

Potential Future Impacts on Visual Air Quality for Class I Areas¹

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Abstract: Visual air quality is most sensitive to degradation by air pollution in areas with good visibility. The protection of visual air quality in mandatory Class I Federal areas has been declared a national goal by Congress. Impacts on visual air quality are calculated for 154 Class I areas where visual air quality is considered an important value. These impacts are potential future impacts in 1985 and 1990 due to DOE's "Mid-Mid" Energy Scenario.

INTRODUCTION

Visual air quality is degraded by air pollution. It is very sensitive to degradation in pristine areas with very good visual air quality. The degradation of visual air quality is of particular concern in the Rocky Mountain region where there is both an abundance of pristine areas and coal resources. The combustion of coal can cause significant air pollution. Congress has recognized visual air quality as an important value. For mandatory Class I Federal areas where impairment in visual air quality results from manmade air pollution, Congress has declared as a national goal the prevention of future impairment and the remedying of existing impairment (Public Law 95-95 subpart 2, Section 169A).

In fiscal year 1979, DOE initiated an intensive study on the socioeconomic and environmental impacts of the Mid-Mid Energy Scenario. This study--the Regional Issue Identification and Assessment (RIIA) program--involves all the national energy laboratories. Each national laboratory directed

one or more aspects of the study. In addition, each laboratory assessed all of the scenario's impacts on its geographical region. Los Alamos Scientific Laboratory (LASL) assumed the lead lab role in visual air quality assessment and was responsible for evaluating energy development impacts in the Rocky Mountain region. This paper describes the methodology employed by LASL to calculate visual air quality in Class I areas in the U.S. in 1985 and 1990, and presents the results of the RITA study pertaining to atmospheric visual air quality.

The scenario, known as the Projection Series C or the TRENDLONG Mid-Mid Scenario, is one of six possible energy futures produced by the Energy Information Administration of the Department of Energy (DOE) for the Department's 1977 Annual Report to Congress. For this scenario, it is assumed that there is medium energy demand and fuel supply through 1990. The national energy supply and demand balance for this scenario is summarized in Table 1. County level sitings of utility and industrial fossil-fueled power plants were projected for 1985 and 1990 for this scenario. The sitings were done by Oak Ridge and Brookhaven National Laboratories.

For the assessment of this scenario, it was assumed that sulfur dioxide and primary particulate emissions from fossil-fueled combustion facilities were effectively controlled. Utility energy facilities with start-up dates before 1984 and industrial energy facilities were assumed to meet the more stringent of either the New Source Performance Standards (NSPS) or the State Implementation Plan (SIP) requirements.

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TABLE 1--1990 ENERGY SUPPLY/DEMAND BALANCE,
MID-MID SCENARIO (QUADRILLION BTU PER YEAR)

	1975	1985	1990
<u>DOMESTIC PRODUCTION</u>			
Crude Oil	17.9	19.0	18.0
NGL & Butane	2.6	2.0	1.8
Shale Oil	0	.1	.3
Natural Gas	19.0	17.2	16.7
Coal	14.6	23.1	27.5
Nuclear	1.8	6.2	10.3
Hydro & Geothermal	<u>3.2</u>	<u>4.2</u>	<u>5.0</u>
TOTAL DOMESTIC PRODUCTION	<u>59.1</u>	<u>71.8</u>	<u>79.6</u>
<u>IMPORTS</u>			
Crude Oil	8.7	16.5	20.9
Petroleum Products	3.8	6.7	7.8
Natural Gas	<u>1.0</u>	<u>1.9</u>	<u>2.6</u>
TOTAL IMPORTS	<u>13.5</u>	<u>25.1</u>	<u>31.3</u>
TOTAL SUPPLY	72.6	96.9	110.0
<u>DOMESTIC CONSUMPTION</u>			
Oil	32.8	43.9	48.5
Natural Gas	20.0	19.1	19.3
Coal	12.8	21.2	25.4
Nuclear	1.8	6.2	10.3
Hydro & Geothermal	<u>3.2</u>	<u>4.2</u>	<u>5.0</u>
TOTAL DOMESTIC CONSUMPTION	70.6	94.6	108.5
<u>EXPORTS</u>			
Coal	1.8	1.9	2.1
Refinery Loss	<u>.2</u>	<u>.4</u>	<u>.3</u>
TOTAL CONSUMPTION & EXPORT	76.6	96.9	110.9
<u>DOMESTIC CONSUMPTION BY SECTOR</u>			
Residential	14.7	19.0	21.2
Commercial	11.3	13.5	15.0
Industrial	26.0	40.7	49.0
Transportation	<u>18.6</u>	<u>21.4</u>	<u>23.3</u>
TOTAL DOMESTIC CONSUMPTION	70.8	94.6	108.5

Utility energy facilities with start-up dates in 1984 and beyond were assumed to be subject to Best Available Control Technology (BACT) requiring 85 per cent removal of sulfur dioxide (SO₂) for locally available coal (90 per cent as a long term average), but subject to an emissions floor of .2 lbs. SO₂/10⁶ Btu. The air pollution emission analysis by county was done by Brookhaven National Laboratory. The impact on visual air quality in 1985 and 1990 due to emission sources other than utility and industrial fossil-fueled power plants was held at the levels which were estimated to exist during the baseline years.

