TITLE: REGIONAL AIR QUALITY IN THE FOUR CORNERS STUDY REGION

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Introduction

The body of information presented in this paper is directed to policy makers, regulators, and energy planners concerned with the effect of energy development and alternative regulatory policies on regional air quality in the Four Corners Study Region. This study was one of 5 regional studies conducted for the National Commission on Air Quality (NCAQ). Potential regional air quality impacts were evaluated out to the year 1995 for alternative energy scenarios under current and alternative regulatory policies. Highlights of the results from the regional air quality analysis are discussed in this paper. More detailed discussions of the regional air quality analysis, one of several analyses conducted for the Four Corners Study, and the study as a whole are presented elsewhere.1,2

The results of the regional air quality analysis are discussed in 4 major sections of this paper--Regional Emissions, Regional Concentrations, Regional Visual Air Quality and Regional Budgets. The study regions emissions for the current regulatory policy are summarized by scenario year. We estimate the ambient regional concentrations and deposition of sulfur oxides (SO\textsubscript{2}) and primary fine particulates (FPM) from sources within the study region and their effect on regional visibility. In addition, we examine the importance of sources located outside of the study region in contributing to visibility reduction within the study region. We also estimate the amounts of sulfur oxides and primary fine particulates produced by sources within the study region with regard to the amounts deposited within and transported out of the Four Corners states.

The study region is a multicounty area located within the Four Corners states (see Figure 1). It is primarily a rural region with no large urban centers and is rich in energy resources--coal, oil, natural gas, uranium, oil shale and tar sands. The air quality in the region frequently approaches pristine conditions and is excellent in comparison to that in the heavily populated and industrialized Eastern US and in urban areas along the Pacific Coast. Because the atmosphere over the region is very clear, it is sensitive to degradation by air pollution, including visual air quality degradation. Air pollution regulations serve as a mechanism to resolve conflicts between air quality and energy development goals.

Energy Development Scenarios

Three energy development scenarios were evaluated in the Four Corners study--a low-growth, a mid-level or "most-likely," and a high-growth scenario. The low-growth scenario reflects obstacles that may exist to possible energy development. The mid-level scenario is the one that seemed most probable to the study team. The high-growth scenario accounts for the richness of the study regions energy resources and their ultimate potential.
for contribution to the nations energy supply. The regional air quality
analysis focuses on the evaluation of the Mid and High scenarios. The
scenarios just discussed are discussed in detail elsewhere.2

The Alternative Regulatory Policies

Seven alternative regulatory policies which are different from the
current regulatory requirements were evaluated—technology based standards,
airshed, state and regional fees, uniform emission standards, Prevention of
Significant Deterioration (PSD) class elimination and airshed ceilings. These
policies fall into 4 general categories.

1. Technology-based standards—both strict and weak applications—along with
   a uniform emissions reduction instrument that is a form of technology-based
   standards applied to all source categories;

2. Emission fees—three levels of geographic implementation are
   considered—airsheds, state and regional;

3. PSD class elimination—the class designations are eliminated while
   maintaining strict technology-based standards of current legislation; and

4. Emission ceilings (marketable emission permits)—airsheds are the only
   level of geographic implementation considered.

The alternative regulatory policies and their analysis are discussed in
more detail elsewhere.

Methodology

This section gives a brief summary of the methods used in the regional
air quality analysis. Detailed discussions of the methods used are presented
elsewhere.1,3 Methods were used to estimate the fate (ambient
concentrations, wet and dry deposition and amounts leaving the Four Corner
states) of air pollutants generated by sources located within the study region
and their effect on regional atmospheric visibility. A regional transport
model4 was used to estimate the concentration and deposition of sulfur
dioxide (SO2), particulate sulfates (SO4) and FPM generated by the sources
located within the study region. The concentrations and depositions were
estimated on an annual average basis for 1 by 1 degree grid cells that extend
vertically to the top of the mixing layer and that cover the Four Corners
states (see Figure 2).

One major advantage of the regional transport model employed is that its
solution involves the calculation of transfer coefficients which relate air
pollutant emissions directly to ambient concentrations and dry and wet
deposition. The transfer coefficients need to be calculated only once for a
given time period and set of model parameters. They can be used repeatedly
for the analysis of alternative scenario-policies with different emission
source configurations.

