AIR QUALITY AND VISIBILITY IMPACTS OF POWDER RIVER BASIN COAL MINING AT BADLANDS NATIONAL PARK

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ABSTRACT

The CALPUFF long-range atmospheric dispersion model was used to calculate pollutant concentrations and visibility impacts in Badlands National Park from air pollutant emissions in the Powder River Basin and surrounding areas. Simulations were carried out for 1990 and 1997 actual emissions (using 1990 meteorological data for both cases). Results were compared to observations over the period 1989 – 1998 that were collected at the Badlands National Park IMPROVE monitoring site.

Only a small portion of observed Badlands pollutant concentrations (less than 20%) were accounted for by modeled emissions, except for nitrate particles, for which the model accounted for 64% of annual mean observed nitrate. The observed changes in pollutant concentrations from 1990 to 1997 were small at the IMPROVE site; model results accounted for about 35% of the observed increase in mean nitrate concentration.

There was an apparent small decrease in "20% cleanest" visual range at Badlands National Park between 1989 – 93 and 1994 – 98. Model results predicted less than 15 percent of the observed change for the 20% of days with best visibility. Increased emissions of nitrogen oxides and carbon particles from coal mining activities and coal transportation were indicated to account for approximately ten percent of the observed decrease in clear day visual range.

Results are presented showing the effects of changes in model input parameters, and of the methodology applied in calculating visibility impacts. Procedures for impact assessment recommended by Federal Land Managers are presented and discussed. It is shown that comparison of model-predicted visibility impacts to natural background conditions can lead to a projection of significant impact on many days, though actual predicted pollutant concentrations may be small.

Acknowledgements

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1.0 INTRODUCTION

Recent natural resource development proposals for Powder River Basin projects have required preparation of Environmental Impact Statements (EISs). As part of the EIS process, impacts on regional air quality and visibility have been assessed. Current methodology for such assessments, as specified by regulatory agencies and Federal Land Managers, calls for use of the CALPUFF long-range air pollution transport computer model (see section 4.1), with specific assumptions and inputs. Recent CALPUFF regional analyses for the Wyodak Coal Bed Methane (CBM) and Horse Creek Coal Lease Application Environmental Impact Statements [(1)] have indicated potentially large regional haze impacts in National Parks and other sensitive areas far from the Powder River Basin (PRB), as a result of emissions associated with future PRB coal mining activities. The realism of these projected impacts, and their magnitude relative to those of other air pollution sources, are of obvious importance to the coal industry.

The CALPUFF modeling methods are relatively new, the models themselves are still evolving, and there have been few systematic comparisons of predicted air quality impacts in pristine areas far from pollution sources to actual measurements of pollutant concentrations and visibility. The present investigation was carried out to examine in detail the results and implications of CALPUFF modeling of coal mining emissions.

Badlands National Park (BNP) in South Dakota is one of the closest Class I areas to the Powder River Basin and it is downwind of the Basin for large portions of the time. Detailed data on pollutant concentrations and visibility have been collected at BNP since 1989. Therefore, the study focused on pollutant impacts in BNP. Since both PRB pollutant emissions and BNP air quality can be established with some confidence for the time period from 1989 to the present, it was possible to

[1] The Wyodak CBM EIS focused on impacts of coal bed methane development in the Powder River Basin. The Horse Creek EIS was prepared to assess impacts of a coal lease application adjacent to the Antelope Mine in the Southern Powder River Basin.

analyze predicted and observed trends in air quality parameters. Results of the analyses, along with related investigation of the CALPUFF modeling methodology and impact assessment procedures, are presented in this report.

2.0 OBJECTIVES

In May of 1999, the U.S. Bureau of Land Management issued a Draft Environmental Impact Statement (EIS) for the Wyodak Coal Bed Methane Project in the Powder River Basin of Wyoming (BLM, 1999). The Draft EIS included a cumulative air quality impact analysis that used the CALPUFF modeling methodology to estimate impacts on regional visibility in future years resulting from projected future PRB activities, including expanded surface coal mining. The results of the analysis suggested a potential for significant degradation in visibility at distant national parks and sensitive areas. The emissions inventory for the analysis indicated that a major contributor to future pollutant levels and impacts would be coal mining and related coal rail transport.

When new coal leasing activities or mine developments occur in the PRB, it is likely that new cumulative air impact analyses will be required. It is important that the implications and reliability of these analyses be better understood. New national and state regulations for control of regional haze and small particle concentrations in the air are currently in development. If new regulations are to be effective and appropriate, it is essential that potential impacts of existing and new mining operations be quantified as realistically as possible. Meaningful evaluation of future impacts is essential both for public policy development, and for development of any mitigating measures that may be necessary.

It was therefore proposed to carry out analyses with the currently recommended air quality and visibility modeling methodology, and to evaluate model results in relation to measured trends. The overall objective of the research was to compare predicted impacts of recent PRB coal mining operations, using current CALPUFF methodology, to observed conditions over the same years at Badlands National Park. In addition, characteristics of the current methodology were investigated, along with sensitivity of results to model inputs. Finally, a critical evaluation was made of the implications of past and proposed new procedures and baseline data specified by Federal Land Managers for Class I area visibility impact analyses.

Specific objectives of the research were to:

1. Determine the historical correlation, if any, between PRB coal mining air emissions and observed visibility at Badlands National Park, SD.
2. Compare observed visibility and pollutant concentration trends at Badlands NP to those predicted by the CALPUFF air modeling methodology as currently applied.
3. Quantify model-predicted impacts resulting from coal mining activities on a pollutant-specific basis.
4. Determine the relative magnitude of coal mining sources compared to other pollutant sources with regard to model-predicted impacts.
5. Determine sensitivity of model results to background concentration and pollutant parameter inputs required by the CALPUFF model.
6. Evaluate and compare results of recommended methods for deriving and presenting visibility impact model results.

3.0 METHODOLOGY

The research that was conducted, as described in the following sections of this report, consisted of the following tasks.

1. Analysis of BNP Monitoring Data

   Data collected at the Interagency Monitoring of Protected Visual Environments (IMPROVE) site in Badlands National Park were analyzed to define average pollutant concentrations, frequency distributions of concentrations, visibility statistics, and trends over the available period of record from 1989 to 1998.

2. Compilation of Emission Inventories

   Emission inventories were assembled for pollutant sources in eastern Wyoming, western South Dakota, and northwestern Nebraska. The inventories included those pollutants relevant to visibility impacts, and consisted of coal mine sources, related coal transportation (rail line) sources, permitted point (stack) sources, and area sources by county for mobile, industrial, commercial, agricultural, and residential sources.

3. CALPUFF Modeling

   The CALPUFF model (version 5.4, Level 000602-1) (Earth Tech, 1998) was used to calculate hourly pollutant concentrations at BNP, for one year of meteorological data, using the complete emissions inventory data as representative of the years 1990 and 1997. Additional CALPUFF model runs were executed, using the same meteorological data, for various subsets of emissions sources, and for different input parameters as required to define pollutant characteristics and background air quality.

4. Analysis of Model Results

   Model results were processed to show average predicted pollutant concentrations in BNP, concentration frequency distributions, contributions by source type, predicted concentration changes from 1990 to 1997, and predicted change in visibility (light extinction). Statistics from the model predictions were compared to similar statistics and trends as shown by the BNP IMPROVE observations.

5. Evaluation of Predicted Visibility Impacts

   Model results for mining sources and all sources were used to quantify potential increases in regional haze according to the methodologies prescribed by Federal Land Manager (FLM) guidance (FLM Air Quality Related Values Workgroup, 2000). This guidance compares new impacts to "natural" or reference visibility conditions. For comparison, incremental impacts relative to existing visibility were derived as well.

6. Analysis and Conclusions

   Results of all above tasks were considered in generating overall conclusions on observed and predicted air quality trends in BNP, the likely sources and magnitude of coal production impacts, and the issues that will need to be addressed in modeling potential effects of future mining activity.

4.0 TECHNICAL DISCUSSION OF ANALYSIS METHODOLOGY

4.1 The CALMET/CALPUFF Model

The CALMET/CALPUFF air quality models (Earth Tech, Inc., 1998) were developed to simulate long-range transport of multiple air pollutants using non-steady-state meteorological fields generated from hourly regional weather observations. The CALMET model generally utilizes predicted wind and temperature distributions varying in time and space (MM4 data[1]), land surface topography and use, and hourly surface weather observations to generate three-dimensional meteorological fields over the region to be modeled. The CALPUFF model then simulates the transport, transformation, deposition and dispersion of pollutants from multiple sources, according to the wind transport and other environmental conditions specified by CALMET. Results of the modeling consist of predicted concentrations of pollutants over averaging times from one hour to one year at selected receptor locations. The receptors are usually selected to coincide with locations where visibility is measured (IMPROVE monitor sites) or other sensitive areas of interest.

For visibility evaluations, modeling is carried out for pollutants that can affect light scattering and visibility (oxides of sulfur, oxides of nitrogen, and particulate matter). The predicted concentrations at receptor locations can then be used to calculate the light extinction caused by the pollutants, which in turn can be compared to a reference or background light extinction to obtain a predicted incremental degradation in visibility.

There are numerous assumptions, approximations, and simplifications involved in application of CALPUFF to predict visibility impacts. Some of these are inherent in the mathematical models or are required by the limitations of available input data. Others are based upon site-specific background conditions and pollutant characteristics; they are typically assigned

[1] MM4 is an advanced mesoscale meteorological forecast model, which was developed and applied at the National Center for Atmospheric Research and universities. It provides computer-generated wind fields at hourly intervals at numerous altitudes. These meteorological fields provide higher resolution data than can be obtained from standard surface and upper air observations. However, since the MM4 model requires advanced computer facilities, model data are not routinely generated. The only year for which complete MM4 data are available for the entire United States is 1990. Though additional data may be generated in the future for limited geographical areas, the 1990 data have been used for most Wyoming CALPUFF analyses.

for each application if representative data exist. Otherwise, “default values” recommended by the model developers or regulatory agencies are used. Default values are usually selected to represent conservative assumptions, and may result in higher predicted concentrations than would be obtained if representative data were available.

For this analysis, the CALMET model was applied, using the available 1990 MM4 meteorological fields, to define meteorological conditions for each hour of the year. CALMET starts with the MM4 predicted hourly distributions, and adjusts/refines those data on the basis of actual surface and upper air meteorological observations at National Weather Service or other weather stations, and the specific terrain and surface land use conditions in the modeling domain.

The total length of the CALMET simulation was 8634 hours. Data from seven surface meteorological stations were included:

1) Casper, WY
2) Lander, WY
3) Rapid City, SD
4) Scottsbluff, NE
5) Sheridan, WY
6) Eagle Butte Mine, near Gillette, WY
7) Badlands National Park

The last two stations, Eagle Butte and Badlands, were not included in previous CALMET analyses and were added to this analysis in order to refine meteorological definition around the two primary areas of interest – the Powder River Basin in Wyoming and the Badlands IMPROVE monitoring site.

Data from two upper air stations were used: Lander and Rapid City. Input data also included four precipitation stations: Scottsbluff, Rapid City, Casper and Lander.

The modeling domain used in the CALMET simulation consisted of eight vertical, 136 east-west, and 94 north-south grid cells. Each grid cell covered a 5 km x 5 km horizontal area. Total domain coverage was 680 km x 470 km.

Modelers have the option in CALMET to use either a UTM Cartesian coordinate grid or a Lambert Conformal Projection coordinate system. The advantage of the Lambert Conformal system is that it accounts for the curvature of the earth's surface – an effect that becomes more significant as the modeling domain size increases. A Lambert Conformal system was used in this analysis.

Input options and parameters for the present CALMET/CALPUFF simulations followed regulatory/FLM guidance, and with the exception of the two added surface meteorological data sets noted above, were identical to those utilized for the Wyodak CBM analysis (BLM, 1999) and the Horse Creek EIS analysis (McVehil-Monnett Associates, 1999). Specific changes are noted in following sections of this report. A CALPUFF input list, showing parameter and option definitions, is included in Appendix A.

Two receptors were modeled in the study – both located within the Badlands National Park. One receptor was located at the IMPROVE monitoring site, the other at the meteorological station formerly operated and maintained by the National Park Service.

4.2 Emission Inventories

Annual average emission rates were determined for the five pollutant types that have a significant effect on atmospheric light extinction: nitrogen oxides (NO_x, which is transformed by atmospheric reactions to nitrate particles), sulfur dioxide (SO_2, which forms sulfate particles), small particulate matter (PM10) and organic carbon (OC) and elemental carbon (EC) particles. Carbon particles are in fact a subset of total PM10 particles. However, they are accounted for separately because their contribution to light extinction is markedly greater than other components of PM10.

Total emissions of these pollutants were estimated for the years 1990 and 1997. Inventories were defined separately for permitted point sources, large permitted fugitive sources, large area (county) sources, PRB coal mines, and coal trains traveling to and from PRB mines. The determination of emissions for each source type is described in the following subsections. Tables, spreadsheets, and emission factors showing details of the emission inventory data are included in Appendix A.

4.2.1 Point Sources

A point source emission inventory for the Wyoming counties included in the analysis (Campbell, Crook, Weston, Converse, Niobrara, Goshen, and Platte) was compiled through a detailed review of permit files at the Wyoming Department of Environmental Quality (WDEQ). All permitted facilities with total point source PM10, SO_2, or NO_x emissions greater than 5 tons per year in 1990 or 1997 were included in the inventory. Sources with multiple emission points were defined for the inventory as a single stack with the dimensions and flow parameters of the primary facility stack, in order to minimize the total number of stacks to be modeled. All facility emissions were assumed to be emitted from the single stack.

The South Dakota Department of Environment and Natural Resources provided a point source emissions inventory for Pennington County (Rapid City). It consisted of ten facilities, each of which have total emissions greater than 2.5 tons per year for one or more pollutant. As for the Wyoming sources, these ten South Dakota facilities were each represented as a single stack for purposes of CALPUFF modeling. Since emission changes with time were unavailable for the South Dakota sources, 1990 emissions were assumed to be equal to the 1997 emissions listed in the current inventory.

Several large permitted fugitive PM10 sources in Wyoming were also included in the modeling inventory, and represented as separate area sources. For each source, actual annual average emission rates for 1990 and 1997 were defined for each pollutant, along with required stack parameters (geographical coordinates, base elevation, stack diameter, gas temperature, and gas exit velocity). These data were entered into the CALPUFF model input file for the appropriate 1990 and 1997 model simulations. A tabulation of source names, emission rates, and coordinates for the 64 Wyoming point sources, ten South Dakota point sources, and five Wyoming fugitive sources is provided in Appendix A-3.

4.2.2 Area Sources

Emissions information was obtained from EPA's AIRS database for seven counties in northeast Wyoming, eleven counties in southwestern South Dakota, and four counties in northwestern Nebraska. (The modeling area is shown in Figure 4-1). The AIRS data contain EPA's best estimate of county-wide emissions of each pollutant; data were obtained for the years 1990 and 1997. The EPA emission estimates include point sources, area emissions from commercial and residential sources, transportation (mobile source) emissions, and miscellaneous sources such as agriculture and traffic on paved and unpaved roads. Since point source emissions were already included in the modeling data for Wyoming, emissions from those sources were subtracted from the appropriate AIRS county-wide emission totals in order to prevent double counting. For South Dakota, point sources were subtracted only for Pennington County. For all other areas, modeled emissions were the total EPA AIRS area source emissions that include county-wide point, area, and fugitive sources.

4.2.3 PRB Coal Mines

Total annual emissions of NO_x, SO_2, PM10, OC and EC were estimated for 1990 and 1997 for each of the following Powder River Basin coal mines.

Buckskin	Belle Ayr
Rawhide	Caballo Rojo
Eagle Butte	Cordero
Dry Fork	Coal Creek
Ft. Union	Jacobs Ranch
Wyodak	Black Thunder
Caballo	North Rochelle
North Antelope	Antelope
Rochelle	

Emissions estimates for PM10 were obtained by calculating the emissions per unit coal production for 1997, as shown in the most recent air quality permit applications on file at

WDEQ. Estimated emissions for 1990 and 1997 were then calculated from this ratio (specific to each mine) using actual reported total coal production in the respective years.

Emissions of NO_x and SO_2 from blasting were based upon the mine-specific volumes of coal and overburden removed in each year. Quantities of blasting agent per unit coal and overburden removed were obtained for each mine from permit application data. Finally, total emissions in 1990 and 1997 were calculated using emission factors of 2 pounds of SO_2 per ton of blasting agent (ANFO) and 11.56 pounds of NO_x per ton of ANFO. The SO_2 emission factor is from AP-42, Table 13.3-1 (EPA, 1995). The NO_x emission factor was estimated by analysis of recent test data collected by the Bureau of Mines (Green, 1999).

The inventory also included emissions from mine diesel-fueled equipment and on-site locomotives. Annual fuel use was estimated for each mine, again using actual coal production data, and permit application information for each mine that related equipment usage (hours or miles) to fuel consumption and coal production. Total fuel consumption was multiplied by appropriate emission factors (See Appendix A-5) to estimate annual emissions. In addition to total emissions of NO_x, SO_2, and PM10, emissions of organic and elemental carbon were determined using EPA speciation data for diesel emissions that break down total particulate matter emissions into 55% elemental carbon, 21% organic carbon, and 24% non-carbon PM10.

4.2.4 Off-Site Coal Trains

Emissions of each pollutant for each year resulting from diesel-fueled locomotives were estimated from total PRB coal production in the respective years, fuel consumption data provided by Burlington Northern Santa Fe and Union Pacific railroads, and EPA emission factors for diesel locomotives. EPA line-haul diesel locomotive emission factors for current uncontrolled engines (EPA, 1997) are 270 grams/gallon of fuel (NO_x), and 6.7 grams/gallon of fuel (PM10). SO_2 emissions were calculated by assuming that all sulfur in fuel is emitted as SO_2, and average fuel sulfur content is 0.25%, resulting in an SO_2 emission factor of 16 grams/gallon of fuel.

Average fuel consumption for Powder River Basin coal trains, as provided by railroad representatives (McVehil-Monnett Associates, 1999), is 21 gallons per round-trip train mile. Thus, average coal train pollutant emissions are

NO_x	5670 grams/mi
SO_2	336 grams/mi
PM10	141 grams/mi

where the data are expressed as emissions per mile of rail line for round-trip (loaded and empty) travel. Again, total PM10 was divided into EC, OC, and other PM10 using EPA speciation data.