METHODOLOGY

Through a relationship proposed by Koschmieder (Middleton 1952), visual range for black objects can be related to the extinction coefficient, b , defined in the Beer-Lambert law. The relationship has also been found to be a good approximation for calcu-

lating the visual range of dark topographical features such as forest covered mountains. The relationship for the limiting distinguishable contrast of a black object against the horizon sky for a standard observer is given by the following simple relationship:

$$V = \frac{3.912}{b} \quad (1)$$

V is known as the "meteorological range." The value used for the limiting distinguishable contrast for the standard observer is .02 (Middleton 1952).

The extinction coefficient can be represented by the sum of the following components (Charlson 1969): the light scattering coefficient due to atmospheric particles, b_{sp} , the light scattering coefficient due to air molecules (Rayleigh Scattering) b_{sg} , the light absorption coefficient due to gases such as NO₂, b_{ag} , and the light absorption due to particles such as carbon black, b_{ap} . The relationship can be represented as follows:

$$b = b_{sp} + b_{sg} + b_{ag} + b_{ap} \quad (2)$$

For nonurban areas, where the Class I areas of interest are located, the anthropogenically related extinction is primarily due to light scattering by particles. The concentration of NO₂ tends to be too low for light absorption by gases to be important and the light absorption coefficient due to particles tends to be an order of magnitude less than the light scattering coefficient due to particles.

The light scattering coefficient for a particulate species can be calculated as a product of its scattering to mass ratio, b_s/m , and its mass concentration, m . Particles in the size range comparable to the wavelength of light, .1 to 1 microns in radius, are the most effective light scatterers per unit mass (White and Roberts 1977). Particles in the accumulation mode, formed by the chemical reaction and condensation of gases, are found in this size range (Friedlander 1977). The bulk of the particulates in the accumulation mode are composed of sulfate, nitrate, and organics with particulate sulfate typically comprising the largest mass fraction. Submicron particles, in the nuclei mode, and particles greater than 1 micron, in the coarse particle mode, are not effective light scatterers per unit mass.

For hygroscopic particles, the particles will grow in size with increasing relative humidity. The particle growth will cause the scattering to mass ratio to increase which can be mathematically expressed as follows (Cass 1976):

$$(b_s/m)_{RH} = (b_s/m)_0 \cdot (1 - (RH/100))^n \quad (3)$$

$(b_s/m)_{RH}$ = the scattering to mass ratio at relative humidity, RH.

$(b_s/m)_0$ = the scattering to mass ratio at zero relative humidity.

Cass has estimated values of n for Los Angeles which range from -.53 to -1.09 for particulate sulfates and nitrates. Trijonis and Yuan (1977 and 1978) used a value m for of -1 in their regression analyses. An inspection of plots of the scattering coefficient versus relative humidity based upon measurements in Seattle, Washington, Denver, Colorado, and Altadena, California, indicates that a value of $n = -1/2$ fits the data better than a value of $n = -1$ (Covert, Charlson, and Ahlquist 1972).

The extinction coefficient calculated from visual range observations has been significantly correlated with the concentrations of particulate sulfates (SO_4), particulate nitrates (NO_3), total suspended particulates

(TSP), excluding the former two components, and relative humidity. Regression relationships with these pollutants as independent variables have been fitted to extinction coefficient data. (Trijonis and Yuan 1977 and 1978, White and Roberts 1977, Cass 1976). The regression coefficients can be interpreted as the extinction coefficient per unit mass for each pollutant.

The extinction coefficient and visual range are used as the indices of visual air quality. The use of the extinction coefficient to characterize visual air quality has been recommended by Charlson, Waggoner, and Thielke (1978). The limitations of the extinction coefficient for characterizing visual air quality are the following: It does not account for coloration effects. The visual perception of a scene is affected by the position of the observer and the sun. It does not completely characterize the visual range of colored objects. It is assumed that atmospheric concentrations of light scattering aerosols are spatially homogeneous. It does not characterize the case of plume blight. Plume blight needs to be examined on a case by case basis. The major advantages of the extinction coefficient are that it is simple to calculate and interpret, the scattering portion can be directly measured, its components are additive, and its relationship to visual range has been successfully tested.

The total light extinction for Class I areas is calculated as the sum of the following three components: (1) light scattering due to gas molecules, b_{sg} , Rayleigh scattering, (2) extinction due to the sources

and light scattering aerosols accounted for in long-range transport calculations, and (3) the remaining light extinction due to the sources and light scattering aerosols not accounted for in long-range transport calculations. The equation used for the calculation of the total light extinction coefficient, b_r , is expressed as follows:

$$b_r = b_{sg} + \sum_j b_{sij} + b_r \quad (4)$$

b_{sg} = light scattering due to air molecules. $b_{sg} = .15 \times 10^{-4}$ meters⁻¹ at sea level.

b_{sij} = light scattering due to aerosol i and source j .

b_r = the remaining light extinction due to the sources and light scattering aerosols which were not accounted for in the long range transport calculations.

The light scattering coefficient, b_{sij} , is calculated using Equation (3). The estimation of the scattering to mass parameters is discussed in the next section. The mass concentrations are from long-range transport predictions which were supplied by Pacific Northwest Laboratory for the western United States and Brookhaven National Laboratory for the entire United States. Pacific Northwest Laboratory predicted the concentrations of particulate sulfates due to sulfur dioxide emissions from major industrial process sources and from utility and industrial fossil-fueled power plants and predicted the concentrations of primary particulates (PP) due to emissions from utility and industrial fossil-fueled power plants. Brookhaven National Laboratory predicted the concentrations of particulate sulfates due to sulfur dioxide emissions from utility and industrial fossil-fueled power plants.

