## 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

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

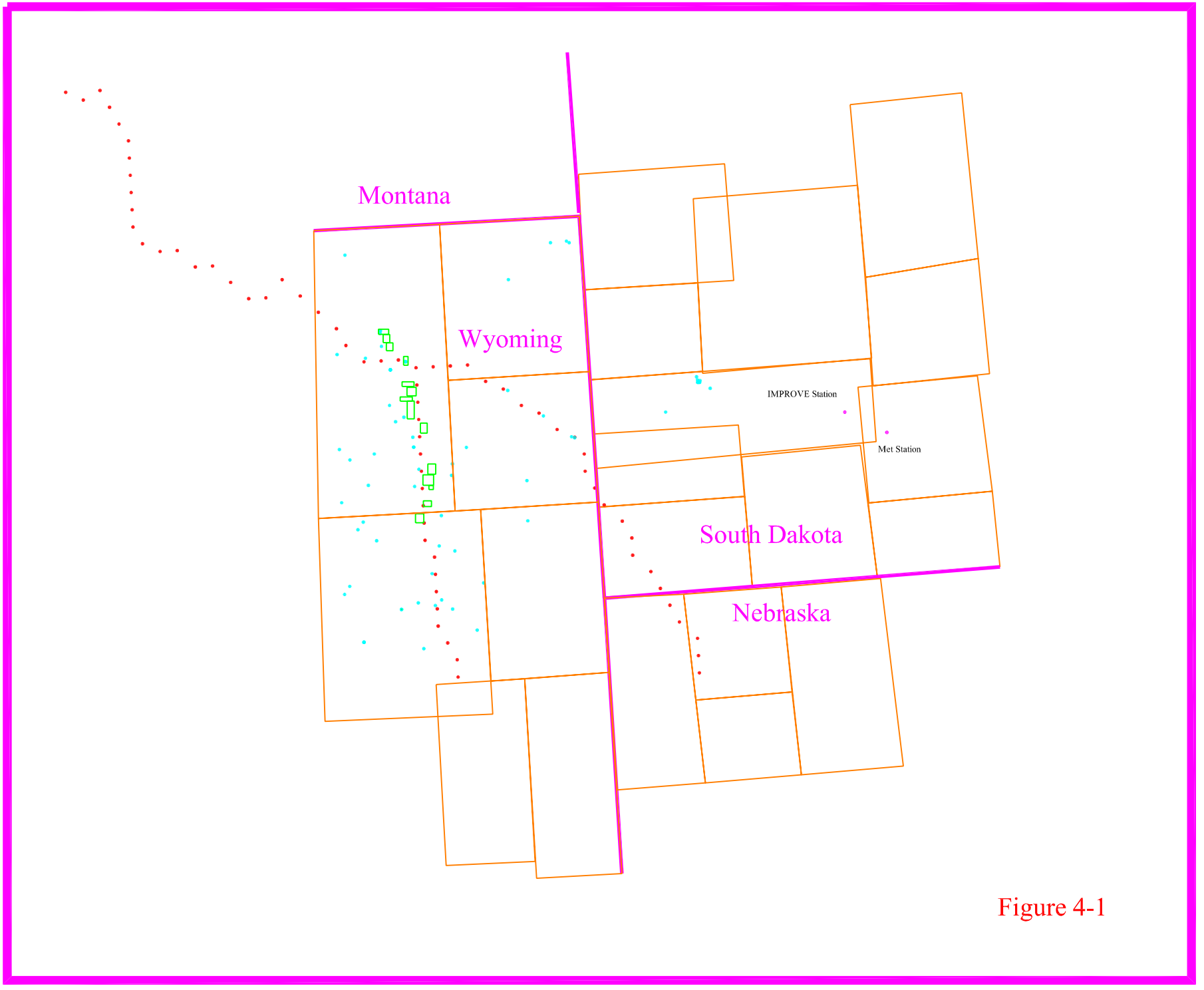
Montana
Wyoming
IMPROVE Station
Met Station
South Dakota
Nebraska

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.