It was assumed that the average coal train transported 13,000 tons of coal; the total number of coal trains per year was then determined for total PRB production in 1990 and 1997. These trains were apportioned between the southern, southeastern, and northwestern routes out of the PRB in accordance with current train volume data. Finally, total emissions were calculated for each mile of rail line on each route for the rail segments within the modeling domain. For modeling purposes, each rail line was divided into 10 km (6.2 mi) segments, and emissions for each segment were represented by a single volume source.

4.2.5 Emission Summary

Table 4-1 summarizes total air pollutant emissions for each year as calculated for the CALPUFF modeling inventory. It can be seen from Table 4-1 that total regional emissions increased modestly (on the order of 20%) for NO_x and SO_2 from 1990 to 1997. PM10 emissions are indicated to have increased by 95%, but the increase is due almost entirely to an indicated large increase of Wyoming county emissions shown in the AIRS database. The reason for the

TABLE 4-1

TOTAL ESTIMATED EMISSIONS (TONS/YEAR) FOR MODELING

	1990					1997				
Source Type	NO_x	SO_2	PM10	EC	OC	NO_x	SO_2	PM10	EC	OC
Wyoming Point Sources	28,406	37,200	2,569	-0-	-0-	28,260	38,773	1,899	-0-	-0-
South Dakota Point Sources	10,560	2.546	1,165	-0-	-0-	10,560	2,546	1,165	-0-	-0-
Wyoming Area Sources	38,985	11,996	40,675	232	186	44,419	22,748	165,825	184	141
South Dakota Area Sources	10,043	3,030	51,940	531	506	9,212	3,049	47,396	407	354
Nebraska Area Sources	3,824	530	22,697	118	78	4,304	591	18,264	104	63
PRB Coal Mines	5,324	579	3,680	157	60	9,624	1,066	6,473	272	104
Coal Trains	11,277	669	68	154	58	19,735	1,170	119	269	102
Misc. Fugitive Sources	56	4	1,088	-0-	-0-	45	4	819	-0-	-0-
TOTAL	108,475	56,554	123,882	1,192	888	126,159	69,947	241,960	1,236	764

apparent increase is unknown, but could have resulted from a change in the methodology of emissions calculation or the inclusion of additional source types.

There were only small differences between 1990 and 1997 emissions of EC and OC. Table 4-1 also indicates that pollutant emissions from coal mines and coal trains increased by approximately 75% from 1990 to 1997, reflecting overall PRB production increases.

The geographical area included in the modeling analysis and the location of all modeled sources are shown in Figure 4-1. Dots represent point sources and the volume sources used to represent rail lines. Small rectangles represent PRB mines (area sources) and the large rectangular areas approximate counties, as idealized to generate area sources for modeling. The locations of the BNP IMPROVE monitor site and meteorological station are also shown; receptors for modeling were located at these monitor sites.

4.3 VISIBILITY ANALYSIS

4.3.1 Background and Equations

The horizontal visibility (visual range) is defined in general as the greatest distance at which a large dark object can be seen. Visual range (VR) is related to the light-extinction coefficient (b_{ext}) (the attenuation of light per unit distance due to scattering and absorption by particles and gases in the atmosphere) by

$$VR = 3912/b_{ext}$$

where VR is in kilometers, and b_{ext} is expessed in units of $(Mm)^{-1}$ (inverse megameters). A megameter is one million meters.

Calculations of visibility or "regional haze" impacts of pollutants in the atmosphere are made by evaluating the change in extinction coefficient caused by predicted concentrations of the pollutants. The extinction coefficient can be expressed as a sum of terms, each of which represents the effect of a given particle type or light attenuation process

$$b_{ext} = b_{SN}f(RH) + b_{OC} + b_{coarse} + b_{ap} + b_{Ray} \quad (1)$$

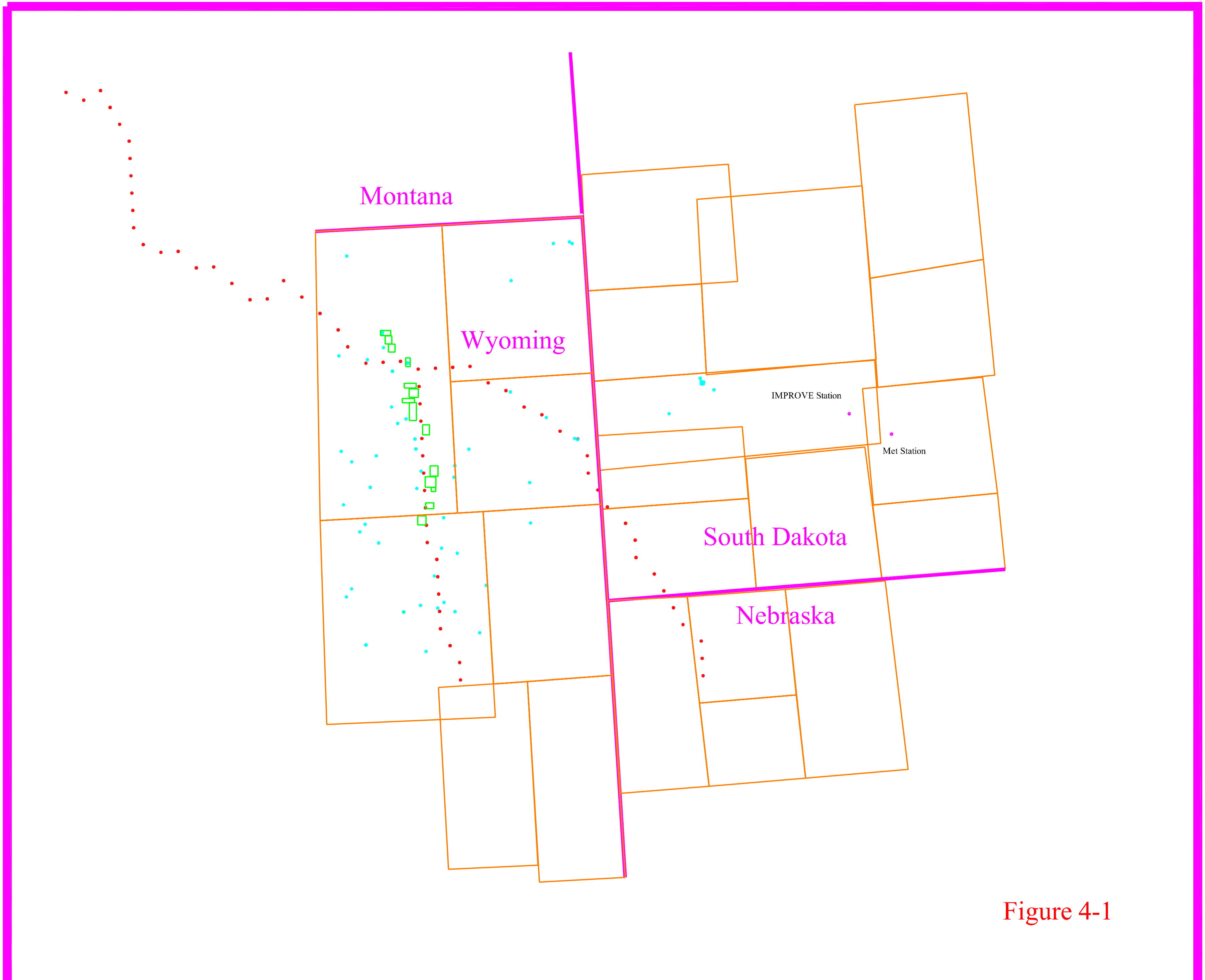

Montana
Wyoming
IMPROVE Station
Met Station
South Dakota
Nebraska

Figure 4-1

The terms in equation (1) have the following meanings and definitions

$b_{SN}f(RH)$ represents light scattering by sulfate and nitrate particles. These particles are "hygroscopic", which means that they absorb water vapor from the air. Their size and resulting scattering efficiency therefore depend on relative humidity.

$$b_{SN}f(RH) = [4.125\ (SO_4) + 3.870\ (NO_3)]\ f(RH) \quad (2)$$

SO_4 and NO_3 are the concentrations of sulfate and nitrate particles in micrograms per cubic meter ($\mu g/m^3$); f(RH) is a given function of ambient relative humidity that varies from 1.0 at low humidity to values greater than 10.0 at RH above 95%.

The constants in equation (2) represent the scattering efficiency of the particles (3.0), and the relative weights of ammonium sulfate and ammonium nitrate to the sulfate and nitrate ions (1.375 for $(NH_4)_2\ SO_4$, and 1.290 for $NH_4\ NO_3$). The sulfate and nitrate particles in the air are assumed to be comprised of the respective ammonium compounds.

b_{OC} is scattering by organic carbon particles;

$$b_{OC} = 4\ (OC) \quad (3)$$

where OC is the concentration in $\mu g/m^3$.

b_{coarse} represents scattering by coarse particles (PM10);

$$b_{coarse} = 0.6\ (PM10) \quad (4)$$

with PM10 concentration in $\mu g/m^3$.

b_{ap} accounts for light absorption by elemental carbon (soot) particles;

$$b_{ap} = 10\ (EC) \quad (5)$$

with elemental carbon concentration in $\mu g/m^3$.

b_{Ray} represents Rayleigh scattering by air molecules; it is essentially constant with a value of 10 Mm^{-1}.

Thus, the total extinction due to modeled or measured concentrations of all pollutants can be calculated as the sum of equations (2) through (5);

$b_{ext} = 4.125\ (SO_4)\ f(RH) + 3.870(NO_3)\ f(RH) + 4(OC) + 0.6(PM10) + 10(EC)$

When the concentrations are all given in $\mu g/m^3$, b_{ext} is in units of Mm^{-1}. The relative change in extinction compared to a reference background condition is

b_{ext}/b_{back}

where b_{back} is the reference or background extinction including Rayleigh scattering. The predicted visual range, after addition of given pollutant concentrations, can be calculated by

$VR = 3912/(b_{ext} + b_{back})$

where b_{ext} is the extinction contributed by the added pollutant concentrations.

4.3.2 Visibility Impact Analysis and Criteria

The procedures and criteria for evaluating the significance of new visibility impacts in National Parks and sensitive areas are generally prescribed by the Federal Land Managers (FLMs) responsible for maintenance of those areas. Current guidance is provided in the Federal Land Managers' Air Quality Related Workgroup (FLAG) Phase I Report (2000).

The FLAG guidance generally recommends modeling of emissions from a proposed new source or sources with CALPUFF, and prediction of hourly pollutant concentrations at receptor locations throughout the sensitive area(s). One or more years of meteorological data should be used. Predicted concentrations at each receptor are then used with the equations given in the preceding section to calculate daily (24-hour average) extinction coefficients for each day. The ratio of the source extinction to a background or reference extinction value defines a percent change, or visibility impact, for each day and receptor. The overall impact can then be characterized on the basis of the number of days and/or receptors at which impacts greater than specified percentage levels are predicted to occur.

In the past, FLMs normally provided background or reference visibility values for individual sensitive areas based upon the 20% of cleanest days as measured by IMPROVE data over a recent multi-year period. For example, for BNP, the following baseline conditions were recommended for the Wyodak Coal Bed Methane EIS analyses (Greystone, 1999). They were obtained from BNP IMPROVE monitoring data for winter of 1987 through summer of 1997.

Season	Visual Range (km)	b_{back} (Mm^{-1})	f(RH)
Spring	147.8	26.5	3.01
Summer	143.0	27.4	2.73
Fall	169.1	23.1	2.69
Winter	169.8	23.0	3.24

The f(RH) data correspond to seasonal average f(RH). In calculating the incremental change from these baseline visibility conditions, one can either use the recommended constant value of f(RH) for each day in the season, or use site-specific hourly f(RH) data if available. Some results from use of these two alternatives are discussed later in this report.

In the December 2000 FLAG report, the FLMs provide new baseline data for National Parks and sensitive areas. These new data are intended to represent natural or unpolluted conditions, rather than actual observed conditions in recent years. For comparison, the new recommendations for BNP are

Season	Visual Range(km)	b_{back} (Mm^{-1})	f(RH)
Spring	243.0	16.1	2.6
Summer	247.6	15.8	2.2
Fall	241.5	16.2	2.8
Winter	238.5	16.4	3.1

It is obvious that these new "reference" conditions represent much cleaner air and better visibility than the prior "background" conditions based on current visibility. Accordingly, a given incremental light extinction will represent a larger percent reduction in visual range.

There are no regulatory thresholds for acceptability of visibility impacts. However, the FLMs have adopted general guidelines as expressed in the FLAG report. They state that an increment of light extinction (over the reference level) of 0.4 percent or less is below de minimis levels and would not require further analysis; impacts of less than 5.0% are generally considered acceptable; impacts between 5 and 10% are of concern and generally will require more detailed cumulative analyses of all potential new sources; and for impacts exceeding 10%, "the FLMs will likely object to the proposed action". As will be shown, impacts of 5 to 10% on a single-day basis are often predicted as a result of relatively small increases in pollutant emissions at large distances from the sensitive area.

4.4 IMPROVE DATA

The IMPROVE database containing all historical data from the BNP monitoring station was obtained and data were analyzed to provide statistics on daily and annual pollutant concentrations and visibility. The available data covered the period from 1989 through 1998. Particle concentrations are measured from 24-hour integrated samples collected two times weekly on every Wednesday and Saturday; visibility (light extinction coefficient) is measured hourly for all days.

Mean values and frequency distributions of all relevant variables were calculated for each of the ten years. Figures 4-2 through 4-7 summarize the measured data. The figures show 10, 50, and 90th percentile levels for all valid data for each year. "Validity Code zero" data for visual range represent the highest quality visual range determinations. They generally exclude periods of high relative humidity, precipitation, or other factors which could tend to make the measurement unrepresentative of existing air pollution conditions.

It can be seen that there has been significant year-to-year variability in BNP pollution and visibility conditions. However, no long-term trends over the data period are obvious. In a subsequent analysis, data from the two periods 1988 – 1993 and 1994 – 1998 were examined separately in an attempt to distinguish any long-term trends. Results of those analyses are presented in Section 5.0.

The median visual range at BNP for the period 1989 – 98 is indicated by Figure 4-7 to be approximately 110 km. The 90th percentile visual range is indicated to be on the order of 160 km. This is consistent with the "20% cleanest" conditions previously provided by the National Park Service, but much less than the "natural" reference visual range from the FLAG report of about 240 km.

Figure 4-2: BNP PM-10 Trends (1989-1998)

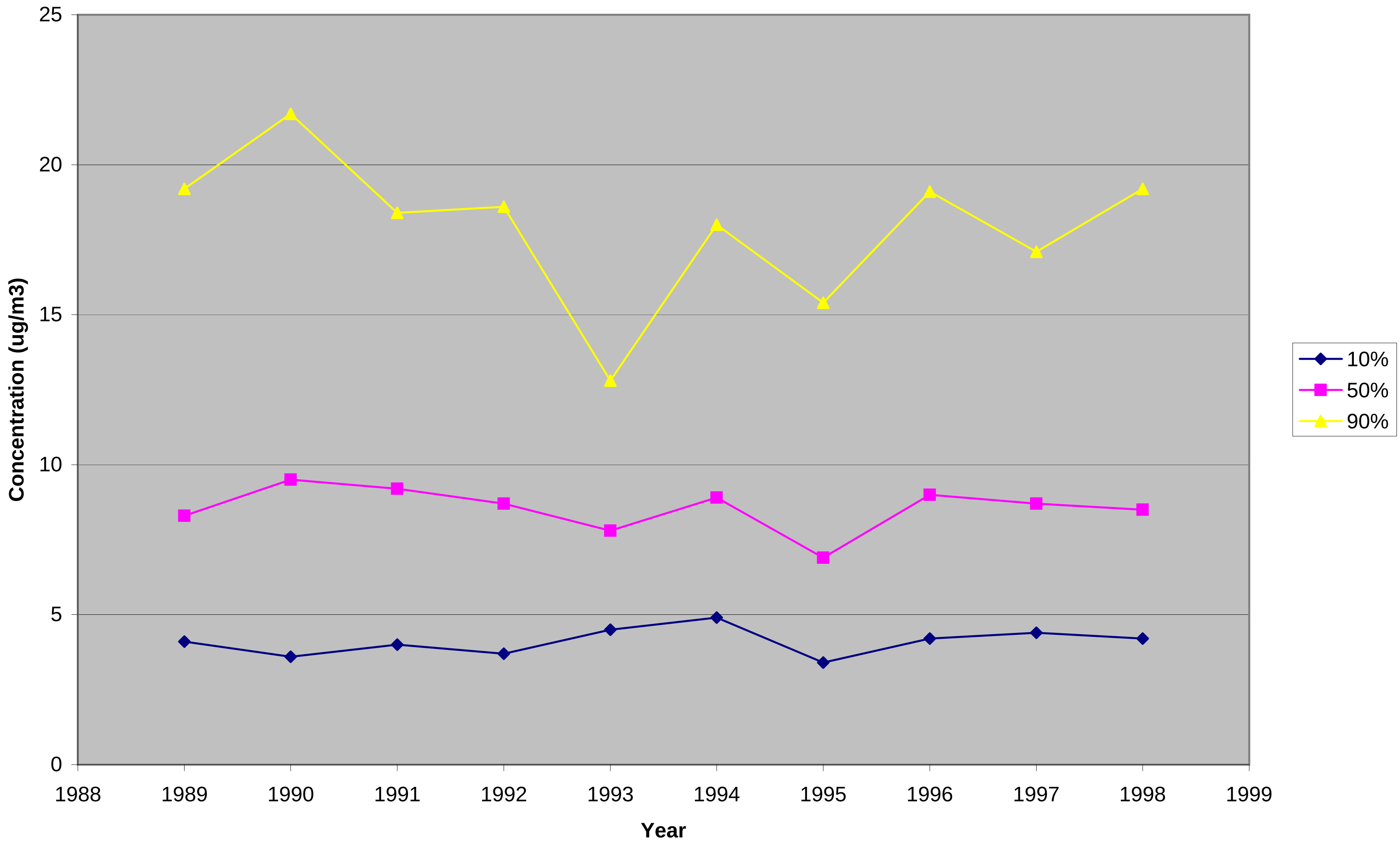


Figure 4-3: BNP OC Trends (1989-1998)