The major share of the calculated light extinction is accounted for by b_{sij} . The major anthropogenic sulfur dioxide emission source categories were accounted for in the long range transport calculations (Table 2). Extinction budget calculations summarized in Table 3 indicate that the major share of the light extinction in nonurban areas is due to particulate sulfates which are formed by the oxidation in the atmosphere of sulfur dioxide. These results are supported by the extinction budgets for the southwest and northeast prepared by Trijonis and Yuan (1977 and 1978). The greatest uncertainty in the calculation of the total light extinction coefficient is the contribution of natural sources. Except for meteorologically related impairment of visual

TABLE 2--REGIONAL SULFUR DIOXIDE EMISSIONS
BY POLLUTANT AND SOURCE CATEGORY¹

Lab Region	States In Lab Region	Source Category	Sulfur Dioxide Emissions (tons/yr)	Percent of Total Emissions
ANL	IL, IN, IA, KS, MI, MN, MO, NE, ND, OH, SD, WI	Utility	6,627,454	53.1
		Indus.	2,726,342	21.8
		Indus.	754,627	6.0
		Process Total	12,479,843	
BNL	CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT	Utility	4,076,303	57.6
		Indus.	1,372,133	19.4
		Indus.	464,996	6.6
		Process Total	7,077,186	
LBL	CA, NV	Utility	113,776	14.8
		Indus.	61,011	7.9
		Indus.	434,390	56.4
		Process Total	769,609	
LASL	AZ, CO, MT, NM, UT, WY	Utility	193,903	5.4
		Indus.	42,091	1.2
		Indus.	3,280,944	91.1
		Process Total	3,600,612	
ORNL	AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, VA, WV	Utility	5,393,078	68.8
		Indus.	668,959	8.5
		Indus.	885,003	11.3
		Process Total	7,842,900	
PNL	ID, OR, WA	Utility	421	.1
		Indus.	44,107	11.1
		Indus.	294,051	73.2
		Process Total	401,411	

¹Source: (U.S.E.P.A. 1974)

²ANL = Argonne National Laboratory
BNL = Brookhaven National Laboratory
LBL = Lawrence Berkeley Laboratory
LASL = Los Alamos Scientific Laboratory
ORNL = Oak Ridge National Laboratory
PNL = Pacific Northwest Laboratory

³Industrial refers to industrial fossil fuel combustion facilities.

air quality, visual air quality as indicated by airport observations of visual range is strongly related to regional anthropogenic air pollutant emissions. (Trijonis and Yuan 1977 and 1978 and Trijonis and Shapland 1978).

The light extinction budget presented in Table 3 is a summary by National Energy Laboratory Region of the estimated per cent of the extra extinction due to particulates sulfates, particulate nitrates, and total suspended particulates (TSP), excluding sul-

fates and nitrates. The light extinction is calculated from relative humidity and non-urban air quality data for the period of 1970 to 1974. The scattering to mass ratio estimates discussed in the next section were used in the calculations. Extra extinction accounts for all extinction except for the extinction due to Raleigh scattering.

The remaining light extinction is assumed to remain at existing, baseline levels. It is calculated from the baseline extinction and factors which account for excluded emission sources and light scattering aerosols. The baseline extinction is calculated from median visual range statistics (Trijonis and Shapland 1978), using the Koschmieder relationship. The remaining extinction is calculated as follows:

$$b_r = (b_b \quad b_{sg}) * (\sum_i F_{lik} * F_{2il}) \quad (5)$$

b_b = baseline extinction.

F_{lik} = the fraction of the total emissions of pollutant i in region k for sources not accounted for in the long range transport analyses. It is calculated from data in the 1972 National Emissions Report (U.S.E.P.A. 1974).

F_{2il} = the fraction of the total light extinction due to aerosol i in region 1.

PARAMETER ESTIMATION

The scattering to mass ratios typical of nonurban locations and at zero relative humidity as defined by Equation 3 were estimated using linear regression analysis. This approach has been used in previous studies (Trijonis and Yuan 1977 and 1978, White and Roberts 1977, Cass 1976). The scattering to mass ratios for fine particulate matter (FPM) and for Total Suspended Particulates (TSP) excluding FPM were estimated. The former accounts for light scattering due to particles in the accumulation mode and the latter accounts for light scattering due to particles in the coarse particle mode. The sum of particulate sulfate and nitrate concentrations was used to represent the concentration in the FPM mode. The sulfate and nitrate concentrations were multiplied by 1.3 to account for the mass of associated cations which are thought to be primarily the ammonium ion.

Averages of annual average nonurban air quality data for the period of 1970 to 1974 were used in the regression analysis. These were data from measurements taken at 39 nonurban National Air Surveillance

TABLE 3--EXTINCTION BUDGETS BY LAB REGION, SUMMARY STATISTICS¹

Lab Region	Sample Size	PERCENT EXTRA EXTINCTION					
		Sulfates (SO_4)		Nitrates (NO_3)		(TSP - (SO_4) (NO_3))	
		Mean	Range	Mean	Range	Mean	Range
ANL	6	75.2	70.2-88.6	10.3	.266-16.4	14.6	11.2-18.3
BNL	9	77.1	69.9-83.4	9.46	5.52-13.2	13.4	9.86-17.0
LBL	2	74.0	69.9-78.2	11.2	10.4-12.1	14.7	11.3-18.1
LASL	7	75.1	52.7-90.3	10.5	.208-35.3	14.4	9.38-22.0
ORNL	12	68.8	57.2-79.0	13.6	6.62-20.6	18.6	9.58-28.0
PNL	3	74.0	66.5-81.4	10.3	5.54-17.5	15.6	10.7-20.4

¹They are the summary statistics grouped by lab region of the extinction budgets calculated for nonurban ambient air quality monitoring sites.

