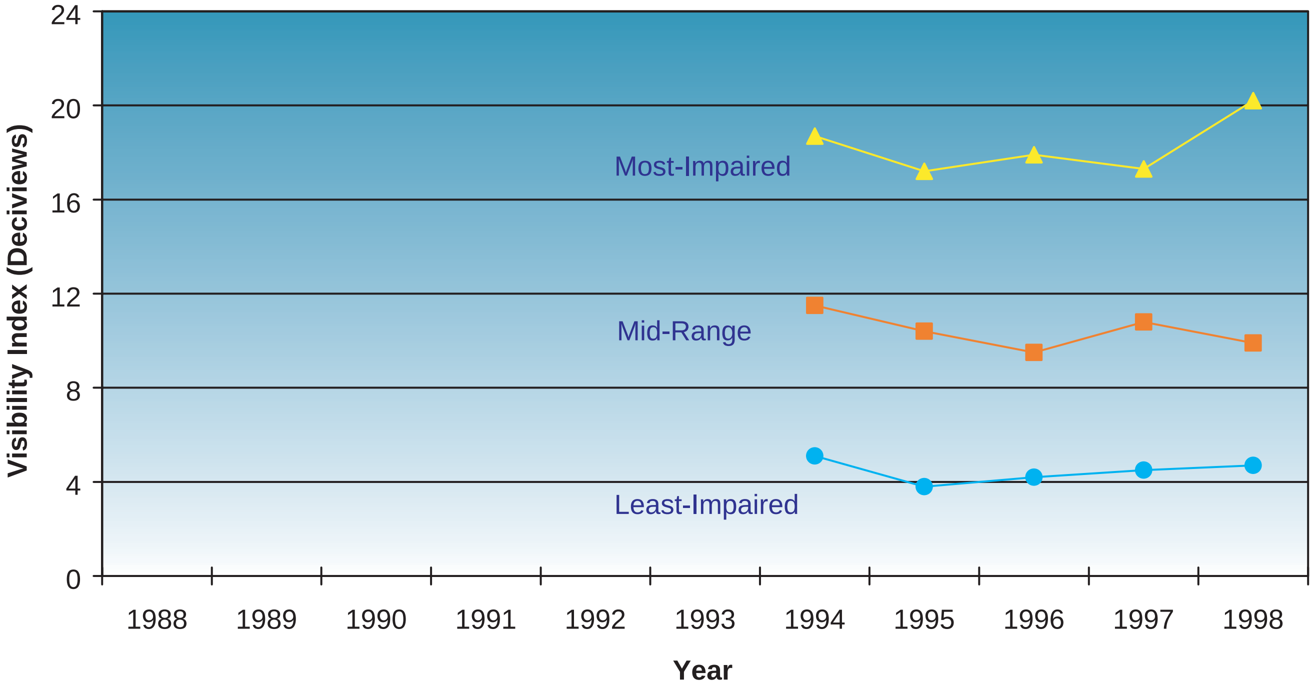

Figure OR–7. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1994–1998 for the Three Sisters IMPROVE Particulate Sampler

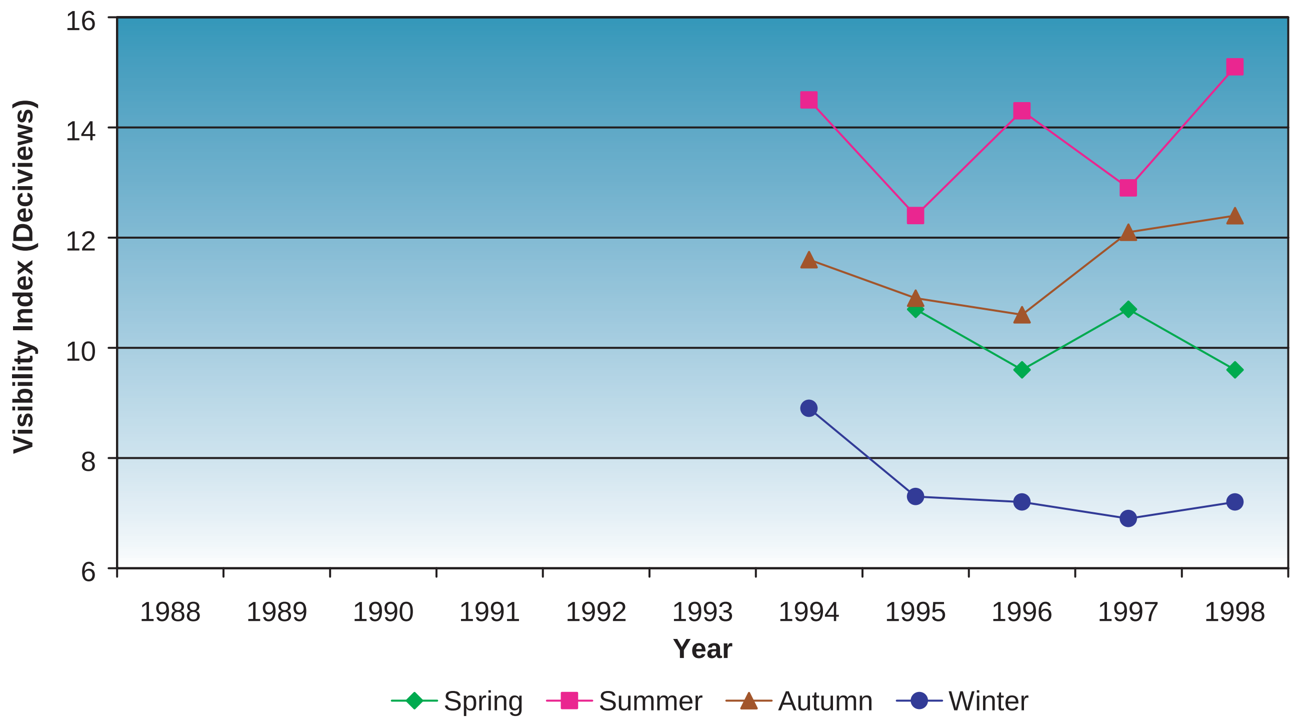

Figure OR–8. Seasonal Deciview Averages from 1994–1998 for the Three Sisters IMPROVE Particulate Sampler

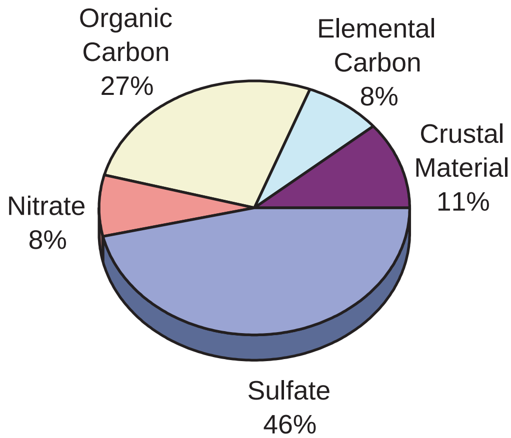

Figure OR–9. Contribution to Calculated Annual Light Extinction from 1994–1998 for the Three Sisters IMPROVE Particulate Sampler

calculated for this season. Interested readers can view the data for other species at http://improve.cnl.ucdavis.edu/cgi-bin/SSDisplay.cgi. The indices for summer were 1 to 5 deciviews higher than the indices for spring and autumn, and the indices for the spring and autumn were 2 to 5 deciviews higher than those of winter. No statistically significant trends were observed in the spring, summer, or autumn. The winter indices showed a statistically significant decrease of more than 1 deciview over five years.

Figure OR–9 presents a chart showing the calculated fractional contribution to Three Sister's light extinction by each aerosol species on an annual basis. Figure OR–10 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles and organic carbon. Sulfate particles were responsible for 39 to 52 percent of

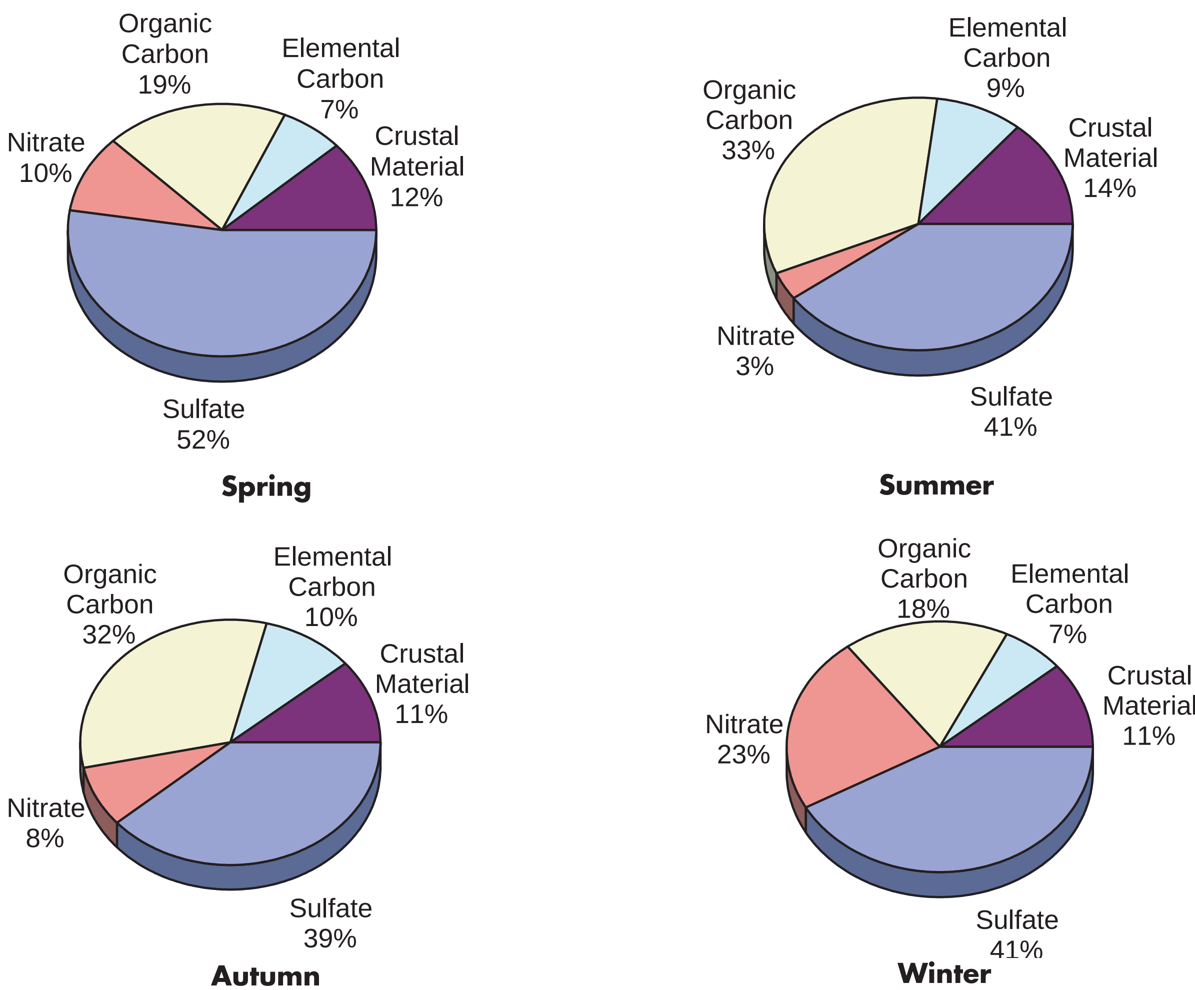

Figure OR–10. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Three Sisters IMPROVE Particulate Sampler

the light extinction at the Three Sisters site, averaging 46 percent on an annual basis over a five-year period. The contributions from sulfates were highest in the spring and lowest during the autumn. Organic carbon percentages ranged from 18 to 33 percent for the seasons, averaging 27 percent. The percent contributions from organic carbon were highest in the summer and autumn. The nitrate contributions ranged from 3 to 23 percent with the highest contributions in winter. Annually, the contributions from elemental carbon and crustal material were near 8 and 11 percent.

Figure OR–11 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Three Sisters site from 1994 to 1998. Over the five-year period, the total annual aerosol light extinctions ranged from 20 to 25 Mm^{-1} with no statistically significant trend in visibility. Similarly, the annual light extinctions for sulfates, organic carbon, elemental carbon, and crustal material showed no significant trends in their values.

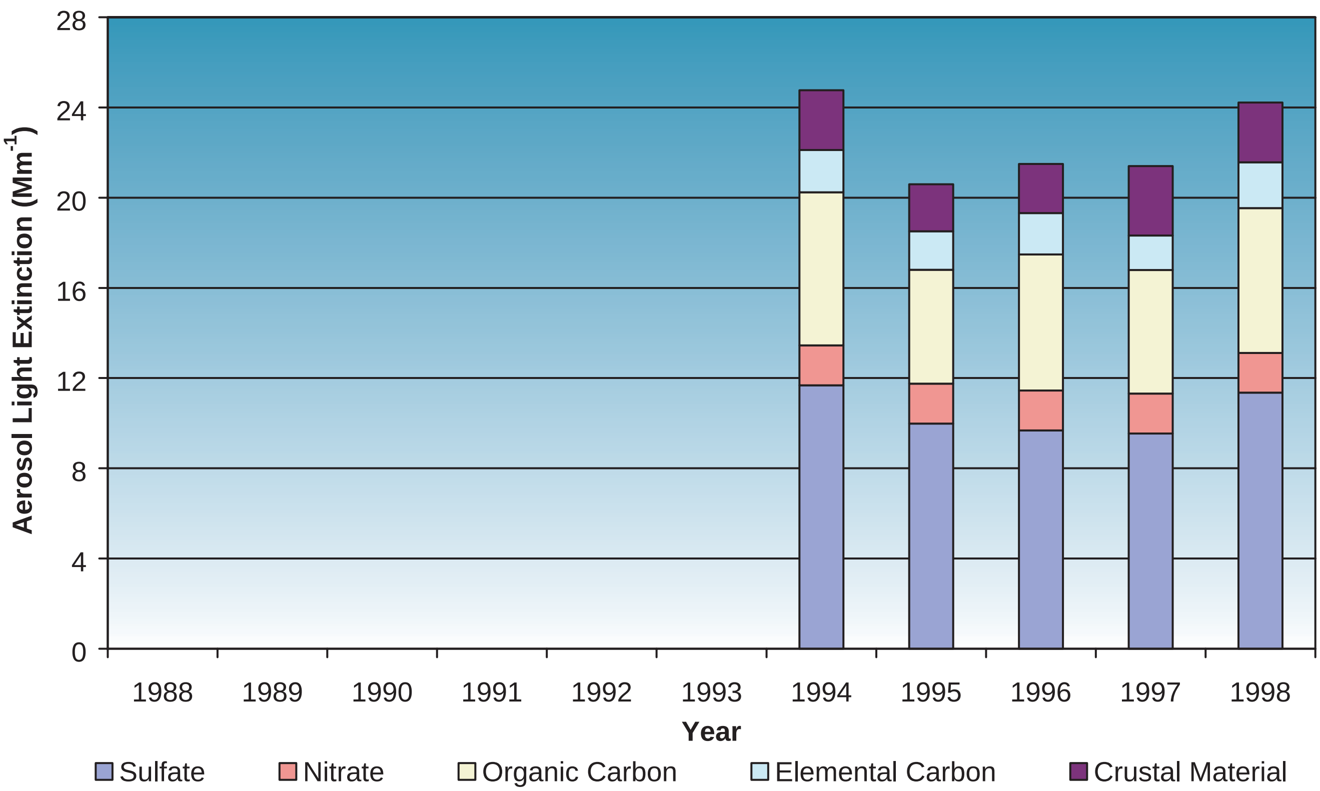

Figure OR–11. Contributions to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Three Sisters IMPROVE Particulate Sampler

Oregon State Summary

The two IMPROVE monitoring sites in Oregon are just 100 miles apart, but the calculated visibility is considerably more impaired at Three Sisters Wilderness than at Crater Lake National Park. Table OR–1 shows the calculated aerosol light extinction coefficients for the two sites. The average visual ranges for the Three Sisters and Crater Lake sites are 75 and 105 miles.

The average measured concentrations of sulfate at the Three Sisters and Crater Lake sites were 0.45 and 0.71 μg/m^3. The annual average relative humidities used to calculate light extinction at the Crater Lake and Three Sisters sites correspond to relative humidity adjustment factors (Appendix C) of 2.60 and 4.91. As a result, although the ambient concentrations of sulfate and nitrate were only about 30 percent lower at the Crater Lake site than at Three Sisters, the calculated extinction coefficients for sulfates and nitrates at the Three Sisters site were almost triple those at the Crater Lake site (Table OR–1). This example illustrates the importance of meteorological conditions (e.g., relative humidity) to visibility impairment.

Table OR–1. Oregon Calculated Total Extinction Coefficients from 1994–1998

IMPROVE Site	Calculated Total Aerosol Extinction Coefficient (Mm^{-1})	Pollutant Extinction Coefficient (Mm^{-1})				
		Sulfate	Nitrate	Organic Carbon	Elemental Carbon	Crustal Material
Crater Lake NP	13.2	3.5	0.7	4.5	2.1	2.3
Three Sisters Wilderness	22.5	10.4	1.8	6.0	1.8	2.5

17. SOUTH DAKOTA

The only IMPROVE particulate sampler in South Dakota is located in Badlands National Park. Figure SD–1 shows the Badlands monitor location (43.74°N, 101.94°W, elevation 2493 feet) in the southwestern portion of the state. The only additional mandatory Federal Class I area in South Dakota covered under the Regional Haze Rule is Wind Cave National Park. Wind Cave did not have IMPROVE monitor data for the years prior to 1999.

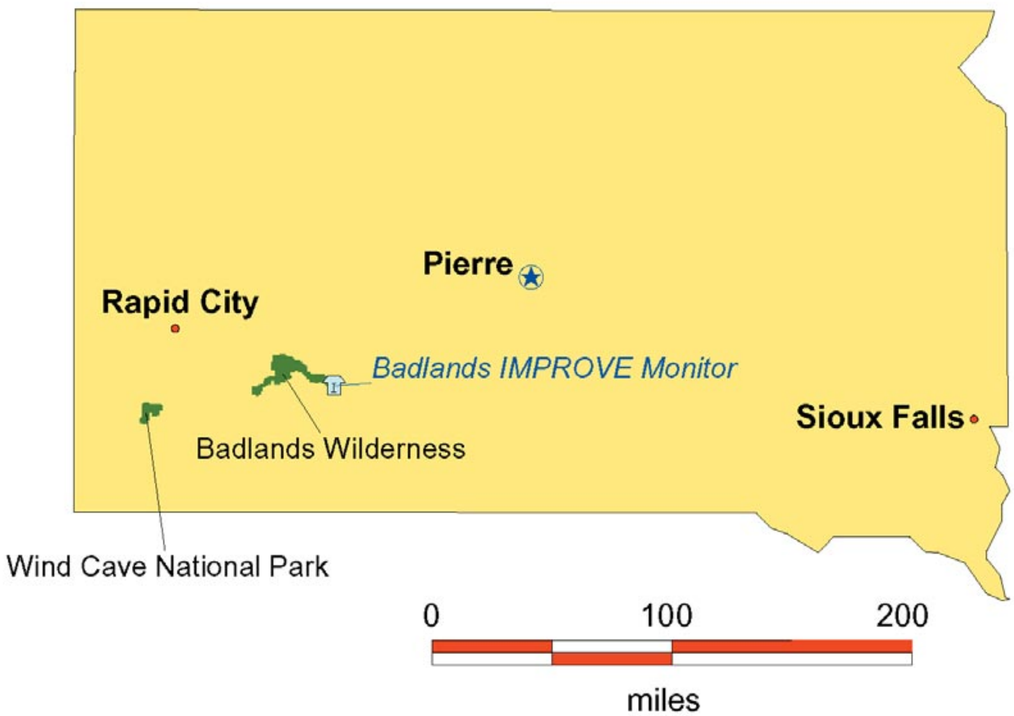

Figure SD–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in South Dakota

Badlands National Park

The Badlands IMPROVE particulate sampler started reporting data in March of 1988. Figure SD–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most-impaired days was generally between 17 and 19 deciviews (VR between 45 and 36 miles), with no statistically significant trend in visibility. The visibility indices on the mid-range days remained near 12 deciviews (VR 75 miles), with no significant trend in visibility. The indices on the least-impaired days decreased from 8.3 to 7.4 deciviews (VR from 105 to 115 miles), with a significant trend toward improved visibility.

Figure SD–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The visibility indices for all four seasons were generally between 11 and 15 deciviews. The indices for summer were most frequently the highest, and indices for winter the lowest. The visibility indices for all four seasons showed no statistically significant trends over the eleven-year period.

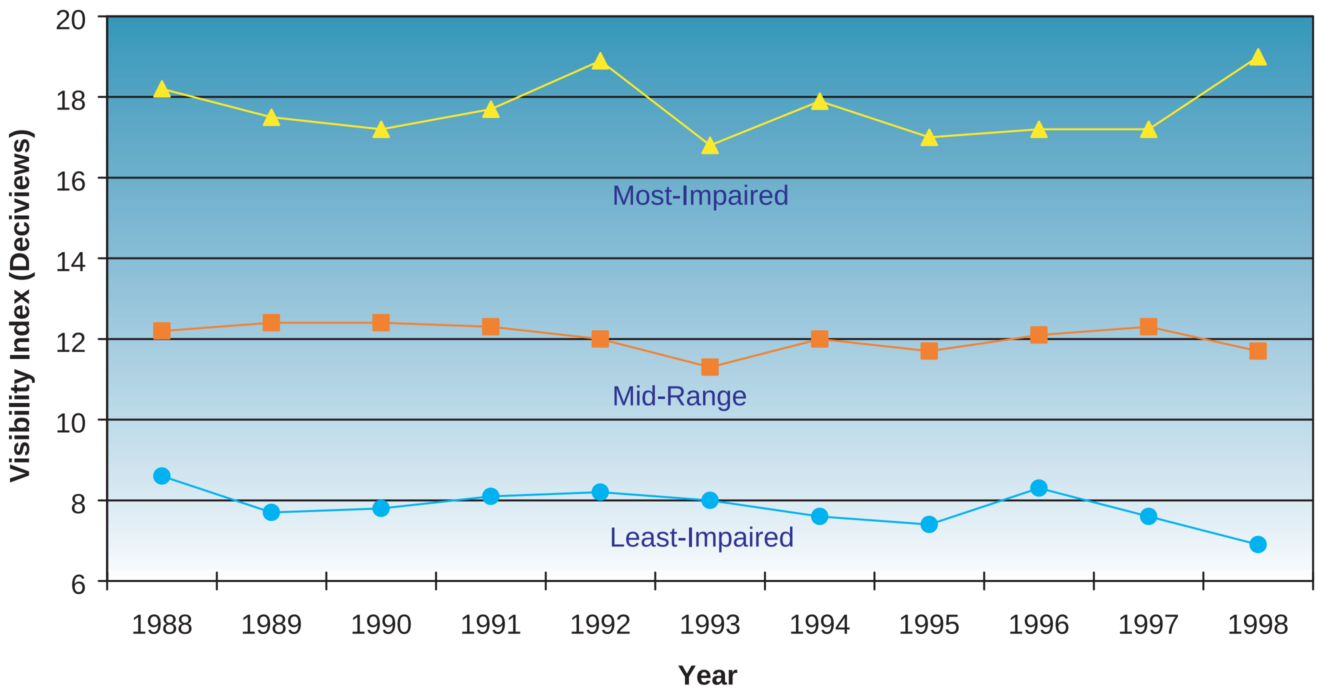

Figure SD–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Badlands IMPROVE Particulate Sampler

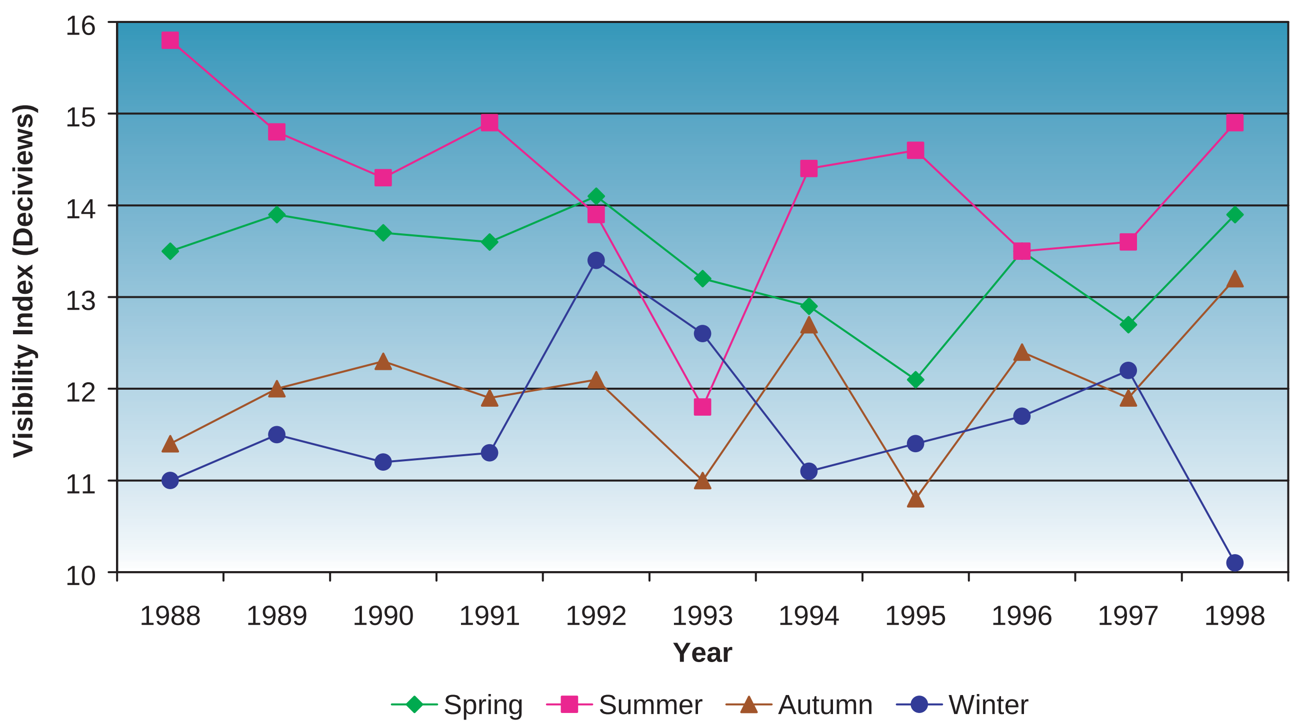

Figure SD–3. Seasonal Deciview Averages from 1988–1998 for the Badlands IMPROVE Particulate Sampler

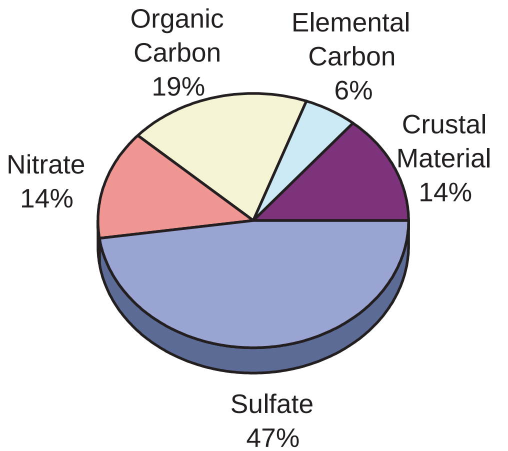

Figure SD–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Badlands IMPROVE Particulate Sampler

Figure SD–4 presents a chart showing the calculated fractional contribution to Badland's light extinction by each aerosol species on an annual basis. Figure SD–5 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles. Sulfate particles were responsible for 43 to 55 percent of the light extinction at the Badlands site, averaging 47 percent on an annual basis over a five-year period. The contributions from sulfates were highest in the spring and lowest during the autumn. The contributions from nitrate ranged from 11 to 18 percent, with the highest concentrations in the winter and the lowest concentrations in the summer. Organic carbon percentages ranged from 13 to 25 percent for the seasons, averaging 19 percent. The summer and autumn percent contributions from

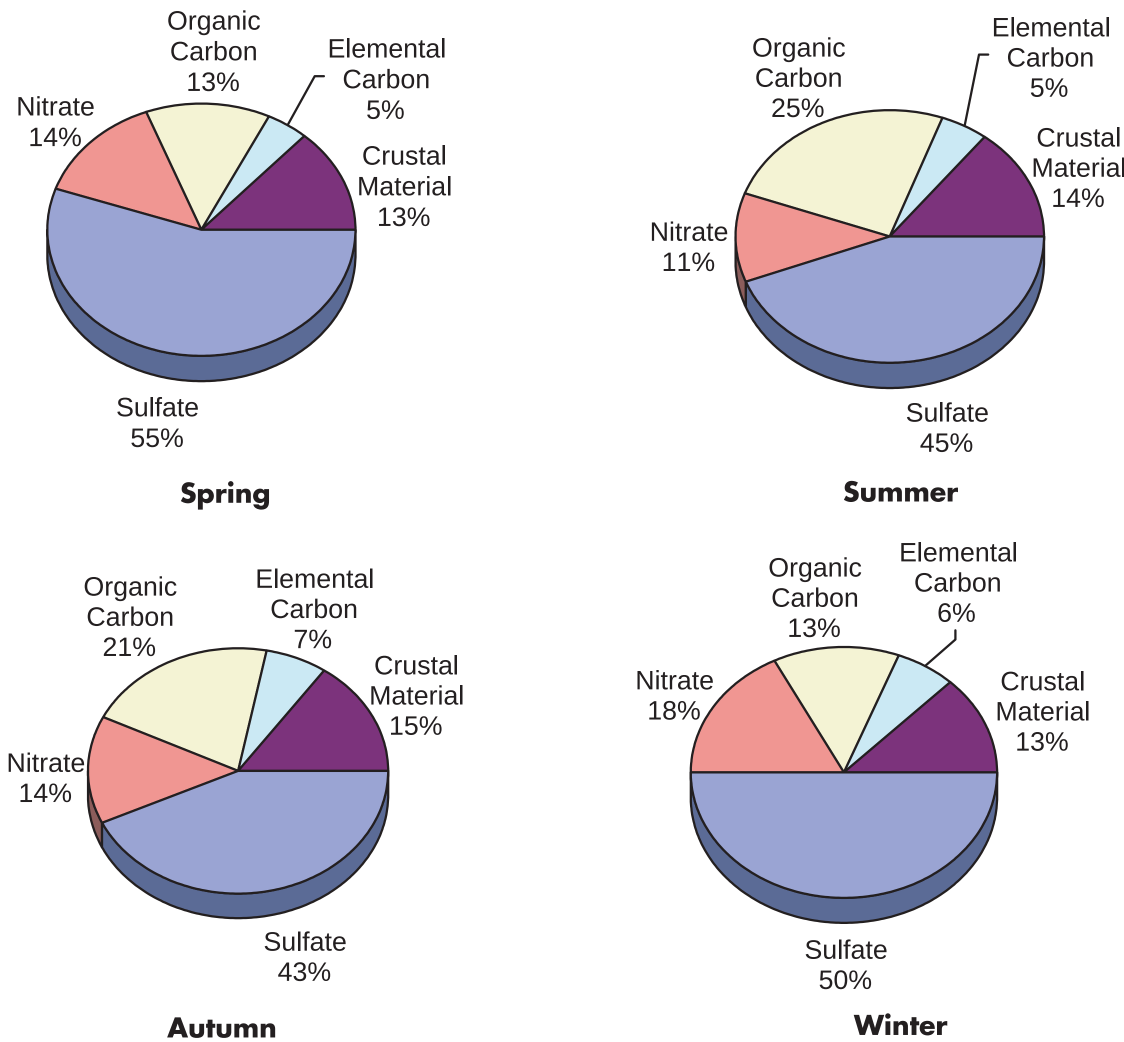

Figure SD–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Badlands IMPROVE Particulate Sampler

organic carbon were double those of the winter and spring. Elemental carbon and crustal material measured at the Badlands site were responsible for 6 and 14 percent of the calculated aerosol light extinction, with only small percent differences between the seasons.