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

$SO_4$ 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;

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

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

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

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

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

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

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

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 90$^{th}$ 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 90$^{th}$ 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)**

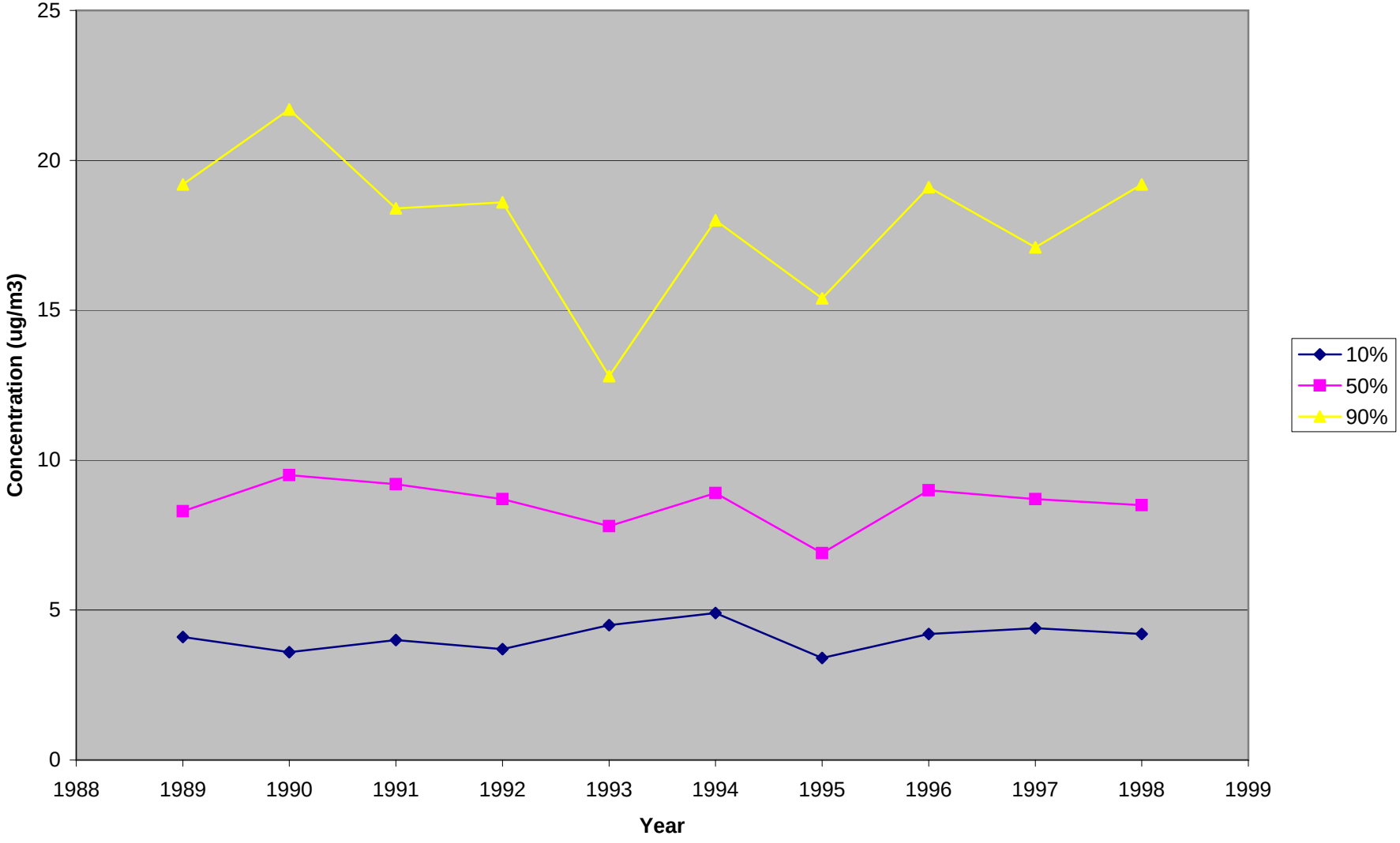

**Figure 4-3: BNP OC Trends (1989-1998)**

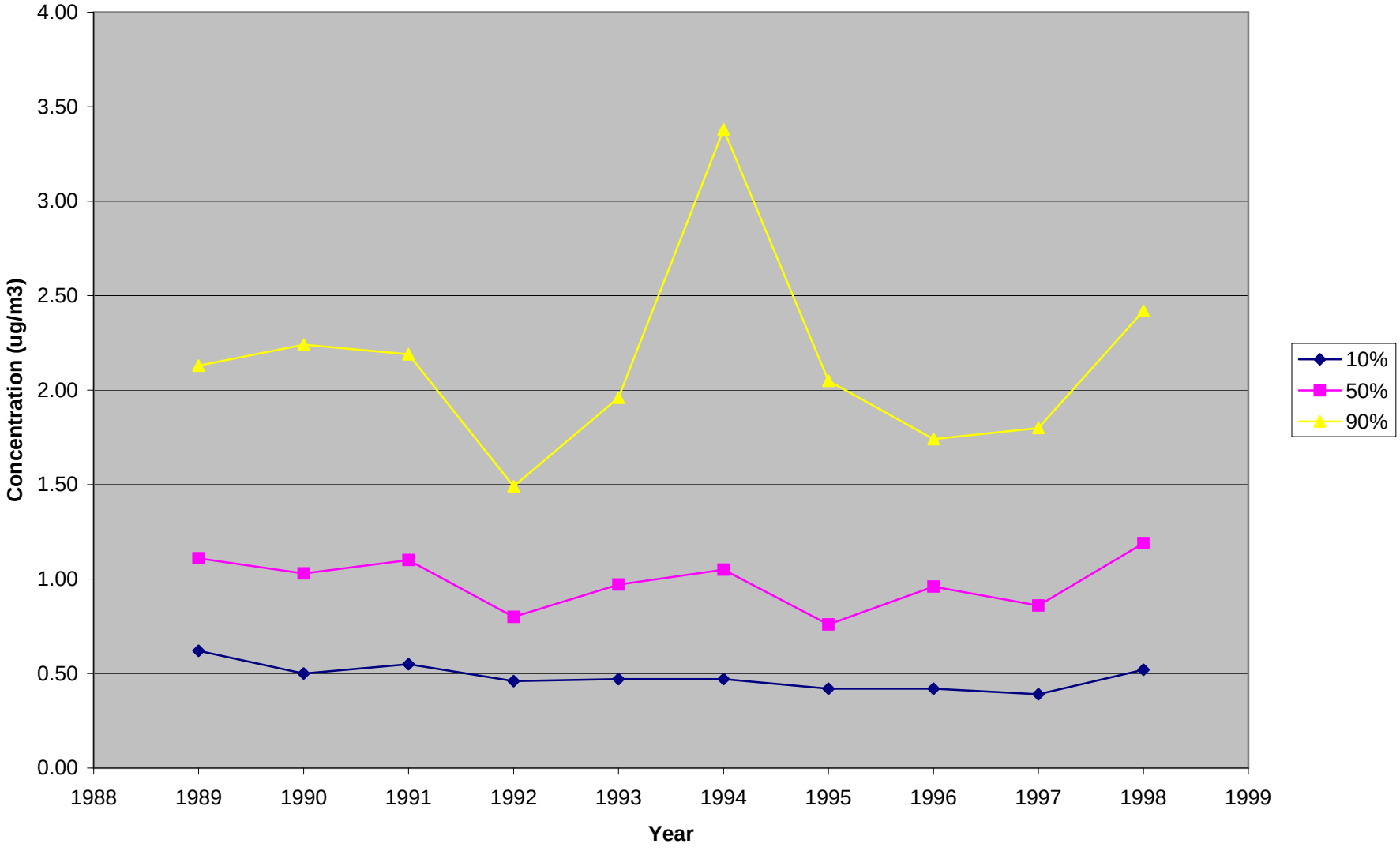