²TSP = Total Suspended Particulates.

Network air quality monitoring sites (Table 4). Seventeen sites were located in western states and twenty-two were located in eastern states. Mean daily relative humidities, (annual), which were typical of the area in the vicinity of the sites were used (Baldwin 1973). The observed values for the light extinction coefficient were calculated from the observed visual range data using the Koschmieder relationship. The observed visual range data were taken from isopleth maps compiled by (Trijonis and Shapland 1978). They are median values for the period of 1974 to 1976.

The scattering to mass ratios were estimated for three values of the relative humidity exponent, $-1/2$, $-2/3$, and -1 (table 4). The regression equation for which the exponent was $-1/2$ gave the best fit to the data. As would be expected, the scattering to mass ratio for FPM was estimated to be much higher than for TSP minus FPM in both the western and the eastern states. The higher scattering to mass ratio for TSP minus FPM in the east as compared to the west could be explained by the coarser particles in the west being larger in size due to a greater contribution from wind blown dust and a smaller contribution from industrial sources. The standard deviation of the parameter estimates was relatively smaller for FPM as compared to TSP minus FPM. The variance explained in the regression for the exponent of $-1/2$ was 66.7 per cent.

RESULTS

Currently, there are no quantitative criteria of acceptable visual air quality for Class I areas. By August 1979, EPA must promulgate regulations which will (1) provide guidelines to states for including visibility in State Implementation Plans (SIP) where needed, and (2) require SIP's for affected states to include emission limits, schedules

for compliance, and other measures as may be necessary to make reasonable progress toward

TABLE 4--NONURBAN AMBIENT AIR QUALITY MONITORING SITE LOCATIONS

State	Location
Arizona	Grand Canyon National Park Maricopa County
Arkansas	Montgomery County
California	Humboldt County
Colorado	Mesa Verde County
Delaware	Kent County
Florida	Hardee County
Idaho	Butte County
Indiana	Monroe County Parke County
Louisiana	Iberville Parish
Maine	Acadia National Park
Maryland	Calvert County
Mississippi	Jackson County
Missouri	Shannon County
Montana	Glacier National Park
Nebraska	Thomas County
Nevada	White Pine County
New Hampshire	Coos County
New Mexico	Rio Arriba County
New York	Jefferson County
North Carolina	Cape Hatteras
Oklahoma	Cherokee County
Oregon	Curry County
Pennsylvania	Clarion County Indiana County
Rhode Island	Washington County
South Carolina	Richland County
South Dakota	Black Hills National Park
Tennessee	Cumberland County
Texas	Matagorda County Tom Green County
Vermont	Orange County
Virginia	Shenandoah National Park Wythe County
Washington	King County
Wisconsin	Door County
Wyoming	Grand Teton National Park Yellowstone National Park

TABLE 5--SCATTERING TO MASS RATIO PARAMETER ESTIMATES¹

Relative Humidity Exponent	Sum of the Squares of the Errors	Fine Particulate Matter		Total Suspended Particulates -1.3 * (Sulfate + Nitrates)			
		Estimate	Standard Deviation	West		East	
				Estimate	Standard Deviation	Estimate	Standard Deviation
-.5	6.51	.0576	.0106	.00207	.00310	.00511	.00429
-.667	7.94	.0364	.0114	.00296	.00250	.00961	.00545
-1.00	9.68	.0246	.00782	.00199	.00173	.00526	.00371

¹10⁴ meters⁻¹/(μg/m³)²((10⁻⁴) meters⁻¹/(•g/m³))²

meeting national visibility goals (Coleman and Karash 1978). Congress recognized that it would be unreasonable to have a uniform visibility goal for all Class I areas. This means that the regulations promulgated by EPA can be different between regions of the country and between Class I areas within a region.

A first cut at defining criteria for rating visual air quality impacts due to both regional haze and plume blight conditions was made (Table 6). It is recognized that visual air quality is an aesthetic value which is subjective and has many dimensions. The criteria were selected based upon LASL's experience in producing computer simulated pictures of plume blight and regional haze under different conditions of meteorology, source characteristics, atmospheric chemistry, aerosol characteristics, background atmosphere, and plume geometry. Due to the inverse relationship between extinction and visual range, the per cent change in visual range is most sensitive to the marginal

change in extinction in areas which experience the best visual air quality. The implications of this relationship are that areas with the best visual air quality are the most susceptible to degradation and the areas with the poorest will require a substantial decrease in air pollution before a significant improvement will occur.

Impairment in visual air quality due to regional haze was projected to occur in fifteen Class I areas in the United States (Table 7). Class I areas in the Rocky Mountain states (Arizona, Colorado, Montana, New Mexico, Utah, and Wyoming) were screened for having potential for impairment in visual air quality due to plume blight. Seven Class I areas were identified as having potential for impairment due to plume blight (Table 8).