Figure SD–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Badlands site from 1988 to 1998. Over the eleven-year period, the total annual aerosol light extinctions remained between 23 and 28 Mm^{-1} with no statistically significant trend in visibility. Similarly, the annual light extinction contributions from the sulfate, organic carbon, and elemental carbon species showed no statistically significant trend. However, the annual light extinctions for crustal material showed a significant trend in its values toward smaller contributions to the light extinction coefficient, indicating lower ambient concentrations.

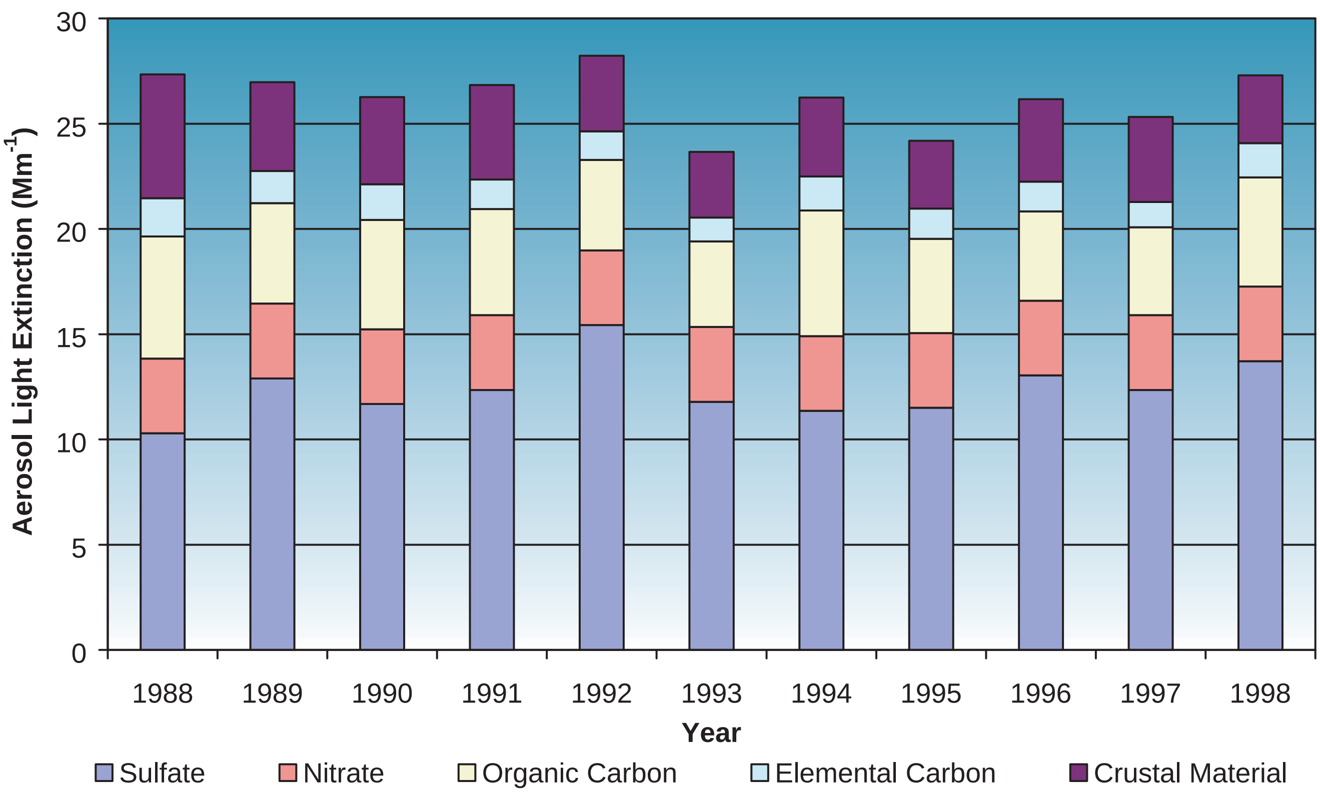

Figure SD–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Badlands IMPROVE Particulate Sampler

18. TENNESSEE

The only IMPROVE particulate sampler in Tennessee that collected data between 1994 and 1998 is located in Great Smoky Mountains National Park. Figure TN–1 shows the Great Smoky Mountains particulate sampler location (35.63°N, 83.94°W, elevation 2500 feet) on the Tennessee-North Carolina border. The Great Smoky Mountains National Park and the Joyce Kilmer-Slickrock Wilderness Area are both located in Tennessee and North Carolina. Joyce Kilmer-Slickrock Wilderness Area is a mandatory Federal Class I area covered under the Regional Haze Rule. The wilderness area did not have IMPROVE monitor data for the years prior to 1999.

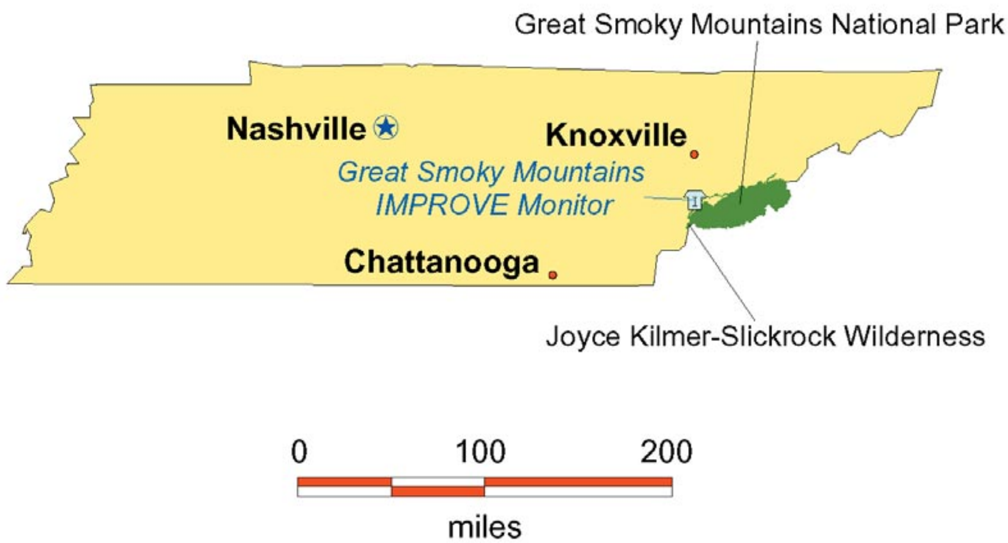

Figure TN–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in Tennessee

Great Smoky Mountains National Park

The Great Smoky Mountains IMPROVE particulate sampler started reporting in March of 1988. Figure TN–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most-impaired days generally remained near 30 deciviews (VR 12 miles), with no statistically significant trend in visibility. Similarly, the visibility indices on the mid-range days remained relatively constant, near 21 deciviews (VR 30 miles), with no significant trend in visibility. The indices on the least-impaired days remained near 15 deciviews (VR 55 miles), with no significant trend in visibility.

Figure TN–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. The visibility indices for the summer season were generally at least 5 deciviews higher than those during the other seasons. Winter registered the lowest visibility indices. The visibility indices for all four seasons showed no statistically significant trends over the eleven-year period.

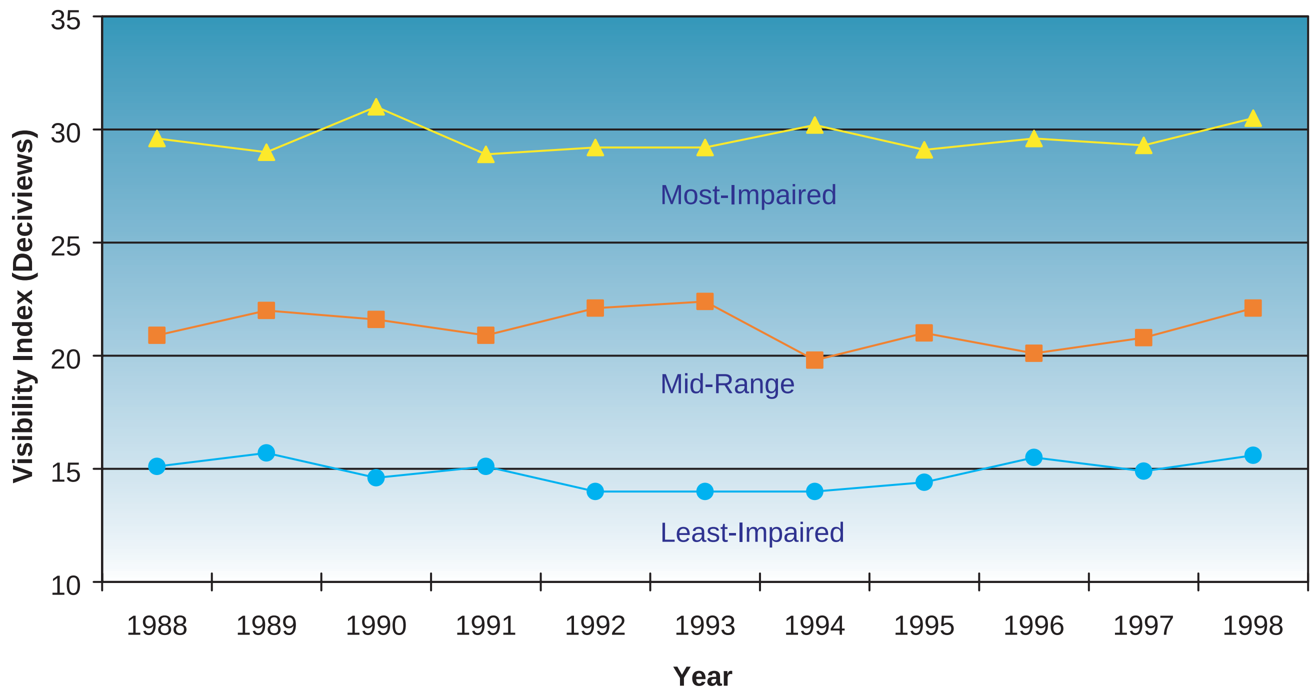

Figure TN–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Great Smoky Mountains IMPROVE Particulate Sampler

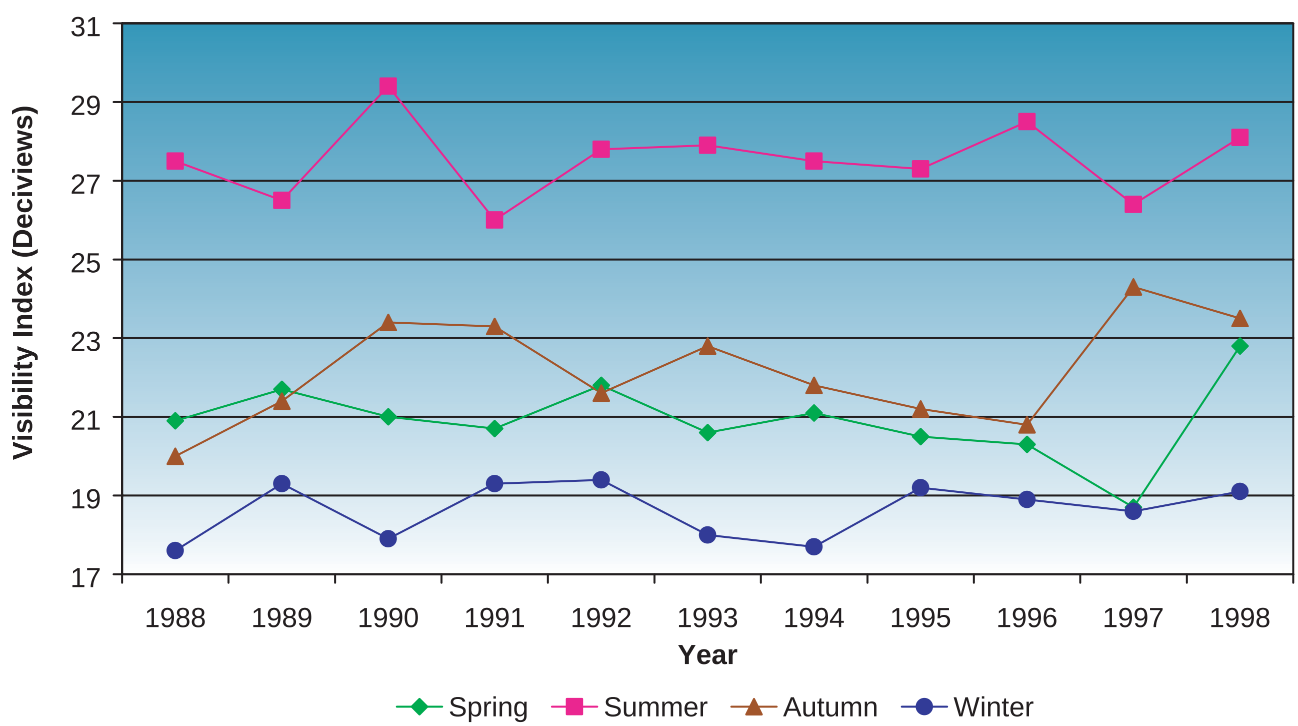

Figure TN–3. Seasonal Deciview Averages from 1988–1998 for the Great Smoky Mountains IMPROVE Particulate Sampler

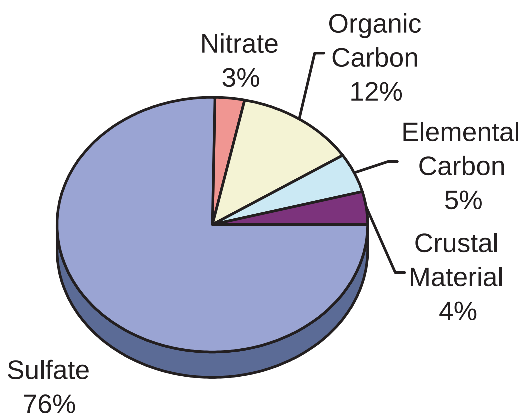

Figure TN–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Great Smoky Mountains IMPROVE Particulate Sampler

Figure TN–4 presents a chart showing the calculated fractional contribution to the Great Smoky Mountains' light extinction by each aerosol species on an annual basis. Figure TN–5 shows the same information for the four seasons. Since the summer light extinction coefficients were much larger than those in other seasons, the annual averages presented in TN-4 appear weighted to the summer. These five pie charts show that sulfate particles were the largest contributor to light extinction. Sulfate particles were responsible for 66 to 82 percent of the light extinction at the Great Smoky Mountains site, averaging 76 percent on an annual basis over a five-year period. The contributions from sulfates were highest in the summer and lowest in the winter. The

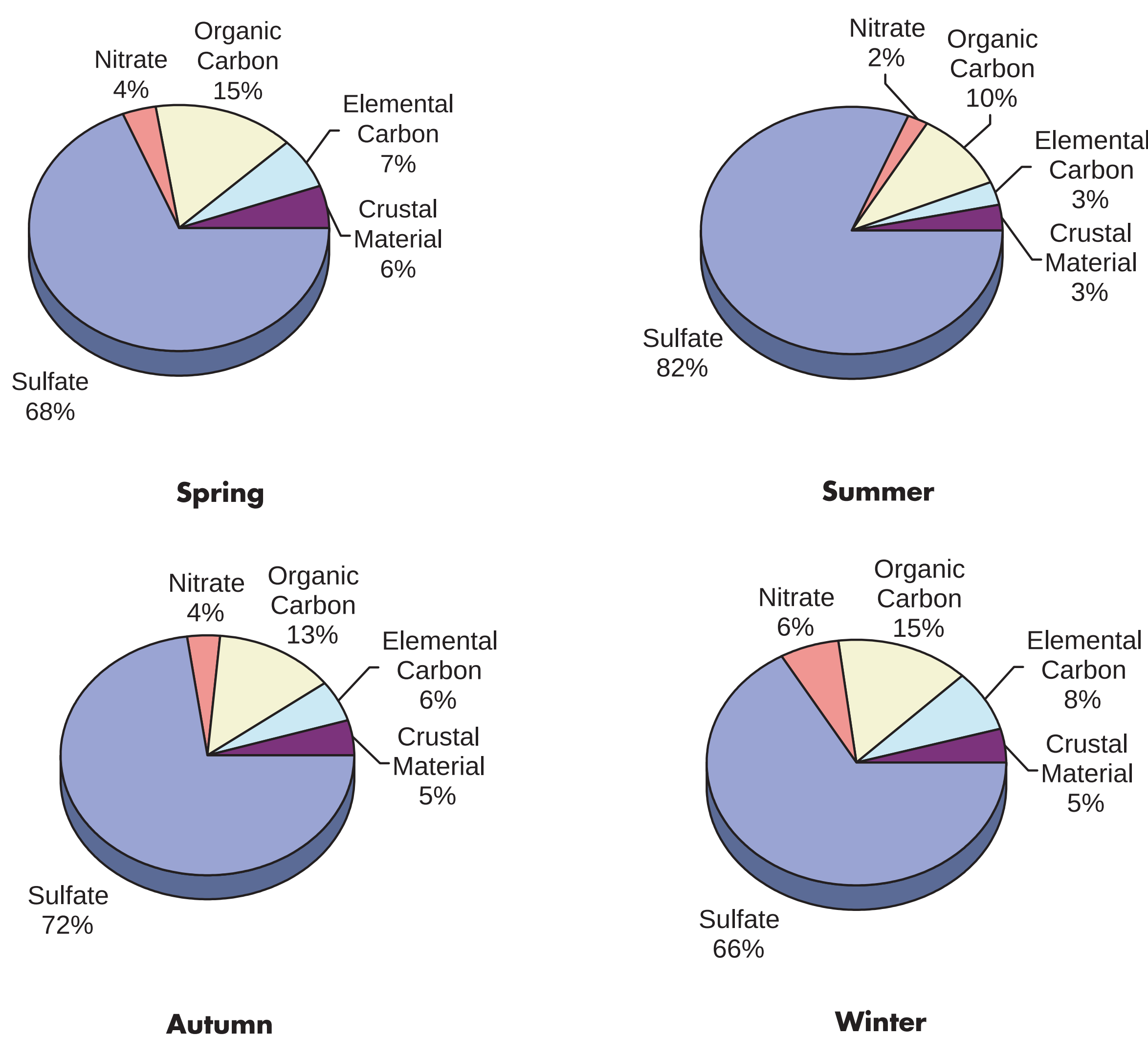

Figure TN–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Great Smoky Mountains IMPROVE Particulate Sampler

contributions from nitrate ranged from 2 to 6 percent, with the highest concentrations in the winter. Organic carbon, elemental carbon, and crustal material percentage contributions remained near 12, 5, and 4 percent year-round.

Figure TN–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Great Smoky Mountains site from 1988 to 1998. The total annual aerosol light extinctions remained between 75 and 100 Mm^{-1} with no statistically significant trend in visibility. Similarly, the annual light extinctions for sulfates, organic carbon, elemental carbon, and crustal material showed no significant trends over this time period.

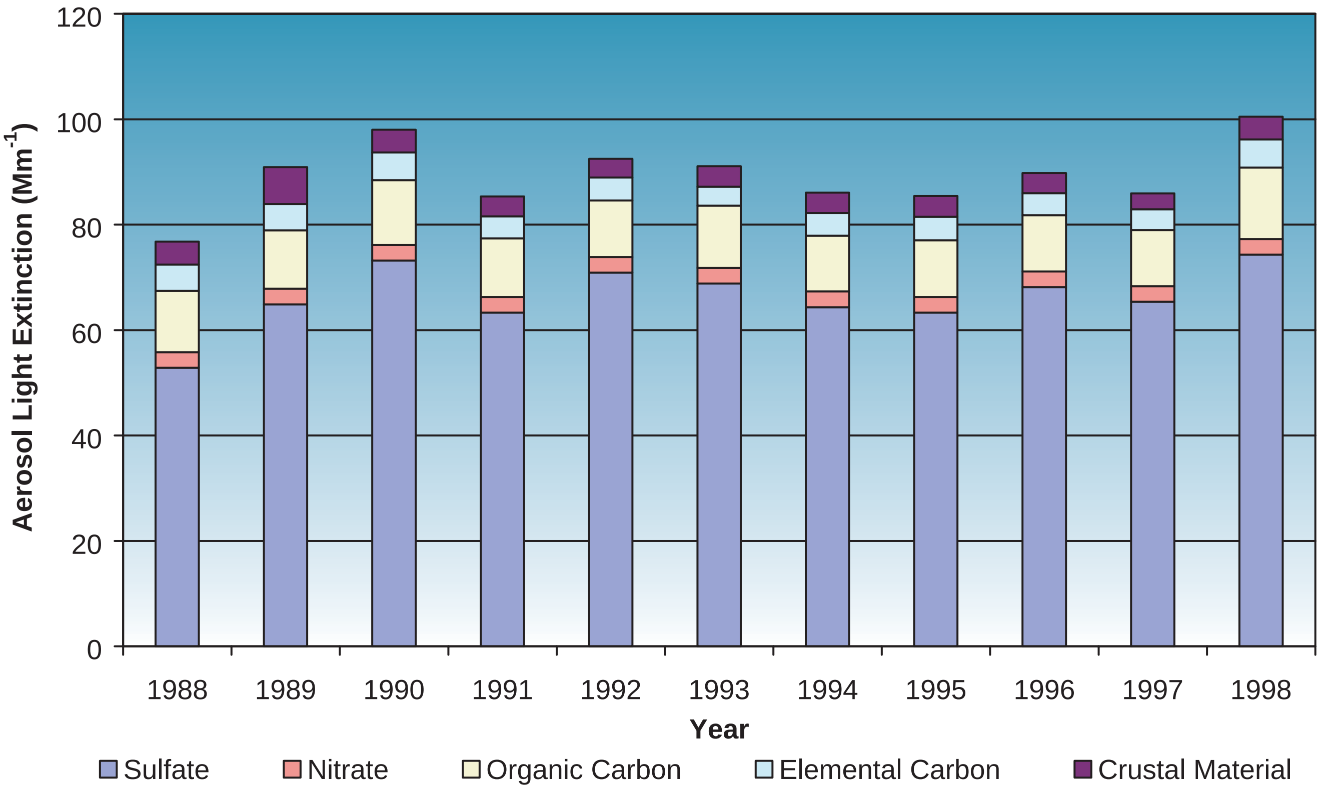

Figure TN–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Great Smoky Mountains IMPROVE Particulate Sampler

19. TEXAS

Two Texas national parks, Big Bend and Guadalupe Mountains, are mandatory Federal Class I areas covered by the Regional Haze Rule. IMPROVE particulate samplers are located in Big Bend (29.33°N, 103.55°W, elevation 3500 feet) and Guadalupe Mountains (31.83°N, 104.81°W, elevation 5400 feet). Both monitors collected data between 1992 and 1998. Figure TX–1 shows the monitor locations near the Mexican and New Mexican borders.

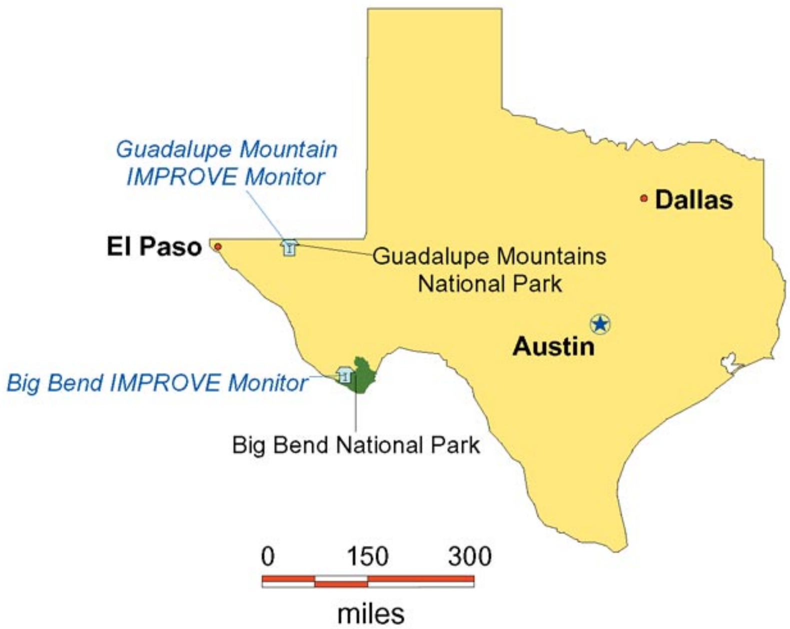

Figure TX–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Sites in Texas

Big Bend National Park

The Big Bend IMPROVE particulate sampler started reporting data in March of 1988. Figure TX–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most impaired days increased from 16 to 20 deciviews (VR 50 to 33 miles), but the trend was not classified as statistically significant. The visibility indices on the mid-range days remained relatively constant between 12 and 13 deciviews (VR between 75 and 65 miles), with no significant trend in visibility. The indices on the least-impaired days remained near 8 deciviews (VR 110 miles), with no significant trend in visibility.

Figure TX–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. Most of the visibility indices for the four seasons were between 10 and 15 deciviews, with winter values most frequently the smallest. The visibility indices for spring, autumn, and winter showed no statistically significant trends over the eleven-year period. However, the summer indices increased over the eleven-year period with a statistically significant trend, indicating additional visibility impairment in later years.

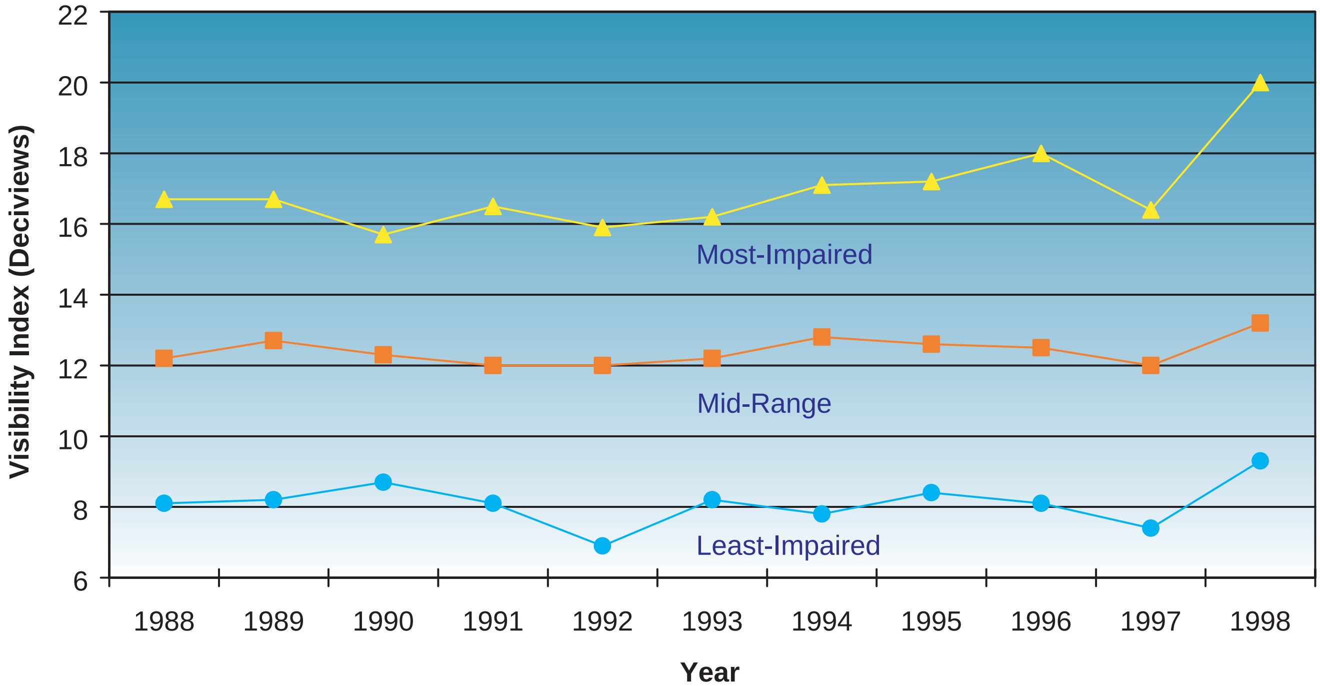

Figure TX–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Big Bend IMPROVE Particulate Sampler

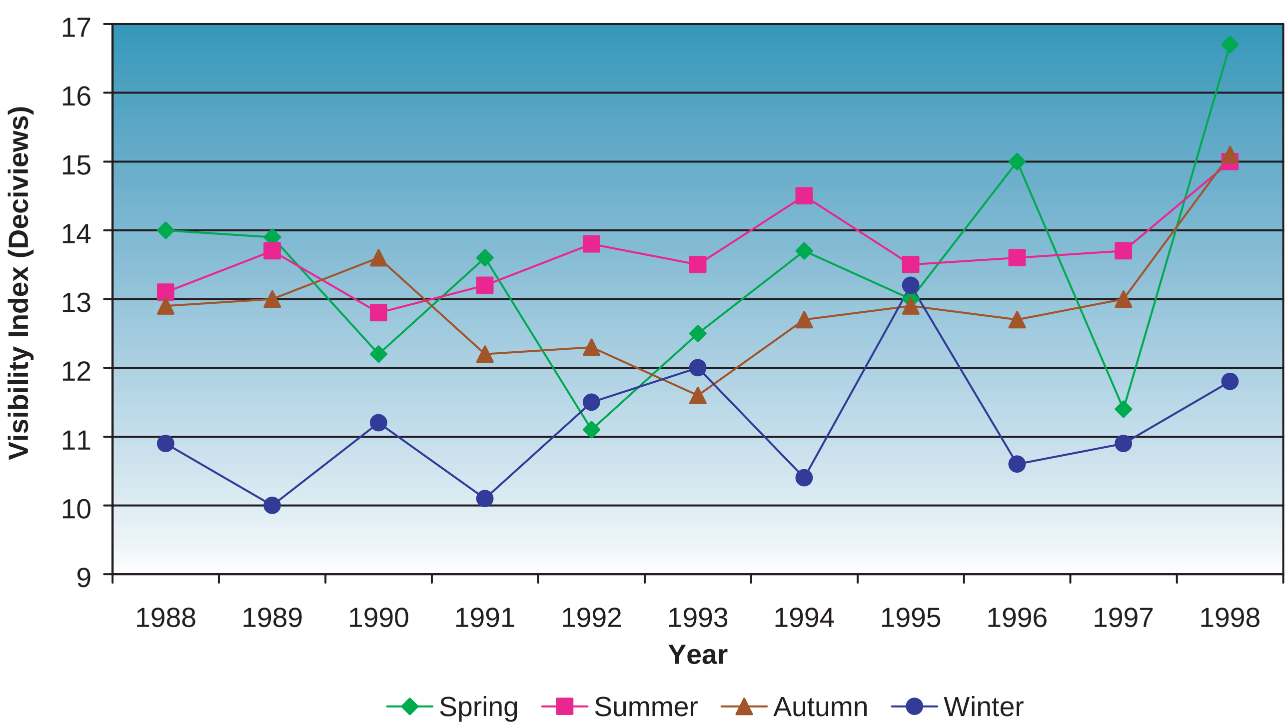

Figure TX–3. Seasonal Deciview Averages from 1988–1998 for the Big Bend IMPROVE Particulate Sampler

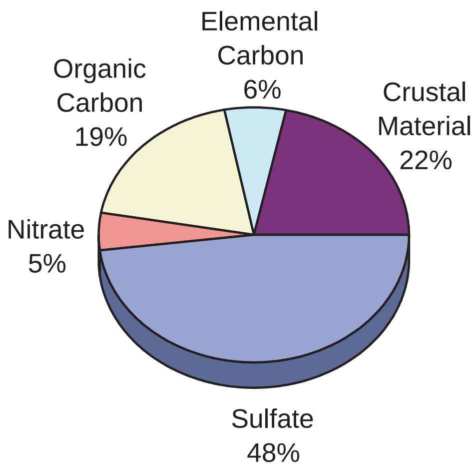

Figure TX–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Big Bend IMPROVE Particulate Sampler

Figure TX–4 presents a chart showing the calculated fractional contribution to Big Bend's light extinction by each aerosol species on an annual basis. Figure TX–5 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles. Sulfate particles were responsible for 39 to 59 percent of the light extinction at the Big Bend site, averaging 48 percent on an annual basis over a five-year period. The contributions from sulfates were highest in the autumn and lowest in the spring. Organic carbon contributions ranged from 16 to 24 percent. The contributions from nitrate and elemental carbon were near 5 and 6 percent year-round. Crustal material percentage contributions were only 14 percent in the autumn, but near 24 percent for the rest of the year.