The regional transport model has undergone some testing. A simplified
version of the model was shown to give estimates of ambient sulfate
concentrations which compared well with observations.4 When the model was
used with methods for calculating the contribution of SO$_4$ to regional atmospheric visibility reduction, the model's estimates were consistent with estimates from historical relationships between SO$_x$ emissions and regional visibility reported by Marians and Trijonis (see Table I).

The outputs from the regional transport model were used as inputs to regional atmospheric visibility and mass budget calculations. The contribution to visibility reduction within the study region caused by light-scattering aerosols generated by anthropogenic sources located outside of the study region (urban areas, copper smelters, power plants, industrial sources and other major source categories), were accounted for by using the results from a previous study. This previous study evaluated regional visibility impacts related to future energy development projected for the National Energy Plan (NEP) II. Energy supply and demand projections were made out to the year 2000 and environmental impact evaluations were made for all regions of the continental US. For both the NCAQ and the NEP II studies, light-scattering by SO$_4$ and FPM aerosols was estimated as a function of their concentration and relative humidity. Visual range was calculated from the total light-scattering by these aerosols and by air molecules (Rayleigh scattering) using the Koschmieder relationship.

Results

Regional Emissions

The SO$_2$, NO$_x$, and total suspended particulates (TSP) emissions for 4 scenario years under the assumption of current regulatory policy are shown in Figures 3, 4 and 5, respectively. Emissions of primary SO$_4$ and FPM were also projected. SO$_x$ emissions were also projected for the alternative regulatory policies. The 1980 baseline emissions are based on information received from a survey of existing sources. The emissions for the projected new sources were based on information from technical documents prepared for facilities proposed to be located within the study region.

Coal-fired power plants are currently the dominant air pollutant emission sources within the study region. Synthetic fuel facilities, particularly oil shale processing facilities, are expected to become significant air pollutant emission sources in the study region in the future, especially with regard to particulate emissions. The highest air pollutant emissions under current regulations were projected for the high scenario in 1995. SO$_2$ and primary SO$_4$ emissions show a 124% increase between the 1980 baseline and the 1995 high scenario. TSP shows a 242% increase, FPM shows a 255% increase and NO$_x$ shows a 230% increase. Currently, TSP is well controlled in modern coal-fired power plants. SO$_2$ is expected to be effectively controlled in new power plants and other new energy facilities that are now or are expected to be constructed. According to current opinion, there is no cost-effective, high-efficiency control technology for NO$_x$. Subsequently, NO$_x$ emissions are expected to increase at a much greater rate than SO$_2$ emissions.

For the 1995 high scenario under current regulations, the regional siting locations of existing and new coal-fired power plants include northeastern, central, and southern Utah; northwestern Colorado; northwestern New Mexico; and north-central and east-central Arizona. For the same scenario year, the regional siting locations of oil shale development include western Colorado
and northeastern Utah. Tar sands development is expected in eastern Utah. Siting of coal gasification and liquefaction facilities is projected for south-central Utah, northwestern Colorado, and northwestern New Mexico.

Regional Concentrations

The results from the regional concentration estimates by the regional transport model are presented in this section. For primary pollutants such as \( \text{SO}_2 \) and \( \text{PM}_2.5 \), there are large spatial gradients in concentration surrounding the site of their emission. For example, for the isopleth map of \( \text{SO}_2 \) concentration for the high scenario in 1995 (see Figure 6), there is a peak of 2.5 \( \mu \text{g/m}^3 \) and a sharp spatial gradient in concentration in northwestern New Mexico, where a large number of energy facilities are sited. Other peaks occur at other siting locations with high emissions from coal-fired power plants and synthetic fuel facilities. The highest peak in \( \text{PM}_2.5 \) concentration for the high scenario in 1995 is estimated to occur in an area of intensive energy development in northeastern Utah and northwestern Colorado.