A summary by laboratory region of visual air quality calculations for 1990 is presented in Table 9. Visual air quality in Class I areas is the best in the western states, particularly in the Rocky Mountain states. It is the poorest in the eastern states, particularly in the southeast. In the

TABLE 6--DEFINITION OF CRITERIA FOR RATING VISUAL AIR QUALITY IMPACTS

High	Medium	Low
There is a greater than 20% decrease in calculated visual range in Class I areas. Power plants sited in counties with Class I areas are greater than 1000 MW in size for coal and oil-fired plants and greater than 2500 MW in size for gas-fired plants.	There is between a 10 and 20% decrease in visual range in Class I areas. Power plants sited in counties or adjacent to Class I areas are between 500 and 1000 MW in size for coal and oil-fired plants and between 1250 and 2500 MW in size for gas-fired plants.	There is less than a 10% decrease in calculated visual range in Class I areas. Power plants sited in counties or adjacent to Class I areas are less than 500 MW in size for coal and oil-fired plants and less than 1250 MW in size for gas-fired plants.

TABLE 7--CLASS I AREAS PROJECTED TO HAVE MEDIUM (M) AND HIGH (H) REGIONAL HAZE IMPAIRMENT

State	Class I Area	Impact
Colorado	Eagles Nest Wilderness	M
	Flat Tops Wilderness	M
	La Garita Wilderness	M
	Maroon Bells-Snowmass Wilderness	M
	Mesa Verde National Park	M
	Rocky Mountain National Park	M
	West Elk Wilderness	H
	Mount Zirkel Wilderness	H
	Rawah Wilderness	H
	Weminuche Wilderness	M
	San Pedro Parks Wilderness	H
	Lost Wood Wilderness	H
New Mexico	Theodore Roosevelt National Monument	H
North Dakota	Badlands Wilderness	H
	Wind Cave National Park	H

eastern states, power plants are a major contributor to impairment of visual air quality in Class I areas whereas in the western states industrial process sources, smelters in particular, are a major contributor. In the western states, particulate sulfates due to fossil fuel combustion facilities are a much greater contributor to impairment of visual air quality in Class I areas than are primary particulates.

Computer generated maps displaying the visual range calculations in 1977 and 1990 for four southwestern states are shown in Figs. 1 and 2, respectively. The Class I areas displayed are defined in Fig. 3 and Table 10. This region has the best visual air quality in the nation (Trijonis and Shapland 1978). The poorest visual air quality is found in the southern part of the region, in the vicinity of 9 copper smelters located in Southern Arizona and New Mexico. The greatest deterioration in visual air quality is indicated to occur in Colorado. In this study, it is assumed that the sulfur dioxide emissions from the copper smelters will remain at their 1977 levels. The installation of improved sulfur dioxide control technology for the smelters would mean an improvement in visual air quality, particularly in the southern part of the region. The trend is toward improved sulfur dioxide control technology for the smelters. The major uncertainty concerns the pace at which the control technology will be installed.

TABLE 8--CLASS I AREAS IDENTIFIED TO HAVE POTENTIAL MEDIUM (M) and High (H) PLUME BLIGHT IMPAIRMENT

State	Class I Areas	Impact
Arizona	Grand Canyon National Park	M
Colorado	Flat Tops Wilderness	H
	Mount Zirkel Wilderness	H
	Mesa Verde National Park	H
	San Pedro Parks	H
New Mexico	Wilderness	
	Bridger Wilderness	
Wyoming	Fitzpatrick Wilderness	M
		M

ERROR ANALYSIS

An estimation of the magnitude of the errors in calculating the light extinction coefficient, b , and the visual range, V , is attempted. One can compare calculated, X_c , and observed, X_o , values and take their differences. Their differences can be termed errors, e , or residuals.

$$e = (X_c - X_o)$$

The difference between a calculated and an observed value is due to different causes which include the following: (1) The observed value is not equal to the true value because of sampling and/or measurement error. (2) The long-range transport model (methodology), its parameters, and its input data, used for calculating aerosol concentrations (particulate sulfates and primary particulates) are an approximation to the true state of nature. Thus, the aerosol concentration

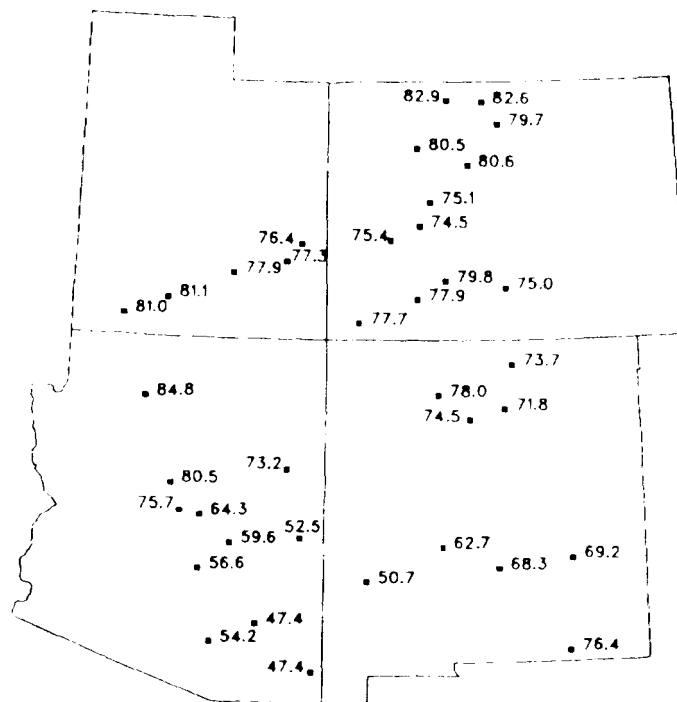


Fig. 1. Calculated visual range in Class I areas in the southwest - 1977.