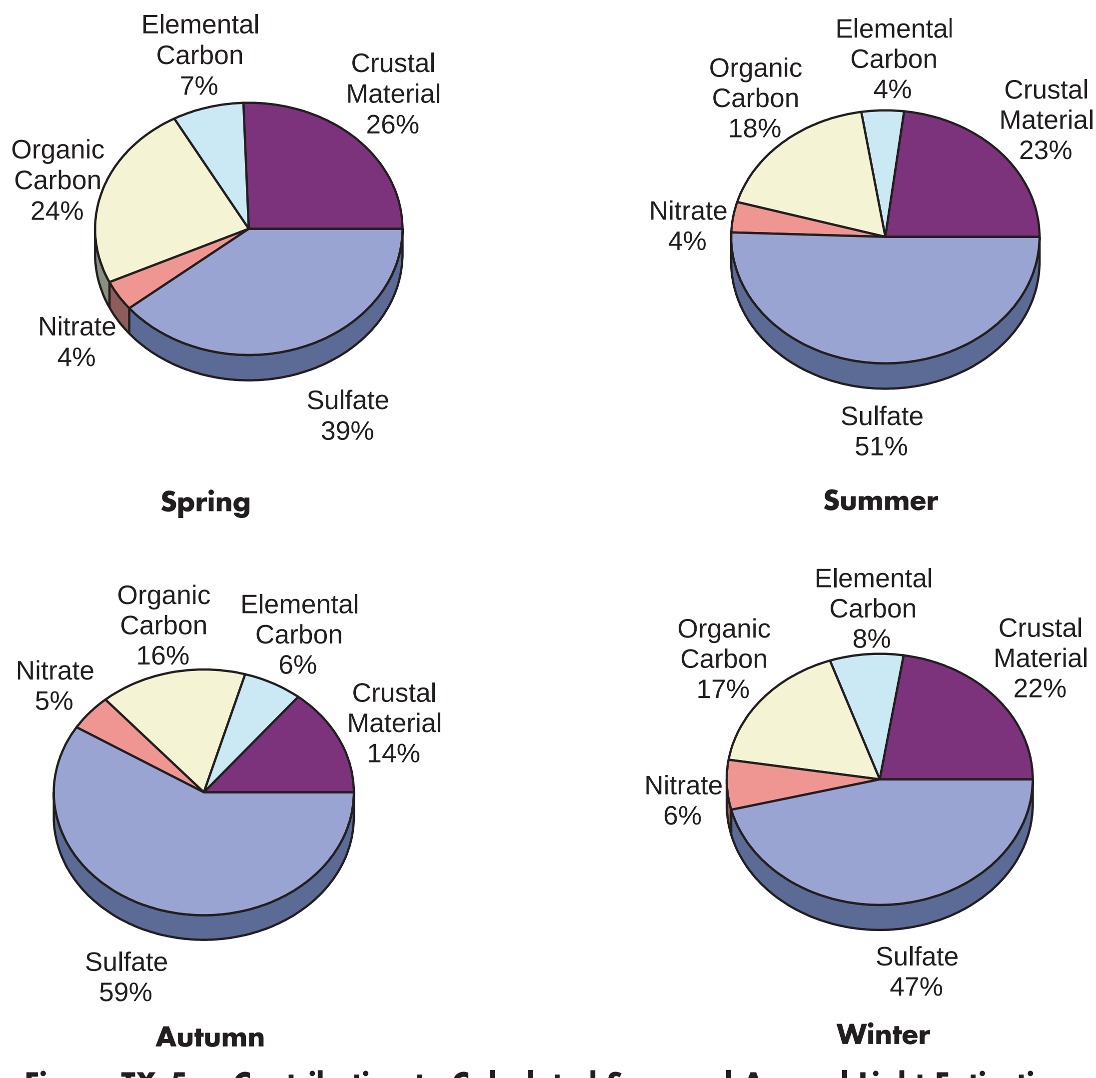

Figure TX–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Big Bend IMPROVE Particulate Sampler

Figure TX–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Big Bend site from 1988 to 1998. The total annual aerosol light extinctions remained between 24 and 34 Mm^{-1}. The 1998 average showed considerably higher concentrations of sulfate, organic carbon, and elemental carbon. Despite a higher value in 1998, there was no statistically significant trend in visibility. The sulfate contribution during this time period increased from 11 to 14 Mm^{-1}, with a significant trend toward higher sulfate concentrations and greater contributions to light extinction coefficients. The annual light extinctions for organic carbon, elemental carbon, and crustal material showed no significant trends over this time period.

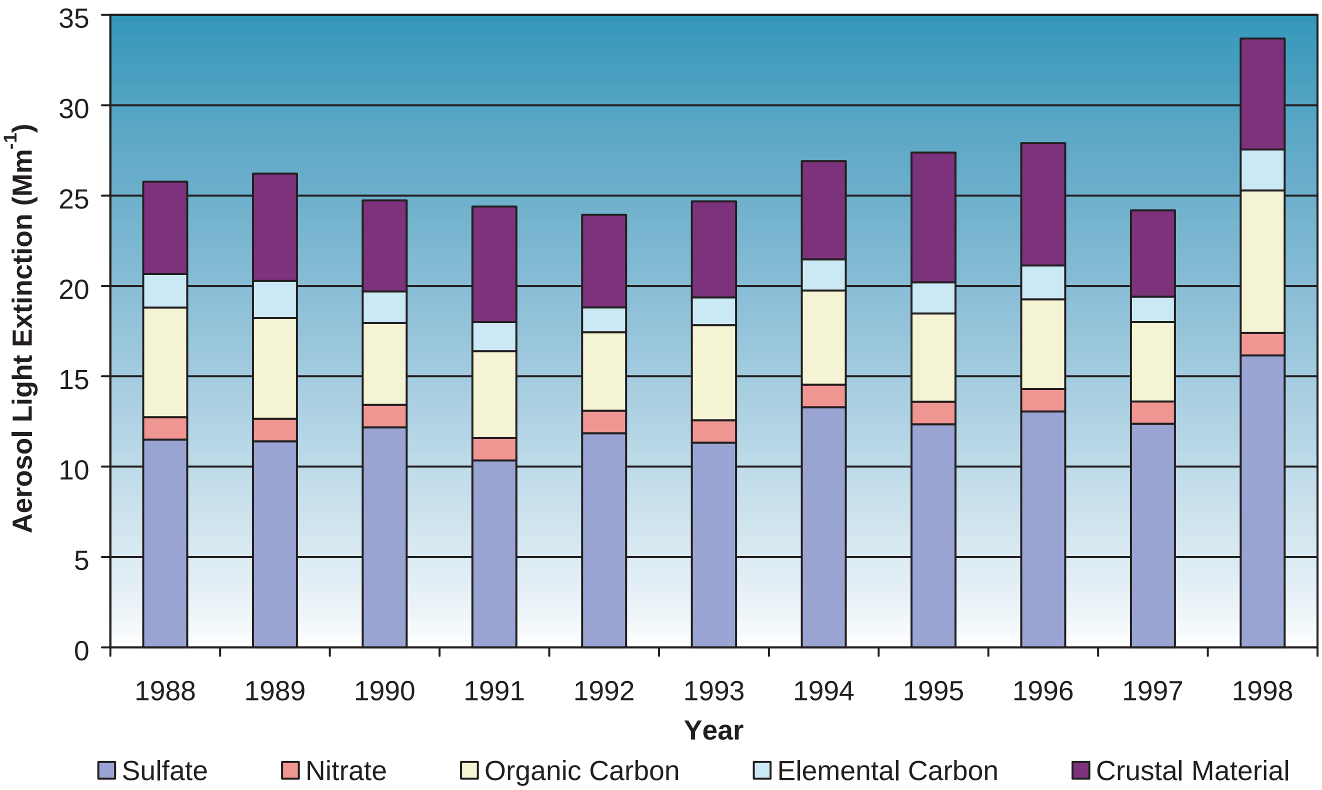

Figure TX–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Big Bend IMPROVE Particulate Sampler

Guadalupe Mountains National Park

The Guadalupe Mountains IMPROVE particulate monitoring site started reporting data in March of 1988. Figure TX–7 presents the calculated visibility indices for selected data sets in 1988 through 1998. While the visibility index for the most-impaired days ranged from 14 to 17 deciviews (VR 60 to 45 miles), there was no statistically significant trend in visibility. While the visibility indices of the mid-range data ranged from 10 to 13 deciviews (VR 90 to 65 miles), there was no significant trend in visibility. The indices on the least-impaired days remained near 8 deciviews (VR 110 miles), with no significant trend in visibility.

Figure TX–8 shows the seasonal averages for the calculated visibility index from 1988 through 1998. A summary value for autumn 1996 was not reported by CIRA, and this is reflected in Figure TX–8. Readers interested in the autumn 1996 data should go to http://improve.cnl.ucdavis.edu/cgi-bin/SSDisplay.cgi. Most of the visibility indices for the four seasons were between 10 and 14

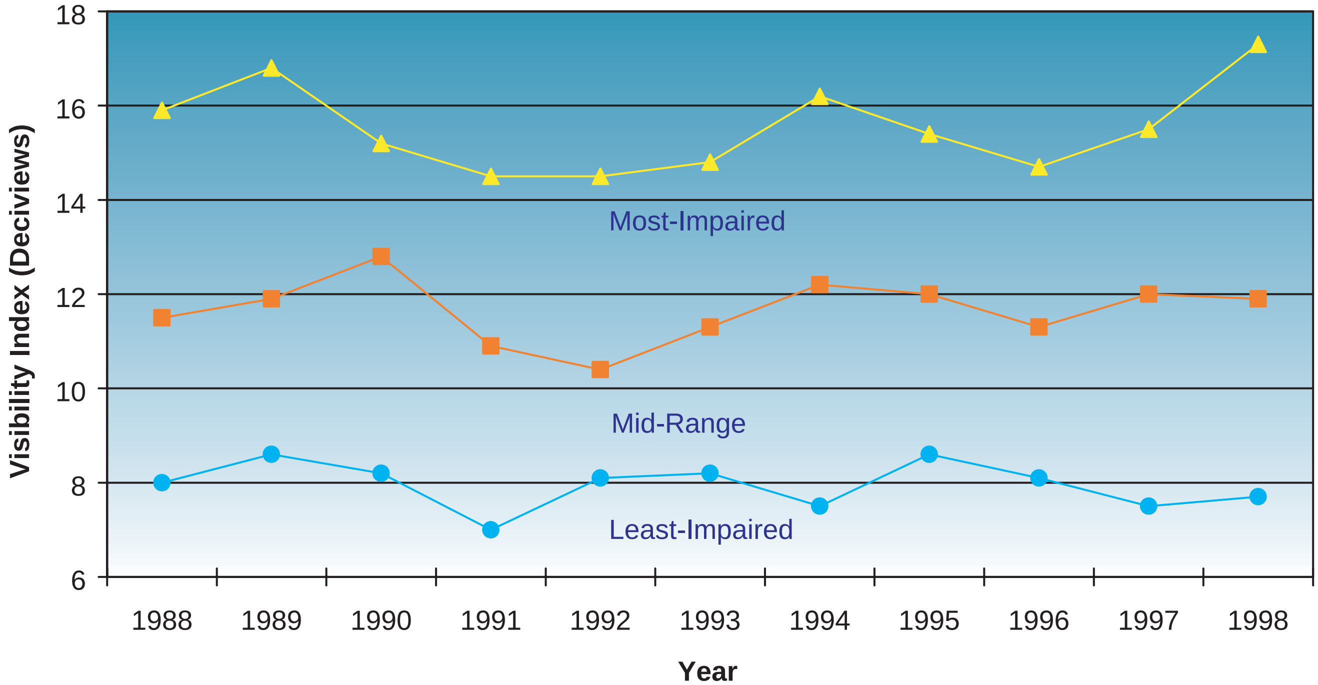

Figure TX–7. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Guadalupe Mountains IMPROVE Particulate Sampler

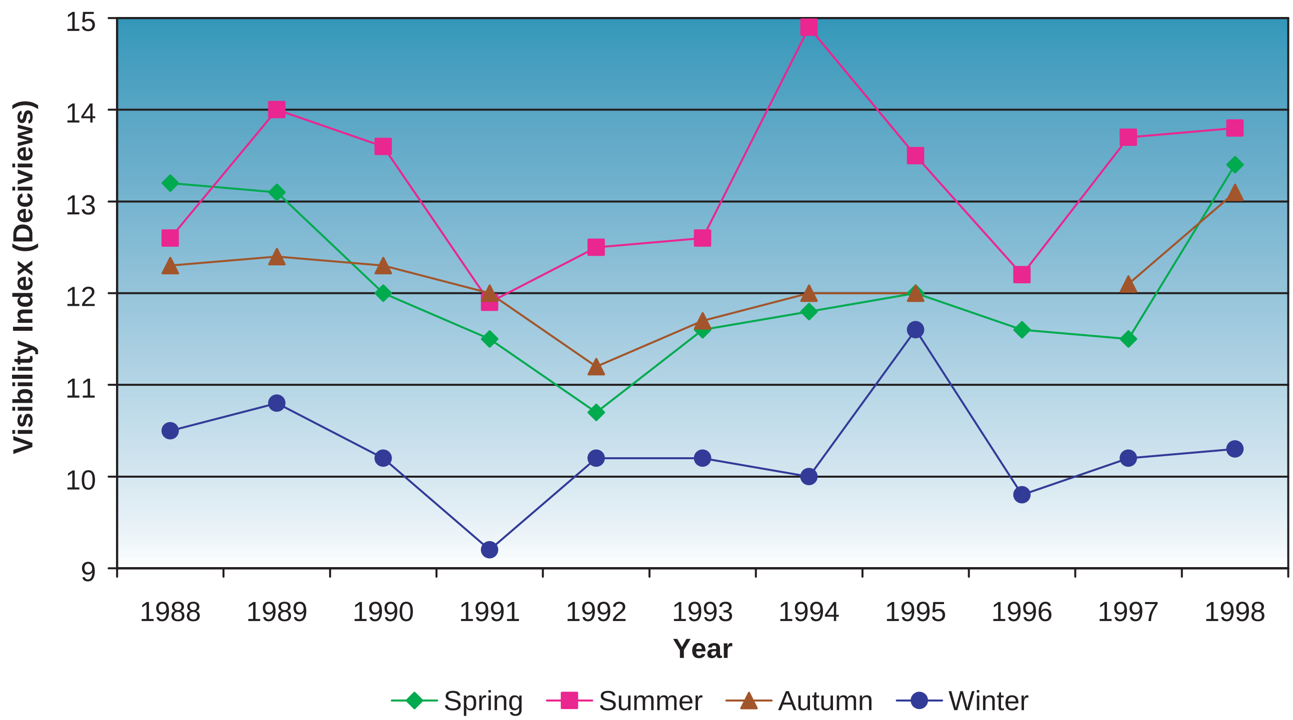

Figure TX–8. Seasonal Deciview Averages from 1988–1998 for the Guadalupe Mountains IMPROVE Particulate Sampler

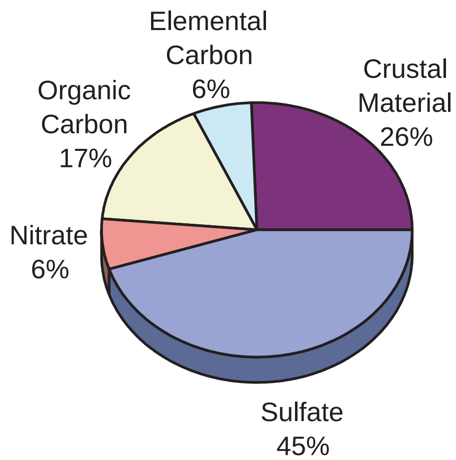

Figure TX–9. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Guadalupe Mountains IMPROVE Particulate Sampler

deciviews, with winter values always being the lowest and summer most frequently the highest. The visibility indices for all four seasons showed no statistically significant trends over the eleven-year period.

Figure TX–9 presents a chart showing the calculated fractional contribution to Guadalupe Mountain's light extinction by each aerosol species on an annual basis. Figure TX–10 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles. Sulfate particles were responsible for 33 to 53 percent of the light extinction at the Guadalupe Mountains site, averaging 45 percent on an annual basis over a five-year

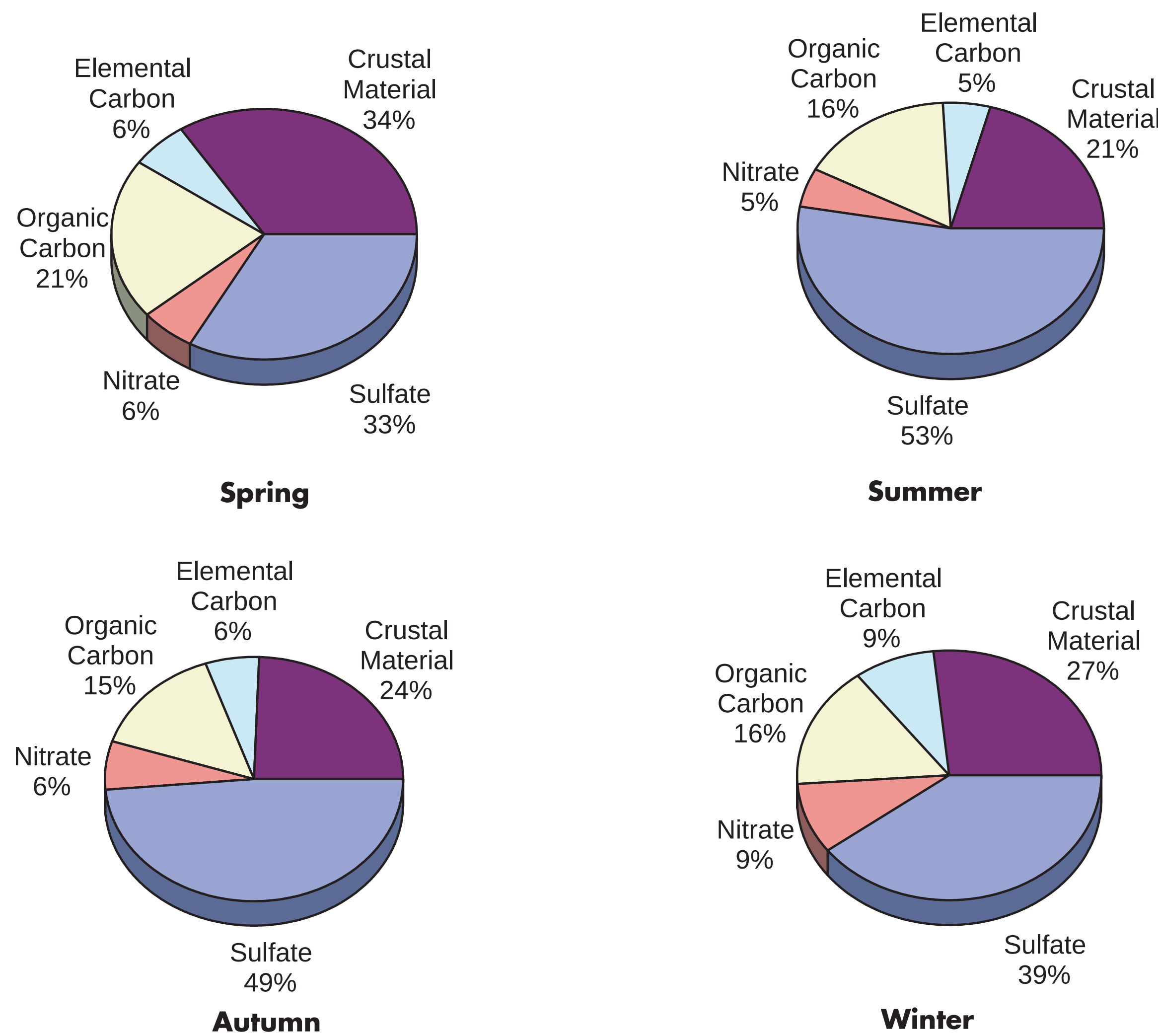

Figure TX–10. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Guadalupe Mountains IMPROVE Particulate Sampler

period. The contributions from sulfates were lower in the spring than the other three seasons. The contributions from nitrate, organic carbon, and elemental carbon were near 6, 17, and 6 percent year-round. Crustal material percentage contributions were 34 percent in the spring but near 21 percent for the rest of the year.

Figure TX–11 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Guadalupe Mountains site from 1988 to 1998. During the eleven-year period, the total annual aerosol light extinctions ranged from 20 to 26 Mm^{-1} with no statistically significant trend in visibility. The annual light extinctions for sulfates, elemental carbon, and crustal material showed no significant trends over this time period. However, the annual light extinction contributions from the organic carbon species showed a statistically significant trend toward lower concentrations and lower contributions to light extinction coefficients.

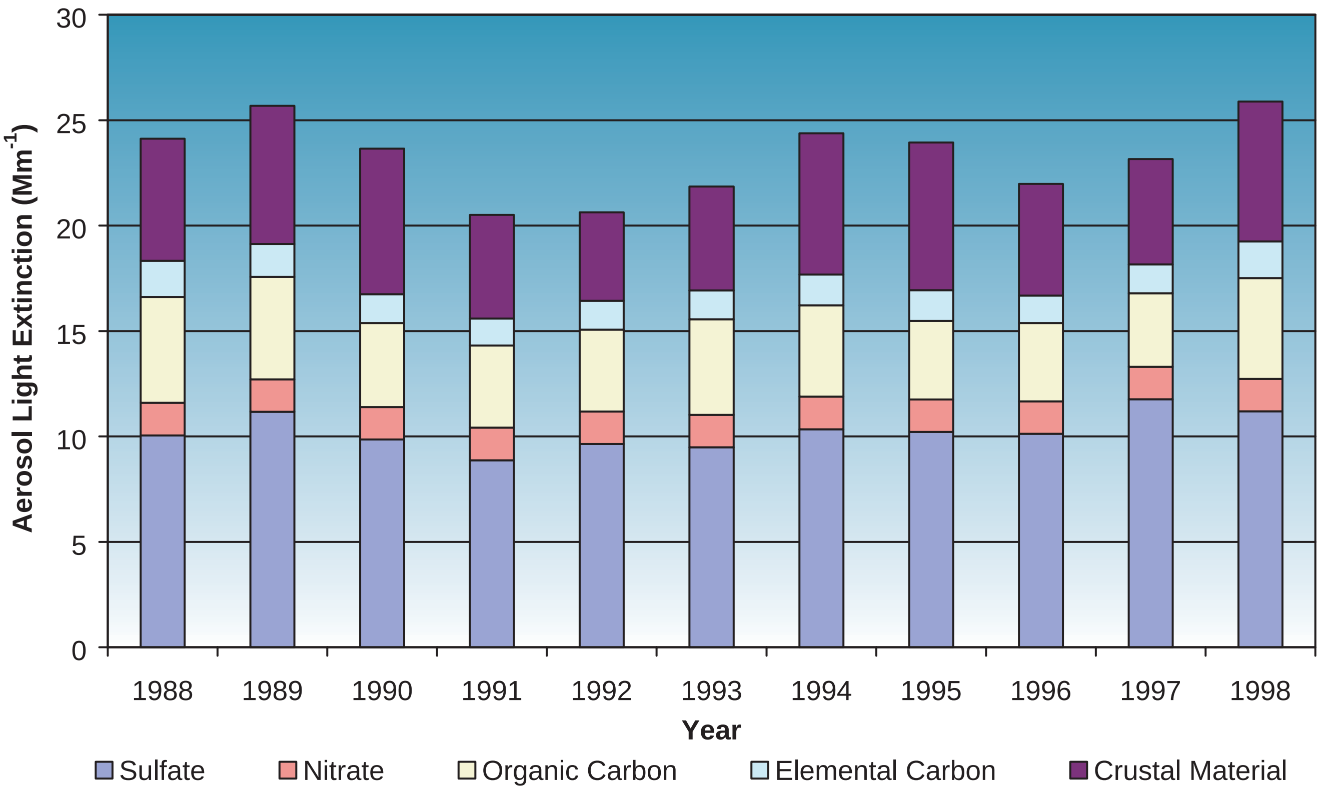

Figure TX–11. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Guadalupe Mountains IMPROVE Particulate Sampler

Texas State Summary

The calculated annual average aerosol light extinction coefficients at the two Texas IMPROVE monitoring sites are presented in Table TX–1. The calculated total aerosol extinction coefficient at the Guadalupe Mountains site was just fifteen percent lower than that at Big Bend. The extinction coefficients for the individual species were also similar (within 30 percent of one another) at both sites. Both sites showed similar rankings for contributions of the species to light extinction: sulfate, followed by crustal material, organic carbon, elemental carbon, and lastly nitrate. The same general rankings were observed for the Arizona, Colorado, and Wyoming sites in Tables AZ–1, CO–1, and WY–1.

Table TX–1. Texas Calculated Total Extinction Coefficients from 1994–1998

IMPROVE Site	Calculated Total Aerosol Extinction Coefficient (Mm^{-1})	Pollutant Extinction Coefficient (Mm-1)				
		Sulfate	Nitrate	Organic Carbon	Elemental Carbon	Crustal Material
Big Bend NP	28.0	13.4	1.2	5.5	1.8	6.1
Guadalupe Mtns NP	23.9	10.7	1.5	4.0	1.5	6.1

20. UTAH

Figure UT–1 shows the five national parks located in Utah that are mandatory Federal Class I areas: Zion, Bryce Canyon, Capitol Reef, Canyonlands, and Arches. IMPROVE particulate samplers that operated between 1994 and 1998 are located in Bryce Canyon (37.62°N, 112.17°W, elevation 8000 feet) and Canyonlands (38.45°N, 109.82°W, elevation 5900 feet). Additional monitors are expected to be installed in Arches and Capitol Reef. An additional IMPROVE protocol particulate sampler is located near the Lone Peak Wilderness Area at Timpanogas Caves National Monument (between Salt Lake City and Provo), but this area is not a mandatory Federal Class I area and is not discussed in this chapter of the report.

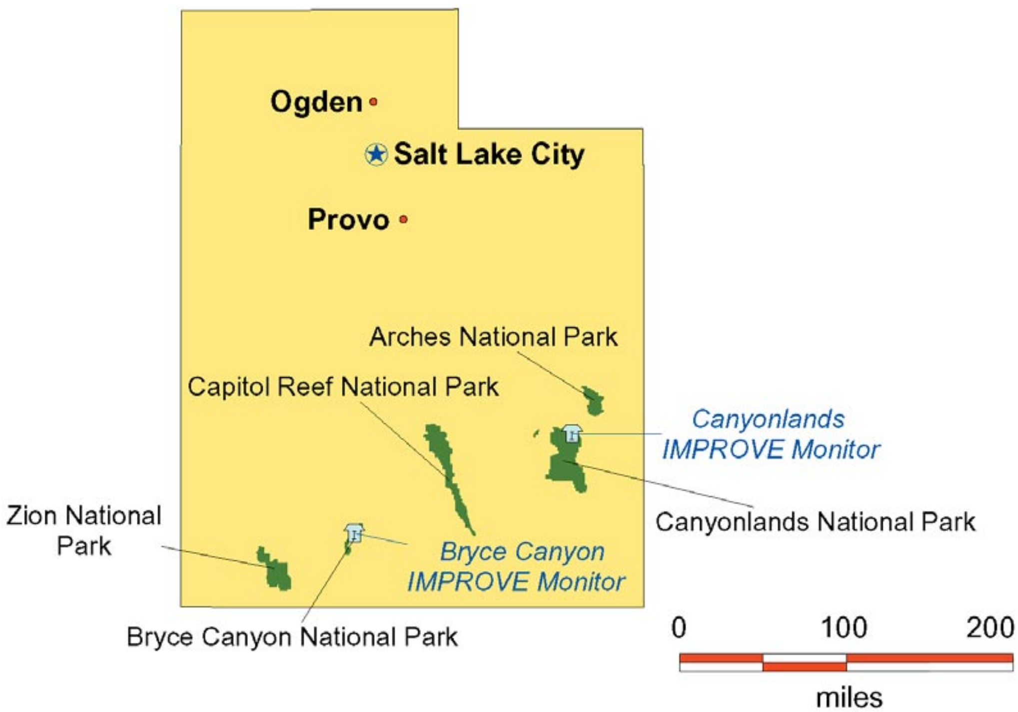

Figure UT–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Sites in Utah

Bryce Canyon National Park

The Bryce Canyon IMPROVE particulate sampler started reporting data in March of 1988. Figure UT–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most-impaired days generally remained between 12 and 14 deciviews (VR 75 to 60 miles). There was no statistically significant trend in visibility. The visibility indices on the mid-range days ranged from 8 to 10 deciviews (VR 110 to 90 miles), with no significant trend toward improved visibility. The indices on the least-impaired days remained near 5 deciviews (VR 150 miles), with no significant trend toward improved visibility.