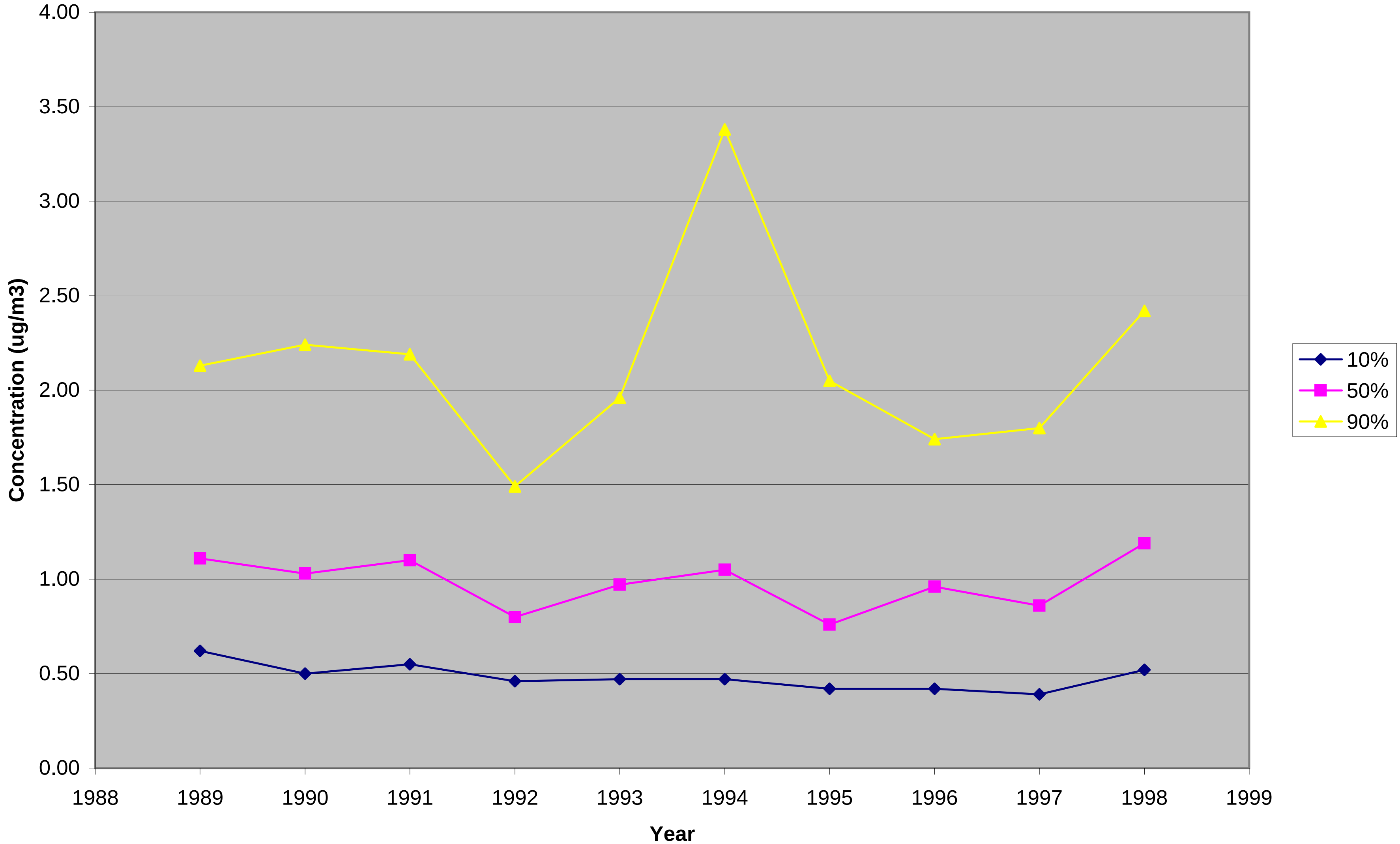


Figure 4-4: BNP EC Trends (1989-1998)

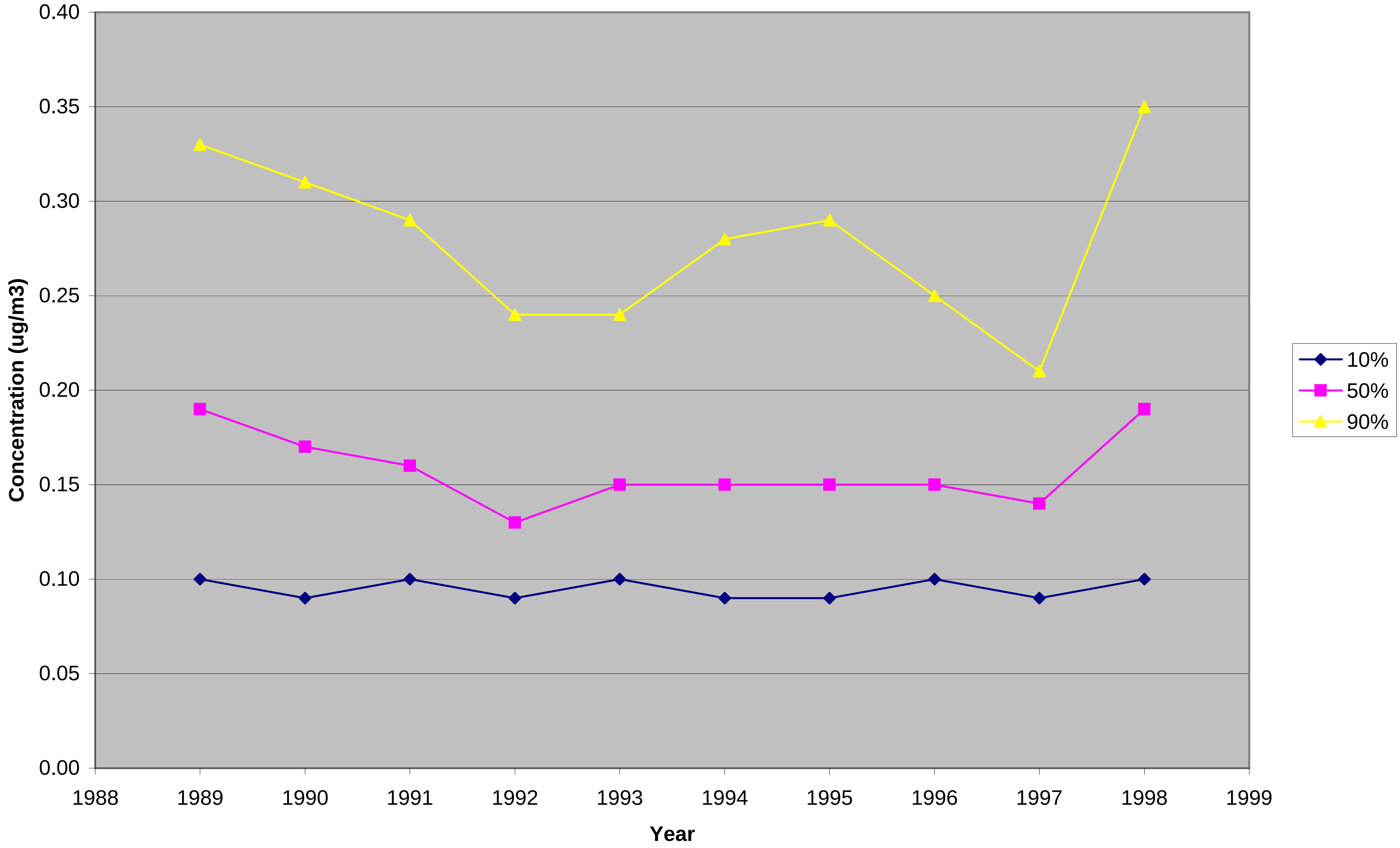


Figure 4-5: BNP Ammonium Sulfate Trends (1989-1998)

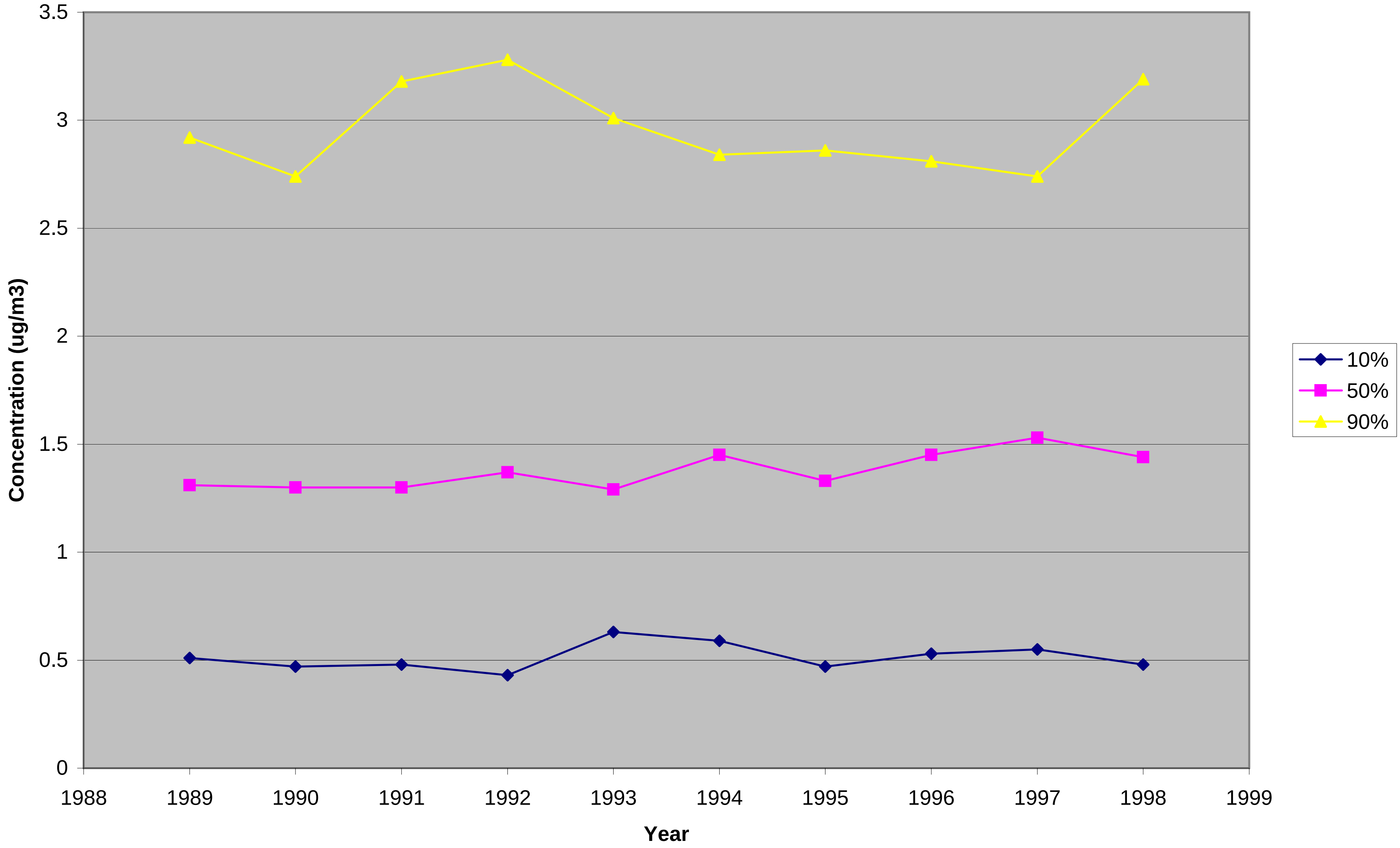


Figure 4-6: BNP Ammonium Nitrate Trends (1989-1998)

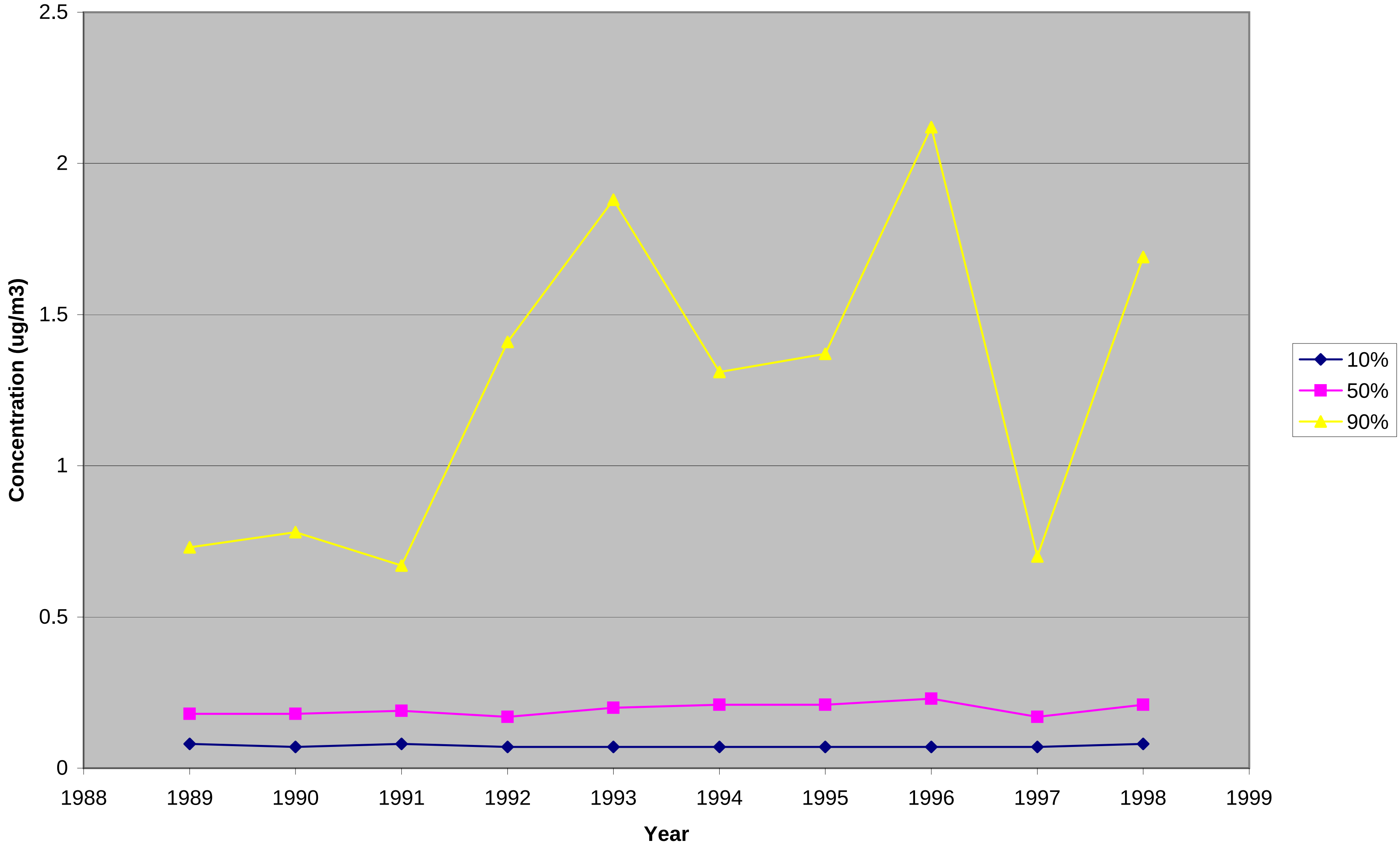
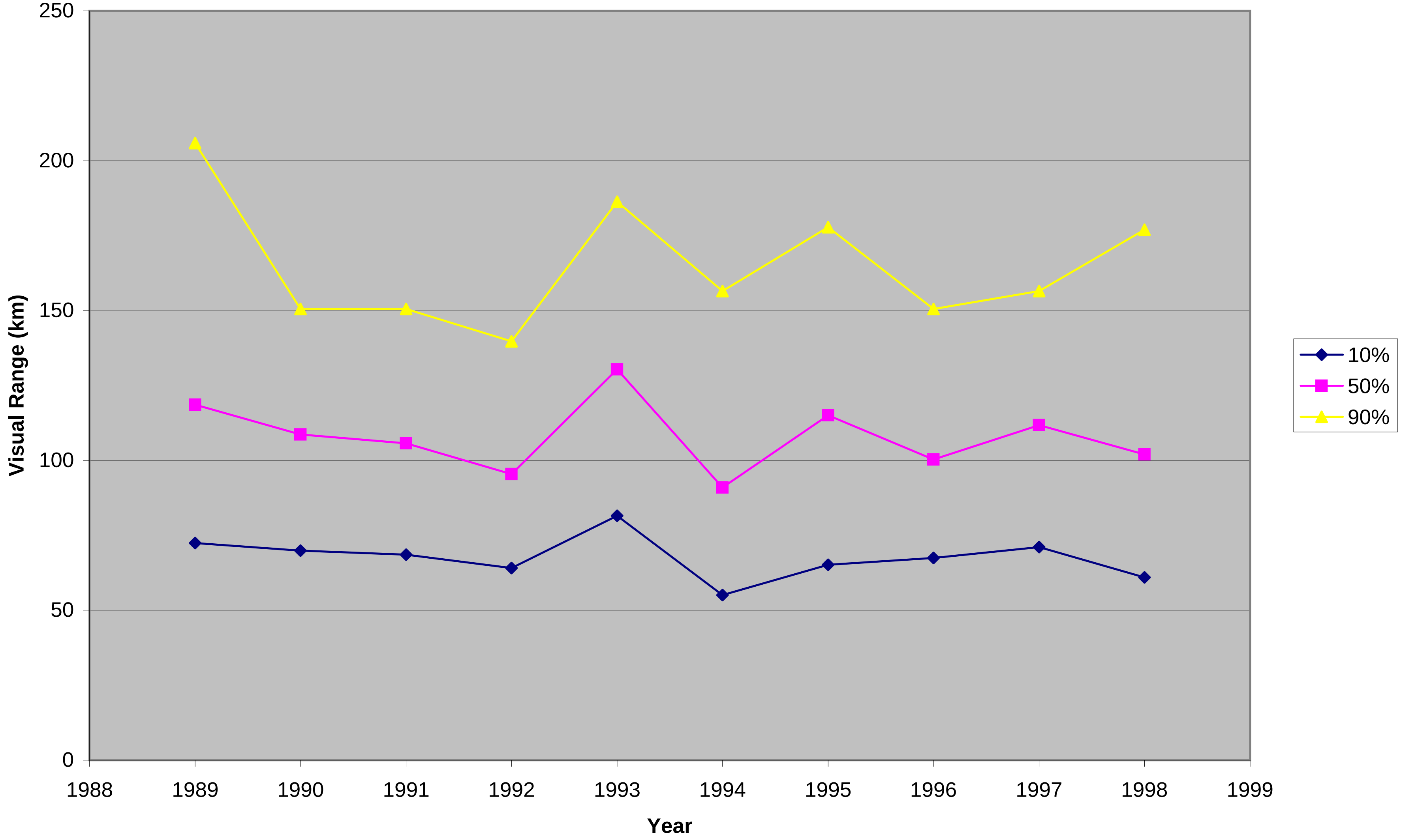


Figure 4-7: BNP NP Visual Range (1989-1998) - Validity Codes 0 Only



5.0 MODEL RESULTS

5.1 Predicted Pollutant Concentrations and Comparison to Observed Concentrations

The CALPUFF model was used as described in preceding sections to calculate daily 24-hour and annual average concentrations at BNP of sulfate (SO_4), nitrate (NO_3), organic carbon (OC) and elemental carbon (EC) particles, and total PM10. One model run used the 1990 emission inventories as described in Section 4.2; a second run simulated impacts from 1997 emissions. Both runs utilized the CALMET meteorological fields for 1990, as described in section 4.3. As explained in section 4.3, 1990 is the only year for which suitable meteorological input data are available. It is assumed that the range and frequency of various meteorological conditions are generally similar from year-to-year. Thus, the average pollutant concentrations and their frequency distributions for the two years should differ only because of changed pollutant emissions.