Annual regional \( \text{SO}_2 \) concentrations also were calculated for only the new sources covered under PSD regulations. The highest \( \text{SO}_2 \) concentrations under current regulations are estimated for the high scenario in 1995, which assumes the most rapid energy development. The largest \( \text{SO}_2 \) peak again occurs near the intersection of the four Corners states in northwestern New Mexico. This peak of 0.863 \( \mu \text{g/m}^3 \) of \( \text{SO}_2 \) is less than the most stringent PSD annual increment, the Class I annual increment, which is 2 \( \mu \text{g/m}^3 \). The regulatory questions of ambient air quality standard violation are addressed in detail in the local air quality analysis report in which concentrations are estimated for the shorter 3-hour (h) and 24-h averaging times and in which more detailed information concerning local atmospheric wind and temperature structure and topography are considered.

Secondary pollutants formed by the chemical conversion of primary pollutants such as \( \text{SO}_4 \), which is formed by the atmospheric oxidation of \( \text{SO}_2 \), have much more gradual spatial gradients in concentration. This point is illustrated by comparing the concentration isopleth maps for \( \text{SO}_4 \) and \( \text{SO}_2 \) for the same scenario years, Figures 6 and 7, respectively. Secondary pollutants formed by chemical conversion or condensation processes are found primarily in the accumulation mode size range, 0.2-2.0 microns in diameter. Particles in this size range have high residence times in the atmosphere because they are slow to be removed by dry deposition processes. They are believed to be slow in being transported by Brownian diffusion across the laminar boundary layer at the earth's surface. For this reason, they can be transported over long distances (hundreds to thousands of kilometers) before being completely removed from the atmosphere. Subsequently, one can expect that sources far outside of the study region can contribute significantly to the concentration of fine particulates, including sulfates, within the study region. This conclusion is supported by results from this study and the earlier NEP II study. From the results of these studies it is estimated that the anthropogenic sources located outside of the study region (urban areas, copper smelters, power plants, industrial sources, and other major source categories) contribute to approximately 85-90% of the anthropogenically related \( \text{SO}_4 \) within the study region on an annual average basis for the 1980 baseline year, the Mid scenario in 1987 and 1995 and the High scenario in 1995, assuming the current regulatory policy.
The concentration and deposition of NO\textsubscript{x} species (nitrogen oxide (NO), nitrogen dioxide (NO\textsubscript{2}), nitric acid (HNO\textsubscript{3}), particulate nitrates (NO\textsubscript{3}), peroxy acetyl nitrate (PAN) and other organic nitrates) were not estimated in the regional analysis. Parameterization of the chemistry, in particular, and the deposition of NO\textsubscript{x} species are not as far along as for SO\textsubscript{x} species. Regional modeling of the fate of NO\textsubscript{x} species is currently in an early stage of development and has not undergone validation. The fate of NO\textsubscript{x} species is more difficult to study than that of SO\textsubscript{x} species because there are more types of NO\textsubscript{x} species and because the nitrate species can be in gaseous or particulate form, depending on atmospheric temperature and relative humidity.

**Regional Visual Air Quality**

Atmospheric visual air quality is an aesthetic air quality value. The appearance of scenic vistas is affected by the quality of the atmosphere between the observer and the scenic background. Particles and gases in the atmosphere generated by human activities can absorb and scatter light and cause a degradation of the color, texture, line and form of a background scene. The color and texture are the first to be degraded, followed by line and form. A local or regional haze caused by light-scattering aerosols make a background scene appear washed out. A colored plume across one's field of view can diminish one's appreciation of a scenic vista. Meteorological conditions such as fog, precipitation and high relative humidity also can impair visibility. In this section, we address the effect of regional haze on visibility reduction.

Regional haze can be caused by air contaminants transported in an air mass over distances of hundreds to thousands of kilometers. The haze can have a large number of emission sources contributing to it, including urban areas. It is generally vertically homogeneous up to the top of the mixing layer and horizontally homogeneous over distances on the order of hundreds of kilometers. Regional haze cannot readily be traced back to its sources of origin.