TABLE 9--SUMMARY OF VISUAL AIR QUALITY CALCULATIONS FOR 1990

Lab Region	N	Per Cent Extra Extinction										Visual Range	
		Particulate Sulfates						Primary Particulates					
		Utility		Industrial		Industrial Process		Utility		Industrial			
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
ANL	10	28.1	0-54.2	.85	0-8.5	-	-	-	-	-	-	46.8	14.5-90.0
BNL	6	36.9	0-47.0	5.5	0-19.2	-	-	-	-	-	-	38.6	15.8-65.7
LBL	30	2.9	0-11.8	.4	0-5.9	5.2	0-22.2	0	0	.6	0-7.7	67.2	28.2-97.2
LASL	57	8.0	0-34.5	2.6	0-8.7	29.2	0-72.7	1.0	0-10.3	1.1	0-5.6	66.2	38.6-86.8
ORNL	26	37.3	0-64.8	5.0	0-13.0	-	-	-	-	-	-	19.1	10.7-60.8
PNL	25	1.3	0-6.4	4.8	0-13.7	4.9	0-29.2	0	0	3.3	0-9.8	46.4	28.9-75.9

¹Number of class 1 areas in Lab Region.

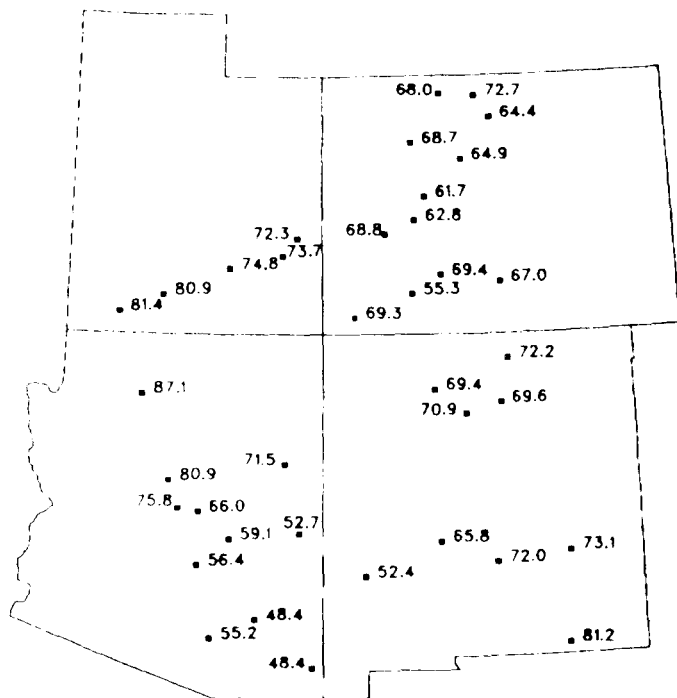


Fig. 2. Calculated visual range in Class I areas in the southwest - 1990.

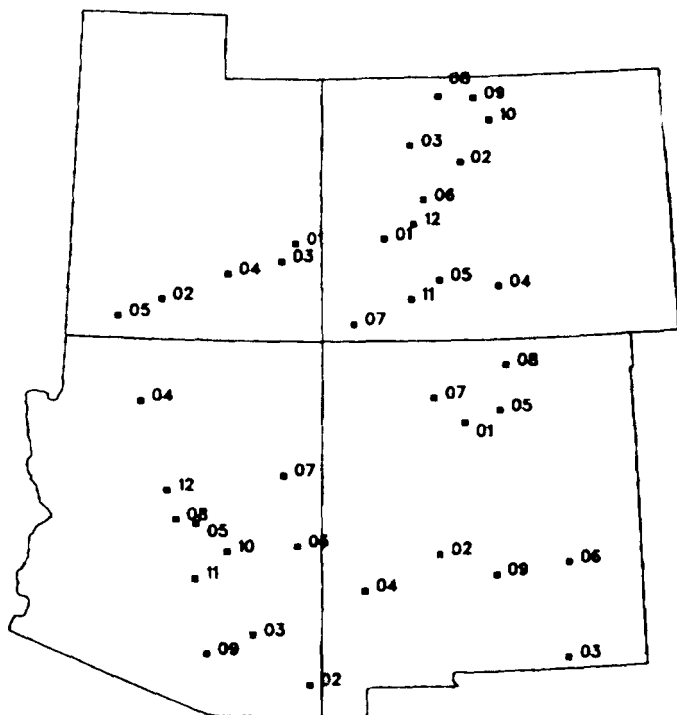


Fig. 3. Class I areas in the southwest.

predictions have errors associated with them.
(3) The visibility model (methodology), its parameters, and its input data, used for

TABLE 10--CLASS I AREAS IN ARIZONA, COLORADO, NEW MEXICO, AND UTAH

State	Number	Name
Arizona	1	Chiricahua National Monument Wilderness
	2	Chiricahua Wilderness
	3	Galiuro Wilderness
	4	Grand Canyon National Park
	5	Mazatzal Wilderness
	6	Mount Baldy Wilderness
	7	Petrified Forest National Park
	8	Pine Mountain Wilderness
	9	Saguaro Wilderness
	10	Sierra Ancha Wilderness
	11	Superstition Wilderness
	12	Sycamore Canyon Wilderness
Colorado	1	Black Canyon of the Gunnison Wilderness
	2	Eagles Nest Wilderness
	3	Flat Tops Wilderness
	4	Great Sand Dunes Wilderness
	5	La Garita Wilderness
	6	Maroon Bells-Snowmass Wilderness
	7	Mesa Verde National Park
	8	Mount Zirkel Wilderness
	9	Rawah Wilderness
	10	Rocky Mountain National Park
	11	Weminuche Wilderness
	12	West Elk Wilderness
New Mexico	1	Bandelier Wilderness
	2	Bosque del Apache Wilderness
	3	Carlsbad Caverns National Park
	4	Gila Wilderness
	5	Pecos Wilderness
	6	Salt Creek Wilderness
	7	San Pedro Parks Wilderness
	8	Wheeler Peak Wilderness
	9	White Mountain Wilderness
Utah	1	Arches National Park
	2	Bryce Canyon National Park
	3	Canyonlands National Park
	4	Capitol Reef National Park
	5	Zion National Park