Model-predicted concentrations were compared to measured concentrations at the BNP IMPROVE monitoring site. To provide the most representative IMPROVE results and utilize all available measurements, monitoring data from 1989 – 1993 were used for comparison to 1990 model predictions, and IMPROVE data for 1994 – 1998 were taken as representative of 1997.

5.1.1 Modeled/Observed Concentrations for 1990

Table 5-1 compares predicted concentrations for each pollutant for 1990 to measured concentrations at BNP from 1989 through 1993. It is clear that predicted concentrations are significantly lower than observed concentrations at BNP. This result was expected, since the modeled Wyoming/South Dakota sources represent only a portion of the many pollutant sources, both natural and manmade, that can potentially affect air quality in Badlands National Park.

TABLE 5-1

PREDICTED AND OBSERVED CONCENTRATION STATISTICS FOR 1990 (µg/m^3)

Pollutant	Model Predictions		IMPROVE Measurements (1989 – 93)	
	Annual Average	95th Percentile 24-hour	Annual Average	95th Percentile 24-hour
Nitrate (NO_3)	0.228	0.90	0.362	1.58
Sulfate (SO_4)	0.044	0.17	1.199	3.12
PM10	1.83	4.21	10.16	22.98
Organic Carbon (OC)	0.033	0.07	0.853	1.80
Elemental Carbon (EC)	0.039	0.08	0.177	0.34

It will be noted that the fraction of observed concentrations that are accounted for by the model results varies with pollutant. Over 50% of observed NO_3 is predicted by the CALPUFF simulation; about 20% of measured PM10 and EC concentrations are predicted from modeled sources, and much smaller fractions of sulfate and organic carbon are accounted for by the model results. The difference between NO_3 and SO_4 probably reflects both the more rapid conversion of NO_x to NO_3 in the atmosphere and the fact that most major SO_2 sources that can potentially affect SO_4 concentrations at BNP are outside of the modeling source inventory region (further west and southwest, and in other directions). Thus, the modeled NO_x sources in the PRB and western South Dakota have a relatively high impact in BNP, while observed SO_4 is overwhelmingly produced by sources outside of the modeling region.

The significant fraction of observed PM10 that can be attributed to modeled sources is reasonable since PM10 has a relatively short residence time in the atmosphere. Modeled sources within a few hundred kilometers of BNP apparently account for around 20% of the observed concentrations. But it should be recognized that local sources (roadways, fires, and wind erosion) likely have the highest impacts, and may not be included in the emission inventory. The difference between the comparisons for organic and elemental carbon is likely due at least in part to the predominant sources of the two types of particulate matter. Elemental carbon is generated primarily from diesel exhaust, while organic carbon originates from natural and anthropogenic organic emissions, and combustion of wood and organic materials. The elemental carbon sources were generally included in the modeled inventory, while forest and range fires and natural organic emission sources were not included.

An attempt was made to correlate 24-hour pollutant concentrations measured at BNP to model predictions for the same days in 1990 when IMPROVE measurements were obtained. For

NO_3, there were several periods during which model results were in reasonable agreement with measured values, suggesting that the impacts of modeled sources were reproduced realistically. In other cases, there was little correspondence between predicted and observed NO_3 concentrations; usually observed concentrations were higher than predicted. For the other pollutants, observed concentrations were nearly always much higher than predictions, and there was no significant correlation between predicted and observed values. It therefore proved impossible to draw any quantitative conclusions on the accuracy of the model predictions. The most that can be concluded is that the predicted NO_3 impacts appear to be realistic in magnitude, and that there is no evidence of major overprediction of impacts for any pollutant.

5.1.2 Modeled/Observed Concentrations for 1997

A comparison between predicted and observed concentrations for 1997 is shown in Table 5-2. The same features as discussed above are evident; the 1997 model results indicate slightly increased impacts over 1990 for NO_3 and SO_4, and slightly lower impacts for PM10, OC, and EC.

It is more instructive to compare predicted and observed changes in concentration from 1990 to 1997, as shown in Table 5-3. For both predicted and observed concentrations, most of the indicated trends are very small and of questionable significance. However for NO_3, the increase in measured concentration represents a more than 20% increase; the CALPUFF model results suggest that about one-third of the observed increase can be ascribed to the modeled emission sources. As discussed in a subsequent section, the predicted and observed changes in nitrate concentration are sufficient to imply a significant visibility impact.

TABLE 5-2

PREDICTED AND OBSERVED CONCENTRATION STATISTICS FOR 1997 ($\mu g/m^3$)

Pollutant	Model Predictions		IMPROVE Measurements (1994 - 98)	
	Annual Average	95^{th} Percentile 24-hour	Annual Average	95^{th} Percentile 24-hour
Nitrate (NO_3)	0.258	1.01	0.449	1.90
Sulfate (SO_4)	0.054	0.21	1.206	2.86
PM10	1.82	4.19	9.87	21.12
Organic Carbon (OC)	0.024	0.06	0.880	2.27
Elemental Carbon (EC)	0.033	0.07	0.173	0.34

TABLE 5-3

PREDICTED AND OBSERVED CONCENTRATION CHANGES, 1990 to 1997 ($\mu g/m^3$)

Pollutant	Model Predictions		IMPROVE Measurements	
	Annual Average	95th Percentile 24-hour	Annual Average	95th Percentile 24-hour
Nitrate (NO_3)	+0.03	+0.12	+0.09	+0.33
Sulfate (SO_4)	+0.01	+0.04	+0.01	-0.26
PM10	-0.01	-0.03	-0.29	-1.86
Organic Carbon (OC)	-0.01	-0.02	+0.03	+0.47
Elemental Carbon (EC)	-0.01	-0.01	0.0	-0.01

5.2 Source Culpability

The relative contributions of the different types of modeled sources to average predicted concentrations for the 1990 CALPUFF simulation is shown in Table 5-4. The results were obtained by executing complete CALPUFF model runs with individual source groups.

Table 5-4 indicates that point sources were the major contributor to NO_3 and SO_4 concentrations, with the county area sources also making large contributions. For PM10, OC, and EC, the county area sources were the overwhelming contributor. Coal mines and coal trains contributed very little to SO_4, OC, and PM10 concentrations, eight percent of EC concentrations, and 13 percent of predicted NO_3 concentrations. Coal trains had approximately twice the impact of PRB mining operations.

Table 5-5 shows the contribution of coal mines and trains to the predicted change in BNP concentrations from 1990 to 1997. The contribution was negligible except for nitrate. For NO_3, 78% of the predicted increase was due to increased coal mining activity; the predicted increase from coal mines and trains accounts for 26% of the increase in average NO_3 concentration actually observed at the BNP IMPROVE monitoring station.

5.3 Model Sensitivity to Input Parameters

Model runs were carried out to determine the sensitivity of model results to several input parameters. The parameters evaluated were background ammonia and ozone concentrations, and particle size parameters for PM10, EC, and OC. Background pollutant concentrations affect the chemical transformation rates of NO_x to NO_3 and SO_2 to SO_4. Particle sizes have a strong influence on the rate at which particles are removed from the atmosphere through surface deposition.

TABLE 5-4

CONTRIBUTION TO PREDICTED 1990 ANNUAL AVERAGE CONCENTRATIONS BY SOURCE TYPE

Pollutant	Point Sources		County Sources		Coal Mines		Coal Trains		Total
	Conc. (μg/m^3)	% of Total	Conc. (μg/m^3)	% of Total	Conc. (μg/m^3)	% of Total	Conc. (μg/m^3)	% of Total	(μg/m^3)
Nitrate (NO_3)	.099	43	.100	44	.008	4	.021	9	.228
Sulfate (SO_4)	.034	76	.010	22	.001	1	.001	1	.044
PM10	.026	1	1.801	98	.005	1	<.001	0	1.832
Organic Carbon (OC)	0	0	.032	97	.001	1	.001	2	.033
Elemental Carbon (EC)	0	0	.036	92	.001	3	.002	5	.039

TABLE 5-5

CONTRIBUTION TO PREDICTED CHANGE IN ANNUAL CONCENTRATION 1990 – 1997 BY COAL MINES AND TRAINS

Pollutant	Predicted Change ($\mu g/m^3$)	Mines & Trains ($\mu g/m^3$)	% of Total Predicted	Observed Change ($\mu g/m^3$)
Nitrate (NO_3)	+.030	+.023	78	+.087
Sulfate (SO_4)	+.010	+.001	8	+.007
PM10	-.014	+.003	---	-.292
Organic Carbon (OC)	-.008	+.001	---	+.027
Elemental Carbon (EC)	-.006	+.002	---	-.004

Table 5-6 shows the effect of changes in background ammonia and ozone concentrations on predicted NO_3 and SO_4 concentrations for 1990. Higher background ammonia produces slightly higher predicted concentrations; higher background ozone levels lead to significantly higher predicted sulfate concentrations, and to slightly higher predicted nitrate concentrations. Results presented elsewhere in this report are based on 5 ppb ammonia and 40 ppb ozone.

Effects of changed particle size parameters are illustrated in Table 5-7. Case 1 represents the "base case" that was used for all results presented in this report. The mean particle diameters and standard deviations are the default values recommended for general use in the absence of source-specific data (Earth Tech, 1998). In Case 2, the mean sizes of all particles were increased. The result was a decrease in predicted PM10 concentration (due to more rapid deposition of PM10 particles), and a very minor increase in EC and OC concentrations. In Case 3, EC and OC particles were the same as the base case, but PM10 particles were assumed to be smaller with a mean diameter of 2.5 microns. As would be expected, model-predicted PM10 impacts increased significantly because of reduced fallout of particles during transport.

One other modeling parameter was varied in modeling tests. Prior PRB CALPUFF analyses (and the present study) represented railroad emission sources by individual volume sources spaced at ten kilometer intervals along the rail route. The individual sources were characterized by vertical and horizontal standard deviations of 3.0 and 1000 meters, respectively. This representation has been criticized as an oversimplification, since it represents an actual line of emissions by widely spaced discrete emission sources.

The current versions of the CALPUFF model permit railroad sources to be represented as a series of long, narrow area sources with moderate computation time penalty. Therefore, the railroad emissions for the present study were modeled as more realistic area sources to

TABLE 5-6

EFFECT OF BACKGROUND CONCENTRATIONS ON PREDICTED SULFATE AND NITRATE CONCENTRATIONS

	NO_3 (µg/m^3)		SO_4 (µg/m^3)	
	Annual Average	Maximum 24-hour	Annual Average	Maximum 24-hour
Background Ammonia				
1 ppb	.177	2.84	.044	.623
5 ppb	.228	2.93	.044	.650
Background Ozone				
20 ppb	.201	2.81	.037	.546
40 ppb	.228	2.93	.044	.650
80 ppb	.262	3.17	.055	.745

TABLE 5-7

EFFECT OF PARTICLE SIZE PARAMETERS ON PREDICTED CONCENTRATIONS

	EC (μg/m^3)		OC (μg/m^3)		PM10 (μg/m^3)	
	Annual Average	Maximum 24-hour	Annual Average	Maximum 24-hour	Annual Average	Maximum 24-hour
Case 1						
EC, OC: D = 0.48 SD = 2.0	.039	.131	.033	.108	1.83	8.66
PM10: D = 5.2 SD = 2.3						
Case 2						
EC, OC: D = 1.0 SD = 1.0	.039	.132	.033	.109	.86	7.66
PM10: D = 8.0 SD = 3.0						
Case 3						
EC, OC: D = 0.48 SD = 2.0	.039	.131	.033	.108	3.20	11.66
PM10: D = 2.5 SD = 2.0						

D = geometric mass mean diameter (microns)
SD = geometric standard deviation (microns)

compare with the discrete volume source approach. Results showed no significant difference in predicted impacts at BNP.

The reason for the comparable results using volume and area sources for rail lines in the present case is undoubtedly the large distance between the railroad sources and the model receptors in BNP (greater than 200 km). Where railroad sources must be modeled within 100 km or less of receptor points, model results could be much different, and the use of a more realistic area source representation is recommended.

5.4 Visibility Results

To determine the implied impact of the model results on visibility in BNP, the methods described in Section 4.3 were applied. The reference conditions of the December 2000 FLAG report (representing natural background) were used to calculate percent change in light extinction. Reference light extinction for BNP is

$$b_{ext} = 0.6\ f(RH) + 14.5\ Mm^{-1}$$

where 0.6 represents the contribution of hygroscopic particles and 14.5 Mm^{-1} is the contribution of dry particles and Rayleigh scattering. For the results to be presented here, f(RH) was calculated for each day as the average of hourly f(RH) from measured relative humidity at the BNP monitoring station. The applicable daily f(RH) value was used to calculate both reference extinction and the incremental extinction from model-predicted pollutant concentrations.

5.4.1 Model Results and Observed Extinction

The mean value (average over all days of the year) of extinction due to model-predicted concentrations was 5.08 Mm^{-1} for 1990 and 5.42 Mm^{-1} for 1997. These total modeled impacts represent approximately 33 percent of reference (natural) light extinction. The difference between results for the two years indicates an increase in extinction of 0.34 Mm^{-1} from 1990 to 1997 (about 2 percent of the clean reference condition).

Measured extinction at the BNP IMPROVE monitoring station was analyzed for the two periods 1989 – 93 and 1994 – 98. All measured extinction coefficients not classified as "invalid" were included in the analysis; i.e. "valid" measurements as well as those possibly including interference or otherwise classified as suspect. The median measured light extinction at BNP for 1989 through 1993 was 52 Mm^{-1}, and for 1994 through 1998 was 61 Mm^{-1}. The "20% cleanest" extinction values for the two periods were 33.9 Mm^{-1} (1989-93) and 36.4 Mm^{-1} (1994-98). These data suggest an increase in extinction between 1989-93 and 1994-98 of approximately 7 to 15 %.

Visual range corresponding to the measured extinction values for 1989-93 is 75 km for the median and 115 km for 20% cleanest conditions. For 1994-98 the measured visual ranges are 64 km and 107 km, respectively. These ranges are lower than those shown in Figure 4-7, which is based on only the highest quality data, generally excluding days of high relative humidity or other measurement interferences.

The measured frequency distributions of b_{ext} at BNP were examined in detail, and the two data periods were compared. The major change between 1989 – 93 and 1994 – 98 appears as an increase in the frequency of b_{ext} values in the range of 40 to 50 Mm^{-1}, and fewer days of $b_{ext} < 40$ Mm^{-1}. The change is consistent with an increase in days of significant visibility degradation, and appears to be a real trend in BNP light extinction. However, whether this trend is a result of local pollution sources, an increase in long-range impacts from distant sources, a change in meteorological conditions, or some combination of the three cannot be determined. The modeled increase in extinction from sources in the modeling area can account for only a small fraction of the observed change.

5.4.2 Impacts of Mining and Coal Trains

The incremental pollutant contributions from modeled PRB coal mines and coal trains were used to calculate potential visibility impacts using the recommended FLAG procedures. Results are shown in Table 5-8. The mean daily extinction due to coal-related sources at BNP was calculated to be 0.39 Mm^{-1} in 1990 and 0.66 Mm^{-1} in 1997. The increase in model-predicted extinction over this time period was therefore 0.27 Mm^{-1}, or 1.7% of the FLAG reference extinction for BNP. The total coal activity contribution in 1997 was still less than 5% of the reference level, at 4.1%. The coal mine/train fraction of total model-predicted extinction averaged 4.9% in 1990 and 7.7% in 1997. Thus, coal-related visibility impacts were, on the average, a small fraction of total predicted impacts for both years, and were, again on an average basis, lower than the FLAG level of concern.

However, the FLAG criteria for significant visibility degradation are not based upon average impacts, but rather upon the potential for given incremental impacts on any specific days of the year. A five percent impact is considered a level of concern. Though no specific number of days has been identified as a threshold, the implication of FLM guidance is that the 5% level should be exceeded very rarely if at all. The second line of Table 5-8 shows the number of days per year that modeling indicated greater than 5% increase in extinction (relative to FLAG reference) due to coal mine/train emissions. Despite the small average contribution of these sources, use of the FLAG methodology indicates that increased coal production from 1990 to 1997 caused an impact “of concern” at BNP on 34 additional days per year.

TABLE 5-8

MODEL-PREDICTED VISIBILITY IMPACTS OF COAL MINES AND COAL TRAINS

	1990	1997	Change 1997 – 1990
Mean Extinction (Mm^{-1})	0.39	0.66	+0.27
Days per Year of 5% Impact (Relative to FLAG Reference)	49	83	+34
Days per Year of 5% Impact (Relative to Actual BNP Conditions)	5	19	+14

The above results illustrate the stringent criteria imposed by the FLM guidance on visibility impacts. For comparison, the last line of Table 5-8 shows the annual number of days of 5 percent impact by coal mines/trains if the incremental increase in light extinction is compared to the actual measured extinction at BNP in 1990 and 1997 on a day by day basis. Clearly there were few days when actual visibility was reduced by 5 percent or more. It should be emphasized that FLAG guidance does not allow for use of actual extinction as a reference level, nor is that procedure advocated here. The intent of the visibility assessment procedures is to estimate potential degradation with respect to natural, clean conditions. The results in Table 5-8 are intended simply to illustrate the conservative nature of the FLAG criteria. It is apparent that very low pollutant concentrations from distant sources have the potential to create visibility impacts that exceed the stringent FLAG criteria, especially if they are projected to occur on days with high humidity.

5.4.3 Alternative Procedures for Use of Relative Humidity in Visibility Impact Determination

The FLAG procedures for determination of visibility impact from modeling results allow use of two alternative procedures to account for relative humidity effects:

1. Use a constant seasonal or annual value for f(RH), based on historical relative humidity data for the area of concern. For BNP, the annual f(RH) value is 2.6, corresponding to a relative humidity of 79%. The annual f(RH) value is the average f(RH), not the f(RH) value corresponding to average humidity. Because f(RH) is a non-linear function of relative humidity (see Appendix A), the two averages are not the same. In general, the average f(RH) corresponds to a relative humidity higher than the mean relative humidity for a season or year.