Regional median visual ranges and light-scattering coefficients by pollutant and source category were estimated for the 1980 baseline year, the Mid scenario in 1987 and 1995 and the High scenario in 1995, assuming current regulatory policy. In the regional visibility estimates, we accounted for the contribution to visibility reduction by SO\textsubscript{4} and PM aerosols generated by anthropogenic sources located within and outside of the study region. The estimates for the sources located outside of the study region, the extra-regional sources, were based on the results from the NEP II study. 6

The anthropogenic component to visibility reduction is believed to be the predominant component except during periods of adverse meteorological conditions (fog, precipitation, low clouds), severe dust storms and large-scale forest fires. In a study of airport visibility data by Gins, Nochumson, and Trifonis, the removal of days obviously dominated by adverse meteorological conditions increased median visual range 5-10% in the Rocky Mountain Region. 8 Although these adverse natural conditions occur and have some effect on atmospheric visibility, the Southwestern US still experiences the best visibility in the continental US. In contrast, the heavily populated, industrialized North with the heaviest anthropogenic air
pollutant emission loadings in the US experiences the worst visibility in the country. In a study of visibility in the Southwest, improvement of atmospheric visibility was found during the copper strike of 1967-68. Although the contribution of anthropogenic sources to visibility reduction is better understood and frequently predominates that from natural sources, the natural component and its frequency of occurrence needs to be accurately quantified because air quality regulations define visibility impairment relative to the visibility existing under natural conditions.

Light Extinction Budgets. Budgets of extra light-scattering by SO$_4$ and FPM aerosols generated by anthropogenic sources located within the study region, the intraregional sources, were estimated (see Figure 8). The extraregional component to light-scattering is not included in these budgets. Extra light-scattering excludes the contribution to light-scattering by air molecules—called Rayleigh scattering. The budgets were estimated assuming the current regulatory policy for the 1980 baseline year, the Mid scenario in 1987 and 1995 and the High scenario in 1995. The estimated light-scattering by SO$_4$ is predominant. The percent contribution from FPM is estimated to increase over time, particularly for the High scenario in 1995. Coal-fired power plants are estimated to be the predominant anthropogenic source within the study region contributing to the light-scattering aerosol within the study region. Assuming current regulatory policy, the synthetic fuel facilities are estimated to become significant contributors by 1995, particularly for the High scenario.

Comparison of the Regulatory Policies. Estimates of the median visual range averaged over the study region by scenario-policy-year are presented in Table II. The change in regulatory policy was assumed to affect only the $SO_x$ emissions from the study regions sources. The contribution to visibility reduction by extraregional sources based on the results from the NEP II study$^6$ for the Four Corners Air Quality Control Region (AQCR) are most representative of the baseline year and for the cases of the Mid scenario under current regulatory policy. Percentage changes from the 1980 baseline year in the regional median visual range by scenario policy for the 1995 High scenario are illustrated in Figure 9. Except for the alternative regulatory policies that allow for a substantial increase in $SO_x$ emissions from sources within the study region (airshed ceilings, airshed fees and state fees), there is a small (less than 10%) estimated change in regional median visual range from the 1980 baseline year to the future scenario years. The highest estimated decrease of -21.7% is for airshed fees for the 1995 High scenario. The estimated contribution to visibility reduction by extraregional sources is substantial, 55.6-92.0% of the regional light-scattering (excluding Rayleigh scattering). As expected, the alternative regulatory policies that allow a substantial increase in $SO_x$ emissions from sources within the study region have a substantially lower percent contribution to visibility reduction by extraregional sources than do the other regulatory policies, 50.5-64.8% as compared to 69.2-92.0%, respectively.

The result of little change in estimated regional median visibility for the study region to the year 1995, assuming current regulatory policy, is consistent with the results from the NEP II study$^6$ for the Four Corners AQCR. In the NEP II study, the estimated contribution to the extra light-scattering budget by SO$_4$ originating from southwestern copper smelters in 1975 was substantial, 61.6%, for the Four Corners AQCR. Also in the NEP II
study, it was assumed that the SO\textsubscript{x} emissions from the copper smelters would be effectively controlled (90% control) by 1990. As a result, the estimated percent contribution by copper smelters was reduced to 16.1% in the year 1990 and 15.6% in the year 2000. Although the contribution by copper smelters was estimated to be substantially reduced, there was only a small reduction in total light light-scattering by aerosols for the Four Corners AQCR. This can be attributed to the approximately equal replacement of the copper smelters estimated contribution by the estimated contribution to aerosol loading from the new sources resulting from the projected substantial energy-related growth in the West. However, other AQCRs in the West located farther from the influence of the smelters were estimated in the NEP II study to have a significant decrease (greater than 10%) in median visual range from 1975 to 1990 and from 1975 to 2000. This resulted from a greater than equal replacement of the copper smelters estimated contribution by the estimated contributions from the projected new sources.