calculating b and V are an approximation to the true state of nature. Thus, the calculations of b and V have errors associated with them.

Three error analyses concerning the calculation of b and V were conducted. The first was for the calculation of b and V in the vicinity of the 39 nonurban ambient air quality monitoring sites. The second was for the calculation of b and V for 154 Class I areas in the continental U.S. using Brookhaven's (BNL) long-range transport predictions, as one of the inputs. The third was for the calculation of b and V for 112 Class I areas in the west using Pacific Northwest Laboratory's (PNL) long-range transport

predictions, as one of the inputs. In the case of the monitoring site calculations, the aerosol concentrations (particulate sulfates, particulate nitrates and total suspended particulate concentrations) were known. It should be pointed out that there is sampling and measurement error associated with the aerosol concentration data for the monitoring sites.

Two statistics are used to summarize the prediction errors for b and V. They are the average error, the bias,

$$\text{BIAS} = \frac{\sum_{i=1}^N e_i}{N}$$

and the square root of the mean square error also called the standard error of the estimate, SEE.

$$\text{SEE} = \frac{\sum_{i=1}^N e_i^2}{N}$$

Error analysis summaries for the monitoring site and the Class I area calculations of b and V are found in Tables 11 to 16. The summary statistics are by laboratory region.

TABLE 11--ERROR ANALYSIS, EXTINCTION COEFFICIENT CALCULATIONS FOR NONURBAN AMBIENT AIR QUALITY MONITORING SITES (10⁻⁴ METERS⁻¹)

Lab Region	Sample Size	Mean		BIAS	SEE
		Obs.	Calc.		
ANL	6	1.36	1.23	-.133	.441
BNL	9	1.45	1.69	.241	.407
LBL	2	.770	.692	-.078	.201
LASL	7	.425	.526	.101	.215
ORNL-I ²	5	1.70	1.26	-.332	.534
ORNL-II ³	7	2.04	1.78	-.254	.529
PNL	3	.868	.793	-.075	.221
All	39	1.30	1.25	-.044	.441

1. SEE = the standard error of the estimate.
2. AR, LA, OK, TX.
3. AL, FL, GA, KY, MS, NC, SC, TN, VA, WV.

TABLE 12--ERROR ANALYSIS, VISUAL RANGE CALCULATIONS FOR NONURBAN AMBIENT AIR QUALITY MONITORING SITES (Miles)

Lab Region	Sample Size	Mean		BIAS	SEE ¹
		Obs.	Calc.		
ANL	6	25.0	28.0	3.00	7.10
BNL	9	18.9	14.7	-4.22	6.77
LBL	2	47.5	40.9	-6.61	13.8
LASL	7	61.1	49.3	-11.7	19.8
ORNL-I ²	5	19.0	21.0	1.95	4.64
ORNL-II ³	7	12.1	15.1	2.92	4.25
PNL	3	30.0	36.2	6.20	14.6
All	39	28.5	26.8	-1.70	11.0

1. SEE = the standard error of the estimate.
2. AR, LA, OK, TX.
3. AL, FL, GA, KY, MS, NC, SC, TN, VA, WV.

For the monitoring site calculations, the standard error of the estimate of b and V by lab region tends to be positively correlated with the mean of b and V, respectively. The bias by lab region was less than one quarter and the standard error of the estimate by lab region tended to be from one-quarter to one-third of the observed mean for both b and V. The correlations between observed and calculated values for all regions and all cases were .817 for b and .856 for V.

For the Class I area calculations using BNL's long-range transport predictions, the errors mostly reflect errors in calculating the extinction caused by particulate sulfates due to utility and industrial boilers. This is because the extinction due to non-sulfate aerosols and due to nonutility and industrial boiler sources was apportioned from the observed extinction coefficient according to regional extinction budget and emission inventory factors. Thus, the errors are relatively small when the regional sulfur dioxide emissions from utility and industrial boilers are small in comparison to other sources. This is the case for LBL, LASL, ORNL-I, and

TABLE 13--ERROR ANALYSIS, EXTINCTION COEFFICIENT CALCULATIONS FOR CLASS I AREAS BNL's LONG RANGE TRANSPORT PREDICTIONS (10⁻⁴ Meters⁻¹)

Lab Region	Sample Size	Mean		BIAS	SEE ¹
		Obs.	a c.		
ANL	10	.971	.636	-.335	.379
BNL	6	.935	1.09	.153	.244
LBL	30	.829	.722	-.107	.132
LASL	57	.398	.388	-.011	.016
ORNL-I ²	6	1.11	1.06	-.049	.076
ORNL-II ³	20	1.82	1.78	-.045	.584
PNL	25	.724	.677	-.047	.049
All	154	.806	.750	-.056	.246