2. Determine f(RH) for each hour of the model simulation using observed or model-predicted relative humidity at the receptor location; and then calculate the mean f(RH) for each day from the hourly values. These daily f(RH) data should then be used to calculate both the modeled contribution to light extinction and the reference light extinction for that day.

Note that the reference condition (background) is specified as a combination of hygroscopic and dry particle extinction; i.e., for BNP annual conditions

$$b_{back} = 0.6\ f(RH) + 14.5\ Mm^{-1}$$

When the average f(RH) of 2.6 is applied, this reference extinction is 16.1 Mm^{-1}. But a daily value of f(RH) can be used, in which case the reference extinction varies with humidity, being less on dry days and greater on humid days.

For the visibility results presented in the preceding subsections, the second alternative was used. Since measured relative humidity was available for BNP as part of the meteorological data set, application of those data was viewed as more realistic than use of a constant relative humidity factor. But it is of interest to know whether one alternative tends to predict higher impacts (more days with significant impacts) than the other.

The question was investigated by numerical calculations, and also by mathematical analysis of the equations for calculating percent extinction change. It was found that which alternative predicts lower impacts depends upon the relative contributions of hygroscopic and dry particles.

Results from the two alternatives will in general be different because of the nonlinearity of the f(RH) function. Thus, there will normally be more days in the year when the actual mean f(RH) is below the FLAG reference f(RH), compared to days with mean f(RH) above the reference value. As a consequence of this fact, alternative (2) results in fewer days of high percent extinction increase when the incremental pollutants are mostly hygroscopic, and alternative (1) gives fewer days of high impact for mainly dry particles.

It can be shown that the combination of hygroscopic and dry particle concentrations for which the two alternatives give identical results is given by

(a) x (d) = (b) x (c)

where

a = 4.125 (SO_4) + 3.870 (NO_3)

b = 4 (OC) + 0.6 (PM10) + 10 (EC) + 10

c = reference hygroscopic extinction coefficient (0.6 for Badlands National Park)

d = reference dry extinction (14.5 for Badlands National Park)

(all units Mm^{-1})

If (a) x (d) is greater than (b) x (c), alternative (2) will predict fewer days of high impact; if (a) x (d) is less than (b) x (c), alternative (1) will predict fewer days of impact exceeding a given level.

The above analysis assumed that relative humidity at the receptor site is statistically independent of predicted pollutant concentrations. The conclusion may not hold if there is a correlation between predicted impacts and relative humidity on the days of those impacts. Thus, results from the two alternatives will depend in general upon both the ratio of hygroscopic to dry particles, and the relationship, if any, between predicted concentrations and relative humidity.

6.0 SUMMARY AND CONCLUSIONS

The objectives of the present study were to compare CALPUFF model predictions to observed trends in pollutant concentration and visibility at Badlands National Park, and to evaluate the variation in projected impacts with model input parameters, pollutant source categories, and assessment methodology. It did not prove possible to obtain a quantitative measure of model accuracy; observed impacts at BNP, on either a day-to-day or an average annual basis, are clearly the result of pollutant sources, both natural and anthropogenic, that are often beyond the boundaries of the study emission inventory and/or not included in the inventory. Nonetheless, information was obtained on the apparent long-term trends in emissions and impacts, and the relative effects of different types of emission sources.

The results obtained by the CALMET/CALPUFF modeling system appear to be relatively robust. By this it is meant that results are not highly sensitive to the input modeling parameters or the precise source parameters assigned to each emission source. Predicted concentrations, on both hourly and long-term bases, appear to be realistic and appropriately associated with the magnitude and characteristics of upwind source emissions. Though no direct correlation between predicted and observed impacts could be demonstrated, the relationship of model predictions to observed concentrations and trends is plausible. No indication was found that the model systematically over-predicts impacts or produces anomalous or unrealistic results.

The modeling results indicate that impacts of sources in northeast Wyoming are generally low at BNP in terms of the actual magnitude of pollutant concentrations. The effects of PRB mining emissions are in turn a relatively small fraction of total predicted impacts. However, it appears that increased emissions from mining-related sources during the period 1990- 1997 could have contributed to small increases in nitrate concentrations and light extinction at BNP.

Despite the small magnitude of observed concentration changes, IMPROVE data from BNP suggest a measurable decrease in visibility during the period. The model results only account for about 14% of the observed visibility degradation on the 20% cleanest days. It is not known whether the observed change is a result of a long-term trend in regional pollutant emissions, or reflects a short-term anomaly due to meteorological conditions, fires, or other natural phenomena.

The apparent visibility effect of very small changes in particle concentrations is a reflection of the sensitivity of visual range to particle concentration, particularly for hygroscopic particles. This sensitivity is readily apparent when applying the Federal Land Managers' (FLAG) visibility assessment methods. New FLAG guidance calls for comparison of new source impacts to natural background conditions; i.e., to conditions in the absence of man-made pollution. When this comparison is performed on a day-to-day basis over a full year, the CALPUFF model results indicate that increased coal production in the PRB from 1990 to 1997 had visibility impacts exceeding a five percent degradation from natural conditions on 34 days per year.

Specific findings and conclusions of the study are summarized in the following paragraphs.

- Except for nitrate, more than 80% of <u>average</u> ambient pollutant concentrations in BNP are the result of natural background and sources other than those inventoried in northeastern Wyoming, western South Dakota, and northwestern Nebraska. However, approximately 63% of observed nitrate can be accounted for by the sources included in the inventory.

- Maximum observed 24-hour concentrations at BNP are also much larger (except for nitrate) than model-predicted concentrations. This finding implies that nearby sources and/or major man-made or natural sources not included in the inventory can have a major effect on BNP air quality.
- Model results indicate that on an annual basis PRB coal mines contribute two percent of observed nitrate concentrations in BNP, and less than one percent of observed sulfate, PM10, and carbon particle concentrations. Rail transport of coal contributes about six percent of observed nitrate, one percent of elemental carbon, and much less than one percent for the other pollutants.
- On a 24-hour basis, coal trains can contribute up to 18% of measured nitrate at BNP, up to five percent of observed elemental carbon, and less than one percent of other pollutant concentrations. Coal mines can contribute up to eight percent of 24-hour nitrate in BNP, up to four percent of observed 24-hour elemental carbon, and much smaller fractions for other pollutants.
- Culpability results suggest that the most effective mitigation of coal mining impacts on BNP air quality would be through control of diesel emissions from mine equipment and locomotives. Existing federal regulations will result in some reduction in emissions per unit in future years.
- Analysis of IMPROVE monitoring data at BNP for the period 1989 – 1998 indicates only small changes in air quality. However, nitrate concentrations appear to have increased by about 24%; average visibility has tended to decrease slightly over the same period. The increase in light extinction on the cleanest days at BNP is on the order of 2.5 Mm^{-1}. The latter half of the period has

experienced an increase in the number of days with visibility in the range of 75 to 100 km, and fewer days with visual range exceeding 100 km.

- The cause of the apparent slight visibility degradation at BNP cannot be determined from the present analysis. Model results suggest that about 14% of the change could be explained by the modeled emissions sources. The remainder may be a result of increased emissions elsewhere, or natural factors such as differences in meteorology, forest fires, and wind erosion.
- Visibility impacts of PRB coal mines and coal transportation represent approximately 80% of the total model-predicted incremental impact from 1990 to 1997, but only about 10% of the observed increase in light extinction at BNP.
- Application of the FLAG procedures for assessment of visibility impacts by comparison to natural reference conditions indicates that coal mine/coal train emissions could have a visibility impact exceeding five percent on a number of days per year. The model-predicted change in impacts from 1990 to 1997 indicates an additional 34 days per year of a five percent increase in light extinction compared to natural conditions.
- Very small predicted changes in pollutant concentration can translate into significant visibility impacts under the stringent FLAG procedures. If predicted visibility is compared to existing visibility in BNP (rather than natural background visibility), much smaller percentage changes and many fewer days of impact are indicated.
- It is recommended that determination of visibility impacts using FLAG recommendations utilize hourly relative humidity data when they are available,

rather than seasonal average values of relative humidity factor. Use of hourly data should provide more realistic results; for the typical case where the major impacts are due to hygroscopic particles, there will be less likelihood of overpredicting impacts.

- CALPUFF model results are not highly sensitive to most user-specified model inputs. However, sulfate and nitrate predictions can vary with the assumed background ozone and ammonia concentrations. Because projected visibility impacts can change dramatically for small changes in predicted concentrations, it is important that appropriate input parameters and background concentrations be used. Site-specific data, where available, should be used in preference to conservative default values.

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APPENDIX A

SUPPORTING DATA

APPENDIX A-1

CALPUFF INPUT PARAMETERS

(for all modeling except sensitivity test)

APPENDIX A-1 – INPUT SETTING FOR BASE CALPUFF RUNS

Input Group: 1 – General run control parameters

Parameter	Value(s) Selected	Value(s) Effect
METRUN	1	Run all periods in CALMET file
NSPEC	8	Number of chemical species modeled
NSE	5	Number of chemical species emitted
METFM	1	Specifies CALMET binary file

Input Group: 2 – Technical options

Parameter	Value(s) Selected	Value(s) Effect
MCTADJ	3	Partial plume path terrain adjustment
MWET	1	Wet deposition set to on
MDRY	1	Dry deposition turned on
MPARTL	1	Partial plume penetration of elevated inversion

Input Group: 3 - Species list

Species Name	Modeled 0=no 1=yes	Emitted 0=no 1=yes	Dry Deposited 0=no 1=comp, gas 2=comp, particle	Output Group 0=none
SO2	1	1	1	0
SO4	1	0	2	0
NOx	1	1	1	0
HNO3	1	0	1	0
NO3	1	0	2	0
PM10	1	1	2	0
EC	1	1	2	0
OC	1	1	2	0

Input Group: 4 – Grid control parameters

Parameter	Value(s) Selected	Value(s) Effect
NX	136	No. of columns in meteorological grid
NY	94	No. of rows in meteorological grid
NZ	8	Approximate number of mandatory reporting levels between surface and 500 mb.
DGRIDKM	5	Computational grid spacing (in km.)
ZFACE	0, 20, 50, 100, 250, 500, 750, 1000, and 3000	Vertical layer definitions
XORIGKM	148.475	SW corner of grid in Lambert Conformal Coordinates (km. E)
YORIGKM	4611.926	SW corner of grid in Lambert Conformal Coordinates (km. N)
IUTMZN	13	UTM zone of reference
XLAT	43.68	Latitude (deg.) of modeling domain center
XLONG	105.15	Longitude (deg.) of modeling domain center
XTZ	7	Time zone corresponding to MST
IBCOMP	1	SW corner of computational grid (X cell #)
JBCOMP	1	SW corner of computational grid (Y cell #)
IECOMP	136	NE corner of computational grid (X cell #)
JECOMP	94	NE corner of computational grid (Y cell #)

Input Group: 5 – Output options

Parameter	Value(s) Selected	Value(s) Effect
ICON	1	Ambient concentrations in output file
IDRY	0	No dry deposition fluxes in output file
IWET	0	No wet deposition fluxes in output file
IVIS	1	Relative humidity output for visibility

Input Group: 6a, 6b and 6c – Subgrid scale complex terrain inputs (Not used)

Input Group: 7 – Chemical parameters for dry deposition of gases

Species Name	Diffusivity	Alpha Star	Reactivity	Mesophyll Resistance	Henry's Law Coef.
SO2	0.1509	1000.0	8.0	0.0	0.04
NOx	0.1656	1.0	8.0	5.0	3.5
HNO3	0.1628	1.0	18.0	0.0	0.0

Input Group: 8 – Size parameters for dry deposition of particles		
Species Name	Geometric Mass Mean Diameter	Geometric Standard Deviation
SO4	0.48	2.0
NO3	0.48	2.0
PM10	5.20	2.3
EC	0.48	2.0
OC	0.48	2.0

Input Group: 9 – Miscellaneous dry deposition parameters		
Parameter	Value(s) Selected	Value(s) Effect
RCUTR	30	Reference cuticle resistance
RGR	5	Reference ground resistance
REACTR	8	Reference pollutant reactivity
NINT	9	Number of particle size intervals…
IVEG	1	Set for active and unstressed vegetation

Input Group: 10 – Wet deposition parameters – scavenging coefficient		
Pollutant	Liquid Precip	Frozen Precip
SO2	3.0E-05	0.00E00
SO4	1.0E-04	3.0E-05
HNO3	6.0E-05	0.0E00
NO3	1.0E-04	3.0E-05
PM10	1.0E-04	3.0E-05
EC	1.0E-04	3.0E-05
OC	1.0E-04	3.0E-05

Input Group: 11 – Chemistry parameters		
Parameter	Value(s) Selected	Value(s) Effect
MOZ	0	Used a constant background ozone conc.
BCKO3	40.0	Background ozone concentration
BCKNH3	5.0	Background ammonia concentration

Input Group: 12 – Miscellaneous dispersion and computational parameters		
Parameter	Value(s) Selected	Value(s) Effect
XSAMLEN	1.0	Max travel distance of a puff during one sampling step
WSCALM	1.0	Minimum wind speed allowed for non-calm conditions

Input Group: 13a, 13b, 13c and 13d – Point source parameters

Parameter	Value(s) Selected	Value(s) Effect
NPT1	Variable	Number of constant emission rate point sources
NPT2	0	No point sources with variable emission rates

The point source data presented in Subgroup 13b corresponds to parameters presented in the appendices of this report.

No building downwash was modeled – therefore there were no entries for card 13c . Likewise, there were no variable rate emission point sources, so card 13d was unused.

Input Group: 14a, 14b, 14c and 14d – Area source parameters

Parameter	Value(s) Selected	Value(s) Effect
NAR1	Variable	Number of constant emission rate areasources
NSAR1	0	No scaling factors applied to area sources
NAR2	0	No area sources with variable emission rates

The area source data presented in Subgroup 14b corresponds to parameters presented in the appendices of this report. Subgroup 14c defines the corners of each area source, in lambert conformal coordinates. Subgroup 14d was unused due to no variable rate emissions.

Input Group: 15a, 15b and 15c (Not applicable)

Input Group: 16a, 16b and 16c – Volume source parameters

Parameter	Value(s) Selected	Value(s) Effect
NVL1	69	Number of volume sources
NSVL1	0	No variable emissions/scalars used
IGRDVL	0	No gridded volume sources used

The volume source data presented in Subgroup 16b corresponds to parameters presented in the appendices of this report. 16c was not used due to no variable rate emissions.

Input Group: 17a and 17b – Discrete receptor information

Parameter	Value(s) Selected	Value(s) Effect
NREC	2	Number of discrete receptors – one located at the former NPS meteorological station, the second at the IMPROVE monitoring site.

APPENDIX A-2

f(RH) FOR VARIOUS VALUES OF

RELATIVE HUMIDITY

Table A-2: f(RH) values for various values of relative humidity*

RH(%)	f(RH)	RH(%)	f(RH)	RH(%)	f(RH)	RH(%)	f(RH)
1	1.0	26	1.0	51	1.2	76	2.3
2	1.0	27	1.0	52	1.3	77	2.4
3	1.0	28	1.0	53	1.3	78	2.5
4	1.0	29	1.0	54	1.3	79	2.6
5	1.0	30	1.0	55	1.3	80	2.7
6	1.0	31	1.0	56	1.3	81	2.8
7	1.0	32	1.0	57	1.3	82	3.0
8	1.0	33	1.0	58	1.4	83	3.1
9	1.0	34	1.0	59	1.4	84	3.2
10	1.0	35	1.0	60	1.4	85	3.4
11	1.0	36	1.0	61	1.5	86	3.6
12	1.0	37	1.1	62	1.5	87	3.8
13	1.0	38	1.1	63	1.5	88	4.0
14	1.0	39	1.1	64	1.6	89	4.4
15	1.0	40	1.1	65	1.7	90	4.7
16	1.0	41	1.1	66	1.7	91	5.3
17	1.0	42	1.1	67	1.7	92	5.9
18	1.0	43	1.1	68	1.8	93	7.0
19	1.0	44	1.2	69	1.9	94	8.4
20	1.0	45	1.2	70	1.9	95	9.8
21	1.0	46	1.2	71	2.0	96	12.4
22	1.0	47	1.2	72	2.0	97	15.1
23	1.0	48	1.2	73	2.1	98	18.1
24	1.0	49	1.2	74	2.1	99	18.1 **
25	1.0	50	1.2	75	2.2	100	18.1 **

* The values in Table A-2 are only appropriate for averaging times of 1 hour or less.