Visibility Impairment. With regard to the implementation of the Federal visibility legislation, a critical factor is the definition of visibility impairment. In EPAs visibility rules, visibility impairment is defined as "any humanly perceptible change in visibility (visual range, contrast, coloration) from that which would have existed under natural conditions" and significant impairment is defined as an impairment "which in the judgment of the (EPA) Administrator, interferes with the management, protection, preservation or enjoyment of the visitors visual experience of the mandatory Class I area." Significance of impairment is to be determined on a case-by-case basis. A great deal of uncertainty remains concerning the EPAs visibility regulation with regard to its interpretation in terms of quantitative criteria and implementation.

In a recent study, Trignon attempted to give estimates of thresholds of perception for contrast based on information from a literature review. The estimates were given for the case of the observer embedded in a plume or haze layer, Case A, and the case where the observer is outside of the plume or haze layer and viewing the haze against a cleaner background, Case B. The plume or haze is expected to be more perceptible in Case B where there is a simultaneous comparison of the plume or haze against the background. Trignon also related the change in contrast (AC) to a corresponding change in light extinction and visual range. The estimates of the contrast thresholds and the corresponding estimated perceptible change in visual range are presented in Table III. Two values of the latter are given, one at the point of maximal impact and a second for an average contrast change integrated over the visual range. It should be emphasized that currently there is no consensus concerning acceptable thresholds of perception and that the ones discussed are inadequate for addressing the discoloration problem.

Employing these criteria with caution, one can identify the scenario policies in which there would be a perceptible difference between average regional visibility for a future scenario-policy-year and the 1980 baseline year. The estimated visibility for the baseline year is a lower bound estimate of the visibility that would exist under natural conditions because the baseline year visibility is influenced by anthropogenically generated aerosols. Thus, the number of scenario-policy-years identified as having visibilities perceptibly different than the baseline year will be a lower bound estimate of the number of scenario-policy-years with visibilities
perceptibly different from those that would exist under natural conditions. Comparisons will be made under the following assumption: the shape of the frequency distribution of visibility observations for the region does not change with scenario policy. Under this assumption for Case A and the probably perceptible criteria, there would be perceptible differences in observed visibilities compared with the baseline for airshed ceilings for both the Mid and High scenarios in 1995 and for airshed fees and state fees for the High scenario in 1995. Under the more stringent Case B and probably perceptible criteria, two additional scenario policies would be identified as being perceptibly different from the baseline level. The additional scenario policies would be airshed fees and state fees for the Mid scenario in 1995.

Currently, accurate estimates of the visibility that would occur under natural conditions without man-made influences are unavailable. By employing the above criteria with caution, we can estimate the natural median visual range that is perceptibly different from the 1980 baseline regional median visual range. Under Case A and the probably perceptible criteria, it would be 87.5 miles; under Case B and the probably perceptible criteria, it would be 83.2 miles.

Currently, there is not a consensus on what are the existing visibility levels in the Rocky Mountain West. Trijons and Shapland report median levels of 60-85 miles for the Rocky Mountain Region.12 Medians reported for the telephotometry data from the Visibility Investigative Experiment in the West (VIEW) network, operated by the EPA and the National Park Service, were higher, 95-135 miles. The reasons for these differences have not been determined. Because the region is mountainous and the viewing distances are long, it is expected that the measurements are sensitive to viewing angle, the inherent contrast of the target and the spatial variation of the concentration of the atmospheric aerosol. The differences may also be caused by differences in sensitivity between human observers and telephotometers.13

Nitrates. Contribution to light-scattering by particulate nitrates from sources within the study region was not accounted for in the regional visual air quality analysis because quantifying their concentrations was not attempted in the regional concentration analysis. Particulate nitrates are not expected to be an important factor to regional light-scattering in the summer months, because during conditions when temperatures are high and relative humidity is low, the inorganic nitrate species are expected to be in gaseous form. The significance of nitrates to regional visibility reduction during the other seasons is unclear.