Figure UT–3 shows the seasonal averages for the calculated visibility indices from 1988 through 1998. The indices for the spring and summer were generally 2 deciviews higher the autumn values, and

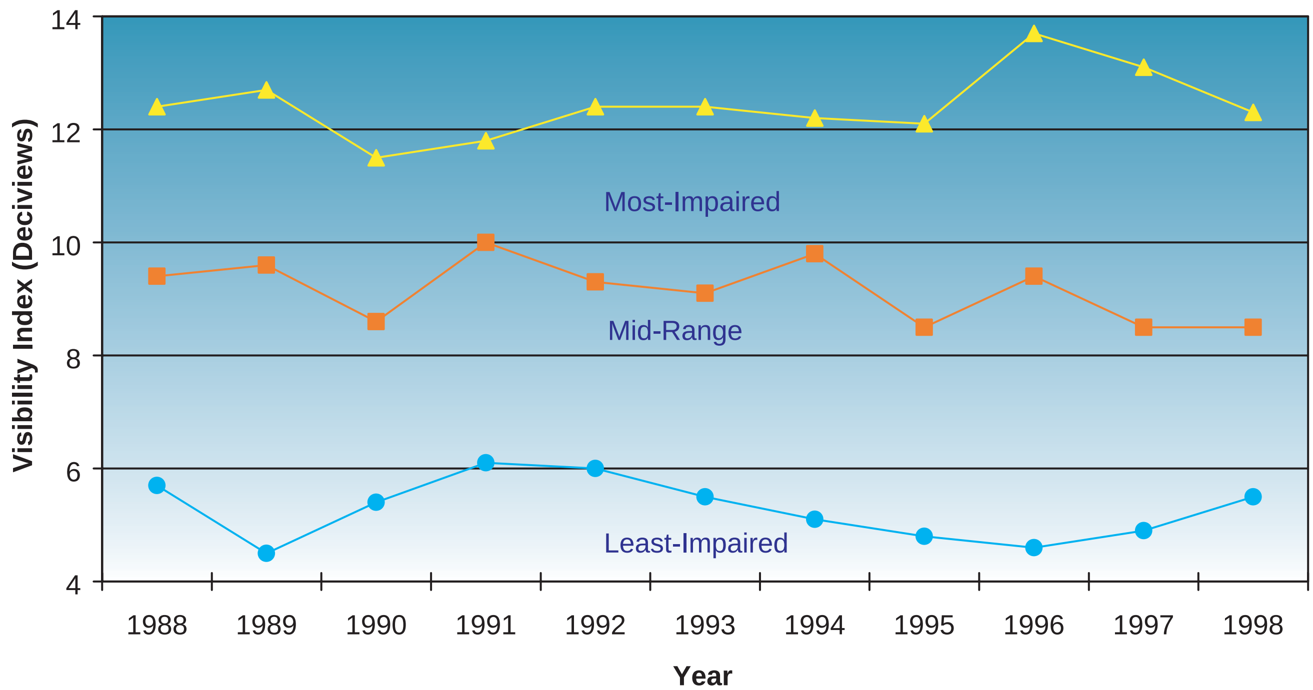

Figure UT–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Bryce Canyon IMPROVE Particulate Sampler

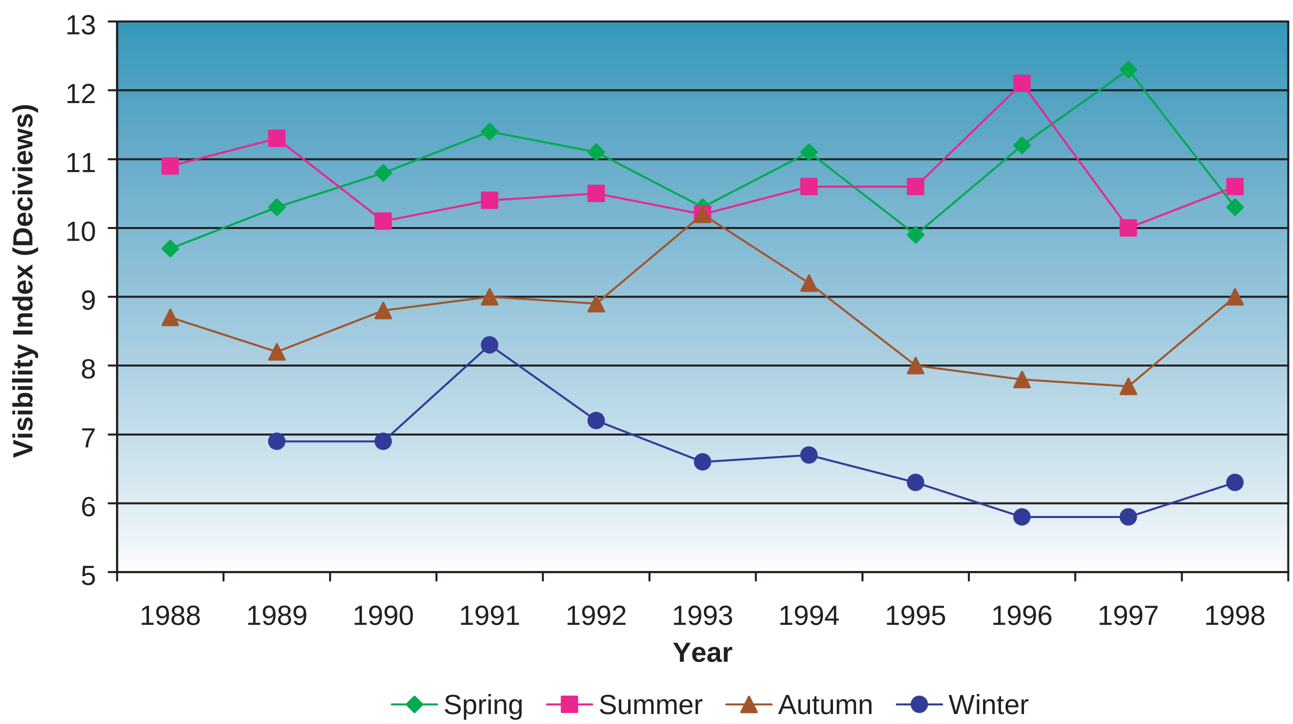

Figure UT–3. Seasonal Deciview Averages from 1988–1998 for the Bryce Canyon IMPROVE Particulate Sampler

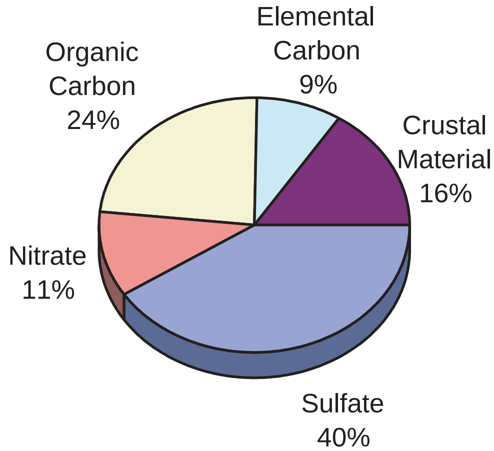

Figure UT–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Bryce Canyon IMPROVE Particulate Sampler

the autumn values were approximately 2 deciviews higher than the indices for winter. The visibility indices for the spring, summer, and autumn showed no statistically significant trends over the eleven-year period. However, the indices for winter decreased approximately 1.5 deciviews from 1989 to 1998, indicating a statistically significant trend toward improved visibility.

Figure UT–4 presents a chart showing the calculated fractional contribution to Bryce Canyon's light extinction by each aerosol species on an annual basis. Figure UT–5 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles. Sulfate particles were responsible for 37 to 45 percent of the light extinction at the Bryce Canyon site, averaging 40 percent on an annual basis over a five-year period. The contributions from sulfates were slightly lower in the winter than the other

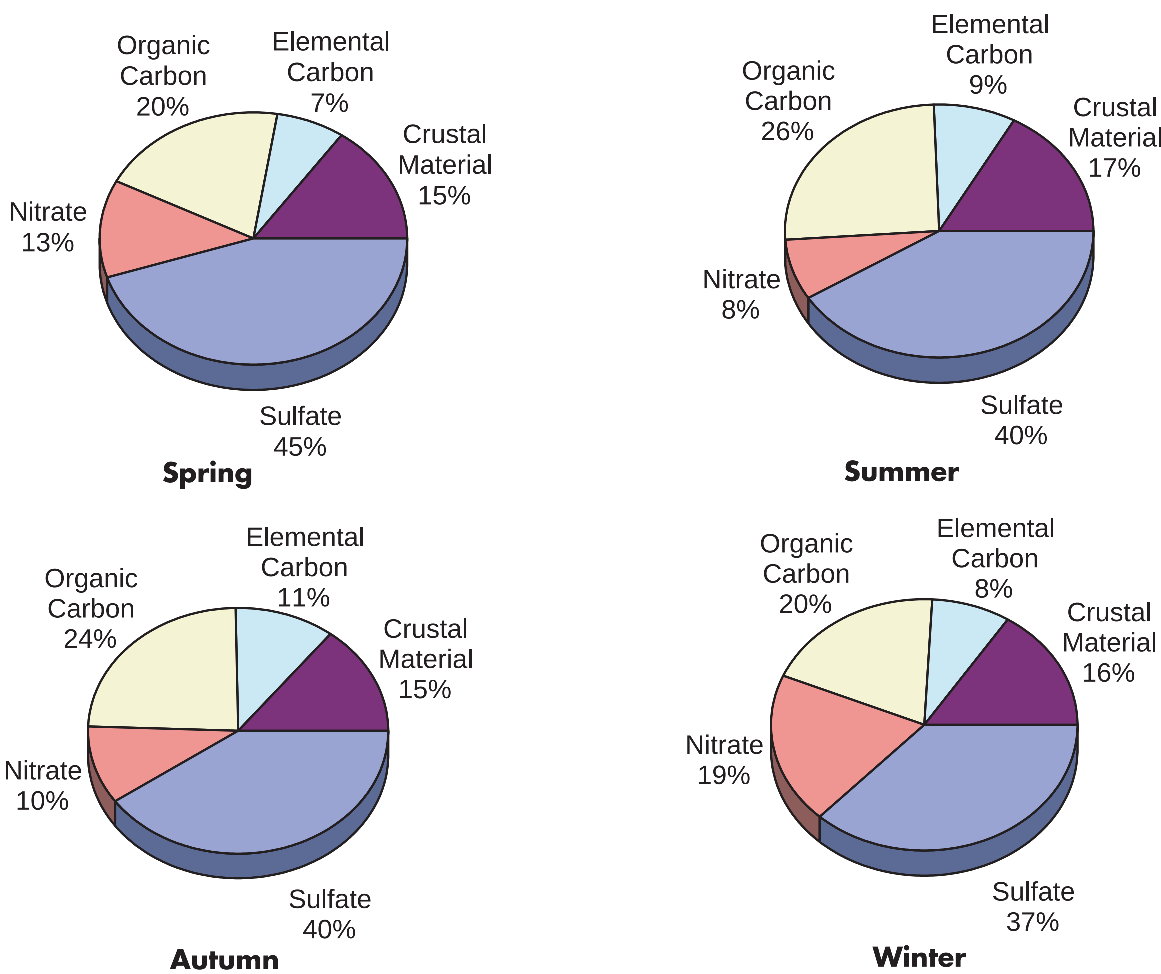

Figure UT–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Bryce Canyon IMPROVE Particulate Sampler

seasons. Nitrate contributions were near 9 percent in the summer and autumn, but rose to 19 percent during winter. The contributions from organic carbon, elemental carbon, and crustal material were near 24, 9, and 16 percent year-round.

Figure UT–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Bryce Canyon site from 1988 to 1998. The total annual aerosol light extinction remained near 15 Mm^{-1} with no statistically significant trend that would indicate improved visibility. The sulfate contributions during this time period decreased approximately 1 Mm^{-1}, indicating a significant trend toward lower sulfate concentrations and contributions to light extinction coefficients. The annual light extinctions for organic carbon, elemental carbon, and crustal material showed no significant trends over this time period.

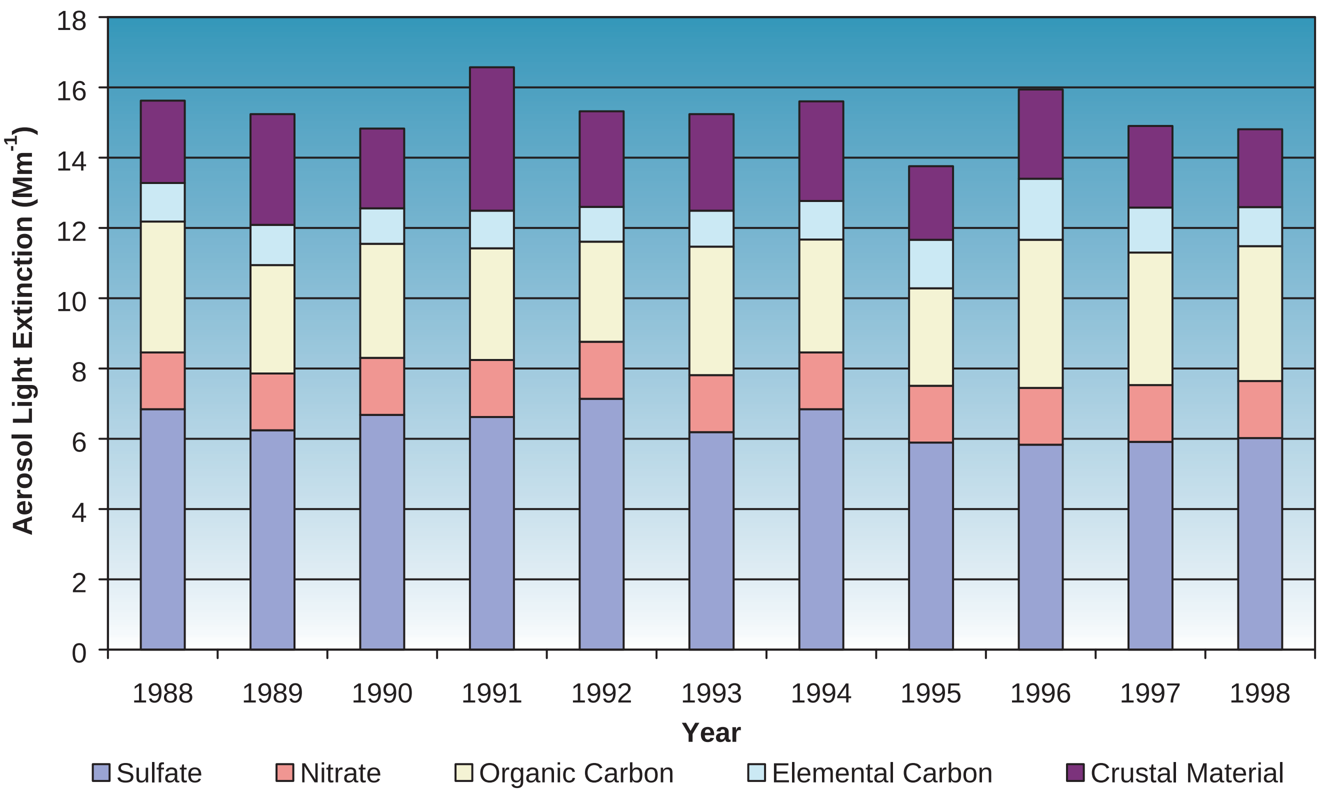

Figure UT–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Bryce Canyon IMPROVE Particulate Sampler

Canyonlands National Park

The Canyonlands IMPROVE particulate sampler started reporting data in March of 1988. Figure UT–7 presents the calculated visibility indices for selected data sets from 1988 through 1998. The indices for the most-impaired days showed a statistically significant trend indicating improvements in visibility. The figure shows that the visibility index for the most-impaired days decreased from more than 12 to nearly 11 deciviews (VR 75 to 80 miles). The visibility indices on the mid-range days remained near 9 deciviews (VR 100 miles), exhibiting no significant trend. The indices on the least-impaired days remained near 6 deciviews (VR 135 miles).

Figure UT–8 shows the seasonal averages for the calculated visibility index from 1988 through 1998. CIRA did not report a summary value for winter 1988, so it was not included in Figure UT–8. Interested readers can view the species data at http://improve.cnl.ucdavis.edu/cgi-bin/SSDisplay.cgi. Most of the visibility indices for the four seasons were between 8 and 11 deciviews, with no single season continually showing the highest or lowest values. Despite the drop in winter values from 1990 to 1995, the visibility indices for all four seasons showed no statistically significant trends over the eleven-year period.

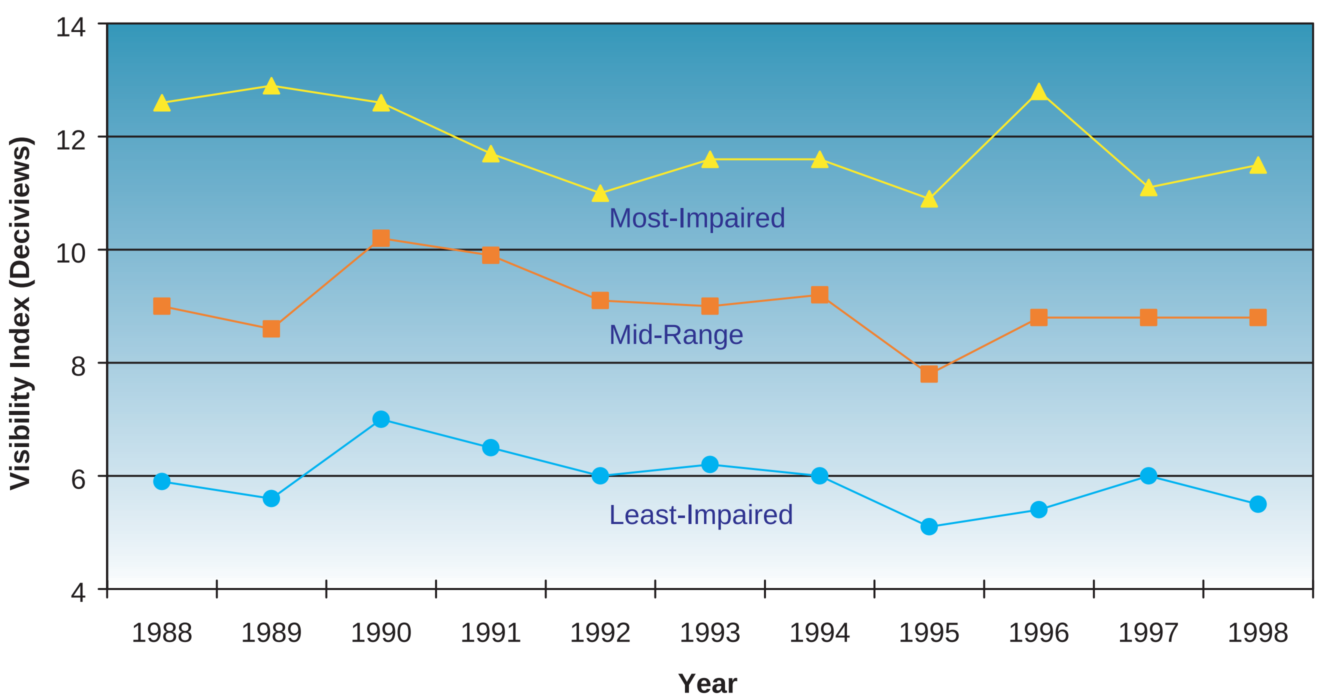

Figure UT–7. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Canyonlands IMPROVE Particulate Sampler

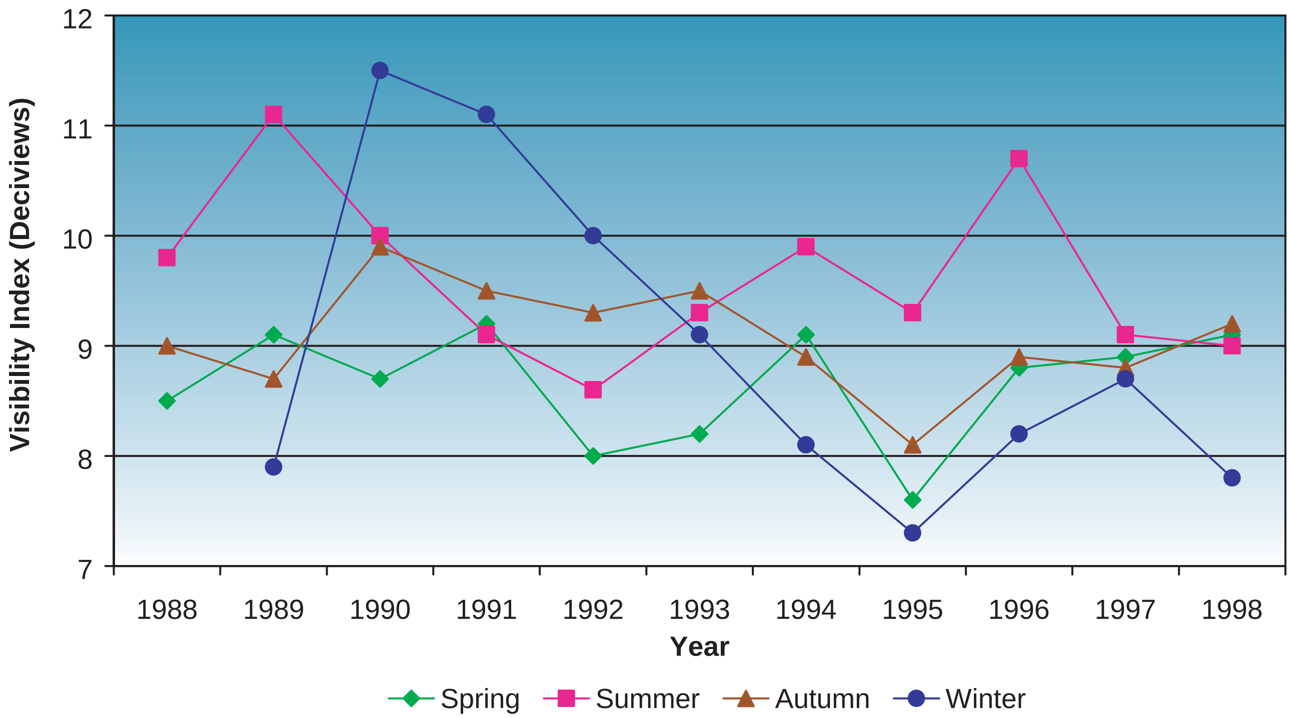

Figure UT–8. Seasonal Deciview Averages from 1988–1998 for the Canyonlands IMPROVE Particulate Sampler

Figure UT–9 presents a chart showing the calculated fractional contribution to Canyonland's light extinction by each aerosol species on an annual basis. Figure UT–10 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles and crustal material. Sulfate particles were responsible for 29 to 38 percent of the light extinction at the Canyonlands site, averaging 34 percent on an annual basis over a five-year period. The contributions from sulfates were lower in the spring and summer than in the other seasons. Crustal material percentage contributions were 33 percent in the spring but 22 percent in the winter, and the average annual contribution was calculated to be 27 percent. The nitrate contributions were 12 percent in the winter but only near 6 percent through the rest of the year. The organic carbon contributions ranged from 17 percent in the winter to 28 percent in the summer. The contributions from elemental carbon were close to 10 percent year-round.

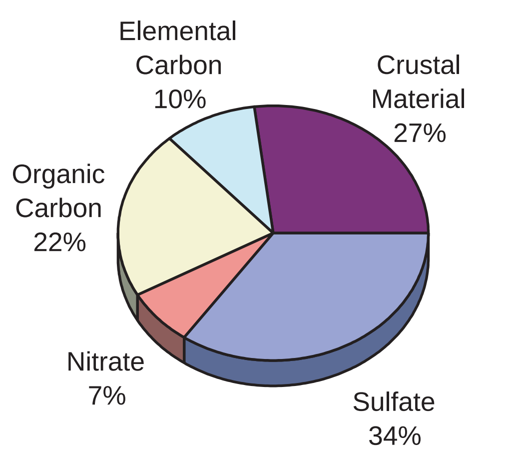

Figure UT–9. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Canyonlands IMPROVE Particulate Sampler

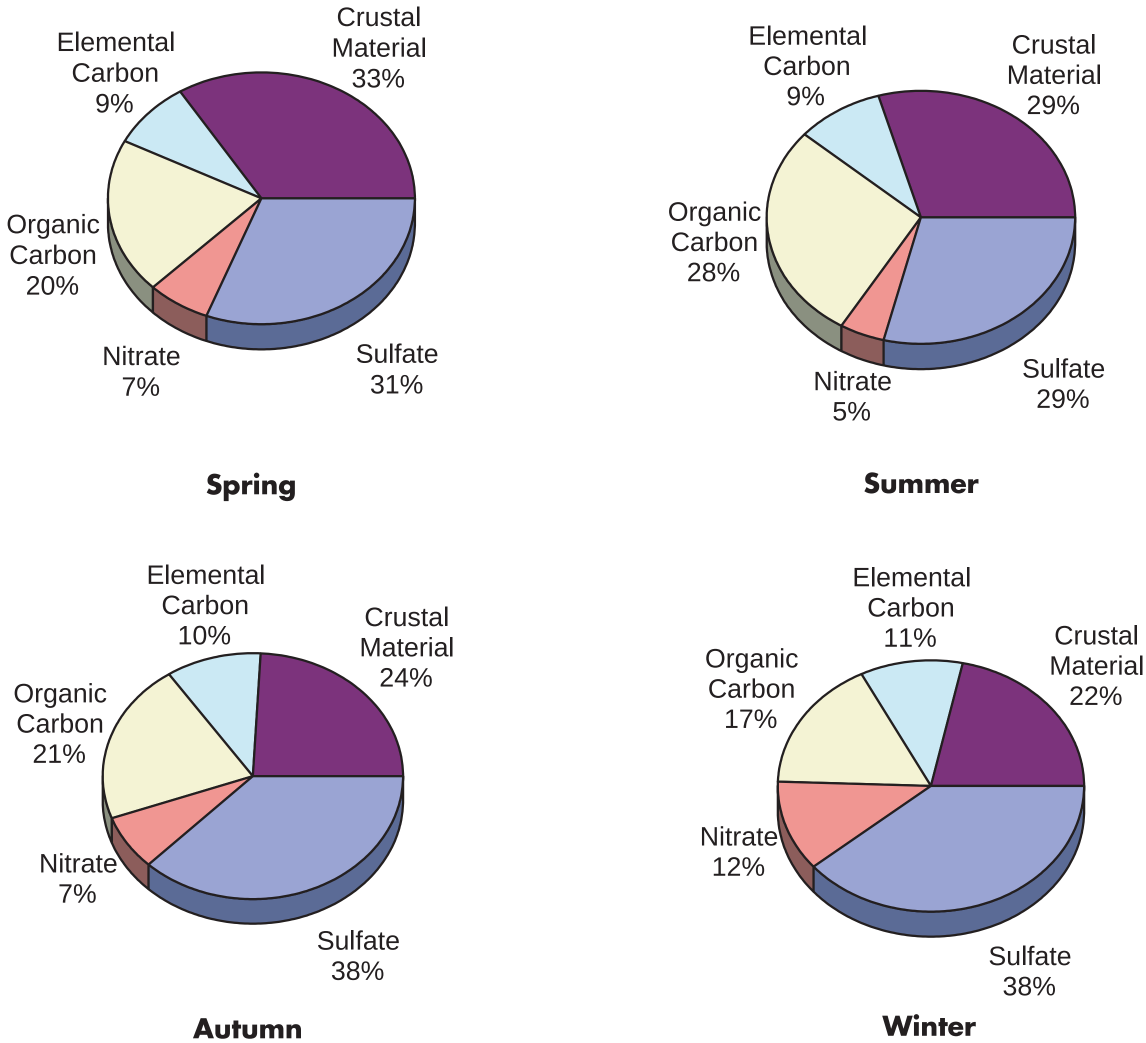

Figure UT–10. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Canyonlands IMPROVE Particulate Sampler

Figure UT–11 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Canyonlands site from 1988 to 1998. The total annual aerosol light extinctions dropped from near 16 to near 14 Mm^{-1} with a statistically significant trend toward improved visibility. The annual light extinctions for organic carbon, elemental carbon, and crustal material showed no significant trends over this time period. However, contributions of the sulfate species to the annual light extinction showed a statistically significant trend toward lower concentrations and contributions to light extinction coefficients.

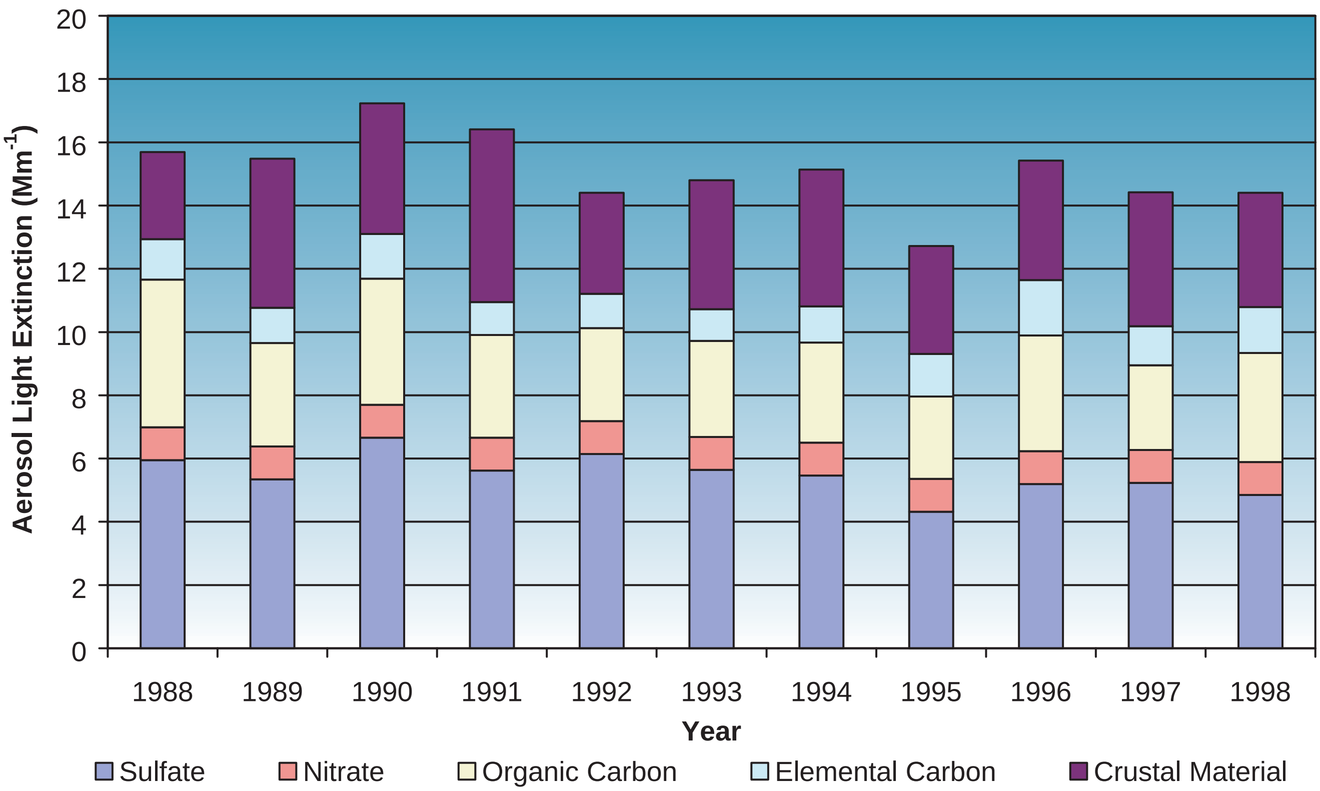

Figure UT–11. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Canyonlands IMPROVE Particulate Sampler

Utah State Summary

The calculated annual average aerosol extinction coefficients at Utah's IMPROVE monitor sites are presented in Table UT–1. The sites are located 140 miles apart. The calculated total aerosol extinction coefficients at the sites were within 5 percent of each other, indicating similar annual visibility conditions at both sites. The extinction coefficients for the individual species were also similar (within 40 percent) at the different sites. The ambient nitrate concentrations at both sites were similar (near 0.2 $\mu g/m^3$), but the nitrate extinction coefficient at Canyonlands was much lower than that at Bryce Canyon because the relative humidity was much lower at Canyonlands (Appendix C). Both sites also showed similar rankings for contributions of the species to light extinction: sulfate, followed by organic carbon and crustal material, and lastly, nitrate and elemental carbon.

Table UT–1. Utah Calculated Total Extinction Coefficients from 1994–1998

IMPROVE Site	Calculated Total Aerosol Extinction Coefficient (Mm^{-1})	Pollutant Extinction Coefficient (Mm^{-1})				
		Sulfate	Nitrate	Organic Carbon	Elemental Carbon	Crustal Material
Bryce Canyon NP	15.0	6.1	1.6	3.6	1.3	2.4
Canyonlands NP	14.4	5.0	1.0	3.1	1.4	3.9

21. VERMONT

Figure VT–1 shows the Lye Brook Wilderness Area in southern Vermont, Vermont's only mandatory Federal Class I area covered by the Regional Haze Rule. An IMPROVE particulate sampler (43.17°N, 73.12°W, elevation 3250 feet) is located at Lye Brook and has been operating since September 1991.