** The values for 99% and 100% RH are rolled back to the value for 98%.

APPENDIX A-3

POINT SOURCE EMISSION INVENTORY

Table A-3.1: Wyoming Point Sources

Facility	County	Source #	UTM E	UTM W	Lambert E	Lambert W	Elev (m)	1990 PM10	1990 Nox	1990 SO2	1997 PM10	1997 Nox	1997 SO2
Dave Johnston Power Plant	Converse	W1	436518	4742915	419548	4752743	1508	1.551	44.923	126.765	1.122	47.411	131.005
	Converse	W2	436518	4742915	419548	4752743	1508	1.520	53.433	130.425	1.099	56.392	134.788
	Converse	W3	436518	4742915	419548	4752743	1508	1.997	150.497	268.260	1.444	158.832	277.235
	Converse	W4	436518	4742915	419548	4752743	1508	33.505	177.757	177.746	24.231	187.602	183.692
Modeling Area Source	Converse		436468	4742865	419502	4752691	1508	11.977	0.142	0.103	8.682	0.150	0.106
Boggy Creek-West Gas	Niobrara	W5	535210	4808070	511264	4820705	1201	0.000	1.605	0.000	0.000	1.502	0.000
Pope and Talbot	Weston	W6	564900	4854700	537452	4867260	1340	0.872	0.547	0.086	0.250	0.127	0.026
Newcastle Plant-West Gas	Weston	W7	535900	4831360	510737	4843239	1306	0.002	4.436	0.000	0.006	2.624	0.000
Gopher Station-KN	Campbell	W8	473583	4841196	450257	4849577	1446	0.000	3.000	0.000	0.000	1.574	0.000
HA Creek Station-KN	Campbell	W9	493241	4843276	469071	4852582	1353	0.000	3.164	0.000	0.000	1.878	0.000
Belle Creek Booster-KN	Campbell	W10	460080	4899545	434302	4905241	1404	0.000	1.545	0.000	0.000	2.851	0.000
Well Draw Booster-KN	Converse	W11	488884	4759413	469143	4771334	1488	0.000	1.525	0.000	0.000	2.112	0.000
Sage Grouse Booster-KN	Converse	W12	429945	4775594	411570	4783995	1694	0.000	2.376	0.000	0.000	2.949	0.000
West Porcupine Booster-KN	Campbell	W13	470579	4831367	447865	4839930	1488	0.000	4.652	0.000	0.000	3.550	0.000
Todd Booster-KN	Weston	W14	501824	4852371	476869	4861801	1377	0.000	1.824	0.000	0.000	2.707	0.000
Thunder Creek Booster-KN	Campbell	W15	492300	4836701	468501	4846183	1405	0.000	2.992	0.000	0.000	1.749	0.000
Hogs Draw Booster-KN	Converse	W16	502494	4746498	482907	4759541	1529	0.000	3.046	0.000	0.000	3.458	0.000
Ross Booster-KN	Converse	W17	439708	4812326	419114	4819978	1524	0.000	1.460	0.000	0.000	0.524	0.000
Mud Springs Booster-KN	Campbell	W18	433859	4848657	411648	4854775	1585	0.000	1.505	0.000	0.000	1.528	0.000
Irwin Ranch Booster-KN	Converse	W19	485233	4813754	462865	4823658	1354	0.000	2.865	0.000	0.000	3.320	0.000
Hay Booster-KN	Campbell	W20	471036	4859868	446858	4867481	1512	0.000	1.548	0.000	0.000	1.953	0.000
Douglas Gas Plant-KN	Converse	W21	471000	4737396	453038	4749147	1504	0.082	17.687	0.000	0.082	20.754	0.000
Osage Plant - Black Hills Power	Weston	W22	547485	4868230	520000	4879437	1316	1.571	26.215	95.142	0.388	23.854	86.575
Modeling Area Source			547435	4868180	519955	4879387	1314	0.302	0.000	0.000	0.075	0.000	0.000
Neil Simpson I - Black Hills Power	Campbell	W23	469116	4903600	442791	4909613	1402	8.239	13.664	18.152	1.044	20.810	15.569
Modeling Area Source			469066	4903550	442745	4909562	1402	0.385	0.000	0.000	0.049	0.000	0.000
Wyodak - Pacificorp	Campbell	W24	469293	4903788	442952	4909803	1402	13.118	208.101	217.307	11.541	143.280	237.004
Modeling Area Source			469243	4903738	442906	4909753	1402	1.582	0.000	0.000	1.392	0.000	0.000
Hilight - Western Gas	Campbell	W25	471255	4854115	447361	4861936	1505	0.000	12.552	0.002	0.000	12.793	0.006
South Hartzog - Western Gas	Campbell	W26	428100	4855010	405785	4860621	1524	0.000	1.542	0.000	0.000	2.166	0.000
Mikes Draw - Phillips Petrol	Converse	W27	478050	4780494	457640	4791159	1457	0.000	0.204	0.000	0.000	0.000	0.000
Moore Comp - Western Gas	Converse	W28	459245	4760721	440534	4771099	1661	0.000	3.225	0.000	0.000	0.811	0.000
Steinle Ranch Booster-KN	Converse	W29	483050	4796250	461653	4806637	1402	0.000	0.742	0.000	0.000	1.387	0.000
Yoss-KN	Converse	W30	478986	4761963	459482	4773298	1519	0.000	1.516	0.000	0.000	0.000	0.000
Sand Dunes - Western Gas	Converse	W31	426690	4771110	408662	4779498	1768	0.000	0.000	0.000	0.000	0.581	0.000
Crossbow - Western Gas	Campbell	W32	466500	4871700	441892	4878679	1421	0.000	0.000	0.000	0.000	1.188	0.000
Bozeman - Western Gas	Converse	W33	436400	4808100	416144	4815728	1585	0.000	0.000	0.000	0.000	0.440	0.000
Lightning Creek	Converse	W34	482833	4765000	463032	4776427	1456	0.000	2.767	0.000	0.000	0.000	0.000
Porcupine - Western Gas	Campbell	W35	460080	4899545	434302	4905241	1404	0.000	0.000	0.000	0.000	2.143	0.000
Pinetree - Western Gas	Campbell	W36	427780	4824185	407034	4830832	1647	0.000	2.701	0.000	0.000	2.762	0.000
Wyoming Refining	Weston	W37	563130	4855330	535717	4867777	1328	4.953	4.454	19.399	2.485	8.794	22.047
American Colloid Upton	Weston	W38	527540	4884060	500000	4893709	1308	2.512	0.526	2.598	4.119	4.404	2.882
Recluse Compr- Western Gas	Campbell	W39	437200	4967230	408859	4969422	1219	0.000	0.921	0.000	0.000	1.602	0.000
Oedekoven- Western Gas	Campbell	W40	460080	4899545	434302	4905241	1404	0.000	0.000	0.000	0.000	3.046	0.000
American Colony East	Crook	W41	556900	4968200	523951	4976428	1060	1.876	1.861	2.568	2.615	2.204	2.569
Scott Booster-KN	Converse	W42	469185	4764015	449940	4774785	1585	0.000	1.516	0.000	0.000	1.706	0.000
Teckla Booster-KN	Converse	W43	491970	4792872	470413	4803825	1469	0.000	1.361	0.000	0.000	2.178	0.000
Kaye Booster-KN	Converse	W44	507732	4773549	486573	4785953	1351	0.000	1.528	0.000	0.000	1.666	0.000
Neiman Sawmills	Crook	W45	531322	4948110	500372	4955737	1158	0.128	0.078	0.045	0.158	0.175	0.035
Powell Booster-KN	Converse	W46	446915	4801152	426617	4809545	1520	0.000	1.487	0.000	0.000	2.100	0.000
Kitty Gas Plant- Western Gas	Campbell	W47	445965	4907000	420344	4911725	1428	0.000	20.137	0.014	0.000	14.418	0.003
House Creek Booster-KN	Campbell	W48	448170	4851375	425283	4858123	1524	0.000	1.536	0.000	0.000	0.009	0.000
Bentonite Mat - Colony Plant	Crook	W49	567750	4967600	534418	4976400	1036	0.797	0.834	5.515	1.835	4.163	1.151
American Colony West	Crook	W50	566200	4968600	532876	4977287	1036	1.171	0.898	6.107	1.999	4.045	1.763
Archibald Booster-KN	Campbell	W51	443782	4833417	421969	4840557	1578	0.000	3.909	0.000	0.000	3.193	0.000

Facility	County	Source #	UTM E	UTM W	Lambert E	Lambert W	Elev (m)	1990 PM10	1990 Nox	1990 SO2	1997 PM10	1997 Nox	1997 SO2
Amos Draw Booster-KN	Campbell	W52	429614	4909981	404462	4913776	1383	0.000	4.660	0.000	0.000	3.397	0.000
South Well - South Sand	Converse	W53	459245	4760721	440534	4771099	1661	0.000	3.268	0.000	0.000	0.000	0.000
Neil Simpson II - Black Hills Power	Campbell	W54	468888	4903894	442556	4909885	1402	0.000	0.000	0.000	0.198	21.693	19.027
Outback Compressor- West Gas	Campbell	W55	461500	4869400	437198	4876204	1463	0.000	0.000	0.000	0.000	0.627	0.000
Mills-Gillette - West Gas	Campbell	W56	460080	4899545	434302	4905241	1404	0.000	0.000	0.000	0.000	0.248	0.000
Reihemann Comp - MIGC Inc.	Campbell	W57	460080	4899545	434302	4905241	1404	0.000	0.000	0.000	0.000	0.833	0.000
Bitter Creek - Redstone Resou	Campbell	W58	455476	4922395	428714	4927068	1306	0.000	0.000	0.000	0.000	0.262	0.000
Buckskin Field - S Bat - Redstone	Campbell	W59	455283	4920860	428606	4925577	1299	0.000	0.000	0.000	0.000	0.250	0.000
Buckskin Field - N Bat - Redstone	Campbell	W60	455476	4922395	428714	4927068	1306	0.000	0.000	0.000	0.000	0.262	0.000
Carter Compressor- West Gas	Campbell	W61	458500	4879000	433824	4885323	1430	0.000	0.000	0.000	0.000	0.006	0.000
Stealth Comp - MIGC Inc.	Campbell	W62	455610	4913370	429300	4918362	1341	0.000	0.000	0.000	0.000	0.584	0.000
Hilite/Reno - West Gas	Campbell	W63	471255	4854115	447361	4861936	1505	0.000	12.552	0.000	0.000	12.793	0.006
Macsy Comp - MIGC Inc.	Campbell	W64	460080	4899545	434302	4905241	1404	0.000	0.000	0.000	0.000	0.685	0.000
Glenrock Coal - Dave Johnson	Converse		459245	4760721	440534	4771099	1661	17.059	1.476	0.000	13.354	0.000	0.000
Total				g/s				88.140	804.736	1070.233	64.816	796.551	1115.484
				TPY				3063.919	27974.139	37203.335	2253.123	27689.630	38776.335
Grieve Unit Cent. Bat- Forrest Oil	Natrona							0.000	0.000	0.000	0.000	0.322	0.000
Barrett Resources - Cave Gulch	Natrona							0.000	0.000	0.000	0.000	0.621	0.000
Black Hills Bentonite Mills	Natrona		388500	4743900							0.000	1.044	0.000

Table A-3.2: South Dakota Point Sources (Pennington County)

Facility	County	Source #	UTM E	UTM W	Lambert E	Lambert W	Elev (m)	1990 PM10	1990 Nox	1990 SO2	1997 PM10	1997 Nox	1997 SO2
Rushmore Forest Products	Pennington	S1	618512	4866703	588422	4881594	1463	1.116	0.391	0.000	1.116	0.391	0.000
Simon Construction Company	Pennington	S2	639418	4883805	607654	4899171	1020	0.066	0.945	0.189	0.066	0.945	0.189
Black Hills Power and Light	Pennington	S3	639160	4882911	607449	4898294	1018	0.358	29.863	21.842	0.358	29.863	21.842
Black Hills Power and Light	Pennington	S4	639166	4882855	607461	4898241	1017	11.459	162.182	42.484	11.459	162.182	42.484
Pete Lien and Sons, Inc.	Pennington	S5	637539	4886139	605723	4901332	1056	1.347	15.327	0.016	1.347	15.327	0.016
Hills Materials Company	Pennington	S6	638012	4882909	606347	4898233	1038	0.756	0.170	0.345	0.756	0.170	0.345
Dakota Block Company	Pennington	S7	638023	4884276	606288	4899554	1037	1.223	0.908	3.326	1.223	0.908	3.326
South Dakota Cement	Pennington	S8	638274	4883022	606593	4898360	1032	13.297	88.821	4.585	13.297	88.821	4.585
Birdsall Sand and Gravel	Pennington	S9	638481	4882858	606797	4898213	1021	0.072	0.000	0.000	0.072	0.000	0.000
Merillat Industries	Pennington	S10	645118	4879077	613384	4894894	973	3.820	5.165	0.449	3.820	5.165	0.449

APPENDIX A-4

COUNTY AREA SOURCE EMISSIONS

County Area Source Emissions (TPY)

Wyoming

	1990 NO2	1990 SO2	1990 PM10	1990 EC	1990 OC
Campbell	2921	577	11038	59	48
Crook	1517	543	5230	34	37
Weston	2602	0	3096	17	21
Converse	6401	2372	4326	28	25
Niobrara	588	57	2660	13	8
Platte	22131	6815	6502	36	28
Goshen	2825	1632	7823	45	19

	1997 NO2	1997 SO2	1997 PM10	1997 EC	1997 OC
Campbell	6942	3345	48952	49	36
Crook	1920	596	21193	29	27
Weston	1802	338	13779	14	15
Converse	10246	7671	23063	24	19
Niobrara	665	52	10040	0	0
Platte	19490	9177	21251	28	20
Goshen	3354	1569	27547	40	24

	1997-1990 NO2	1997-1990 SO2	1997-1990 PM10	1997-1990 EC	1997-1990 OC
Campbell	4021	2768	37914	-10	-12
Crook	403	53	15963	-5	-10
Weston	-800	338	10683	-3	-6
Converse	3845	5299	18737	-4	-6
Niobrara	77	-5	7380	-13	-8
Platte	-2641	2362	14749	-8	-8
Goshen	529	-63	19724	-5	5
Total	5434	10752	125150	-48	-45

South Dakota

	1990 NO2	1990 SO2	1990 PM10	1990 EC	1990 OC
Fall River	571	287	2399	18	25
Shannon	616	75	3315	23	32
Bennett	516	76	3240	21	13
Jackson	722	91	3065	26	15
Haakon	664	107	4296	29	15
Custer	713	108	3804	19	43
Pennington	0	0	12650	245	196
Lawrence	2882	1864	4646	40	55
Meade	2467	295	9424	72	77
Butte	501	66	2576	21	24
Ziebach	391	61	2525	17	11

	1997 NO2	1997 SO2	1997 PM10	1997 EC	1997 OC
Fall River	615	428	2338	15	18
Shannon	803	69	3290	19	22
Bennett	663	87	3404	20	11
Jackson	660	91	3074	20	11
Haakon	797	129	3747	26	13
Custer	843	128	3274	16	29
Pennington	0	1462	10217	171	132
Lawrence	1374	205	4606	29	37
Meade	2220	312	7700	57	54
Butte	748	69	2565	19	18
Ziebach	489	69	3181	15	9

	1997-1990 NO2	1997-1990 SO2	1997-1990 PM10	1997-1990 EC	1997-1990 OC
Fall River	44	141	-61	-3	-7
Shannon	187	-6	-25	-4	-10
Bennett	147	11	164	-1	-2
Jackson	-62	0	9	-6	-4
Haakon	133	22	-549	-3	-2
Custer	130	20	-530	-3	-14
Pennington	0	1462	-2433	-74	-64
Lawrence	-1508	-1659	-40	-11	-18
Meade	-247	17	-1724	-15	-23
Butte	247	3	-11	-2	-6
Ziebach	98	8	656	-2	-2
Total	-831	19	-4544	-124	-152

Nebraska

	1990 NO2	1990 SO2	1990 PM10	1990 EC	1990 OC
Sioux	377	47	2358	13	10
Dawes	824	105	4902	23	21
Box Butte	1420	220	6719	42	20
Sheridan	1203	158	8718	40	27

	1997 NO2	1997 SO2	1997 PM10	1997 EC	1997 OC
Sioux	425	51	2125	11	8
Dawes	907	107	3825	20	16
Box Butte	1508	258	4771	37	17
Sheridan	1464	175	7543	36	22

	1997-1990 NO2	1997-1990 SO2	1997-1990 PM10	1997-1990 EC	1997-1990 OC
Sioux	48	4	-233	-2	-2
Dawes	83	2	-1077	-3	-5
Box Butte	88	38	-1948	-5	-3
Sheridan	261	17	-1175	-4	-5
Total	480	61	-4433	-14	-15

APPENDIX A-5

COAL MINE EMISSION PARAMETERS

AND SPREADSHEETS

Emission Factors

Category	units	PM-10	SO2	NOx
Blasting	lbs/ton of ANFO	--	2	11.56
Trucks	lb/gal	0.0177	0.0312	0.2942
Graders	lb/gal	0.0222	0.0311	0.2538
Wh. Loaders	lb/gal	0.0293	0.0312	0.3212
RT Dozers	lb/gal	0.0148	0.0312	0.2861
Tractors	lb/gal	0.0253	0.0311	0.2849
Scrapers	lb/gal	0.0273	0.0312	0.2586
Drills	lb/gal	0.0301	0.0311	0.3680
Water trucks	lb/gal	0.0177	0.0312	0.2861
Miscellaneous	lb/gal	0.0301	0.0311	0.3680
Locomotives	lb/gal	0.0138	0.0360	0.5044

Table 1

Blasting - ANFO Usage

Mine	Coal (lb/T)	Overburden (lb/BCY)
Eagle Butte	0.37	0.37
Wyodak	0.64	0.47
Caballo	0.35	0.43
Belle Ayr	0.39	0.58
Caballo Rojo	0.40	0.60
Cordero	0.43	0.44
Rochelle	0.41	0.41
North Antelope	0.41	0.41
Antelope	0.28	0.42
ALL OTHERS	0.40	0.50

Table 2

Diesel-Fueled Equipment

	Cordero Rojo	Wyodak	Belle Ayr	Antelope	N Antelope/ Rochelle	ALL OTHERS
Scrapers (gal/hr)	44	20	---	14.6	5.8	20
Graders (gal/hr)	12.5	12	8.3	15.5	7.3	12
Water Trucks (gal/hr)	28	18	---	12.8	---	20
Haul Trucks (gal/mi)	3	1.5	3.6	6.4	2.9	3.5
Wheeled Loaders	14% of scrapers	---	---	0.5 x graders	2.4 x scrapers	---
RT Dozers	25% of Scrapers	---	2.2 x graders	0.36 x graders	3.2 x scrapers	---
Track Dozers	2.4 x scrapers	---	---	4.6 x graders	2.2 x scrapers	---
Drills	21% of Scrapers	---	0.6 x graders	---	1.3 x scrapers	---
Misc Equip	6.5% of scrapers	---	---	---	---	---

Table 3

Locomotives

Mine	Hours/Train	Tons of Coal/Train
Rawhide	4	12,507
Belle Ayr	5	11,200
Caballo	3.5	12,649
Antelope	5	13,039
North Antelope	10	13,444
Rochelle	10	13,444
Wyodak	4	11,000
Cordero Rojo	5	12,364
ALL OTHERS	5	12,500