1. SEE = the standard error of the estimate.
2. AR, LA, OK, TX.
3. AL, FL, GA, KY, MS, NC, SC, TN, VA, WV.

TABLE 14--ERROR ANALYSIS, VISUAL RANGE CALCULATIONS FOR CLASS I AREAS, BNL's LONG RANGE TRANSPORT PREDICTIONS (Miles)

Lab Region	Sample Size	Mean		BIAS	SEE ¹
		Obs.	Calc.		
ANL	10	34.2	55.2	21.0	24.1
BNL	6	29.2	27.3	-1.89	7.63
LBL	30	39.7	44.6	4.95	5.24
LASL	57	62.7	64.4	1.68	2.56
ORNL-I ²	6	29.6	31.0	1.40	1.75
ORNL-II ³	20	13.5	15.2	1.69	5.77
PNL	25	35.9	38.3	2.40	2.45
All	154	43.0	46.6	3.54	7.28

1. SEE = the standard error of the estimate.
2. AR, LA, OK, TX.
3. AL, FL, GA, KY, MS, NC, SC, TN, VA, WV.

PNL regions. There is a large bias for the calculation of b and V in the ANL region. In the ANL region, 8 of 10 sites are located near the Canadian border in the Dakotas, Minnesota, and Northern Michigan. The large biases for the ANL region could be due to sulfates from Canadian sources not being accounted for in the long range transport calculations. They could also be due to the observed values not being representative of the true values. The number of observation sites for visual range were sparse in the region of the Dakotas, Minnesota, and Northern Michigan. The correlations between calculated and observed values for all regions and all cases were .906 for h and .958 for V. The higher regional means for V and the lower ones for b for the Class I area data as compared to the monitoring site data are due to the Class I areas being located in more remote, cleaner parts of the regions than are the monitoring sites.

The errors in the western Class I area calculations are larger for those based upon PNL's long-range transport predictions as compared to those based upon BNL's. This is because the errors mostly reflect the errors in the nonapportioned extinction. Industrial process sources in the west, modeled by PNL, account for a much greater proportion of the sulfur oxide emissions and the extinction in the west than do the industrial and utility boilers, modeled by BNL. Thus, a greater proportion of the nonapportioned extinction was modeled by PNL in 1977 than by BNL in 1975.

TABLE 15 -- ERROR ANALYSIS, EXTINCTION
COEFFICIENT CALCULATIONS FOR CLASS I AREAS,
PNL's LONG RANGE TRANSPORT PREDICTIONS (10^{-4}
Meters⁻¹)

Lab Region	Sample Size	Mean		BIAS	SEE ¹
		Obs.	Calc.		
LBL	30	.829	.534	-.295	.366
LASL	57	.398	.363	-.0351	.0823
PNL	25	.724	.570	-.155	.169
All-West	112	.587	.455	-.132	.214

1. SEE = the standard error of the estimate.

TABLE 16 -- ERROR ANALYSIS, VISUAL RANGE
CALCULATIONS FOR CLASS I AREAS, PNL's LONG
RANGE TRANSPORT PREDICTIONS (Miles)

Lab Region	Sample Size	Mean		BIAS	SEE ¹
		Obs.	Calc.		
LBL	30	39.7	57.1	17.4	18.3
LASL	57	62.7	69.1	6.40	11.7
PNL	25	35.9	45.1	9.16	9.54
All-West	112	50.5	60.5	9.97	13.4

1. SEE = the standard error of the estimate.

For the western Class I area calculations using PNL's long-range transport predictions, the total light extinction was underestimated and the visual range was overestimated, particularly in the LBL and PNL regions. This could result from the following cause(s): the sulfate concentrations due to the major industrial process sources were underpredicted; and/or the apportioned extinction due to non-sulfate aerosols and sources other than the major industrial process sources was underestimated. The correlations between calculated and observed values for all western regions and cases were .948 for b and .876 for V.

SUMMARY AND CONCLUSIONS

Visual air quality is most sensitive to degradation in areas with good visibility. The protection of visual air quality in mandatory Class I Federal areas has been declared a national goal by Congress. This study has evaluated potential impairment in visual air quality due to future energy development as projected by the Mid-Mid Energy Scenario. The light extinction coefficient and visual range have been used as indices of visual air quality. Light extinction coefficients for 154 Class I areas have been calculated from long range transport predictions of particulate sulfate and primary particulate concentrations, relative humidity data, regional emission and extinction budget factors, and estimated scattering to mass ratios. Scattering to mass ratios for Fine Particulate Matter (FPM) and for Total Suspended Particulates (TSP) excluding FPM were estimated using linear regression analysis.

A first cut was made at determining criteria for rating visual air quality impacts due to both regional haze and plume blight conditions. For the assessment of the scenario, it was assumed that sulfur dioxide and primary particulate emissions are effectively controlled through SIP, NSPS, and BACT regulations.

Impacts on visual air quality due to regional haze were predominantly low for the 154 Class I areas. Fifteen Class I areas were projected to have moderate to high impact due to regional haze. Seven Class I areas in the Rocky Mountain states were identified as having potential for impairment due to plume blight. Installation of sulfur dioxide control technology on copper smelters in the southwest could improve the visual air quality there, particularly in the southern part of the region. The error analysis indicated very good agreement between observed and calculated values of visual range and light extinction.

Information on coal-fired power plants under construction or permitted indicates that more capacity will be sited in the Rocky Mountain states than projected by the Mid-Mid Scenario. This will mean a greater impact on visual air quality will occur due to these sources than projected for this scenario.

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