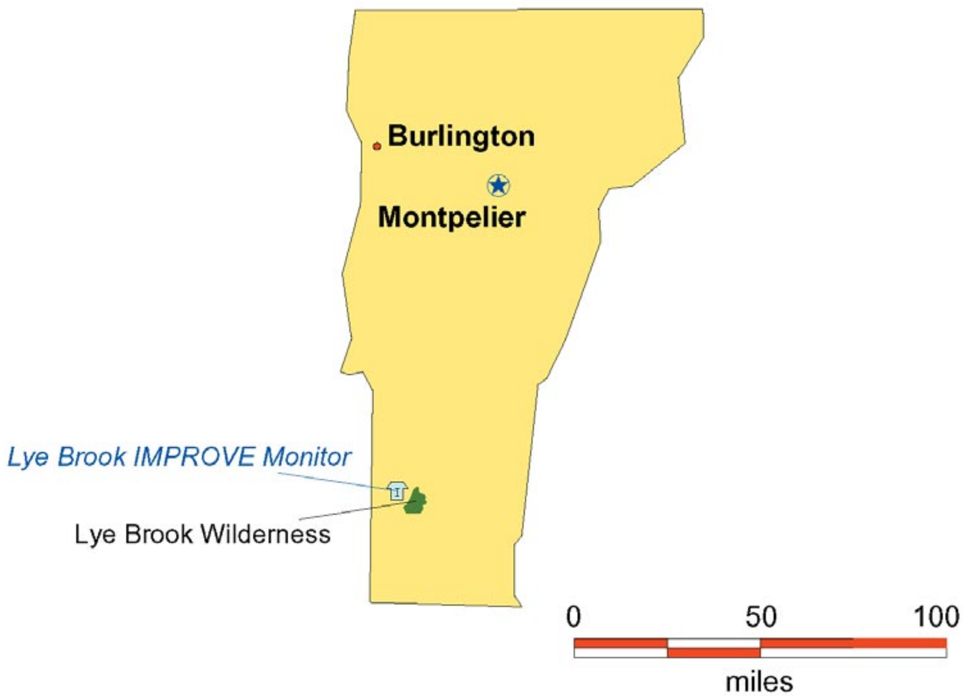

Figure VT–1. Mandatory Federal Class I Area and IMPROVE Monitoring Site in Vermont

Lye Brook Wilderness Area

The Lye Brook IMPROVE particulate sampler began reporting data in September of 1991. Figure VT–2 presents the calculated visibility indices for selected data sets from 1992 through 1998. The figure shows that the visibility index for the most-impaired days remained near 26 deciviews (VR 18 miles). There was no statistically significant trend in visibility. The visibility indices on the mid-range days remained near 16 deciviews (VR 50 miles), with no significant trend in visibility. The indices on the least-impaired days increased from 9 to 10 deciviews (VR 100 to 90 miles), with a significant trend toward declining visibility.

Figure VT–3 shows the seasonal averages for the calculated visibility indices from 1992 through 1998. Coarse mass measurements were not available for spring and summer 1992, so Figure VT–3 reports no values for these seasons. Interested readers can view the data for other species at http://improve.cnl.ucdavis.edu/cgi-bin/SSDisplay.cgi. The indices for summer were generally 5 deciviews higher the autumn values, and the autumn values were approximately 3 deciviews higher

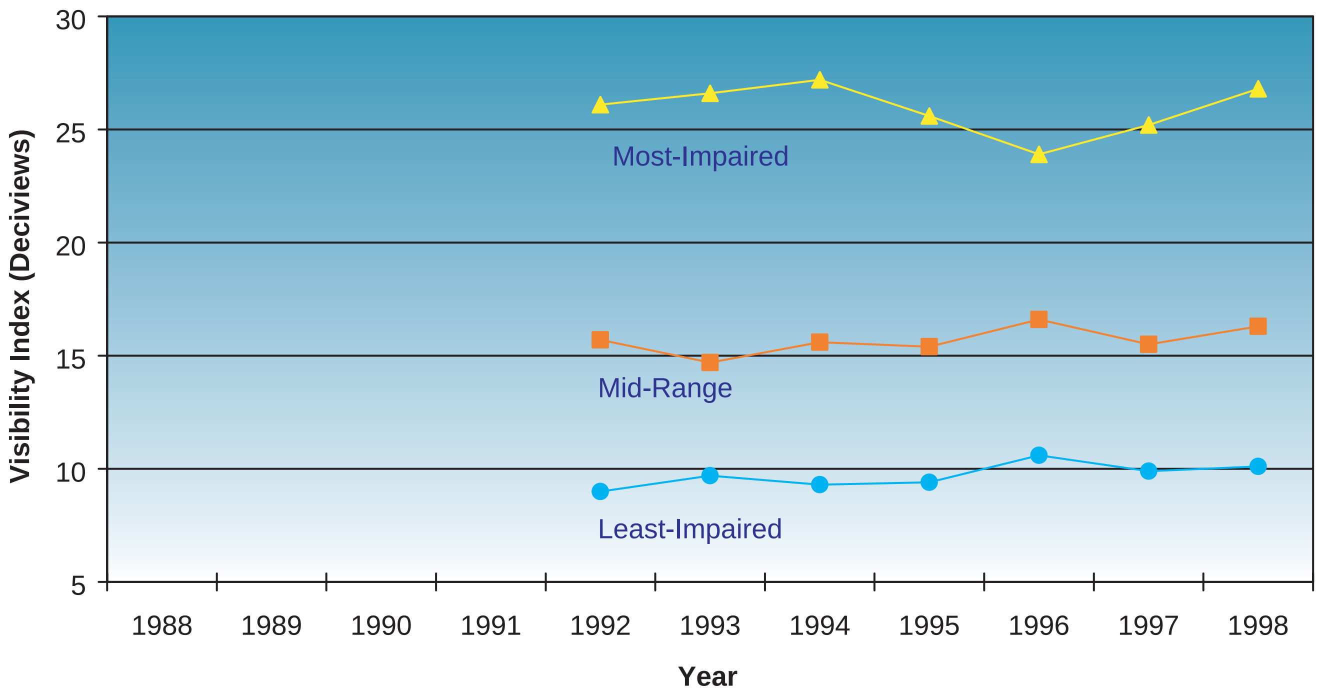

Figure VT–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1992–1998 for the Lye Brook IMPROVE Particulate Sampler

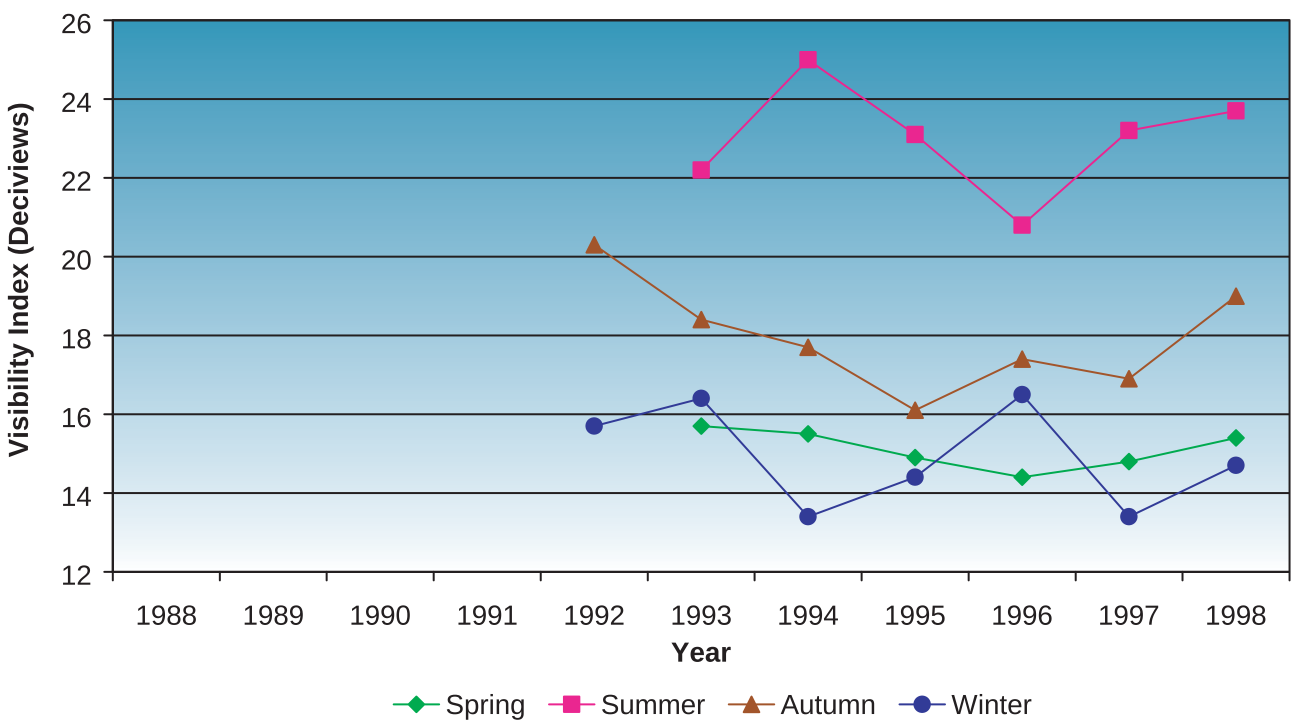

Figure VT–3. Seasonal Deciview Averages from 1992–1998 for the Lye Brook IMPROVE Particulate Sampler

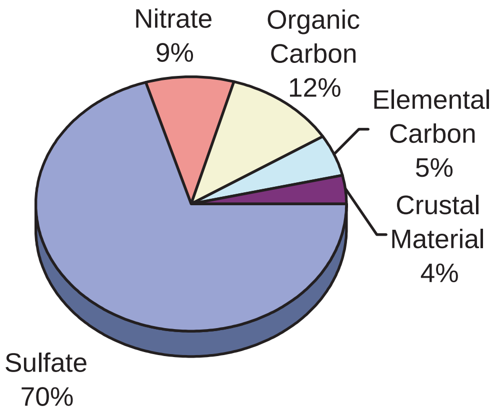

Figure VT–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Lye Brook IMPROVE Particulate Sampler

than the winter and spring indices. The visibility indices for all four seasons showed no statistically significant trends over the seven-year period.

Figure VT–4 presents a chart showing the calculated fractional contribution to the light extinction by each aerosol species on an annual basis. Figure VT–5 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles. Sulfate particles were responsible for 60 to 78 percent of the light extinction at the Lye Brook site, averaging 70 percent on an annual basis over a five-year period. The contributions from sulfates were lower in the winter and higher in the summer. Nitrate contributions were near 6 percent in the summer, but rose to 13 percent during the winter. The contributions from organic carbon, elemental carbon, and crustal material were near 12, 5, and 4 percent year-round.

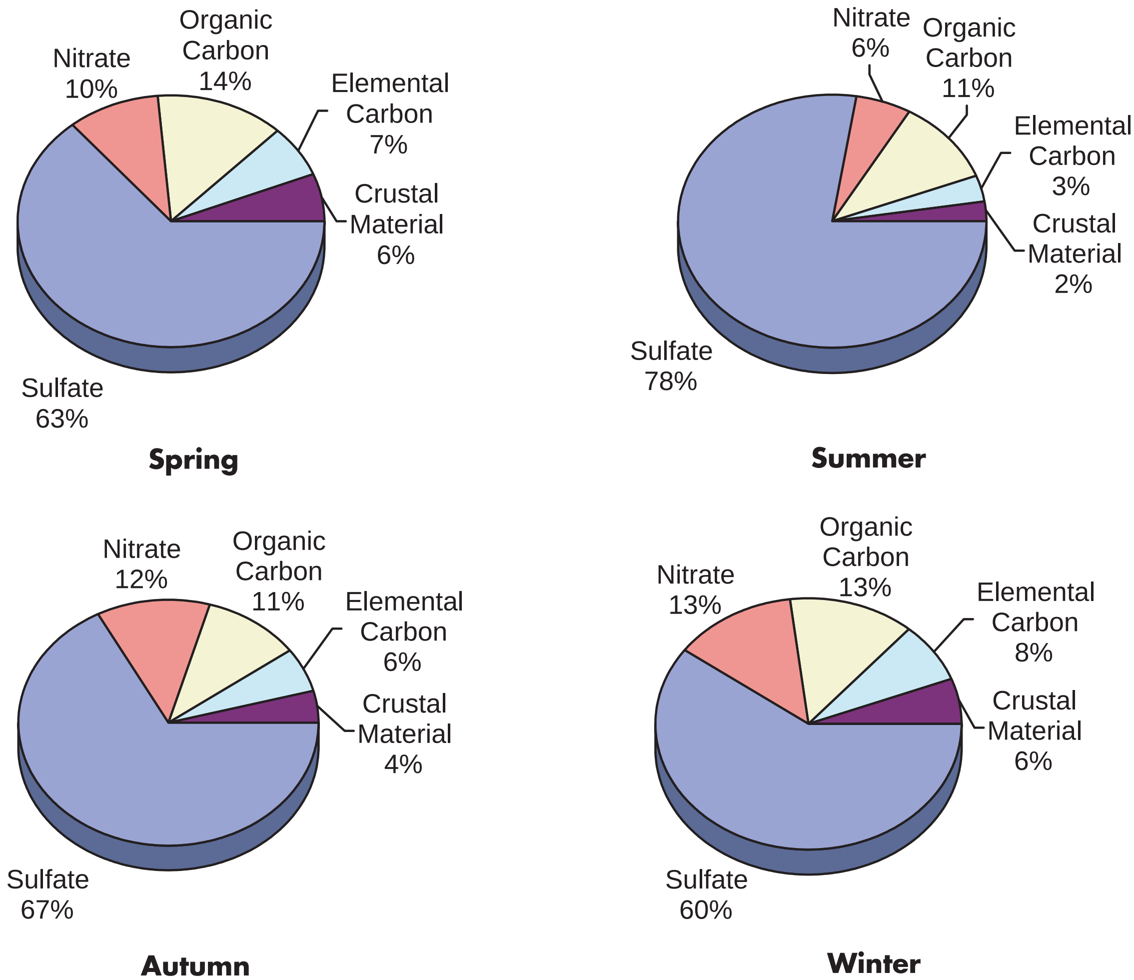

Figure VT–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Lye Brook IMPROVE Particulate Sampler

Figure VT–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Lye Brook site from 1992 to 1998. The total annual aerosol light extinctions remained near 50 Mm^{-1} with no statistically significant trend in visibility. The annual light extinctions for sulfates, organic carbon, elemental carbon, and crustal material showed no significant trends over this time period.

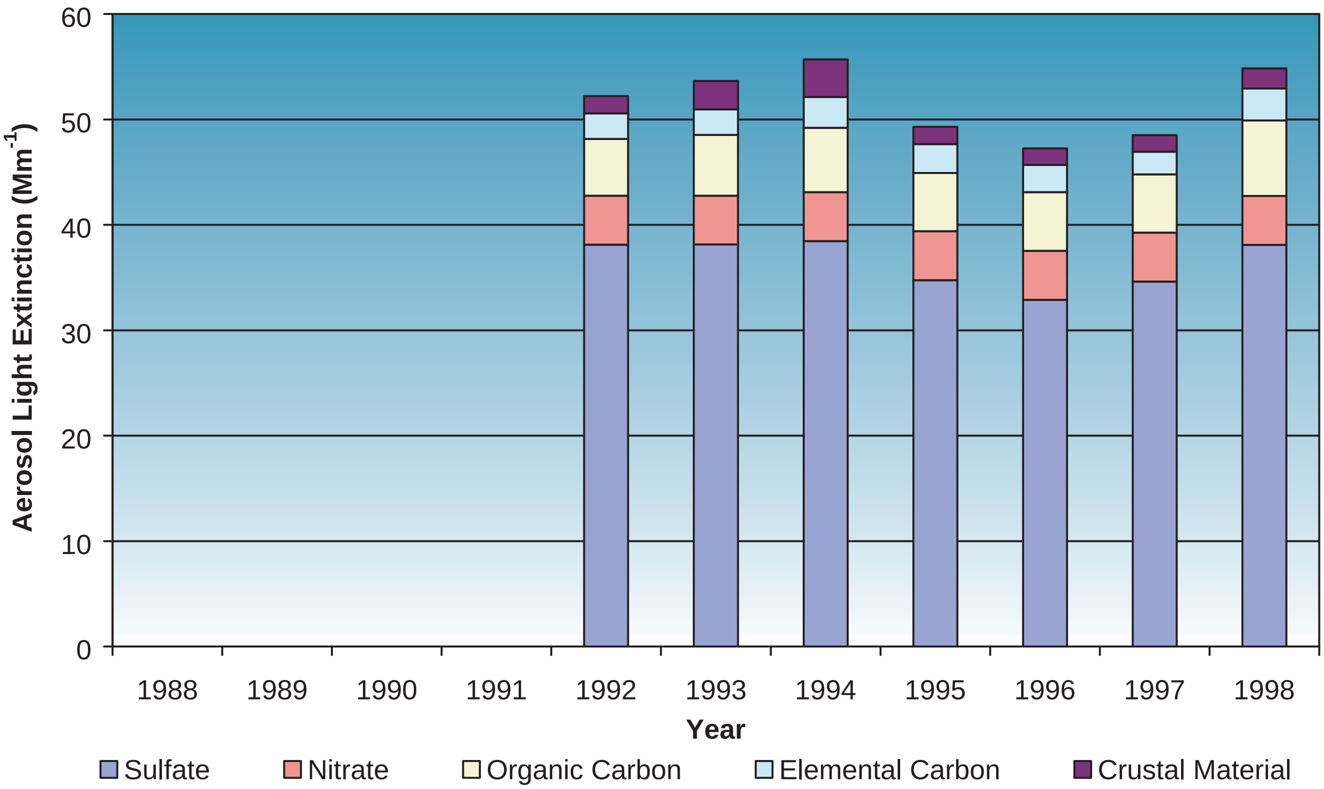

Figure VT–6. Contributions to Calculated Annual Aerosol Light Extinction from 1992–1998 for the Lye Brook IMPROVE Particulate Sampler

22. VIRGINIA

The only IMPROVE particulate sampler in Virginia that operated continuously from 1994 through 1998 was the one located in the Shenandoah National Park. Figure VA–1 shows the Shenandoah particulate sampler location (38.48°N, 78.12°W, elevation 3600 feet) in north-central Virginia. The James River Face Wilderness Area is also covered by the Regional Haze Rule but did not have an IMPROVE particulate sampler operating from 1994 through 1998.

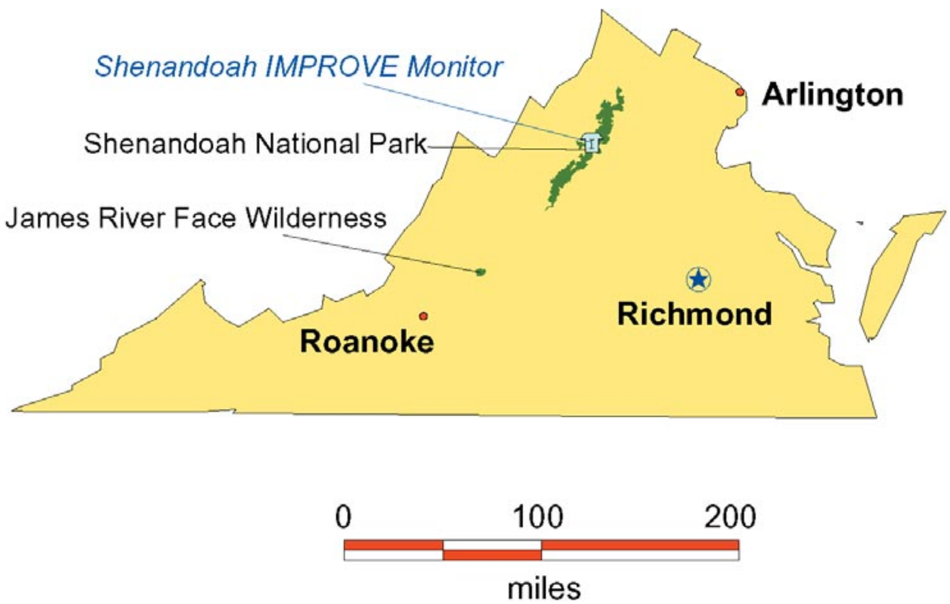

Figure VA–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in Virginia

Shenandoah National Park

The Shenandoah IMPROVE particulate sampler started reporting data in March of 1988. Figure VA–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that from 1988 through 1998 there was no statistically significant trend in the annual average of the visibility index for the least-impaired days, which remained between 14 and 17 deciviews (VR 60 to 45 miles). From 1988 through 1998 there was no significant trend in the annual average of the visibility index for the most-impaired days, which remained relatively constant, near 31 deciviews (VR 11 miles). However, the annual average of the visibility index for the mid-range days showed an improvement as the indices dropped from 23 to 21 deciviews (VR from 24 to 30 miles) over this period, a significant trend toward improved visibility.

Figure VA–3 shows the seasonal averages for the calculated visibility index from 1988 through 1998. During all four years at Shenandoah, the visibility was considerably more impaired during the summer (at least 3 deciviews) than during the autumn. The autumn numbers were 1 or 2 deciviews

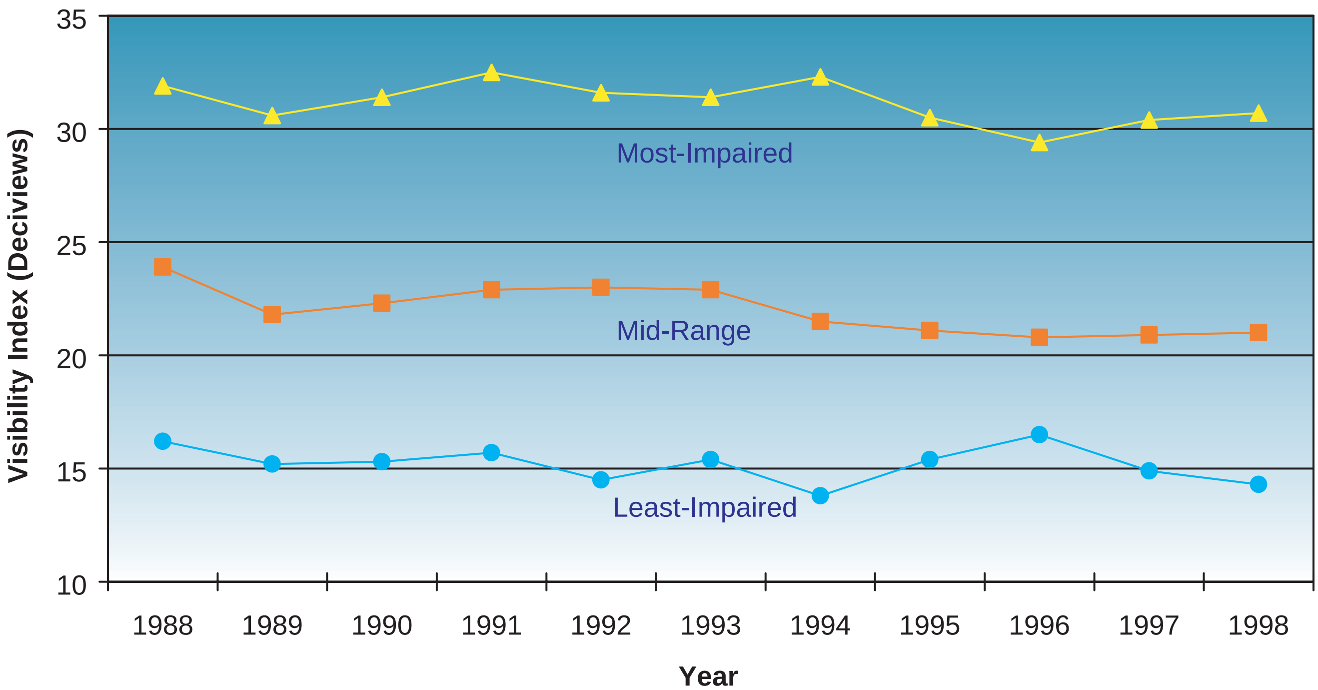

Figure VA–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Daysfrom 1988–1998 for the Shenandoah IMPROVE Particulate Sampler

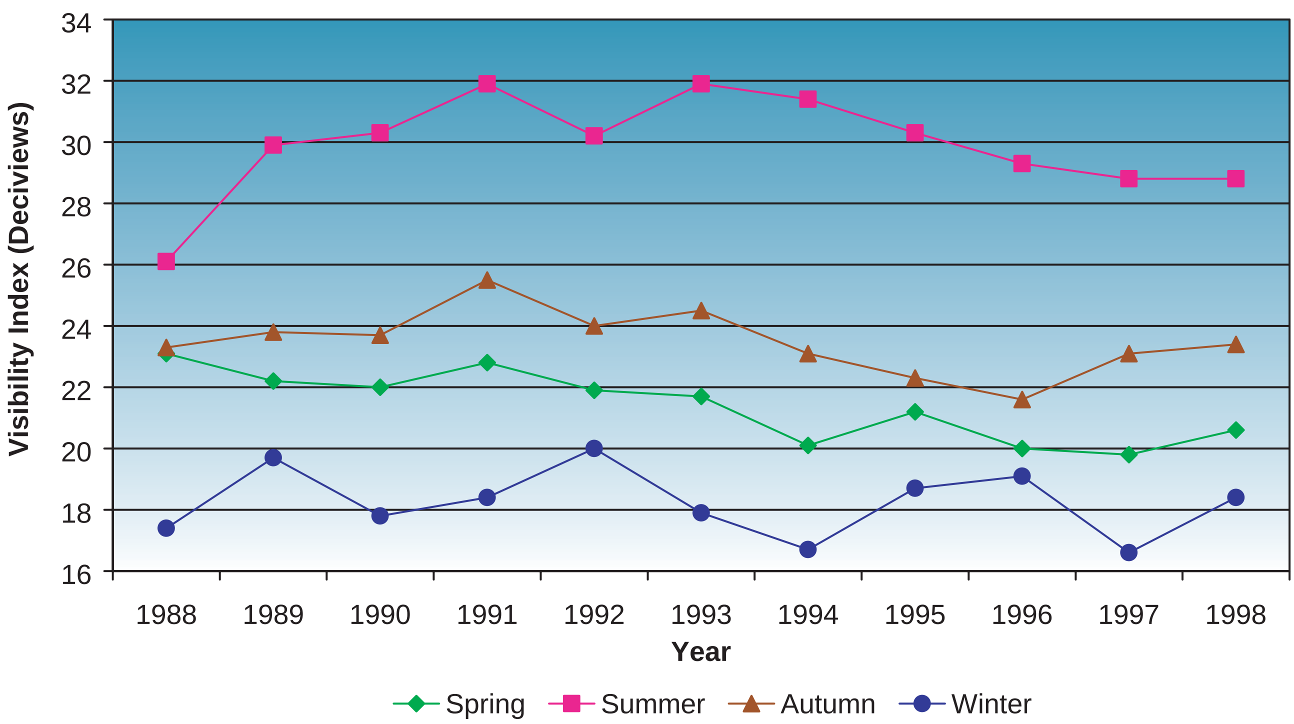

Figure VA–3. Seasonal Deciview Averages from 1988–1998 for the Shenandoah IMPROVE Particulate Sampler

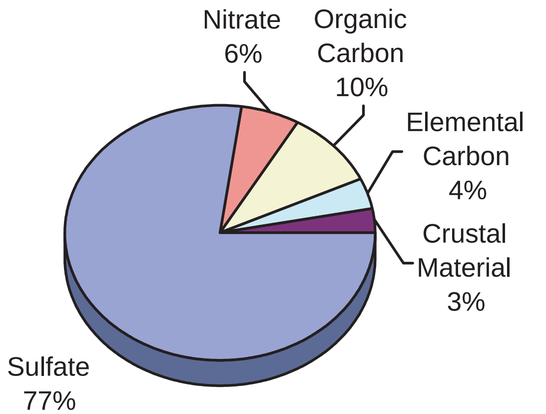

Figure VA–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Shenandoah IMPROVE Particulate Sampler

higher than the spring on average, and the indices for spring were more than 2 deciviews higher than the winter numbers. No significant seasonal trends were observed when the years 1988 through 1998 were compared for the summer, autumn, and winter. However, the indices for spring decreased 3 deciviews over this period with a statistically significant trend toward improved visibility.

Figure VA–4 presents a chart showing the calculated fractional contribution to Shenandoah's light extinction by each aerosol component on an annual basis. Figure VA–5 shows the same information for the four seasons. These five pie charts show that sulfate was responsible for 67 to 84 percent of the light extinction at the Shenandoah site, averaging 77 percent on an annual basis. The contributions from nitrates ranged from 4 to 12 percent depending on the season. The highest observed nitrate percentages occurred in the

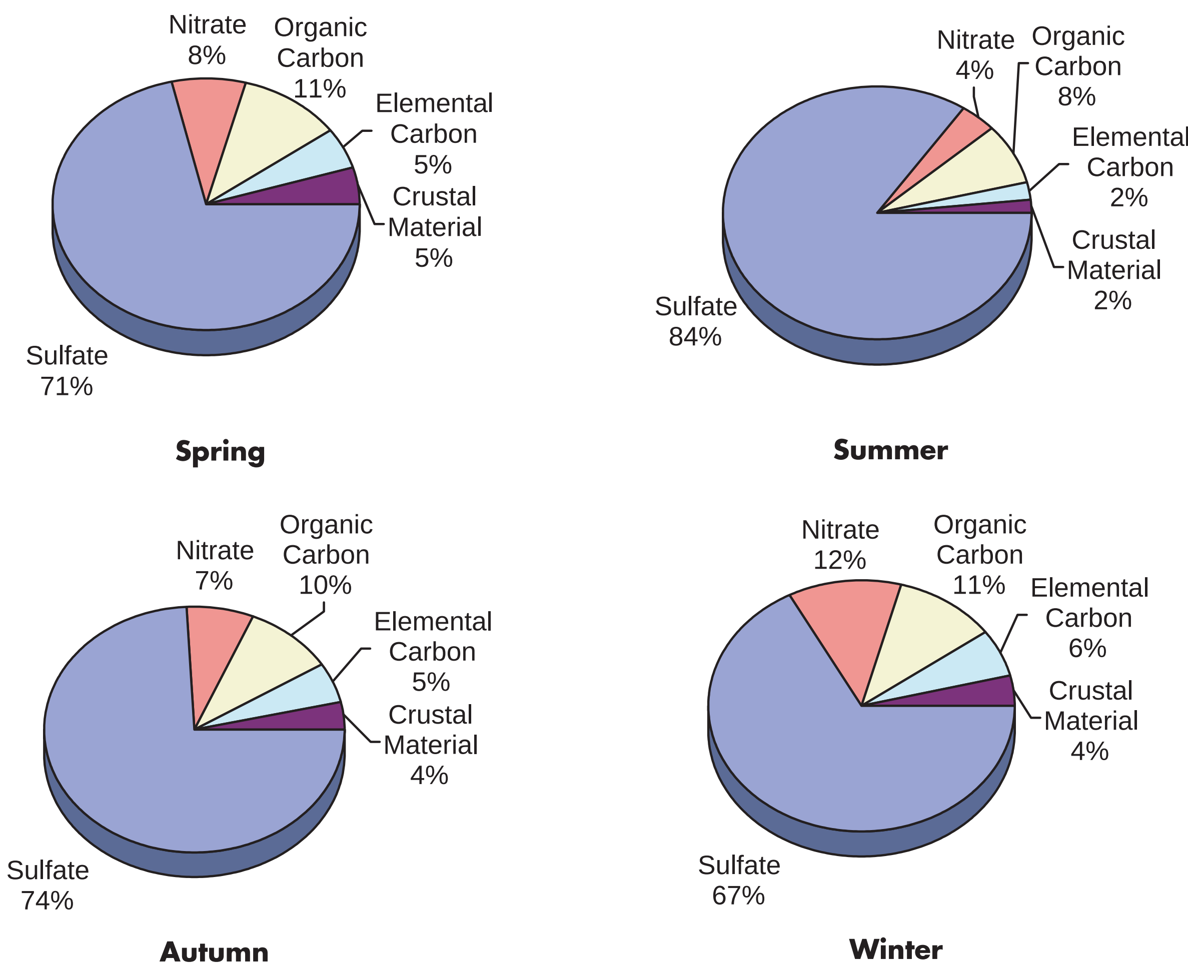

Figure VA–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Shenandoah IMPROVE Particulate Sampler

winter. The contributions from organic carbon remained relatively constant, near 10 percent year-round. Elemental carbon and crustal material measured at the Shenandoah site were each responsible for less than 6 percent of the calculated aerosol light extinction year round.

Figure VA–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinction at the Shenandoah site from 1988 to 1998. Over the eleven-year period, the total annual aerosol light extinctions rose in the early 1990s and then dropped (mainly due to sulfates), but no statistically significant trend was indicated. The sulfate, organic carbon, and crustal material contributions to the aerosol light extinction did not change significantly over this eleven-year period. However, the elemental carbon contributions dropped 1 Mm^{-1}, a statistically significant trend toward lower concentrations.