	1997 Coal Predicted Production (MMTPY)	1997 Coal Actual Production (MMTPY)	1990 Coal Actual Production (MMTPY)	1997 Multiplier	1990 Multiplier	1997 Est. PM10 Emissions (TPY)	1990 Ratioed PM10 Emis (TPY)	1997 Ratioed PM10 Emis (TPY)	1990 Coal Actual Production (MMTPY)	1997 Coal Actual Production (MMTPY)	1997 OB Predicted Production (MMBCY)	1990 Actual OB Remove (MMBCY)	1997 Actual OB Remove (MMBCY)	ANFO Usage Factor Coal (lb/ton)	ANFO Usage Factor OB (lb/BCY)	1990 ANFO Usage Coal (lbs)	1990 ANFO Usage OB (lbs)	1997 ANFO Usage Coal (lbs)	1997 ANFO Usage OB (lbs)	1990 SO2 Emissions (TPY)	1990 NO2 Emissions (TPY)
Buckskin	14.80	14.40	7.70	0.97	0.5203	155.84	81.08	151.63	7.70	14.40	22.63	10.30	30.20	0.40	0.50	3080000	5150000	5760000	15100000	4.12	23.78
Rawhide	11.20	10.71	11.40	0.96	1.02	173.29	176.38	165.71	11.40	10.71	12.10	8.20	13.53	0.40	0.50	4560000	4100000	4284000	6765000	4.33	25.03
Eagle Butte	26.63	17.92	15.37	0.67	0.58	433.49	250.20	291.71	15.37	17.92	40.42	16.87	31.56	0.37	0.37	5686900	6241900	6630400	11677200	5.96	34.47
Dry Fork	6.50	0.92	0.82	0.14	0.13	118.71	14.98	16.80	0.82	0.92	6.12	0.96	0.54	0.40	0.50	328000	480000	368000	270000	0.40	2.34
Ft. Union	3.50	0.59	0.04	0.17	0.01	122.28	1.40	20.61	0.04	0.59	11.03	0.23	0.70	0.40	0.50	16000	115000	236000	350000	0.07	0.38
Wyodak	5.00	3.25	2.91	0.65	0.58	64.87	37.75	42.17	2.91	3.25	3.89	1.47	3.04	0.64	0.47	1862400	690900	2080000	1428800	1.28	7.38
Clovis Pt.	0.00	0.00	0.00																		
Rocky Butte	0.00	0.00	0.00																		
Caballo	30.00	19.95	14.30	0.67	0.48	990.12	471.96	658.43	14.30	19.95	88.00	24.20	54.26	0.35	0.43	5005000	10406000	6982500	23331800	7.71	44.54
Belle Ayr	25.00	22.80	15.53	0.91	0.62	828.77	514.83	755.84	15.53	22.80	73.61	17.08	60.87	0.39	0.58	6056700	9906400	8892000	35304600	7.98	46.13
Caballo Rojo	30.00	14.68	8.57	0.49	0.29	465.83	133.07	227.95	8.57	14.68	57.10	13.76	25.39	0.40	0.60	3428000	8256000	5872000	15234000	5.84	33.77
Cordero	24.00	13.39	12.90	0.56	0.54	449.52	241.62	250.79	12.90	13.39	51.75	22.30	29.04	0.43	0.44	5547000	9812000	5757700	12777600	7.68	44.39
Coal Creek	18.00	2.92	0.14	0.16	0.01	644.54	5.01	104.56	0.14	2.92	41.04	0.29	6.89	0.40	0.50	56000	145000	1168000	3445000	0.10	0.58
Jacob's Ranch	20.00	29.10	16.80	1.46	0.84	577.90	485.44	840.84	16.80	29.10		37.50	57.80	0.40	0.50	6720000	18750000	11640000	28900000	12.74	73.61
Black Thunder	36.00	42.70	28.75	1.19	0.80	766.80	612.38	909.51	28.75	42.70		38.45	133.50	0.40	0.50	11500000	19225000	17080000	66750000	15.36	88.80
N. Rochelle	8.00	15.16	0.03	1.89	0.00	193.40	0.73	366.40	0.03	15.16		0.05	60.47	0.40	0.50	12000	25000	6062400	30233000	0.02	0.11
N. Antelope	36.20	34.97	8.24	0.97	0.23	522.81	119.00	505.05	8.24	34.97	49.62	11.03	57.04	0.41	0.41	3378400	4522300	14337700	23386400	3.95	22.83
Rochelle	24.00	24.94	12.03	1.04	0.50	627.79	314.68	652.38	12.03	24.94	64.80	14.85	60.44	0.41	0.41	4932300	6088500	10225400	24780400	5.51	31.85
Antelope	12.00	13.60	5.20	1.13	0.43	345.99	149.93	392.12	5.20	13.60	28.74	6.00	37.60	0.28	0.42	1456000	2520000	3808000	15792000	1.99	11.49

	1997 SO2 Emissions (TPY)	1997 NO2 Emissions (TPY)	1997-1990 SO2 Diff (TPY)	1997-1990 NO2 Diff (TPY)		Train Hrs	T Coal/Train	1990 Train #	1997 Train #	1990 Hours	1997 Hours	1990 PM10 Emissions (TPY)	1990 SO2 Emissions (TPY)	1990 NO2 Emissions (TPY)	1997 PM10 Emissions (TPY)	1997 SO2 Emissions (TPY)	1997 NO2 Emissions (TPY)	1997-1990 PM10 Diff (TPY)	1997-1990 SO2 Diff (TPY)	1997-1990 NO2 Diff (TPY)
Buckskin	10.43	60.29	6.32	36.50		5	12500	616	1152	3080	5760	0.85	2.23	31.23	1.60	4.17	58.40	0.74	1.94	27.17
Rawhide	5.52	31.93	1.19	6.90		4	12507	911	856	3646	3425	1.01	2.64	36.96	0.95	2.48	34.73	-0.06	-0.16	-2.24
Eagle Butte	9.15	52.91	3.19	18.43		5	12500	1230	1434	6148	7168	1.71	4.45	62.33	1.99	5.19	72.67	0.28	0.74	10.34
Dry Fork	0.32	1.84	-0.09	-0.49		5	12500	66	74	328	368	0.09	0.24	3.33	0.10	0.27	3.73	0.01	0.03	0.41
Ft. Union	0.29	1.69	0.23	1.31		5	12500	3	47	16	236	0.00	0.01	0.16	0.07	0.17	2.39	0.06	0.16	2.23
Wyodak	1.75	10.14	0.48	2.76		4	11000	265	295	1058	1182	0.29	0.77	10.73	0.33	0.86	11.98	0.03	0.09	1.25
Clovis Pt.																				
Rocky Butte																				
Caballo	15.16	87.61	7.45	43.07		3.5	12649	1131	1577	3957	5520	1.10	2.86	40.12	1.53	3.99	55.97	0.43	1.13	15.85
Belle Ayr	22.10	127.73	14.12	81.59		5	11200	1387	2036	6933	10179	1.92	5.02	70.29	2.82	7.37	103.19	0.90	2.35	32.90
Caballo Rojo	10.55	61.00	4.71	27.23	*	5	12364	693	1187	3466	5937	0.96	2.51	35.14	1.65	4.30	60.19	0.69	1.79	25.05
Cordero	9.27	53.57	1.59	9.18	*	5	12364	1043	1083	5217	5415	1.45	3.77	52.89	1.50	3.92	54.90	0.05	0.14	2.01
Coal Creek	2.31	13.33	2.21	12.75		5	12500	11	234	56	1168	0.02	0.04	0.57	0.32	0.85	11.84	0.31	0.80	11.27
Jacob's Ranch	20.27	117.16	7.54	43.55		5	12500	1344	2328	6720	11640	1.86	4.86	68.13	3.23	8.42	118.01	1.36	3.56	49.88
Black Thunder	41.92	242.27	26.55	153.47		5	12500	2300	3416	11500	17080	3.19	8.32	116.59	4.74	12.36	173.16	1.55	4.04	56.57
N. Rochelle	18.15	104.89	18.13	104.79		5	12500	2	1212	12	6062	0.00	0.01	0.12	1.68	4.39	61.46	1.68	4.38	61.34
N. Antelope	18.86	109.02	14.91	86.19		10	13444	613	2601	6129	26012	1.70	4.44	62.14	7.22	18.82	263.72	5.52	14.39	201.58
Rochelle	17.50	101.17	11.99	69.32		10	13444	895	1855	8948	18551	2.48	6.47	90.72	5.15	13.42	188.08	2.66	6.95	97.36
Antelope	9.80	56.64	7.81	45.15		5	13039	399	1043	1994	5215	0.55	1.44	20.22	1.45	3.77	52.87	0.89	2.33	32.66

	1997 Multiplier	1990 Multiplier	1997 Scraper Estimate (hours)	1997 Grader Estimate (hours)	1997 Water Tk Estimate (hours)	1997 Hauling Estimate (miles)	1990 Scrapers (hours)	1990 Graders (hours)	1990 Water Tk (hours)	1990 Hauling (miles)	1990 Fuel Use Scrapers (gal)	1990 Fuel Use Graders (gal)	1990 Fuel Use Water Tk (gal)	1990 Fuel Use Hauling (gal)	1990 Fuel Use Whl Load (gal)	1990 Fuel Use Rt Dozer (gal)	1990 Fuel Use Trk Dozer (gal)	1990 Fuel Use Drills (gal)	1990 Fuel Use Misc. Eq. (gal)	1990 PM10 Emissions (TPY)	1990 SO2 Emissions (TPY)	1990 NO2 Emissions (TPY)
Buckskin	0.97	0.52	1219	3929	7665	200029	634	2044	3988	104069	12684	24530	79757	364242						4.37	7.51	69.74
Rawhide	0.96	1.02	5212	8223	26280	484000	5305	8370	26749	492643	106101	100438	534986	1724250						22.56	38.46	356.63
Eagle Butte	0.67	0.58	2197	18202	4255	638642	1268	10506	2456	368604	25361	126067	49117	1290114						13.60	23.25	216.08
Dry Fork	0.14	0.13	2084	12681	13950	128187	263	1600	1760	16171	5258	19197	35197	56599						1.10	1.81	16.48
Ft. Union	0.17	0.01	19790	3038	0	111333	226	35	0	1272	4523	417	0	4453						0.11	0.15	1.29
Wyodak	0.65	0.58	2000	4160	2334	53987	1164	2421	1358	31420	23280	29053	24451	47131						1.27	1.93	17.13
Clovis Pt.																						
Rocky Butte																						
Caballo	0.67	0.48	23100	58700	16900	1851111	11011	27980	8056	882363	220220	335764	161113	3088270						35.49	59.35	548.41
Belle Ayr	0.91	0.62	8045	31720	9252	1978651	4998	19704	5747	1229138	99951	163547	114947	4424897		359804		98128		47.50	82.06	770.55
Caballo Ro *	0.49	0.29	2791	2017	8760	326812	797	576	2502	93359	35081	7202	70068	280078	4911	8770	84194	7367	2280	5.00	7.79	72.48
Cordero *	0.56	0.54	5726	12729	5424	308303	3078	6842	2915	165713	135420	85523	81631	497139	18959	33855	325008	28438	8802	13.12	18.93	174.21
Coal Creek	0.16	0.01	14200	15800	0	2233126	110	123	0	17369	2209	1475	0	60791						0.58	1.01	9.42
Jacob's Ranch	1.46	0.84	4418	68308	0	1047128	3711	57379	0	879588	74222	688545	0	3078556						35.90	59.89	549.83
Black Thunder	1.19	0.80	12587	20509	0	689201	10052	16379	0	550404	201042	196545	0	1926413						21.97	36.24	334.31
N. Rochelle	1.89	0.00	988.7	3957	0	225863	4	15	0	847	74	178	0	2964						0.03	0.05	0.47
N. Antelope	0.97	0.23	29897	46848	0	800237	6805	10664	0	416340	39471	77845	0	1207385	94730	126306	86835	51312		16.28	26.26	247.68
Rochelle	1.04	0.50	28080	44000	0	1289403	14075	22055	0	670838	81636	161002	0	1945430	195925	261234	179598	106126		28.79	45.70	431.11
Antelope	1.13	0.43	2532	6400	6400	549117	1097	2773	2773	285689	16019	42987	35499	1828411	21493	15475	197739			20.12	33.65	315.40

	1997 Multiplier	1990 Multiplier	1997 Scraper Estimate (hours)	1997 Grader Estimate (hours)	1997 Water Tk Estimate (hours)	1997 Hauling Estimate (miles)	1997 Scrapers (hours)	1997 Graders (hours)	1997 Water Tk (hours)	1997 Hauling (miles)	1997 Fuel Use Scrapers (gal)	1997 Fuel Use Graders (gal)	1997 Fuel Use Water Tk (gal)	1997 Fuel Use Hauling (gal)	1997 Fuel Use Whl Load (gal)	1997 Fuel Use Rt Dozer (gal)	1997 Fuel Use Trk Dozer (gal)	1997 Fuel Use Drills (gal)	1997 Fuel Use Misc. Eq. (gal)	1997 PM10 Emissions (TPY)	1997 SO2 Emissions (TPY)	1997 NO2 Emissions (TPY)
Buckskin	0.97	0.52	1219	3929	7665	200029	1186	3823	7458	194623	23721	45874	149157	681180						8.18	14.04	130.43
Rawhide	0.96	1.02	5212	8223	26280	484000	4984	7863	25130	462825	99680	94359	502605	1619888						21.19	36.13	335.05
Eagle Butte	0.67	0.58	2197	18202	4255	638642	1478	12249	2863	429758	29568	146983	57266	1504154						15.85	27.11	251.93
Dry Fork	0.14	0.13	2084	12681	13950	128187	295	1795	1974	18143	5899	21538	39489	63502						1.23	2.03	18.49
Ft. Union	0.17	0.01	19790	3038	0	111333	3336	512	0	18768	66721	6145	0	65686						1.56	2.16	19.07
Wyodak	0.65	0.58	2000	4160	2334	53987	1300	2704	1517	35092	26000	32448	27308	52637						1.42	2.16	19.13
Clovis Pt.																						
Rocky Butte																						
Caballo	0.67	0.48	23100	58700	16900	1851111	15362	39036	11239	1230989	307230	468426	224770	4308461						49.51	82.80	765.10
Belle Ayr	0.91	0.62	8045	31720	9252	1978651	7337	28929	8438	1804530	146741	240108	168756	6496307		528237		144065		69.73	120.48	1131.26
Caballo Ro *	0.49	0.29	2791	2017	8760	326812	1366	987	4287	159920	60092	12337	120024	479760	8413	15023	144221	12619	3906	8.57	13.35	124.16
Cordero *	0.56	0.54	5726	12729	5424	308303	3195	7102	3026	172007	140564	88772	84732	516022	19679	35141	337353	29518	9137	13.62	19.65	180.82
Coal Creek	0.16	0.01	14200	15800	0	2233126	2304	2563	0	362263	46071	30757	0	1267919						12.19	20.98	196.37
Jacob's Ranch	1.46	0.84	4418	68308	0	1047128	6428	99388	0	1523571	128564	1192658	0	5332499						62.19	103.74	952.38
Black Thunder	1.19	0.80	12587	20509	0	689201	14930	24326	0	817469	298592	291911	0	2861141						32.64	53.83	496.53
N. Rochelle	1.89	0.00	988.7	3957	0	225863	1873	7497	0	427897	37462	89958	0	1497641						14.76	25.35	236.56
N. Antelope	0.97	0.23	29897	46848	0	800237	28881	45256	0	773047	167511	330370	0	2241835	402026	536034	368524	217764		43.59	66.47	627.17
Rochelle	1.04	0.50	28080	44000	0	1289403	29180	45723	0	1339905	169243	333780	0	3885723	406183	541577	372334	220016		58.38	92.44	872.06
Antelope	1.13	0.43	2532	6400	6400	549117	2870	7253	7253	622333	41896	112427	92843	3982929	56213	40474	517163			45.56	75.53	707.34

APPENDIX B

DATA ON SCIENTIFIC COLLABORATORS

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Dr. McVehil has more than 37 years of professional experience in boundary layer and air pollution meteorology, and the application of atmospheric science to industrial and environmental impact problems. His consulting practice specializes in air pollution modeling, air permitting and regulatory analysis, assessment of industrial atmospheric impacts, and litigation support services.

Dr. McVehil has authored several hundred papers, technical reports, impact assessments, and permit application documents. He is a nationally recognized authority on atmospheric effects of evaporative cooling towers and industrial cooling systems. Recent analyses and reports prepared by Dr. McVehil have involved analyses of acid deposition, air quality impacts of metals refineries and smelters, power generation facilities, and mining operations, and deposition of heavy metals and hazardous chemicals from contaminated soil and industrial sources.

In addition to the above technical areas, Dr. McVehil's responsibilities at MMA include supervision of complex air modeling analyses, preparation of Title V and PSD/NSR air permit applications, and review and audit of meteorological and air quality data. A significant portion of his time is devoted to litigation support activities, including analyses, consultation to law firms, and expert testimony. Litigation subjects include air dispersion modeling, transport, dispersion, and deposition of hazardous pollutants, and meteorological factors in accident cases.

Dr. McVehil is a Fellow of the American Meteorological Society, and a Certified Consulting Meteorologist. He has been a Certified Consulting Meteorologist since 1972, and was elected a Fellow of the Society in 1984. Dr. McVehil has served as member and Chairman of the Society's Board for Certified Consulting Meteorologists, and has served on other committees of the Society. He is a past President and Director of the National Council of Industrial Meteorologists.

SPECIAL AWARDS

1998 Award for Outstanding Contribution to the Advance of Applied Meteorology, American Meteorological Society, Boston, MA, January 1998

EDUCATION

B.A. Physics, 1958, WASHINGTON AND JEFFERSON COLLEGE
B.S. Meteorology, 1957, MASSACHUSETTS INSTITUTE OF TECHNOLOGY
M.S. Meteorology, 1958, MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Ph.D. Meteorology, 1962, PENNSYLVANIA STATE UNIVERSITY

EXPERIENCE

1987-Presentvice President/Secretary/Treasurer, McVEHIL-MONNETT ASSOCIATES, INC.

1984 - 1987 Partner, McVEHIL-MONNETT ASSOCIATES

1974 - 1984 Independent Meteorological Consultant
Consultation, analysis, reports and testimony for industrial clients and governmental agencies. Primary areas of service included environmental impact assessments, air quality permit applications, analysis of meteorological and pollution data, dispersion modeling, plant siting, and weather effects on industry.

1970 - 1974 BALL AEROSPACE CORPORATION, Environmental Systems Group (Formerly Sierra Research Corporation, Environmental Systems Division)
Manager, Technical Services
Responsible for technical management of BALL's meteorological and air quality monitoring, and consulting services activities. Provided technical oversight for consulting service contracts and air quality impact analyses, specialized consultation to power industry and industrial clients, testimony, and final consulting reports.

1969 - 1970 EG&G, Inc. Environmental Services Operation
Manager Technical Services
Responsible for management and technical direction of field services and research contracts in air pollution, weather modification, and applied meteorology. Provided direct research, report and proposal preparation, and technical supervision of all service contracts.

1962 - 1969 CORNELL AERONAUTICAL LABORATORY, INC.

Research Meteorologist and Head, Dynamic Meteorology Section

Conducted basic and applied research in atmospheric diffusion and turbulence, air-sea interactions, weather phenomena related to the Great Lakes, weather modification, wind tunnel modeling of meteorological flows, radar meteorology, and meteorological influences on military weapons and operations. Principal Investigator on more than ten research contracts.

1958 - 1962 PENNSYLVANIA STATE UNIVERSITY

Graduate Assistant, 1958 - 1960, Instructor, 1960 - 1961, Research Assistant, 1961 - 1962

As Graduate and Research Assistant, performed research on wind structure and turbulence in the planetary boundary layer. As full-time instructor in Meteorology, taught undergraduate courses in dynamic meteorology, thermodynamics of the atmosphere, applications of statistics to meteorology, and synoptic meteorology.