Regional Budgets

The fate of SO$_2$, SO$_4$ and FPM was examined through regional budget calculations based on the results from the regional air quality modeling. We estimated the amounts of SO$_2$, SO$_4$ and FPM emitted within the study region, deposited by dry and wet removal processes and advected out of a control volume over the Four Corners states. The control volume extends to the top of the mixing layer and its perimeter is shown in Figure 2. The budgets were estimated assuming the current regulatory policy for the 1980 baseline year, the Mid scenario in 1987 and 1995 and the High scenario in 1995. The regional budgets for sulfur oxides are shown in Figure 10. Approximately equal amounts of the SO$_4$ and FPM were estimated to be removed from the atmosphere by dry
deposition processes, removed by wet deposition processes or were advected out of the Four Corners states. It was assumed that 2% on a molar basis of the \( \text{SO}_x \) emissions were in the form of primary \( \text{SO}_4 \). Of the \( \text{SO}_2 \) emitted within the study region, a little over 60% was estimated to be removed by dry deposition processes, nearly 15% removed by precipitation scavenging, nearly 10% advected out of the Four Corners states and nearly 15% transformed to \( \text{SO}_4 \). \( \text{SO}_2 \) is a reactive gas, which is believed to be more effectively removed from the atmosphere by dry deposition processes than are fine particulates such as \( \text{SO}_4 \) and FPM. The regional budget estimates varied little by scenario year. Extraregional aerosols were estimated to contribute substantially to the aerosol concentration and light-scattering in the study region. So too, the fine aerosols (\( \text{SO}_4 \) and FPM) from the study regions sources could have a significant cumulative effect on regional visibility reduction and acid deposition in areas outside of the study region when combined with aerosols generated in other areas of the West also experiencing rapid population growth and energy development.

The mountainous portions of the study area contain soils with low buffering capacity and are expected to be sensitive to effects from acid deposition.\(^{14}\) Precipitation events with low pH levels associated with \( \text{SO}_4 \) and nitrate species have been measured in the Rocky Mountain Region.\(^{15}\) Dry and wet deposition are expected to contribute to acid deposition. It is expected that after \( \text{SO}_2 \) and \( \text{NO}_x \) are removed by dry deposition processes, they can be converted into acidic species. \( \text{NO}_x \) is converted into nitric acid which can be effectively removed by dry deposition processes. These dry deposition processes are not well understood and may be a major contributor to acid deposition in arid regions. Particulate sulfates are believed to be primarily in the form of ammonium sulfate and ammonium bisulfate and a smaller fraction is believed to be in the form of sulfate salts and sulfuric acid. Both ammonium bisulfate and sulfuric acid contribute to wet and dry acid deposition. More research is needed to understand the significance of the possible impacts of acid deposition in the Southwest.

Conclusions

The study region has excellent air quality, which is sensitive to degradation from air pollution. The regional air pollutant emissions, associated with the siting of new coal-fired power plants and synthetic fuel development, and their contribution to regional \( \text{SO}_2 \), \( \text{SO}_4 \) and FPM concentrations for the current regulatory policy are expected to increase between the 1980 baseline year and the 1995 scenario year. Although concentrations are expected to increase, no violation of the PSD annual increments for \( \text{SO}_2 \) was indicated in the regional concentration estimates. The alternative regulatory policies are quite different with respect to their \( \text{SO}_x \) emissions and their impacts on regional visibility. The policies favoring substantial increases in \( \text{SO}_x \) emissions (airshed ceilings, airshed fees and state fees) are estimated to contribute to significant decreases in regional visibility.

The extraregional contribution to light-scattering in the study region, estimated to be substantial, generally dominated the intraregional contribution. So too, the fine aerosols (\( \text{SO}_4 \) and FPM) from the study region sources could have a significant cumulative effect on regional visibility and
acid deposition when combined with aerosols generated in other areas of the West also experiencing rapid population growth and energy development. According to the budgets of extra light-scattering, the intraregional component is estimated to be dominated by light-scattering caused by SO\(_4\) aerosols generated by coal-fired power plants. The influence of synthetic fuels development is expected to increase. The local source contribution to light-scattering can be expected to be dominant for local hazes during lengthy periods of poor ventilation.