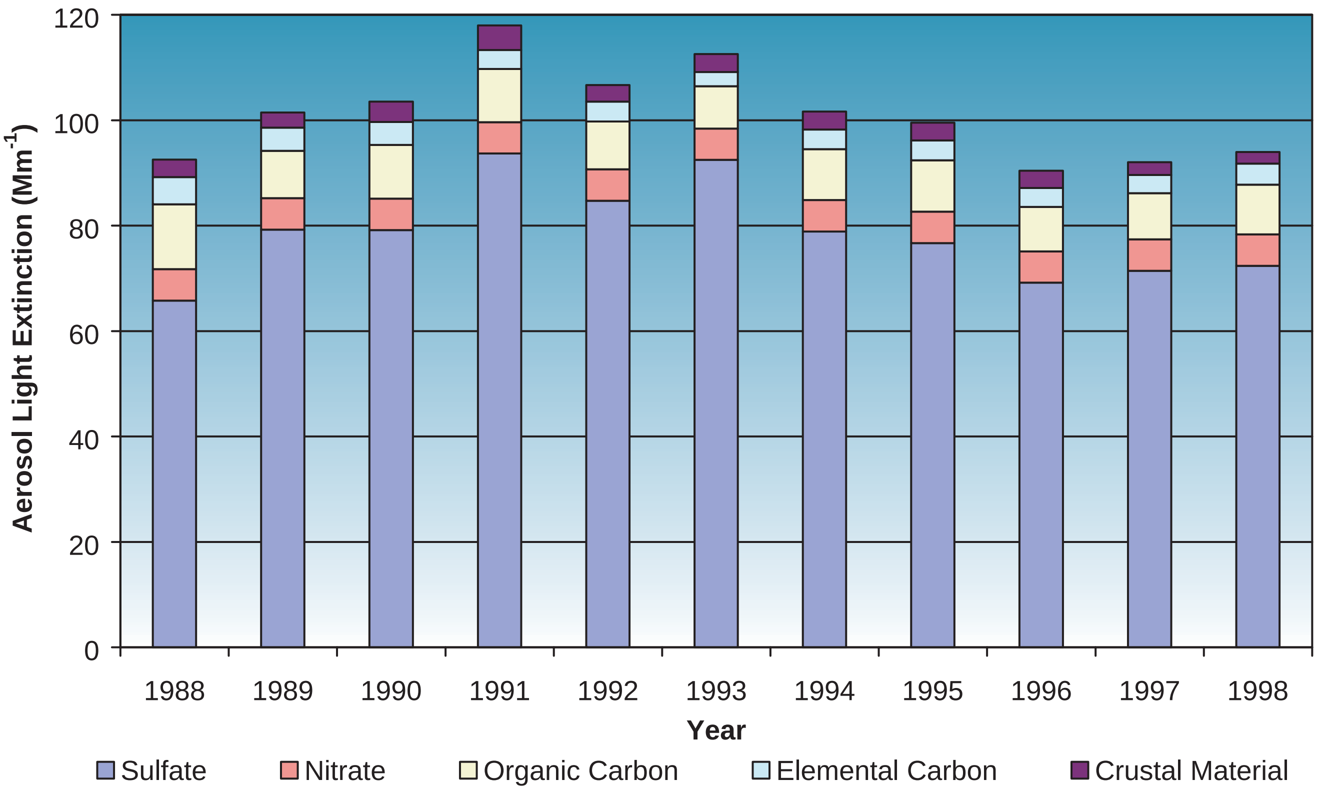

Figure VA–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Shenandoah IMPROVE Particulate Sampler

23. WASHINGTON

Figure WA–1 shows Washington's national parks (Olympic, North Cascades, and Mount Rainier) and wilderness areas (Pasayten, Glacier Peak, Alpine Lakes, Goat Rocks, and Mount Adams) designated as mandatory Federal Class I areas covered by the Regional Haze Rule. The IMPROVE particulate samplers are located near Mount Rainier's headquarters (46.75°N, 122.12°W, elevation 1430 feet) and at Snoqualmie Pass-Alpine Lakes Wilderness Area (47.43°N, 121.42°W, elevation 3600 feet). An additional IMPROVE protocol particulate sampler is located at the Columbia River Gorge National Scenic Area (45.67°N, 120.98°W, elevation 300 feet), but this area is not a mandatory Federal Class I area and is not discussed in this report. Since the Mount Rainier and Snoqualmie Pass monitors are adjacent to mandatory Federal Class I areas, their measurements are discussed in this report. The Spokane Tribal Government has redesignated their lands as Class I, but these areas are not covered by the Regional Haze Rule.

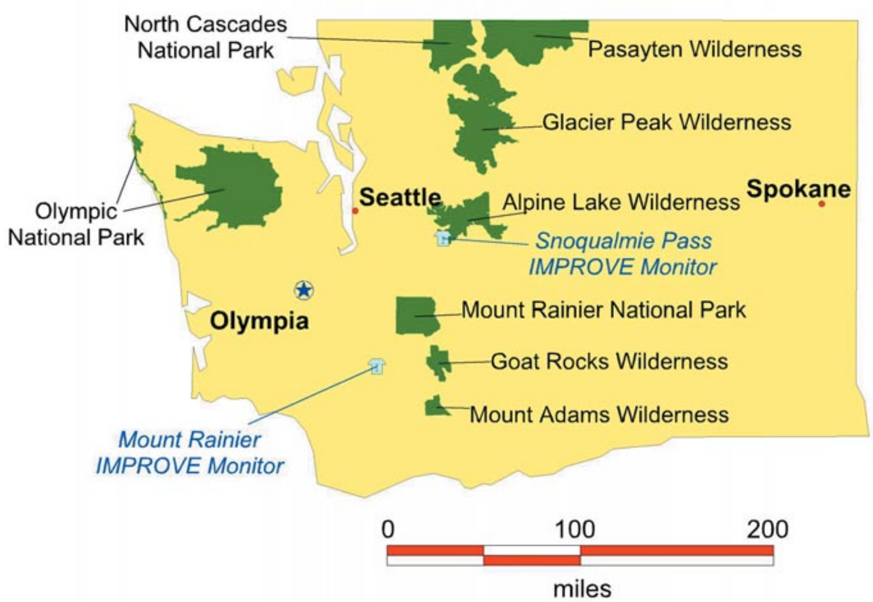

Figure WA–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Sites in Washington

Mount Rainier National Park

The Mount Rainier IMPROVE particulate sampler started reporting data in March of 1988. Figure WA–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The visibility index for the most-impaired days remained near 23 deciviews (VR 24 miles), with no statistically significant trend in visibility. The visibility indices on the mid-range days remained near 16 deciviews (VR 50 miles), with no significant trend in visibility. The indices on the least-impaired days averaged 7.7 deciviews (VR 110 miles), with no statistically significant trend in visibility.

Figure WA–3 shows the seasonal averages for the calculated visibility indices from 1988 through 1998. Since only one sample was collected during summer 1990, that point was omitted from Figure WA–3. The indices for winter were, on average, almost 5 deciviews lower than the values for the other three seasons. The visibility indices for the spring, summer, and autumn showed no statistically significant trends over the eleven-year period. The indices for winter dropped from 15 to 11 deciviews (VR

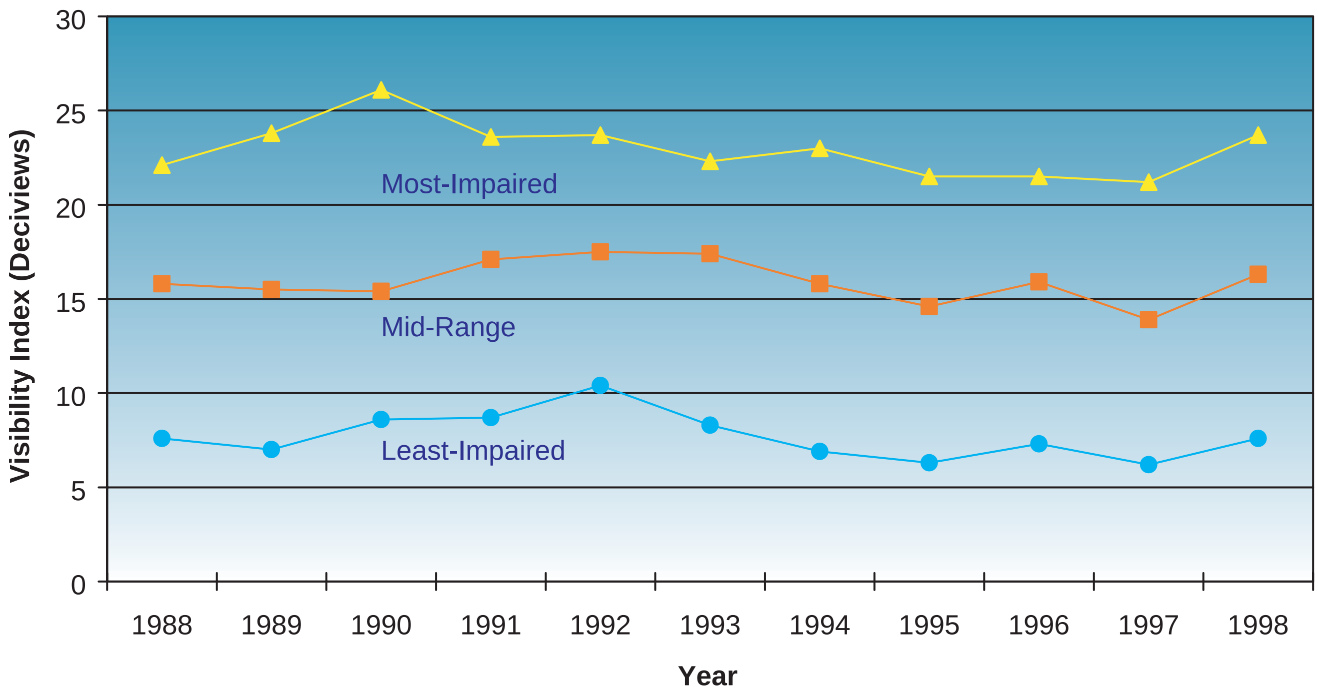

Figure WA–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Mount Rainier IMPROVE Particulate Sampler

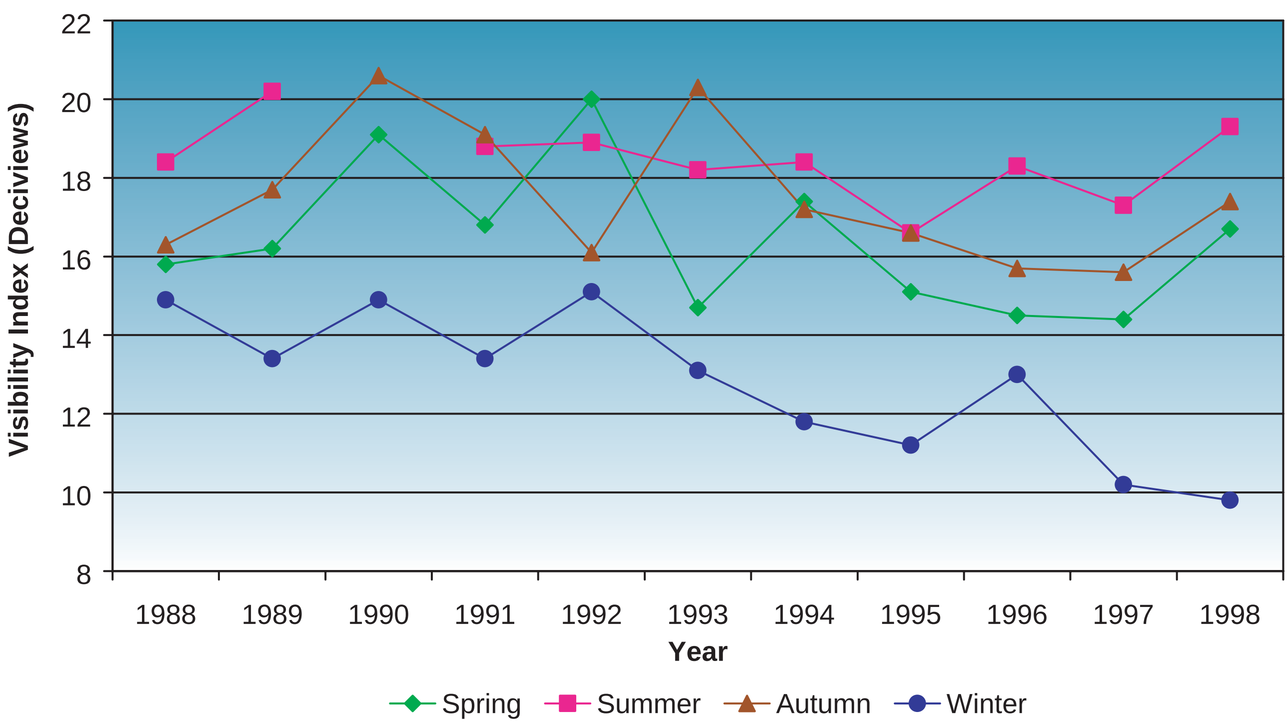

Figure WA–3. Seasonal Deciview Averages from 1988–1998 for the Mount Rainier IMPROVE Particulate Sampler

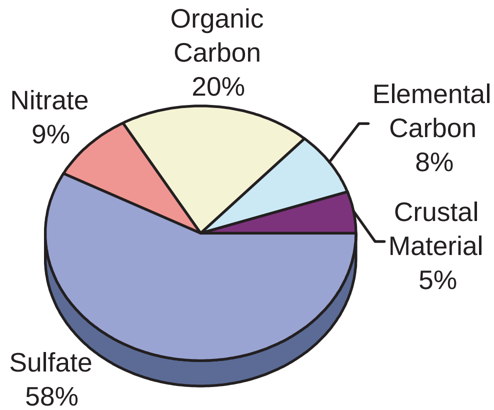

Figure WA–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Mount Rainier IMPROVE Particulate Sampler

from 55 to 80 miles) from 1988 to 1998, indicating a significant trend toward improved visibility.

Figure WA–4 presents a chart showing the calculated fractional contribution to Mount Rainier's light extinction by each aerosol species on an annual basis. Figure WA–5 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles. Sulfate particles were responsible for 38 to 62 percent of the light extinction at the Mount Rainier site, averaging 58 percent on an annual basis over a five-year period. The contributions from sulfates were lower in the winter and higher in the spring and summer. The contributions from organic carbon rose from 18 percent in the spring to 24 percent in the autumn and winter. Elemental carbon contributions were near 7 percent in the spring and summer but rose to 11 percent in the winter. Nitrate contributions were under 10 percent

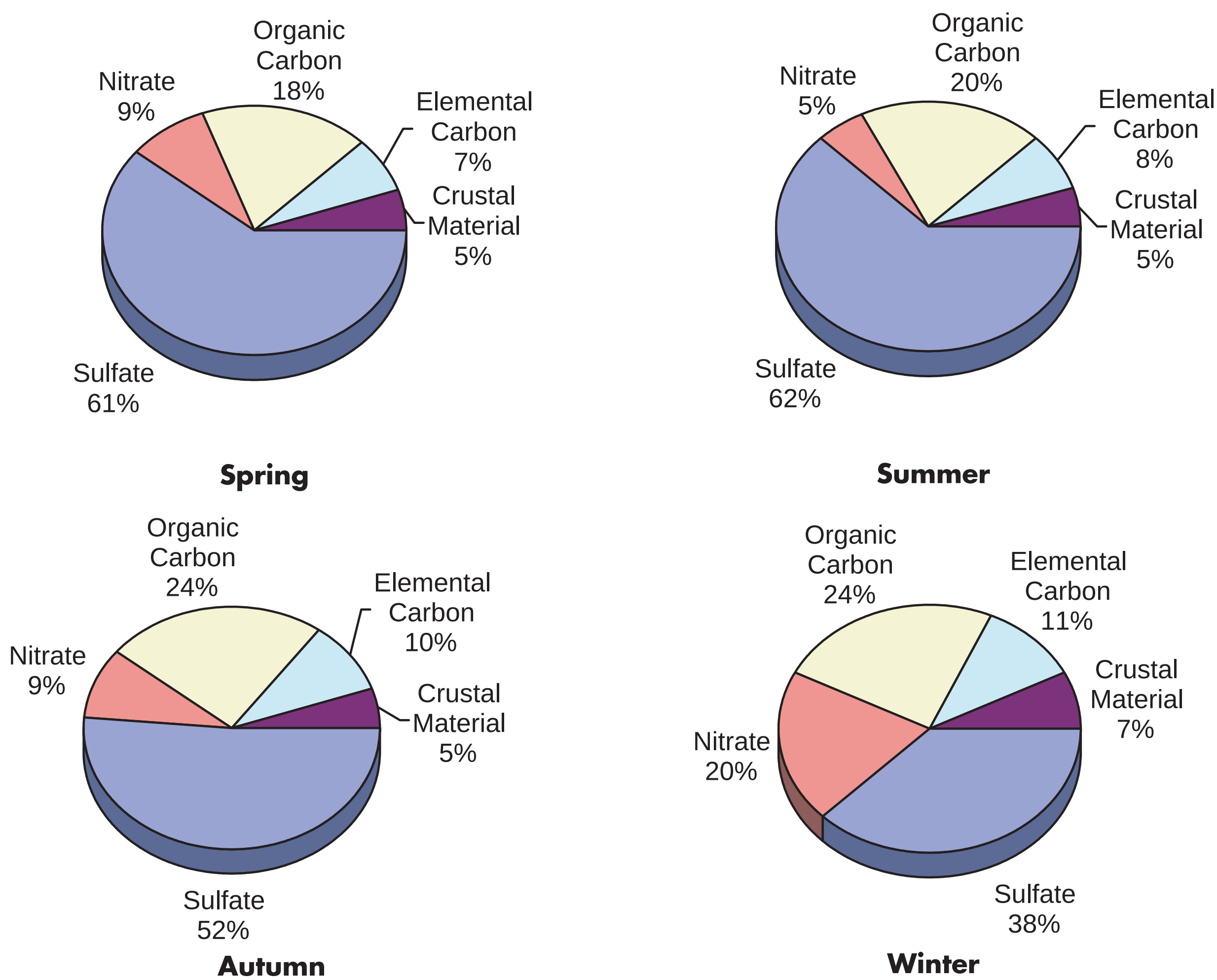

Figure WA–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Mount Rainier IMPROVE Particulate Sampler

in spring, summer, and autumn but rose to 20 percent in the winter. Crustal material contributions averaged 5 percent year-round.

Figure WA–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Mount Rainier site from 1988 to 1998. The total annual aerosol light extinction dropped from near 50 to 40 Mm^{-1}, with a statistically significant trend toward lower light extinction coefficients. The annual light extinctions attributed to sulfates and crustal material showed no significant trends over this time period. However, the annual light extinctions attributed to organic carbon and elemental carbon both showed statistically significant trends toward lower light extinctions and ambient concentrations.

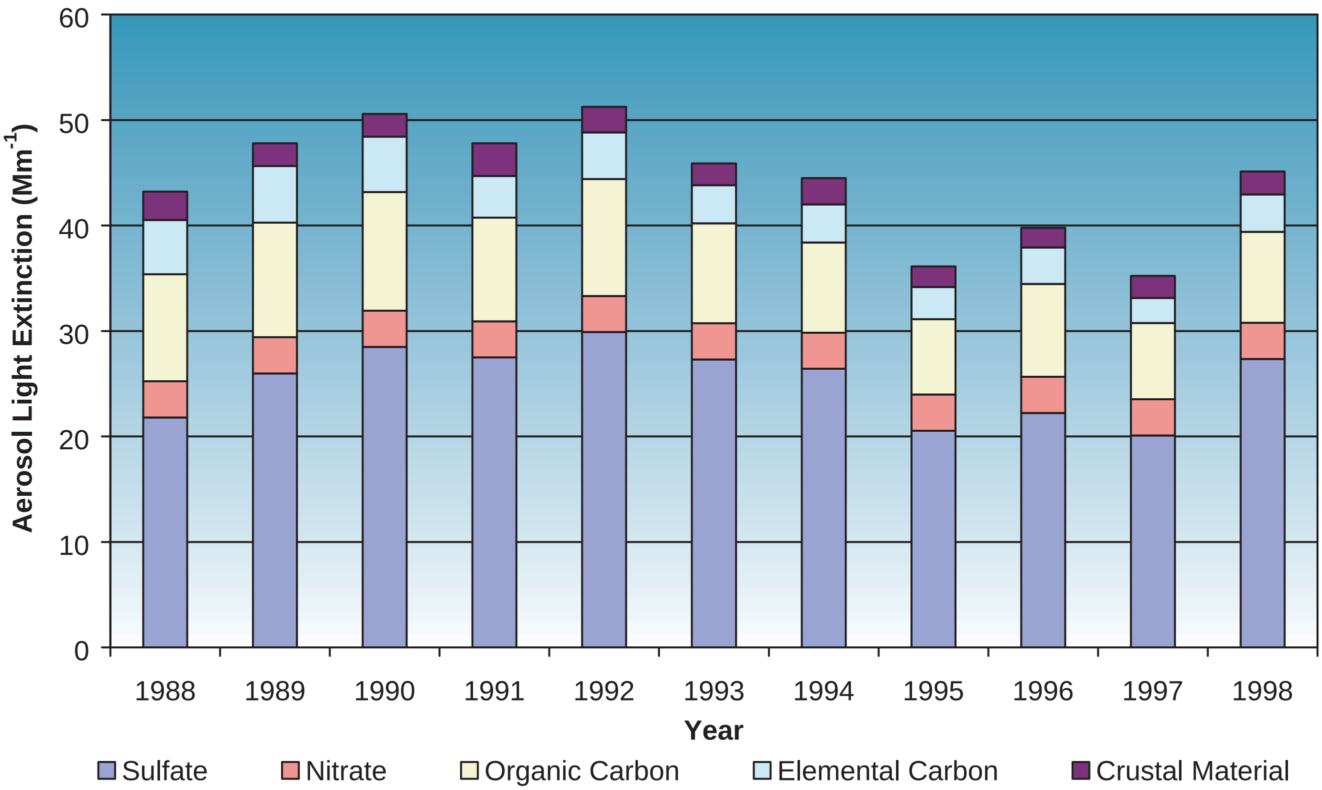

Figure WA–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Mount Rainier IMPROVE Particulate Sampler

Snoqualmie Pass - Alpine Lakes Wilderness Area

The Snoqualmie Pass IMPROVE particulate sampler started reporting in July of 1993. Figure WA–7 presents the calculated visibility indices for selected data sets from 1994 through 1998. The figure shows that the visibility index for the most-impaired days remained near 19 deciviews (VR 35 miles), with no statistically significant trend in visibility. The visibility indices on the mid-range days remained near 13 deciviews (VR 65 miles), with no significant trend in visibility. The indices on the least-impaired days increased from 7 to 8 deciviews (VR from 120 to 110 miles), with a significant trend toward declining visibility.

Figure WA–8 shows the seasonal averages for the calculated visibility indices from 1994 through 1998. Coarse mass and nitrate measurements were not available simultaneously at this site before

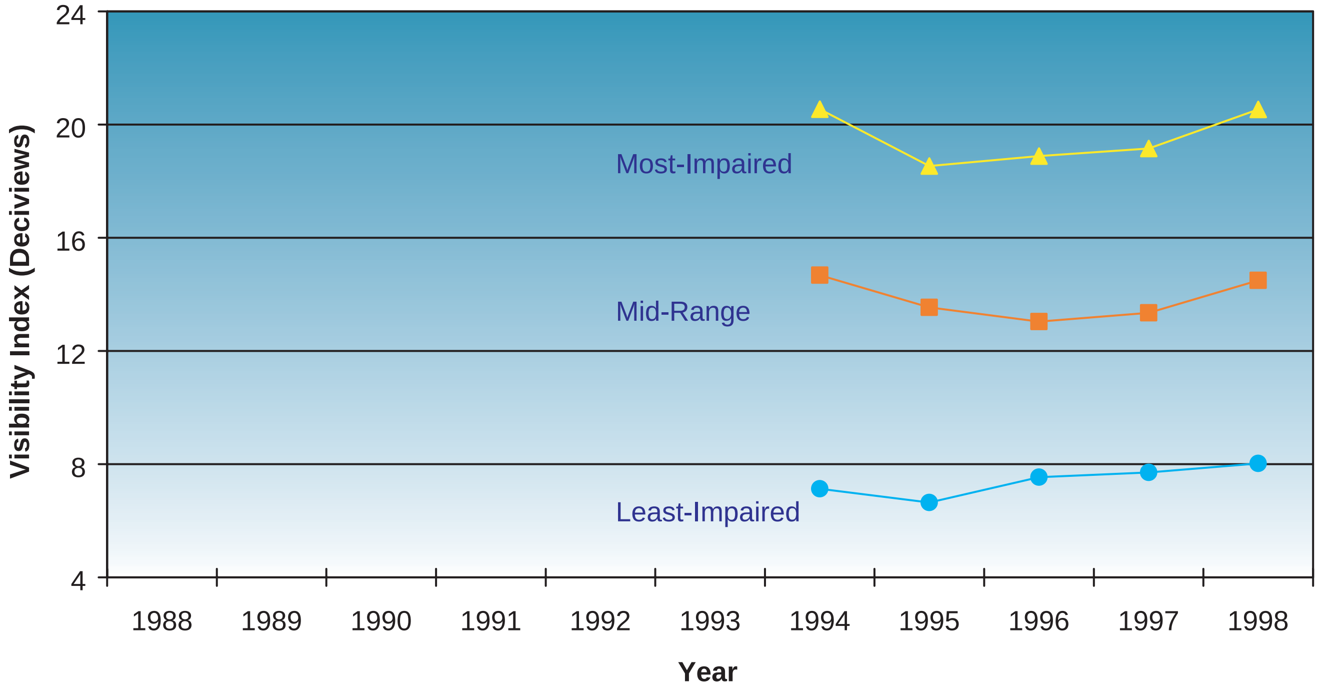

Figure WA–7. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1994–1998 for the Snoqualmie Pass IMPROVE Particulate Sampler

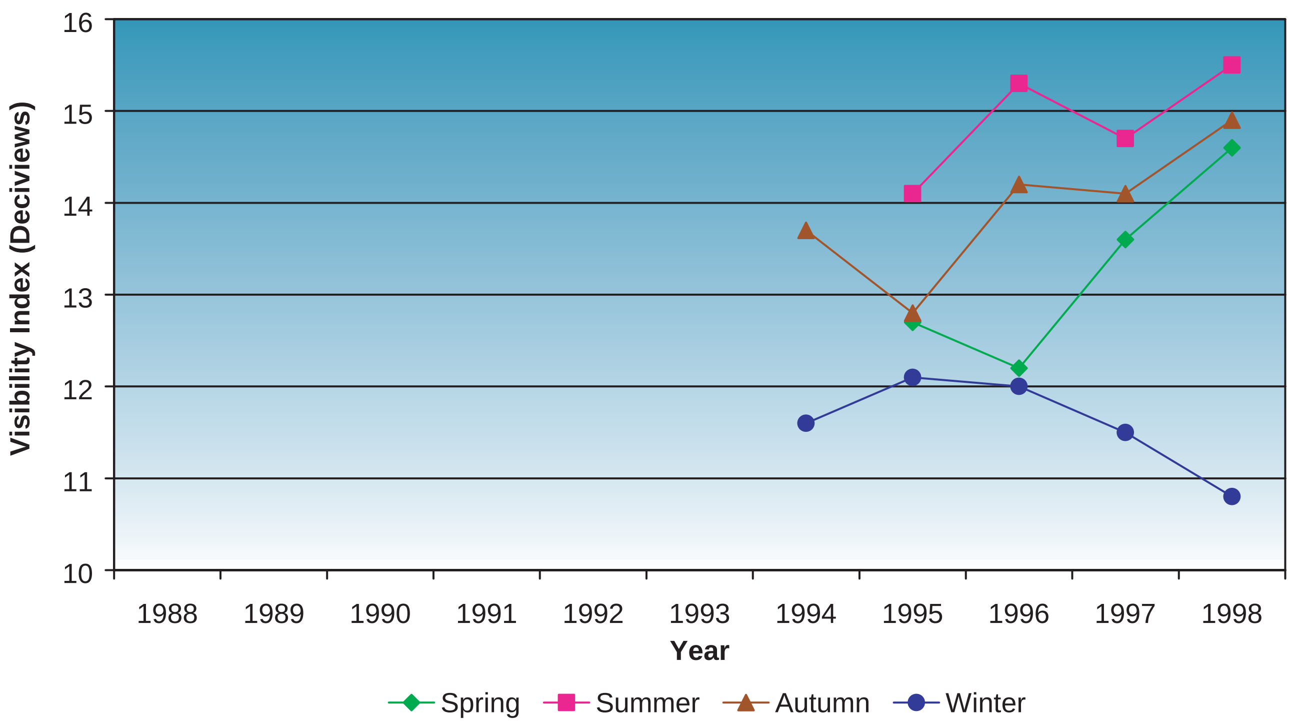

Figure WA–8. Seasonal Deciview Averages from 1994–1998 for the Snoqualmie Pass IMPROVE Particulate Sampler

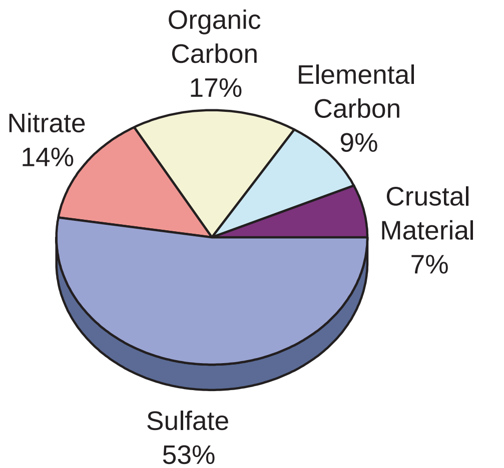

Figure WA–9. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Snoqualmie Pass IMPROVE Particulate Sampler

September 3, 1994, so Figure WA–8 does not include calculated deciviews for spring and summer 1994. Interested readers can view the data for other species at http://improve.cnl.ucdavis.edu/cgi-bin/SSDisplay.cgi. The average seasonal indices were near 13, 15, 14, and 12 deciviews for the spring, summer, autumn, and winter. The visibility indices for the four seasons showed no statistically significant trends over the five-year period.