ORGANIZATIONS/HONORS

AMERICAN METEOROLOGICAL SOCIETY - Fellow, Certified Consulting Meteorologist
ROYAL METEOROLOGICAL SOCIETY, Fellow
AIR & WASTE MANAGEMENT ASSOCIATION (formerly APCA)
NATIONAL COUNCIL OF INDUSTRIAL METEOROLOGISTS - President, 1976-1977
AMERICAN METEOROLOGICAL SOCIETY - 1998 Award for Outstanding Contribution to the Advance of Applied Meteorology

PUBLICATIONS

Panofsky, H.A., Blackadar, A.K., and McVehil, G.E., 1960: "The Diabatic Wind Profile." Quarterly Journal of the Royal Meteorological Society, 86, 390-398.

McVehil, G.E., 1964: "Wind and Temperature Profiles Near the Ground in Stable Stratification." Quarterly Journal of the Royal Meteorological Society, 90, 136-146.

McVehil, G.E., Pilie, R.J., and Zigrossi, G.A., 1965: Some Measurements of Balloon Motions with Doppler Radar." Journal of Applied Meteorology, 4, 146.

Fichtl, G.H., and McVehil, G.E., 1970: "Longitudinal and Lateral Spectra of Turbulence in the Atmospheric Boundary Layer at the Kennedy Space Center." Journal of Applied Meteorology, 9, 51.

American Society of Mechanical Engineers, 1975: "Cooling Tower Plume Modeling and Drift Measurement. A Review of the State-of-the-Art." (Authored by G.E. McVehil and K.E. Heikes) ASME, New York, New York, 170 pages.

McVehil, G.E. and Umenhofer, T.A., 1981: "Assessment of Coal Dust Emissions from Power Plants for PSD Permit Applications." Proceedings of the American Power Conference, Vol. 43. Illinois Institute of Technology, Chicago, Illinois.

McVehil, G.E., 1990: "Model Estimates of Provincial Scale Atmospheric Sulphur Dioxide and Oxides of Nitrogen in Alberta." In "Acidic Deposition: Sulphur and Nitrogen Oxides", A.H. Legge and S.V. Krupa, Editors, Lewis Publishers, Chelsea, Michigan, 48118.

EDWARD L. ADDISON

Environmental Scientist/Engineer
McVehil-Monnett Associates, Inc.

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Building C
Englewood, Colorado 80112
(303)790-1332

Mr. Addison is a graduate environmental engineer with a strong academic background in both engineering (M.S.) and atmospheric sciences (B.S.). He has nearly twelve years of professional experience in the areas of analysis and quality assurance of air quality and meteorological data, dispersion modeling, report writing and scientific programming. At MMA, Mr. Addison is responsible for dispersion modeling, scientific programming and quality assurance/quality control activities.

EDUCATION

Civil Engineering, 1990, SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY

Meteorology, 1987, METROPOLITAN STATE COLLEGE OF DENVER

EXPERIENCE

1992-Present Air Quality Engineer/Meteorologist
McVEHIL-MONNETT ASSOCIATES, INC

1990-1992 Air Quality Meteorologist
AEROVIRONMENT, INC., Lakewood, Colorado

Experienced in the collection and evaluation of air pollution data from throughout the National Park system. Responsible for final level check of both air quality and meteorological data collected from National Park Service baseline and trend sites. Other responsibilities include all in-house scientific programming and monthly data report generation.

1987-1989 Civil Engineering Department, Graduate Research Assistant
SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY

Manipulated a large database of water resources and meteorological data in order to develop water yield models for selected basins within the Black Hills of South Dakota.

ORGANIZATIONS

AMERICAN METEOROLOGICAL SOCIETY
AIR & WASTE MANAGEMENT ASSOCIATION (formerly APCA)

KEITH A. BAUGUES, P.E.
Senior Environmental Engineer
McVehil-Monnett Associates, Inc.

44 Inverness Drive East
Building C
Englewood, Colorado 80112
(303) 790-1332

Mr. Baugues is a registered professional engineer with over 28 years experience in air quality engineering, emission inventory development, facilities permitting and review, dispersion modeling and data analysis. Mr. Baugues had a distinguished career as a national-level expert with the U.S. Environmental Protection Agency (U.S. EPA). His work history spans eight years with the Office of Air Quality Planning and Standards in Research Triangle Park, North Carolina, one year with the Region VI office in Dallas as regional air quality modeler, six years with the Indiana Air Pollution Control Division as engineer and Chief of the Modeling and Data Analysis Section, and over eleven years as a consultant. Mr. Baugues has been responsible for numerous Title V operating permit applications for clients in the aerospace, ceramics, gas transmission, utility, can recycling and mining industries and general permitting of gold and coal mines. In addition, he has prepared numerous databases/programs to demonstrate compliance with Title V requirements and to estimate toxic emission inventory values for TRI or state requirements.

Mr. Baugues' technical areas of expertise include the preparation of emission inventories, dispersion modeling and permitting of industrial facilities. His experience in emission inventory development includes preparation of numerous mobile source emission inventories, estimation of biogenic (vegetation) emissions, photochemical reactivity analyses, preparation of guidance for state agencies and development of a national emission inventory. Mr. Baugues also oversaw the preparation of emission inventories for use in regional photochemical modeling analyses. As a private consultant, Mr. Baugues was responsible for the preparation of air quality permit applications for PSD and minor sources, performed all phases of dispersion modeling, carried out power plant siting studies and developed State Implementation Plans for Colorado, Montana, Minnesota and Indiana.

At MMA, Mr. Baugues leads the firm's activities in emission inventory development and federal operating permit preparation for industrial facilities.

EDUCATION

B.S. Biological Engineering, 1973, ROSE HULMAN INSTITUTE OF TECHNOLOGY

Has successfully completed over 20 EPA and APCD courses covering environmental statistics, data quality assurance, dispersion modeling, air pollution meteorology, combustion evaluation, and air pollution control technology.

EXPERIENCE

1992 - Present McVEHIL-MONNETT ASSOCIATES, INC., Englewood, Colorado

Senior Environmental Engineer

Prepared Title V applications for a wide range of clients. Developed databases/software to track Title V compliance or estimate toxic emissions. Permitted coal and gold mines in the U.S. and worldwide.

1984 - 1992 U.S. ENVIRONMENTAL PROTECTION AGENCY, Durham, North Carolina

Office of Air Quality Planning and Standards

Environmental Engineer

Developed guidance for the application of photochemical models and for the development of emission inventory data. Oversaw preparation of guidance documents on estimating biogenic emissions, procedures for projecting emissions to future years, and techniques for converting a base year inventory into a modeling inventory. Provided guidance to States and participated in national workshops.

1984 U.S. ENVIRONMENTAL PROTECTION AGENCY, Dallas, Texas

Region VI, SIP Section

Regional Air Quality Modeler

Served as Regional Modeler, providing guidance to state agencies, industry and consultants relating to photochemical and dispersion model applications. Reviewed State Implementation Plans. Conducted analyses to estimate the number of areas that would exceed the PM-10 standard.

1981 - 1983	TERA CORPORATION, Dallas, Texas Senior Air Quality Engineer Performed statistical analyses of air quality and meteorological data. Conducted technical analyses and prepared permit applications (PSD and state) for major industrial, mining, biomass, chemical and utility projects. Applied and analyzed results of air quality simulation models. Carried out numerous power plant siting studies.
1979 - 1980	ETA ENGINEERING, INC., Westmont, Illinois Associate Environmental Engineer Reviewed air quality data, developed emission inventories, conducted dispersion model analyses, analyzed the results and prepared control strategies. Developed State Implementation Plans for lead for Colorado, Montana, Minnesota and Indiana. Conducted an analysis for the National Commission on Air Quality reviewing modeling techniques, emission inventory data and assumptions utilized in preparing State Implementation Plans for the Minneapolis, Minnesota area.
1976 - 1979	INDIANA AIR POLLUTION CONTROL DIVISION, Indianapolis, Indiana Section Chief, Modeling and Data Analysis Section Supervised six to eight employees including: engineers, meteorologists, statisticians, physical scientists and sanitarians. Responsible for conducting or reviewing dispersion modeling analyses for: SIP development, monitor placement, PSD/NSR and special studies. Oversaw Emission Inventory Subsystem (EIS/P&R), Air Quality Data Handling System (AQDHS-II) and meteorological data bases.
1973 - 1976	INDIANA AIR POLLUTION CONTROL DIVISION, Indianapolis, Indiana Sanitary Engineer Prepared and maintained emission inventory data bases. Reviewed thousands of air pollution permit applications, issuing operating and construction permits as appropriate. Prepared input and applied dispersion models. Provided engineering assistance to local air pollution control agencies.

ORGANIZATIONS

Professional Engineer - Illinois
Air and Waste Management Association

PUBLICATIONS

K.A. Baugues, "A Look at the Differences Between Base SIP Emission Inventories and Photochemical Modeling inventories", presented at the 86th Annual Meeting of the Air & Waste Management Association, Denver, CO, June 1993.

K.A. Baugues, "Application of Receptor Modeling for VOC Emissions", presented at the Emission Inventory Issues Conference, Durham, NC, October 1992.

K. A. Baugues, J. S. Culbertson, E. J. Laich, E. H. Pechan, S. R. Rothschild, D. A. Solomon, J. H. Wilson, M. C. Wimberly and W. Battye, "Interim 1990 Emission Inventory for the Nation", presented at the Emission Inventory Issues Conference, Durham, NC, October 1992.

A. VanMeter, K. A. Baugues and M. Bouley, "Estimation of Biogenic Emissions for the Atlanta Area: Comparison of Methodologies", presented at the Emission Inventory Issues Conference, Durham, NC, October 1992.

K.A. Baugues, "Further Comparisons of Ambient and Emission Inventory NMOC/NO_x Ratios", presented at the 85th Annual Meeting of the Air & Waste Management Association, Kansas City, MO, June 1992.

K.A. Baugues, "A Review of Speciated NMOC Data", presented at the Measurement of Toxic and Related Air Pollutants, Durham, NC, May 1992.

K.A. Baugues, "A Summary of NMOC, NO_x and NMOC/NO_x Data Collected Between 1984 and 1988", presented at the Measurement of Toxic and Related Air Pollutants, Durham, NC, May 1992.

M.D. Bouley and K.A. Baugues, "PC-BEIS: A Tool for Estimating Biogenic Emissions", presented at the Emission Inventory Issues in the 1990's, Durham, NC, September 1991.

K.A. Baugues, "Mobile Source Emission Factors: Hourly Versus Daily", presented at the Emission Inventory Issues in the 1990's, Durham, NC, September 1991.

T. Pierce and K. Baugues, User's Guide to the Personal Computer Version of the Biogenic Emissions Inventory System (PC-BEIS), EPA-450/4-91-017, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 1991.

K.A. Baugues, "Reconciling Differences Between Ambient and Emission Inventory Derived NMOC/NO_x Ratios: Implications for Emission Inventories", presented at the 84th Annual Meeting of the Air & Waste Management Association, Vancouver, BC, June 1991.

E.L. Meyer, N.C. Possiel, D.C. Doll, K.A. Baugues and K.W. Baldridge, "A Summary of ROMNET Results and Outputs", presented at the Seventh Joint Conference on Applications of Air Pollution Meteorology with AWMA, New Orleans, LA, January 1991.

N. Possiel, D. Doll, K. Baugues, R. Wayiand and E. Baldridge, "Impacts of Regional Control Strategies on Ozone in the Northeast United States", presented at the 83rd Annual Meeting of the Air & Waste Management Association, Pittsburgh, PA, June 1990.

E. L. Meyer, Jr. and K. A. Baugues, Consideration of Transported Ozone and Precursors and Their Use in EKMA, EPA-450/4-89-010, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 1989.

K. Baugues, User's Manual for OZIPM4 (Ozone Isopleth Plotting with Optional Mechanisms - Volume 2: Computer Code, EPA-450/4-89-009b, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 1989.

K. Baugues, User's Manual for OZIPM4 (Ozone Isopleth Plotting with Optional Mechanisms) - Volume 1, EPA-450/4-89-009a, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 1989.

K. Baugues, Procedures for Applying City-specific EKMA, EPA-450/4-89-012, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 1989.

W. Battye, J. Langstaff, M. Smith, N. Possiel, E. Meyer, Jr. and K. Baugues, "Regional Ozone Modeling for Northeast Transport-Development of a Base Year Emissions Inventory", presented at the 82nd Annual Meeting of the Air & Waste Management Association, Anaheim, CA, June 1989.

K. Baugues, A PC Rased System for Generating EKMA Input Files, EPA-450/4-88-016, U.S. Environmental Protection Agency, Research Triangle Park, NC, November 1988.

K. A. Baugues, "Sensitivity of OZIPM4/CB4 to Variations in Carbon Monoxide Inputs", presented at the SIst Annual Meeting of the Air Pollution Control Association, Dallas, TX, June 1988.

K. A,, Baugues and E. L. Meyer, Jr., "A Procedure for Addressing Overwhelming Transport in Urbanscale Model Applications for Ozone", presented at the SIst Annual Meeting of the Air Pollution Control Ass ——, Dallas, TX, June 1988.

H. Hogo, M. W. Gery, K. A. Baugues and E. L. Meyer, Jr., "Sensitivity Analysis of the Effects of EKMA Input Parameters on VOC Control Requirements", presented at the APCA Specialty Conference, The Scientific and Technical Issues Facing Post-l987 Ozone Control Strategies, Hartford, CT, November 1987.

K. A. Baugues, A Review of NMOC, NO_x and NMOC/NO_x Ratios Measured in 1984 and 1985, EPA-450/4-86-015, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1986.

K. A. Baugues, "Results of Recent Non-methane Hydrocarbon Measurements", presented at the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, MN, June 1986.

Roy A. Paul, K. A. Baugues, G. L. Gipson and E. L. Meyer, Jr., "Estimation of Design Values in Overlapping Airsheds", presented at the 78th Annual Meeting of the Air Pollution Control Association, Detroit, MI, June 1985.

K. A. Baugues, "The Role of Calm Winds in Dispersion Estimates", included in the proceedings of the Third Joint Conference on Application of Air Pollution Meteorology, San Antonio, TX, January 1982.

K. Baugues, R. Raufer and J. Schramuk, Technical Support Document: Analysis of Ambient Air Quality Levels of Lead in East Helena, Montana, Contract No. 68-02-2550, Task Order 3, ETA Engineering Inc., Westmont, IL, November 1980.

K. Baugues, R. Raufer and J. Schramuk, Technical Support Document: Analysis of Ambient Air Quality Levels of Lead in Anaconda, Montana, Contract No. 68-02-2550, Task Order 3, ETA Engineering Inc., Westmont, IL, November 1980.

R. K. Raufer and K. A. Baugues, "The Development of State Implementation Plans for Lead", presented at the 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Canada, June 1980.

R. Raufer, D. Kuhanek, A. Jirik, K. Baugues, J. Schramuk and J. Burnham, National Commission of Air Quality Twin Cities/St. Cloud Regional Study: The State Implementation Plan Process, Contract No. 12-AQ-7705, ETA Engineering Inc., Westmont, IL, June 1980.

K. Baugues and R. Raufer, Technical Support Document: Attainment of the lead Standard in Denver, Colorado, Contract No. 69-02-2550, Task Order No. 2, ETA Engineering Inc., Westmont, IL, June 1980.

K. Baugues and R. Raufer, Technical Support Document: Attainment of the Lead Standard in Pueblo, Colorado, Contract No. 68-02-2888, Work Assignment No. 2, ETA Engineering Inc., Westmont, IL, May 1980.

K. Baugues and R. Raufer, Addendum to Lead Emission Inventory of Stationary Sources in Colorado, Contract No. 68-02-2888, Work Assignment No. 2, ETA Engineering Inc., Westmont, IL, May 1980.

K. Baugues and R. Raufer, Technical Support Document: Attainment of the Ambient Air Quality Standard of Lead in Grand Junction, Colorado, Contract No. 68-02-2888, Work Assignment No. 2, ETA Engineering Inc., Westmont, IL, May 1980.

K. Baugues and R. Raufer, Technical Support Document for the State of Minnesota (Minneapolis Area) - Site 360, Contract No. 68-02-2888, Work Assignment No. 2, ETA Engineering Inc., Westmont, IL, March 1980.

K. Baugues and R. Raufer, Technical Support Document for the State of Indiana (East Chicago Area), Contract No. 68-02-2888, Work Assignment No. 2, ETA Engineering Inc., Westmont, IL, March 1980.

K. Baugues and R. Raufer, Technical Support Document for the State of Minnesota (St. Louis Park Area), Contract No. 68-02-2888, Work Assignment No. 2, ETA Engineering Inc., Westmont, IL, March 1980.

K. Baugues and R. Raufer, Technical Support Document: Summary of Lead Air Quality Data for the State of Indiana, Contract No. 68-02-2888, Work Assignment No. 2, ETA Engineering Inc., Westmont, IL, March 1980.

R. Raufer and K. Baugues, Technical Support Document: Analysis of Vehicular Emissions in the Vicinity of Minneapolis Site 941, Contract No. 68-02-2888, Work Assignment No. 2, ETA Engineering Inc., Westmont, IL, December 1979.

R. Raufer and K. Baugues, Technical Support Document for the Vehicular Lead Analysis for the State on Indiana (Jeffersonville Area), Contract No. 68-02-2888, Work Assignment No. 2, ETA Engineering Inc., Westmont, IL, October 1979.

R. Raufer and K. Baugues, Technical Support Document or the Vehicular Lead Analysis for the State of Indiana (Hammond —, — Contract No. 68-02-2888, Work Assignment No. 2, ETA Engineering Inc., Westmont, IL, October 1979.

S. K. Mukherji and K. A. Baugues, "Air Impact Review for New Sources", presented at the 17th Annual Purdue Air Quality Conference, W. Lafayette, IN, May 1979.

S. K. Mukherji, L. Shumway, K. A. Baugues and H. D. Williams, "Rural Fugitive Dust Impacton an Urban Area", presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, TX, June 1978.

K. A. Baugues, EIS/P&R - The Indiana System, Indiana Air Pollution Control Division, April 1978.

S. K. Mukherji, K. A. Baugues, G. W. Enderson and H. D. Williams, "Assessment of Ambient SO_2 Loading by a Power Plant Complex", presented at the 69th Annual Meeting of the Air Pollution Control Association, Portland, OR, June 1976.

J. Eid, M. Bobb, G. W. Enderson and K. A. Baugues, Impact of the Clifty Creek Generating Station on Ambient Air Quality, Indiana Air Pollution Control Division, January 1975.