Based on the results of the NEP II study, copper smelters were estimated to be the major extraregional component to visibility reduction within the study region. As energy development and population growth progresses in the West and assuming that the smelters become effectively controlled, the contribution of the smelters to visibility reduction in the study region is expected to be replaced over time by contributions from new sources located outside of the study region. Based on the NEP II study results, in areas of the West located farther from the smelters than the study region, new sources can be expected to be greater contributors than the smelters, primarily because of expected smelter clean-up.

The significance of regional visibility impacts is dependent on the regulatory definition of significant visibility impairment and its implementation. There is great uncertainty concerning how it will be defined with respect to objective criteria. In this study, we examined the question of perceptible change in visibility by employing contrast thresholds. Under this approach, the alternative policies with substantial increases in SO\(_x\) emissions were indicated to have probably perceptible differences in average regional visibilities as compared with the estimated average regional visibility for the 1980 baseline year. Currently, there is no consensus concerning defining objective criteria for defining perceptible differences in visibility to be employed in defining significant visibility impairment. The contrast threshold approach may serve as an operationally-useful approach, although this approach is inadequate for addressing the discoloration problem. The question of perceptible change can be addressed relative to existing or natural levels of visibility. Currently, there are differences concerning what these levels are for the Rocky Mountain area.

A regional air quality impact that has been an issue in the East but not in the West is the issue of acid deposition. The mountainous portions of the study area contain soils with low buffering capacity and are expected to be sensitive to acid deposition. Precipitation events with low pH levels have been measured in the Rocky Mountain Region, and dry as well as wet deposition may be a significant contributor to acid deposition in this region. More research is needed to understand the significance of possible impacts of acid deposition associated with both SO\(_4\) and nitrate species in the Southwest. More research is also required to understand the possible role of particulate nitrates in regional visibility reduction and acid deposition. The fate of NO\(_x\) species and their parameterization is not as well understood as that of SO\(_x\) species, and thus requires additional study.
REFERENCES


13. Some investigators use a threshold contrast of 0.055 for teleradiometers in order to estimate the visual range perceived by a human observer. This would reduce the VIEW network visibilities by a factor of 0.74. Personal communication with Eric Walther, February 5, 1982.


TABLE I
THE RELATIONSHIP BETWEEN THE LIGHT EXTINCTION COEFFICIENT AND SULFUR OXIDE EMISSIONS

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<th>Correlation Coefficient</th>
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<td>Case B</td>
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<tr>
<td><strong>Observer</strong></td>
<td>Embedded in Plume or Haze</td>
<td>Outside Plume or Haze</td>
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<tr>
<td><strong>Percent Change in Visual Range</strong></td>
<td><strong>ΔC</strong></td>
<td><strong>Point of Maximal Impact</strong></td>
</tr>
<tr>
<td><strong>Possibly Perceptible</strong></td>
<td>0.02</td>
<td>5.4</td>
</tr>
<tr>
<td><strong>Probably Perceptible</strong></td>
<td>0.04</td>
<td>10.9</td>
</tr>
<tr>
<td><strong>Definitely Perceptible</strong></td>
<td>0.06</td>
<td>16.3</td>
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THE STUDY REGION

Fig. 1.

Fig. 2. Regional Air Quality modeling boundaries.
SULFUR DIOXIDE EMISSIONS

Fig. 3.

OXIDES OF NITROGEN EMISSIONS

Fig. 4.
Fig. 5. Total suspended particulate emissions

Fig. 6. Sulfur dioxide concentrations for the High scenario in 1995.
Fig. 7. Particulate sulfate concentrations for the High scenario in 1995.

Fig. 8.
PERCENT CHANGE IN VISUAL RANGE FROM THE BASELINE YEAR BY REGULATORY POLICY
1995 HIGH-SCENARIO

Fig. 9.
REGIONAL BUDGETS FOR SULFUR OXIDES

Fig. 10.