Figure WA–9 presents a chart showing the calculated fractional contribution to Snoqualmie Pass's light extinction by each aerosol species on an annual basis. Figure WA–10 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles. Sulfate particles were responsible for 43 to 57 percent of the light extinction at the Snoqualmie Pass site, averaging 53 percent on

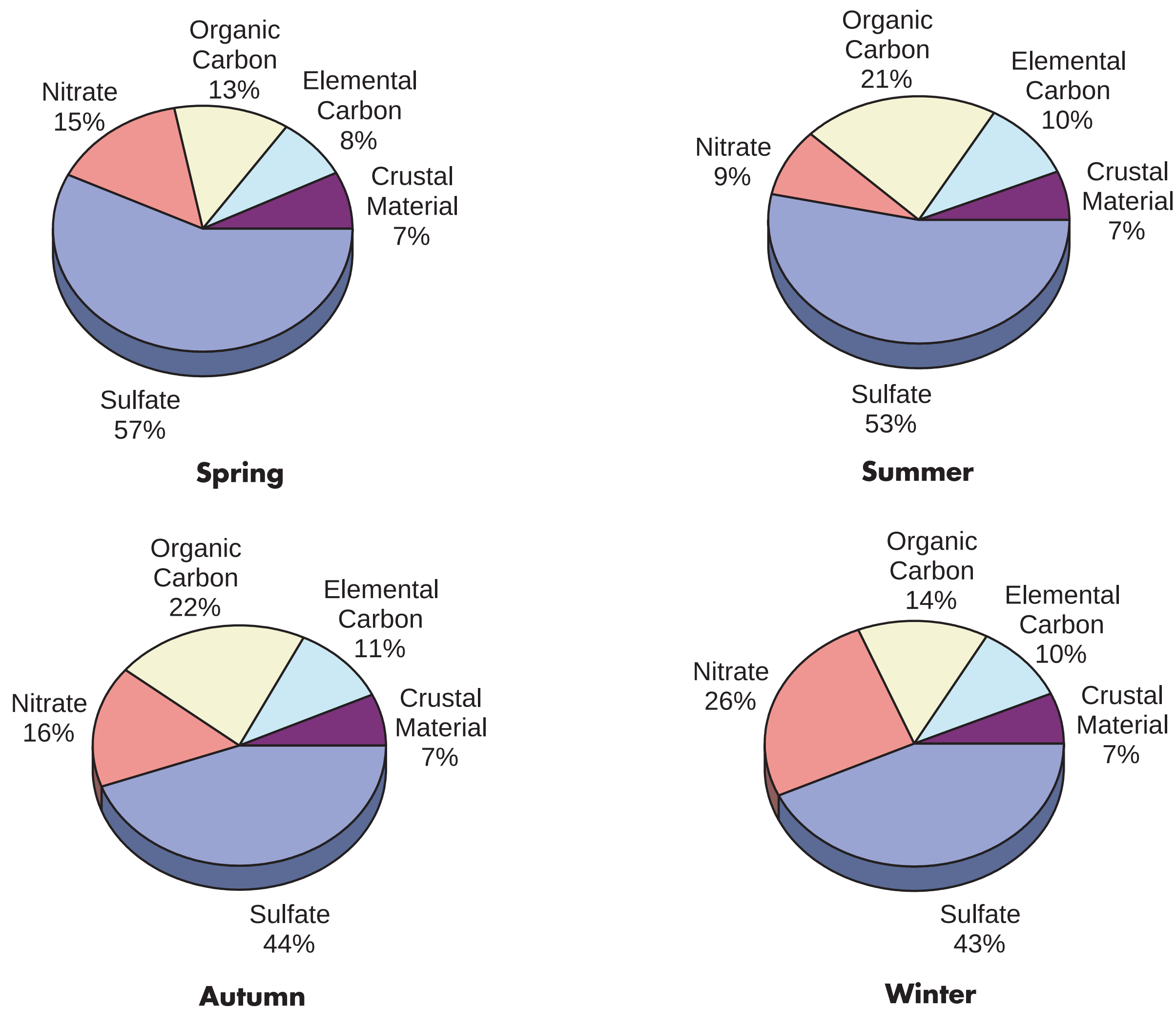

Figure WA–10. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Snoqualmie Pass IMPROVE Particulate Sampler

an annual basis over a five-year period. The contributions from sulfates are lower in the autumn and winter and higher in the spring and summer. Nitrate contributions were just 9 percent in the summer but rose to 26 percent in the winter. The contributions from organic carbon rose from 13 percent in the spring to 22 percent in the autumn. Annually, elemental carbon and crustal material contributions were near 9 and 7 percent.

Figure WA–11 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinction at the Snoqualmie Pass site from 1994 to 1998. While the total annual aerosol light extinction ranged from 28 to 34 Mm^{-1}, there was no statistically significant trend in the total light extinction coefficients. The annual light extinctions for sulfates, organic carbon, elemental carbon, and crustal material showed no significant trends over this time period.

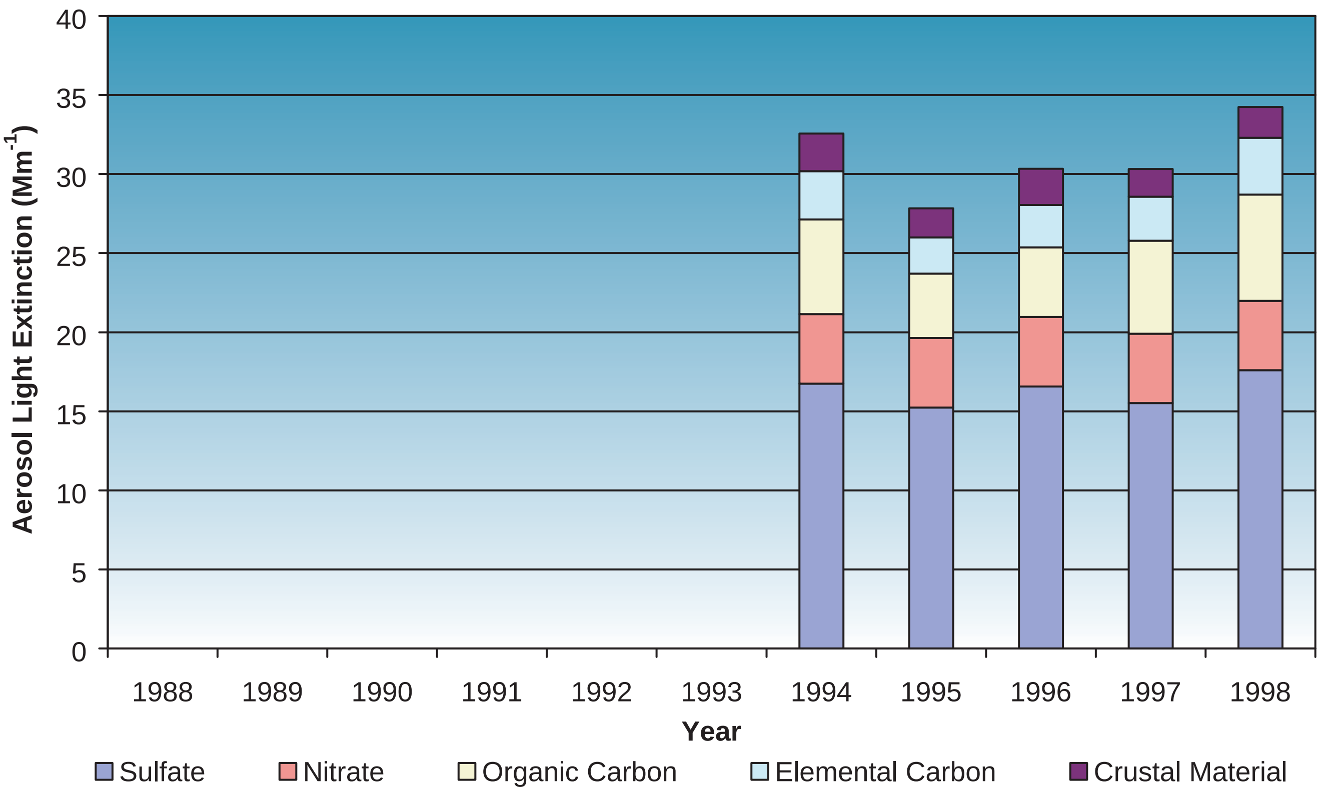

Figure WA–11. Contributions to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Snoqualmie Pass IMPROVE Particulate Sampler

Washington State Summary

The calculated annual average aerosol extinction coefficients at Washington's IMPROVE monitoring sites are presented in Table WA–1. Both sites showed similar rankings for contributions of the species to light extinction: sulfate, followed by organic carbon, nitrate, elemental carbon, and lastly crustal material.

The two sites are located only 60 miles apart, but the calculated visibility at the Mount Rainier site was considerably more impaired than that at Snoqualmie Pass. The calculated aerosol light extinction coefficient was 30 percent higher at Mount Rainier. The major species responsible for the difference in light extinction coefficients was sulfate. The ambient average sulfate concentrations at both sites were similar at Mount Rainier and Snoqualmie Pass (1.2 and 1.1 µg/m^3) for the years 1994 through 1998. However, the sulfate extinction coefficient at Snoqualmie Pass was much lower than the one at Mount Rainier because the average relative humidity adjustment factor was lower at Snoqualmie Pass (4.86) than at Mount Rainier (6.40). Since the relative humidity correction factor (presented in Appendix C) is 30 percent higher at Mount Rainier than at Snoqualmie Pass, the average sulfate extinction coefficient was notably higher at Mount Rainier even though ambient concentrations were similar at both sites.

Table WA–1. Washington Calculated Total Extinction Coefficients from 1994–1998

IMPROVE Site	Calculated Total Aerosol Extinction Coefficient (Mm^{-1})	Pollutant Extinction Coefficient (Mm^{-1})				
		Sulfate	Nitrate	Organic Carbon	Elemental Carbon	Crustal Material
Mount Rainier NP	40.1	23.3	3.4	8.1	3.2	2.1
Snoqualmie Pass	31.1	16.3	4.4	5.4	2.9	2.0

24. WEST VIRGINIA

Figure WV–1 shows the Dolly Sods and Otter Creek Wilderness Areas, West Virginia's mandatory Federal Class I areas covered by the Regional Haze Rule. An IMPROVE particulate sampler (39.11ºN, 79.17ºW, elevation 3800 feet) is located near the Dolly Sods area and has been operating since September 1991.

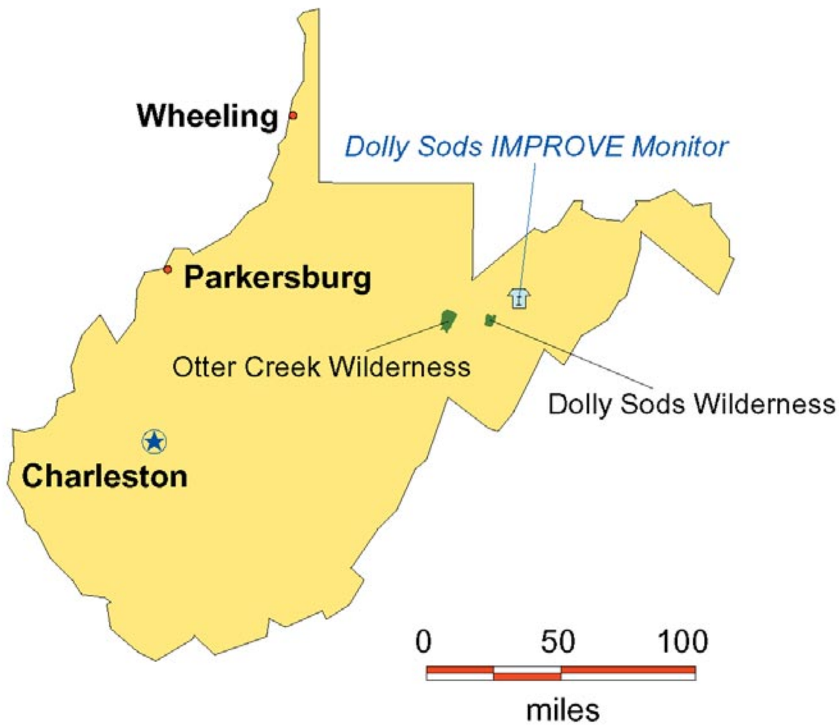

Figure WV–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Site in West Virginia

Dolly Sods Wilderness Area

The Dolly Sods IMPROVE particulate sampler began reporting data in September of 1991. Figure WV–2 presents the calculated visibility indices for selected data sets from 1992 through 1998. The figure shows that the visibility index for the most-impaired days remained near 31 deciviews (VR 11 miles). There was no statistically significant trend in visibility. However, the visibility indices on the mid-range days decreased from 22 to 30 deciviews (VR from 22 to 30 miles), with a significant trend toward improved visibility. The indices on the least-impaired days remained near 16 deciviews (VR 50 miles), with no significant trend in visibility.

Figure WV–3 shows the seasonal averages for the calculated visibility indices from 1992 through 1998. Coarse mass measurements were not available at this site until August 26, 1992, so Figure WV–3 does not include a point for spring 1992. Interested readers can view the data for other species at http://improve.cnl.ucdavis.edu/cgi-bin/SSDisplay.cgi. Similar to observations at the Shenandoah site (Virginia), the indices for summer were on average 7 deciviews higher than the autumn, winter, and

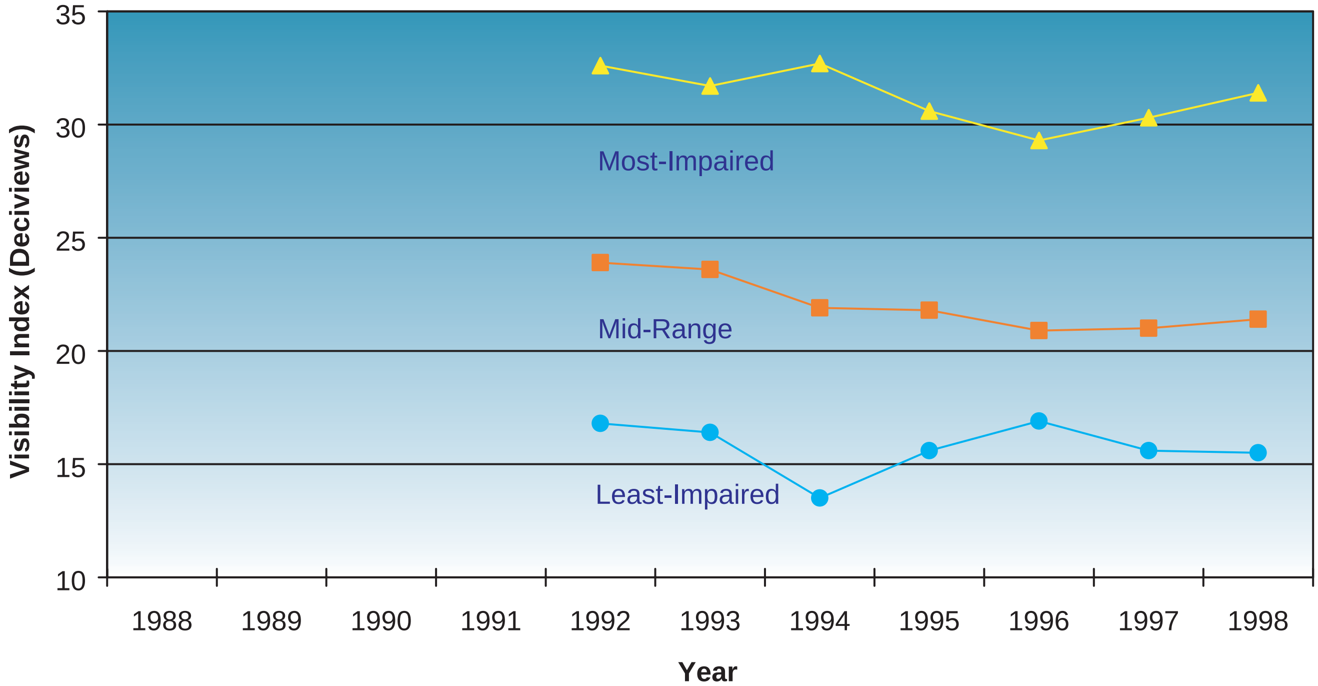

Figure WV–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1992–1998 for the Dolly Sods IMPROVE Particulate Sampler

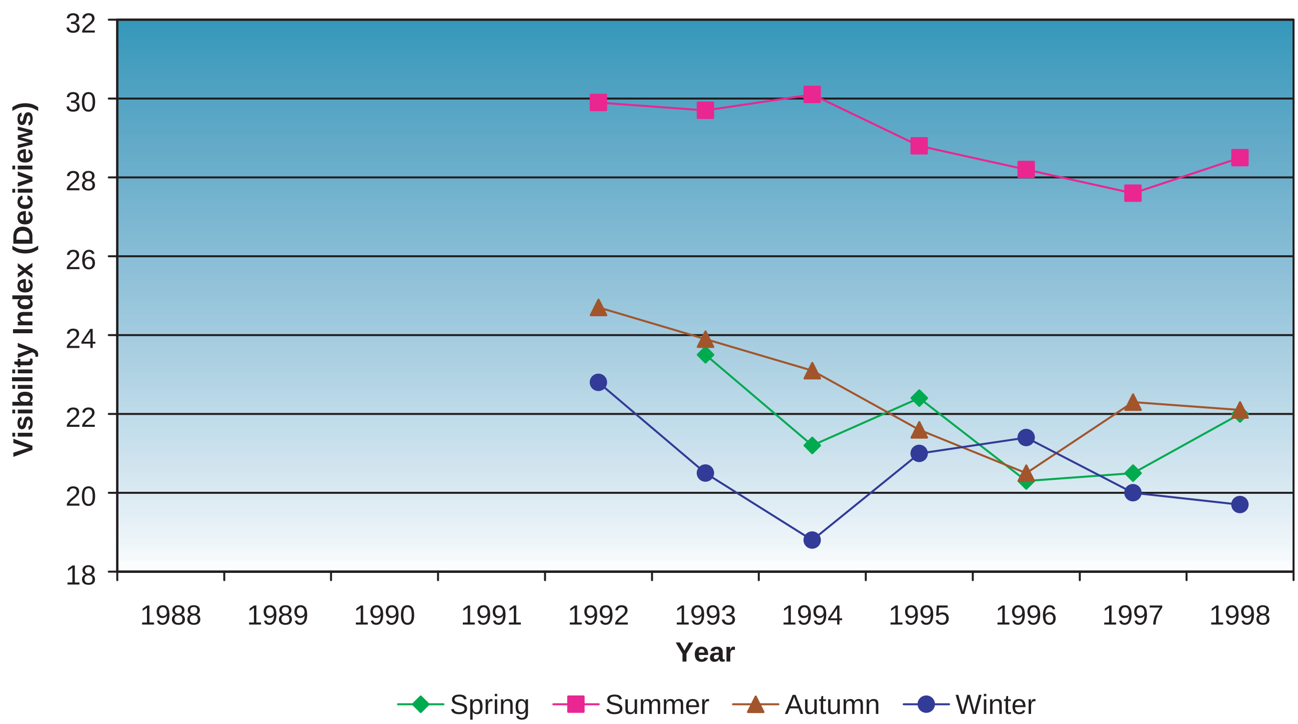

Figure WV–3. Seasonal Deciview Averages from 1992–1998 for the Dolly Sods IMPROVE Particulate Sampler

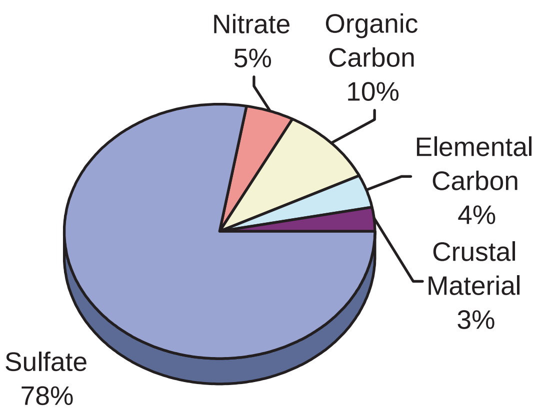

Figure WV–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Dolly Sods IMPROVE Particulate Sampler

spring values. The visibility indices for the winter and spring showed no statistically significant trends over the seven-year period. Statistically significant trends were noted for the summer and autumn; their visibility conditions improved by 2 and 3 deciviews over the seven-year period.

Figure WV–4 presents a chart showing the calculated fractional contribution to Dolly Sods' light extinction by each aerosol species on an annual basis. Figure WV–5 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles. Sulfate particles were responsible for 66 to 86 percent of the light extinction at the Dolly Sods site, averaging 78 percent on an annual basis over a five-year period. The contributions from sulfates were lower in the winter and higher in the summer. Nitrate contributions were just 3 percent in the sum-

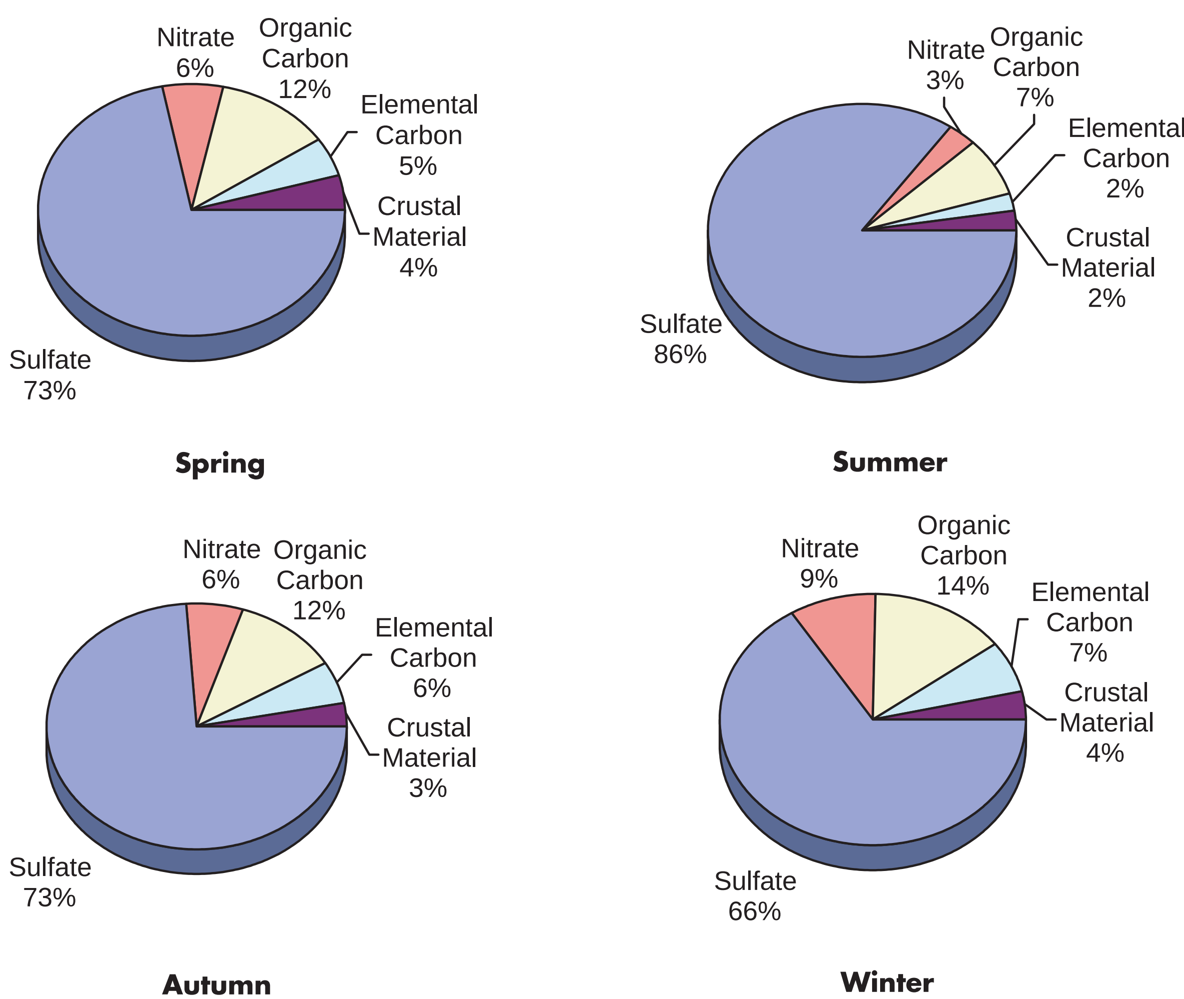

Figure WV–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Dolly Sods IMPROVE Particulate Sampler

mer but rose to 9 percent during the winter. The contributions from organic carbon, elemental carbon, and crustal material were near 10, 4, and 3 percent year-round.

Figure WV–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinction at the Dolly Sods site from 1992 to 1998. The total annual aerosol light extinction decreased from 120 to 90 Mm^{-1}, with a statistically significant trend indicating improved visibility. The statistically significant drop in sulfate species light extinction (30 Mm^{-1}) was responsible for the improvements in aerosol light extinction over this seven-year period. The annual light extinction for organic carbon, elemental carbon, and crustal material showed no significant trends over this time period.

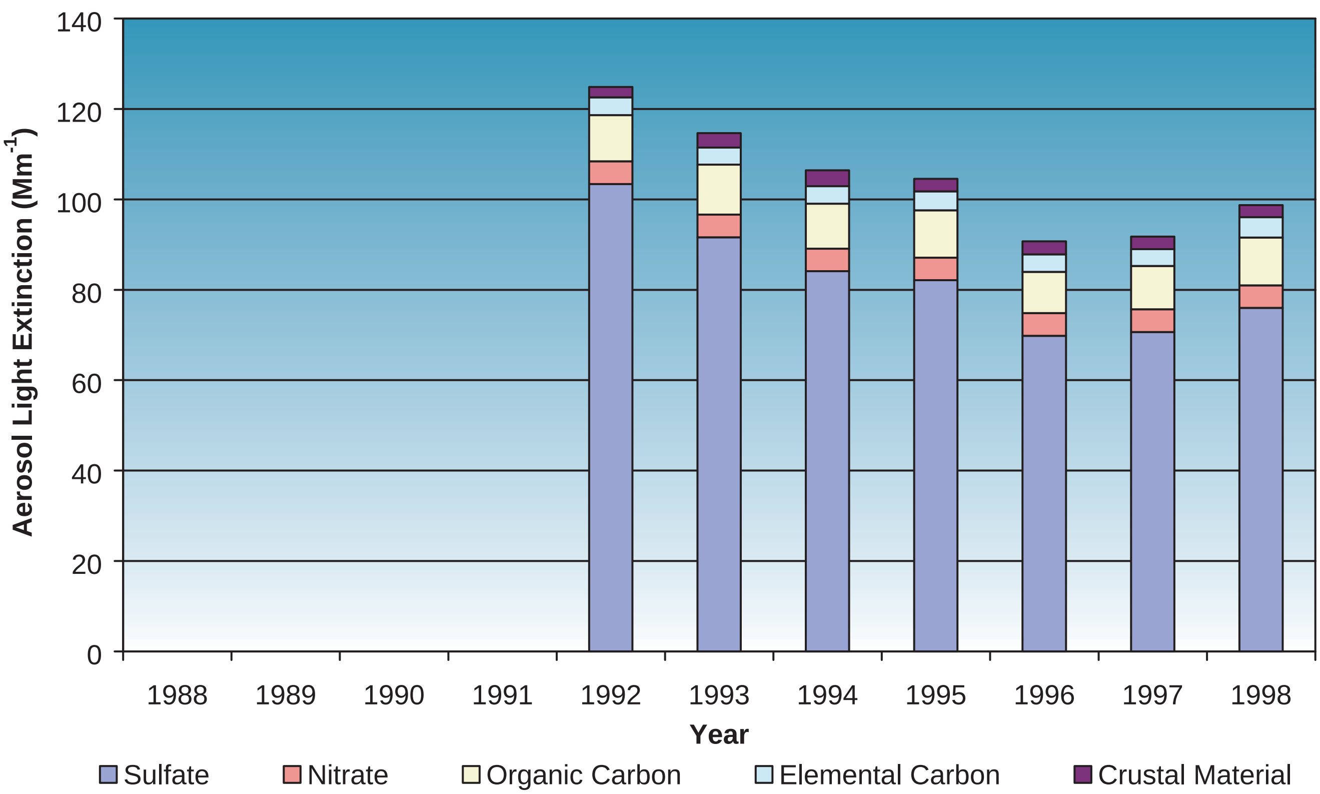

Figure WV–6. Contributions to Calculated Annual Aerosol Light Extinction from 1992–1998 for the Dolly Sods IMPROVE Particulate Sampler

25. WYOMING

Figure WY–1 shows Wyoming's national parks (Grand Tetons and Yellowstone) and wilderness areas (Bridger, Fitzpatrick, North Absaroka, Teton, and Washakie) designated as mandatory Federal Class I areas covered by the Regional Haze Rule. They are all located in the central western and northwestern portion of the State. IMPROVE particulate samplers are located near the Bridger Wilderness Area (monitor at 42.95°N, 109.75°W, elevation 6000 feet) and in Yellowstone National Park (44.56°N, 110.39°W, elevation 6300 feet). Both samplers have been operating since 1988. An IMPROVE protocol particulate sampler located at Brooklyn Lake (41.33°N, 106.30°W, elevation 10300 feet) within the Medicine Bow/Routt National Forest has been operating since September 1993 but is located in the southeast portion of the state. This is outside of the mandatory Federal Class I areas and will therefore not be discussed in this report. In addition, the State of Wyoming has designated the Savage Run Wilderness Area as a Wyoming Class I Area, although this area remains a Federal Class II area, not covered by the Regional Haze Rule.

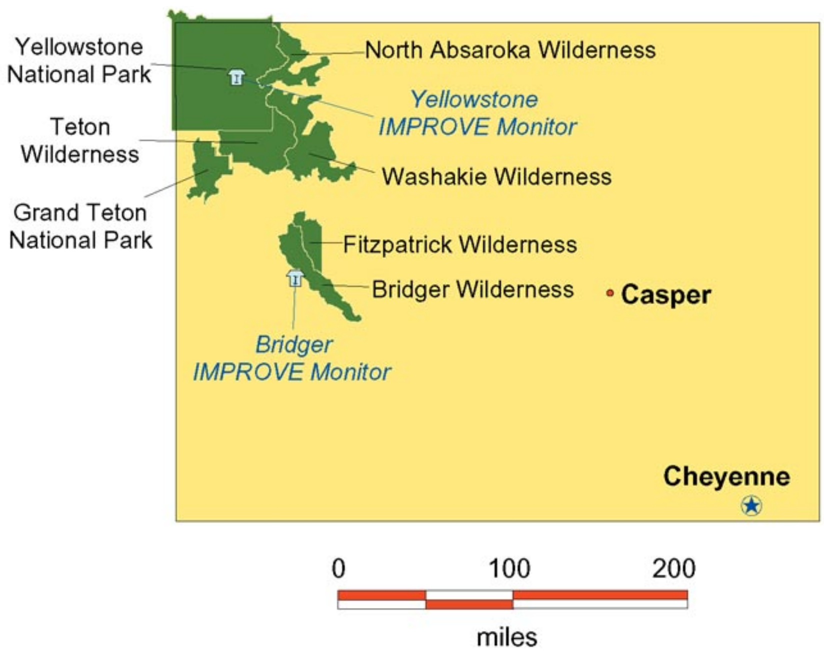

Figure WY–1. Mandatory Federal Class I Areas and IMPROVE Monitoring Sites in Wyoming

Bridger Wilderness Area

The Bridger Wilderness IMPROVE particulate samplers started reporting data in March of 1988. Figure WY–2 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most-impaired days ranged from 10 to 13 deciviews (VR 90 to 65 miles). The visibility indices on the mid-range days remained near 7.6 deciviews (VR 115 miles). The indices on the least-impaired days remained near the average of 4.3 deciviews (VR 160 miles). The index sets for the most-impaired, mid-range, and least-impaired days all showed no statistically significant trends in visibility.

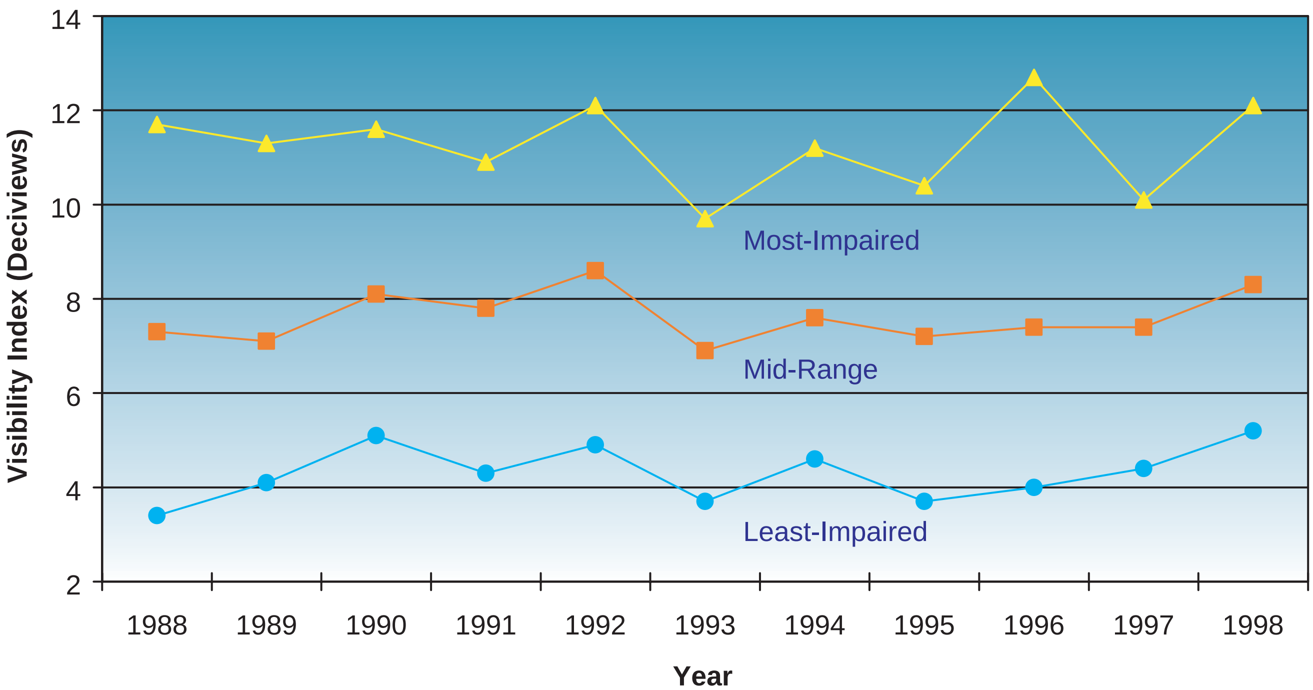

Figure WY–2. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Bridger IMPROVE Particulate Sampler

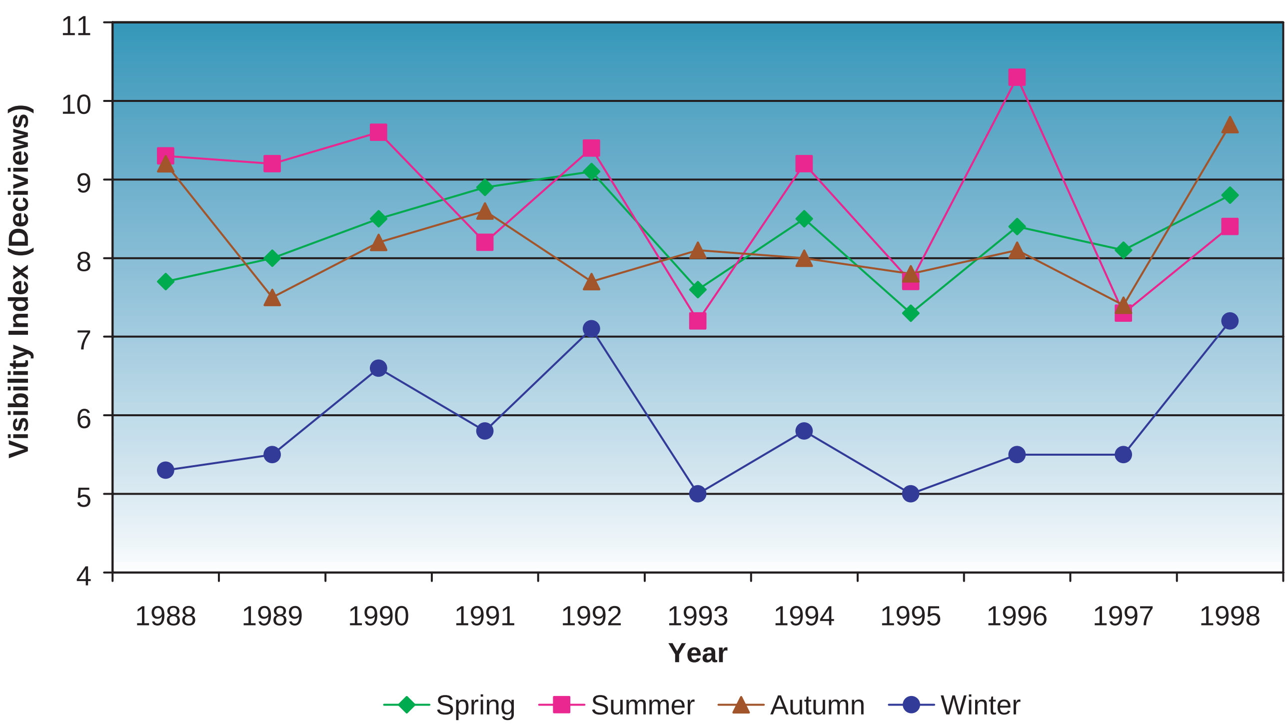

Figure WY–3. Seasonal Deciview Averages from 1988–1998 for the Bridger IMPROVE Particulate Sampler

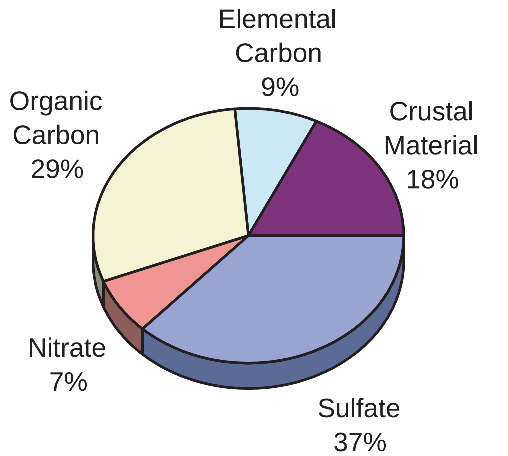

Figure WY–4. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Bridger IMPROVE Particulate Sampler

Figure WY–3 shows the seasonal averages for the calculated visibility indices from 1988 through 1998. The indices for winter were, on average, 2.5 deciviews lower than the values for the other three seasons. The visibility index sets for all four seasons showed no statistically significant trends over the eleven-year period.

Figure WY–4 presents a chart showing the calculated fractional contribution to Bridger's light extinction by each aerosol species on an annual basis. Figure WY–5 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were sulfate particles and organic carbon. Sulfate particles were responsible for 29 to 46 percent of the light extinction at the Bridger Wilderness site, averaging 37 percent on an annual basis over a five-year period. The contributions from sulfates were lower in the

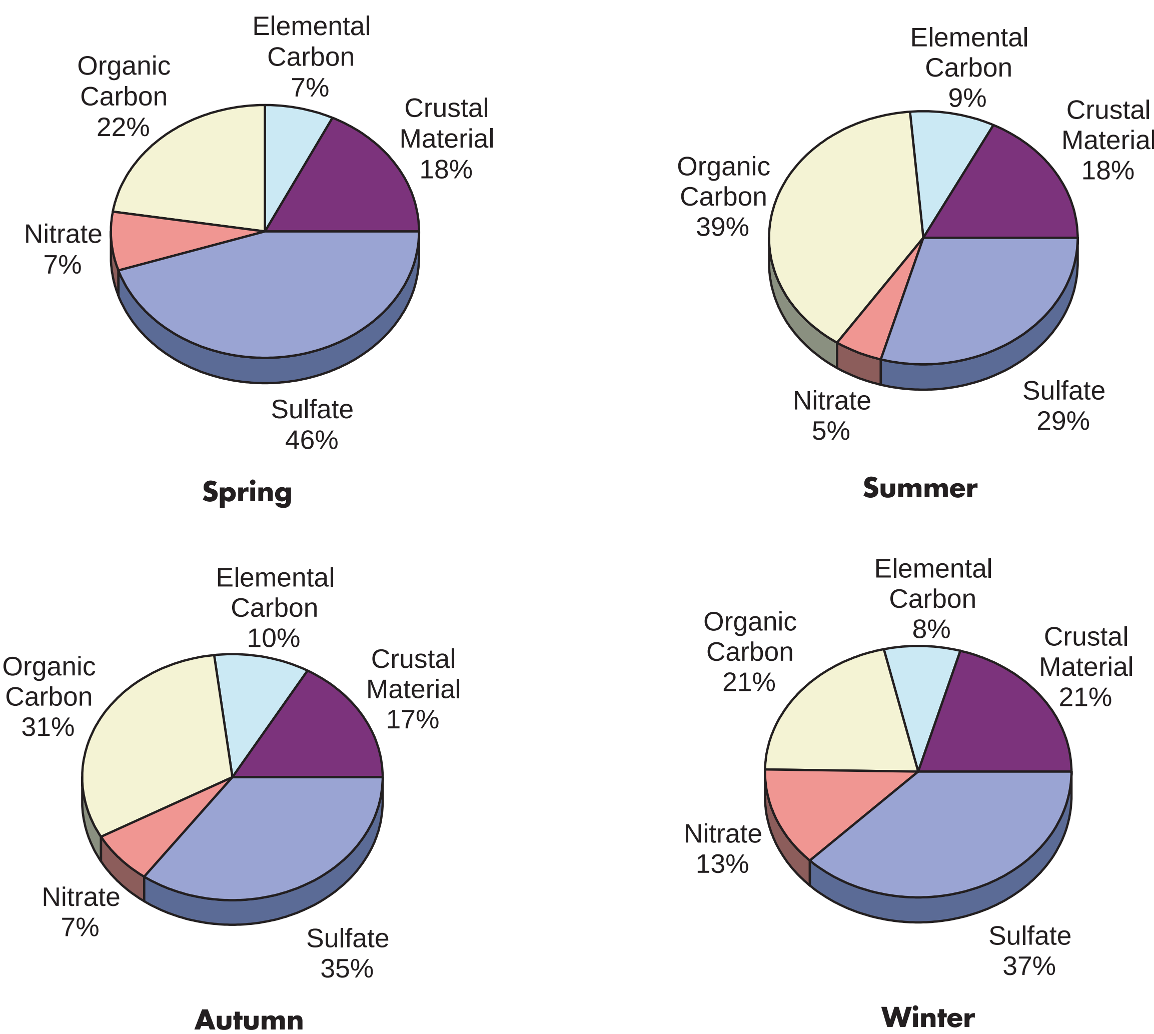

Figure WY–5. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Bridger IMPROVE Particulate Sampler

summer and higher in the spring. The contributions from organic carbon rose from 21 percent in the winter and spring to 39 percent in the summer. Nitrate contributions were just 5 percent in the summer but rose to 13 percent in the winter. Annually, elemental carbon and crustal material contributions were near 9 and 18 percent.

Figure WY–6 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinction at the Bridger Wilderness site from 1988 to 1998. The total annual aerosol light extinction ranged from 10 to 14 Mm^{-1}, indicating no statistically significant trend in light extinction coefficients. The annual light extinction for sulfates, organic carbon, elemental carbon, and crustal material showed no significant trends over this time period.

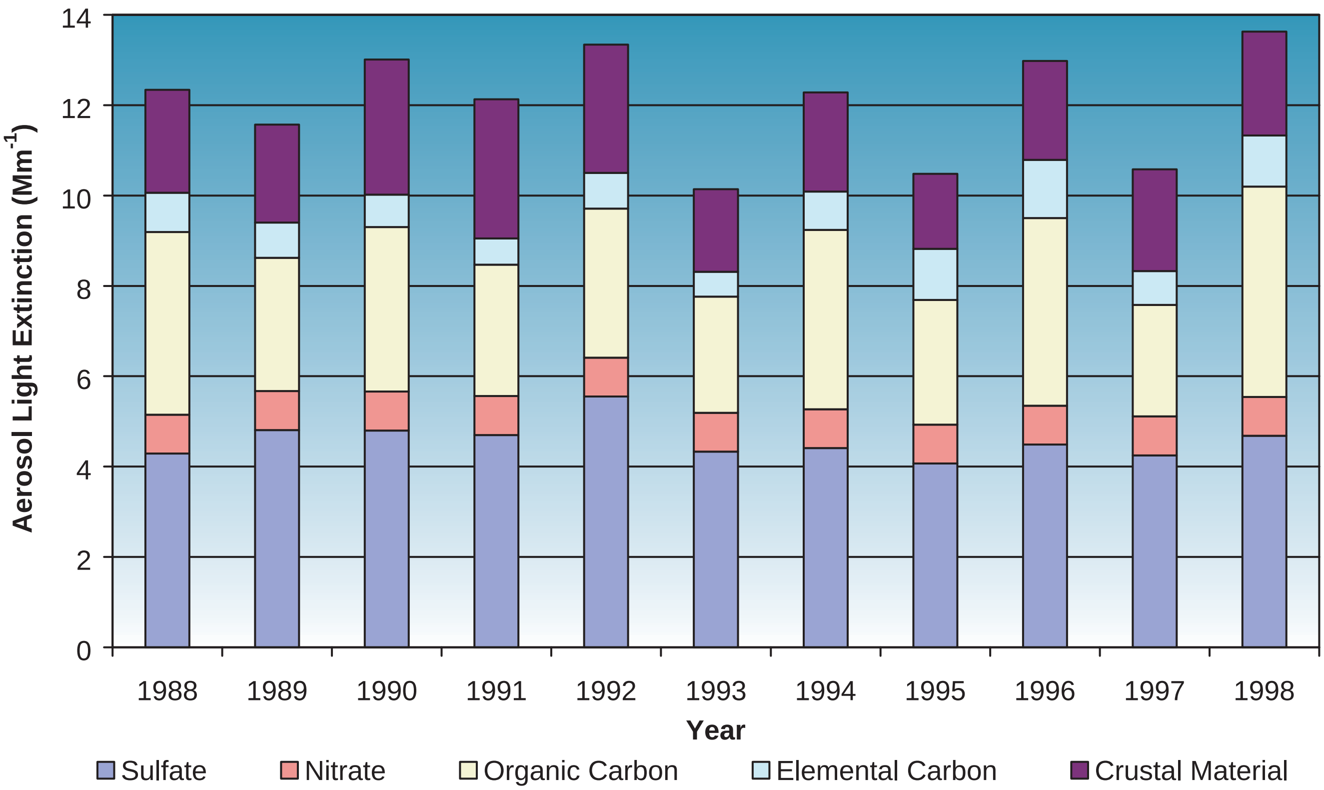

Figure WY–6. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Bridger IMPROVE Particulate Sampler

Yellowstone National Park

The Yellowstone IMPROVE particulate sampler started reporting data in March of 1988. Figures WY-7, WY-8, and WY-11 all show considerably higher values in 1988 than in other years. During the summer of 1988, nearly half of Yellowstone's 2.2 million acres burned in eight major wild fires. In order to capture the behavior outside this anomalous year, the trends in this section will be evaluated only for the years 1989 through 1998. Figure WY–7 presents the calculated visibility indices for selected data sets from 1988 through 1998. The figure shows that the visibility index for the most-impaired days (1989-1998) dropped from 14 to 12 deciviews (VR from 60 to 75 miles), but the trend was not statistically significant. The visibility indices on the mid-range days remained near 9 deciviews (VR 100 miles), indicating no significant trend in visibility. The indices on the least-impaired days

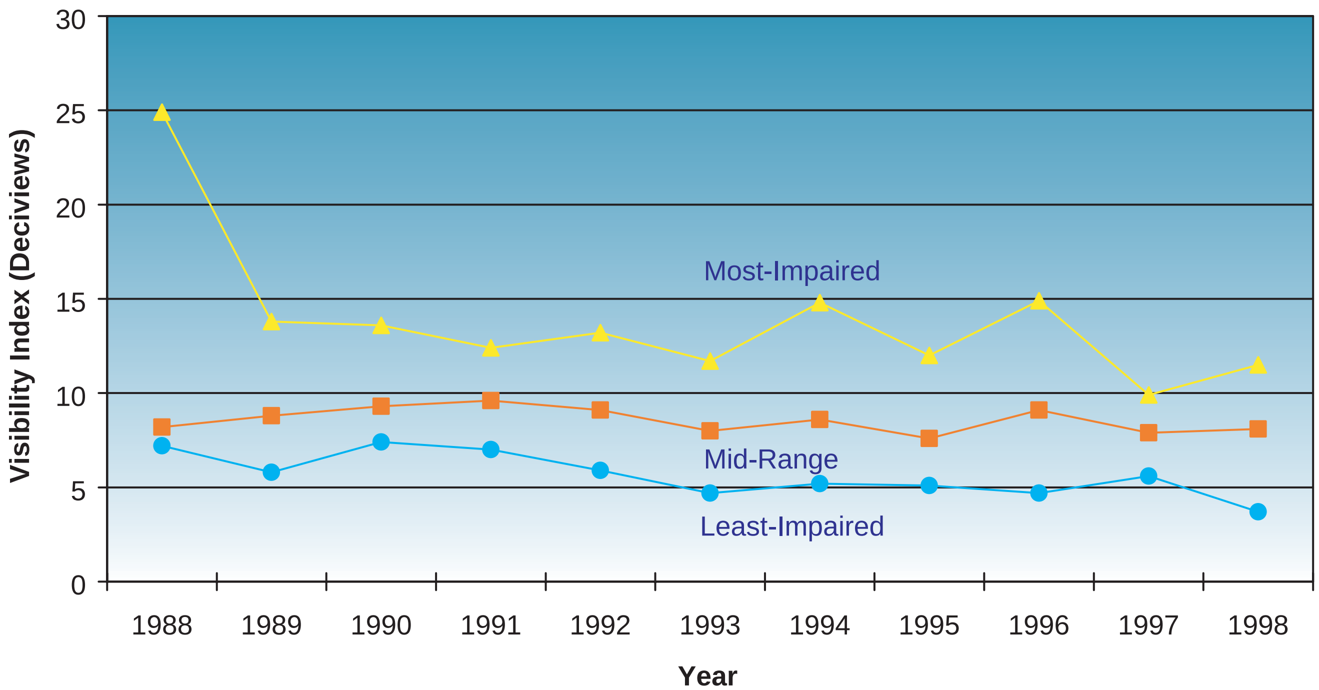

Figure WY–7. Yearly Deciview Averages for Most-Impaired, Mid-Range, and Least-Impaired Days from 1988–1998 for the Yellowstone IMPROVE Particulate Sampler

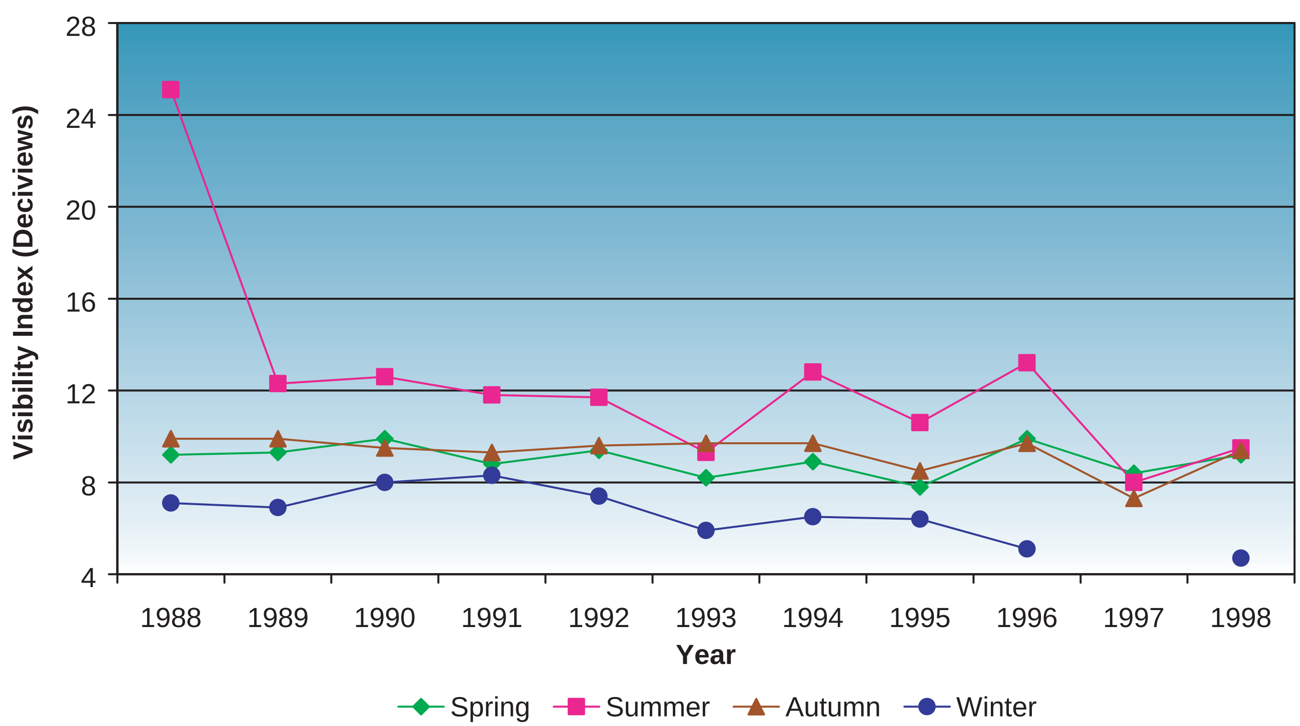

Figure WY–8. Seasonal Deciview Averages from 1988–1998 for the Yellowstone IMPROVE Particulate Sampler

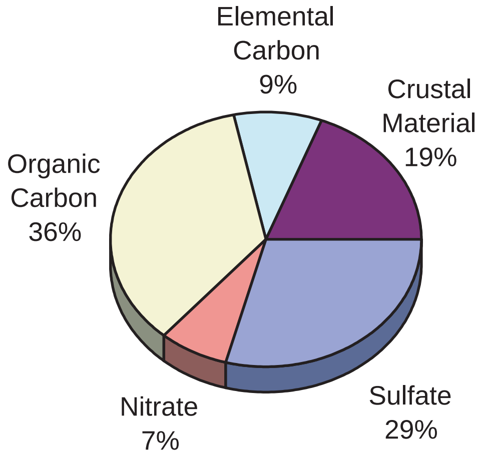

Figure WY–9. Contribution to Calculated Annual Aerosol Light Extinction from 1994–1998 for the Yellowstone IMPROVE Particulate Sampler

decreased from 6.7 to 4.3 deciviews (VR 125 to 160 miles) and showed a statistically significant trend toward improved visibility.

Figure WY–8 shows the seasonal averages for the calculated visibility indices from 1988 through 1998. Since CIRA reported no winter 1997 data, no value is reported for winter 1997 in Figure WY–8. Interested readers can view the ambient concentration data at http://improve.cnl.ucdavis.edu/cgi-bin/SSDisplay.cgi. The average seasonal indices for the summer were approximately 2 deciviews higher than those for the spring and autumn (except in 1993, 1997, and 1998). The spring and autumn values were approximately 3 deciviews higher than those for the winter. The visibility indices for the winter dropped 3 deciviews over the ten-year period, indicating significant trends toward improved visibility. The

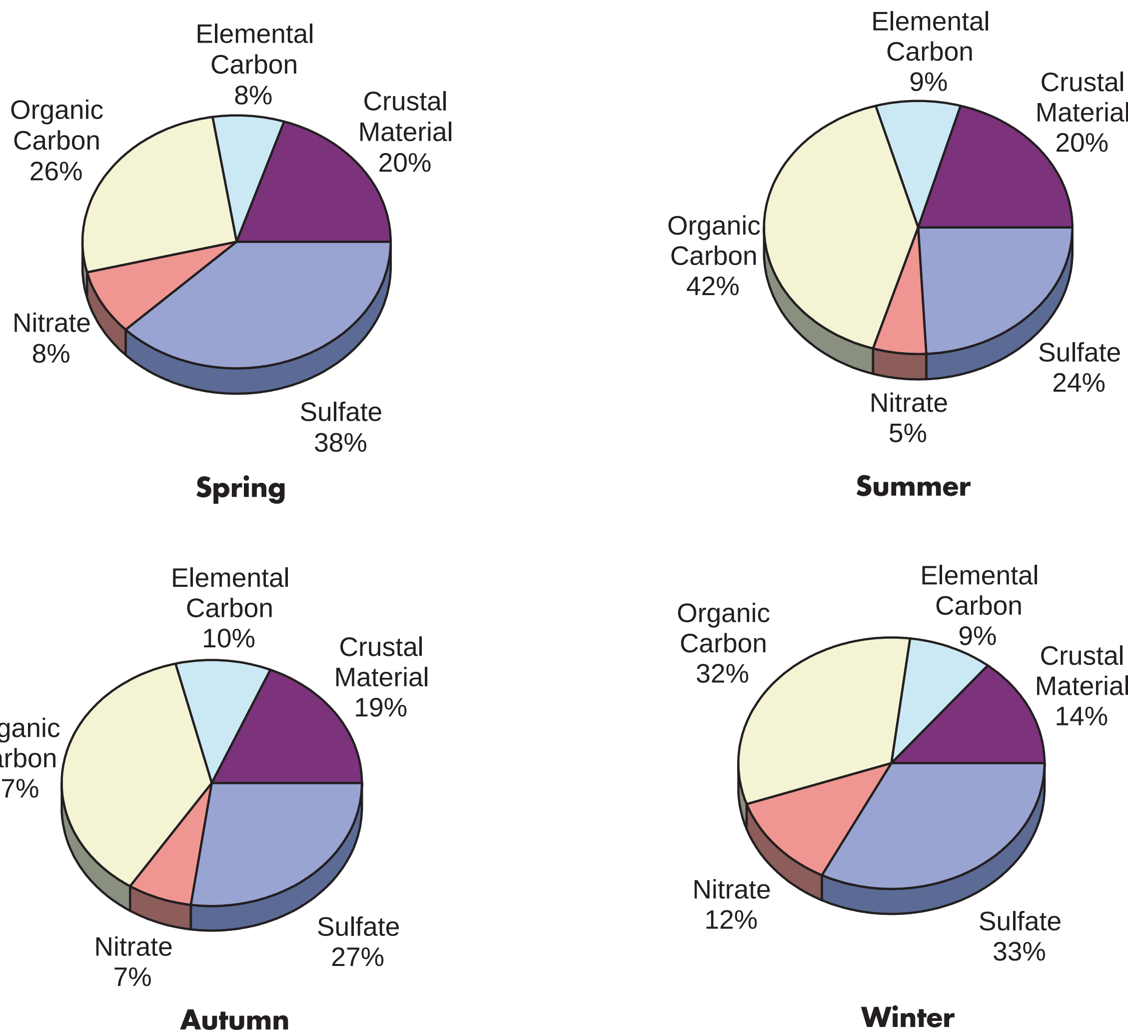

Figure WY–10. Contribution to Calculated Seasonal Aerosol Light Extinction from 1994–1998 for the Yellowstone IMPROVE Particulate Sampler

spring, summer, and autumn indices showed no statistically significant trends toward improved visibility between 1989 and 1998.

Figure WY–9 presents a chart showing the calculated fractional contribution to Yellowstone's light extinction by each aerosol species on an annual basis. Figure WY–10 shows the same information for the four seasons. These five pie charts show that the largest contributors to light extinction were organic carbon and sulfate particles. The contributions from organic carbon rose from 26 percent in the spring to 42 percent in the summer, averaging 36 percent on an annual basis over a five-year period. Sulfate was responsible for 24 to 38 percent of the light extinction at the Yellowstone site, averaging 29 percent on an annual basis over a five-year period. The contributions from sulfates were lower in the summer and autumn and higher in the winter and spring. Nitrate contributions were near 5 percent in the summer but rose to 12 percent in the winter. Annually, elemental carbon and crustal material contributions were near 9 and 19 percent.

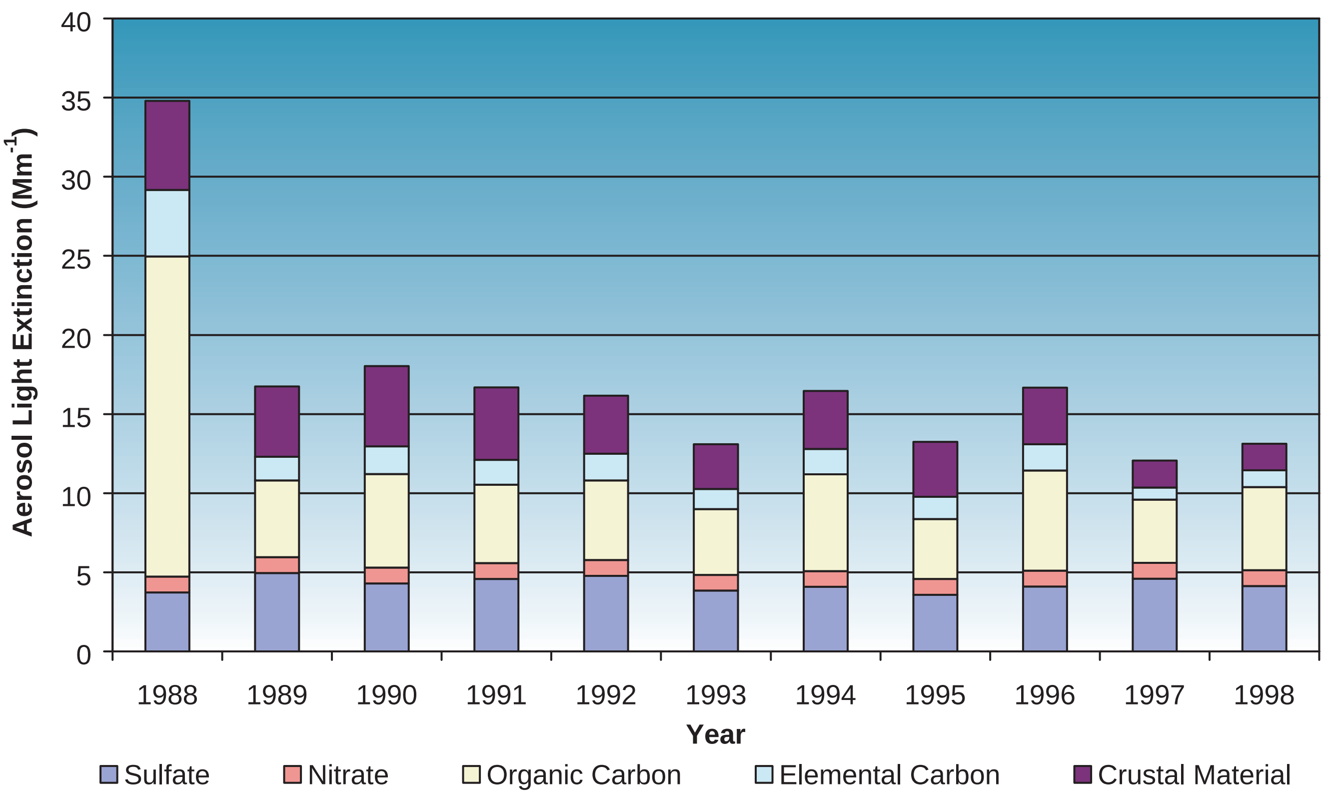

Figure WY–11. Contributions to Calculated Annual Aerosol Light Extinction from 1988–1998 for the Yellowstone IMPROVE Particulate Sampler

Figure WY–11 shows the calculated contributions of each of the aerosol mass components to the annual average aerosol light extinctions at the Yellowstone site from 1988 to 1998. The high light extinction attributed to organic and elemental carbons in 1988 resulted from the major wildfires. From 1989 to 1998, the total annual aerosol light extinctions dropped from 17 to 13 Mm^{-1}, with a statistically significant trend toward lower total light extinction coefficients. The annual light extinctions for sulfates, organic carbon, and elemental carbon showed no significant trends over this time period. However, the annual light extinction coefficients for crustal material decreased 3 Mm^{-1}, indicating statistically significant trends toward lower light extinction coefficients for that species and lower ambient concentrations.

Wyoming State Summary

The calculated annual average aerosol extinction coefficients at Wyoming's IMPROVE monitoring sites are presented in Table WY–1. The sites are located 115 miles apart. The total aerosol extinction coefficients at both sites were within 20 percent of one another, indicating similar annual visibility conditions at both sites. The extinction coefficients for the individual species were also similar at both sites. Both sites also showed similar rankings for contributions of the species to light extinction: sulfate, followed by organic carbon, crustal material, elemental carbon, and lastly nitrate. The same rankings were observed for the Arizona, Colorado, and Texas sites in Tables AZ–1, CO–1, and TX–1.

Table WY–1. Wyoming Calculated Total Extinction Coefficients from 1994–1998

IMPROVE Site	Calculated Total Aerosol Extinction Coefficient (Mm^{-1})	Pollutant Extinction Coefficient (Mm^{-1})				
		Sulfate	Nitrate	Organic Carbon	Elemental Carbon	Crustal Material
Bridger Wilderness	12.0	4.4	0.9	3.6	1.0	2.1
Yellowstone NP	14.3	4.1	1.0	5.1	1.3	2.8