**Figure 4-4: BNP EC Trends (1989-1998)**

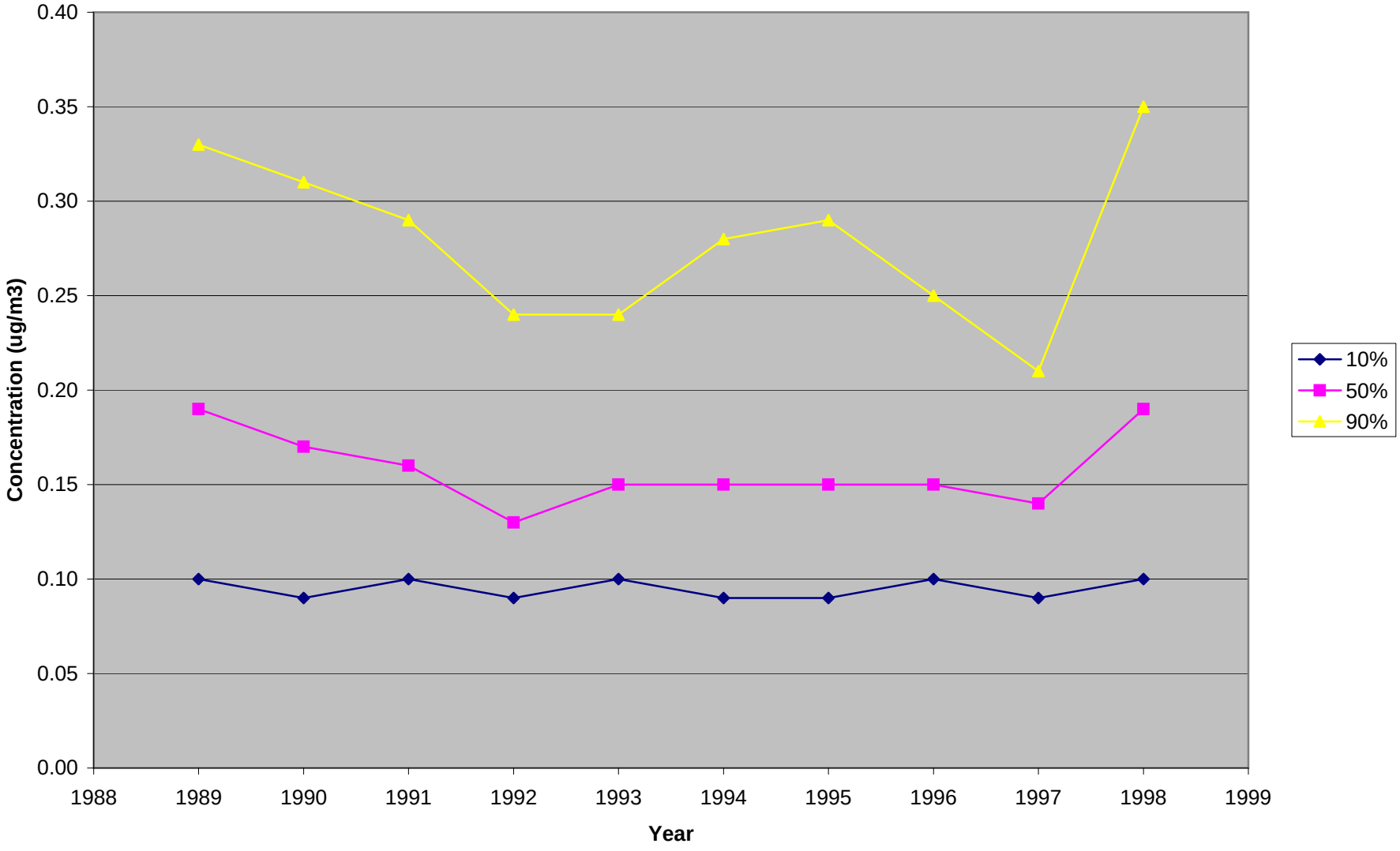

**Figure 4-5: BNP Ammonium Sulfate Trends (1989-1998)**

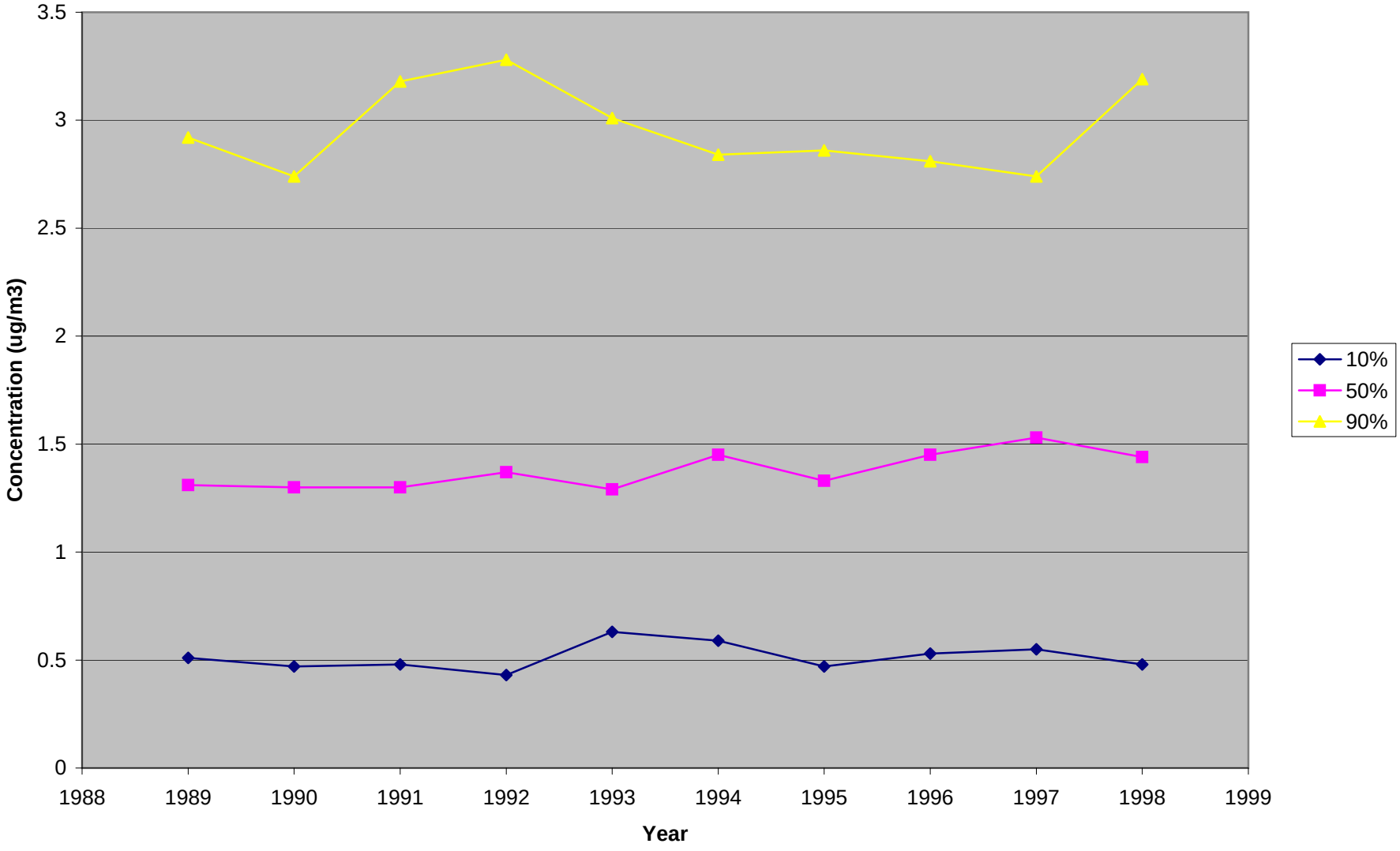

**Figure 4-6: BNP Ammonium Nitrate Trends (1989-1998)**

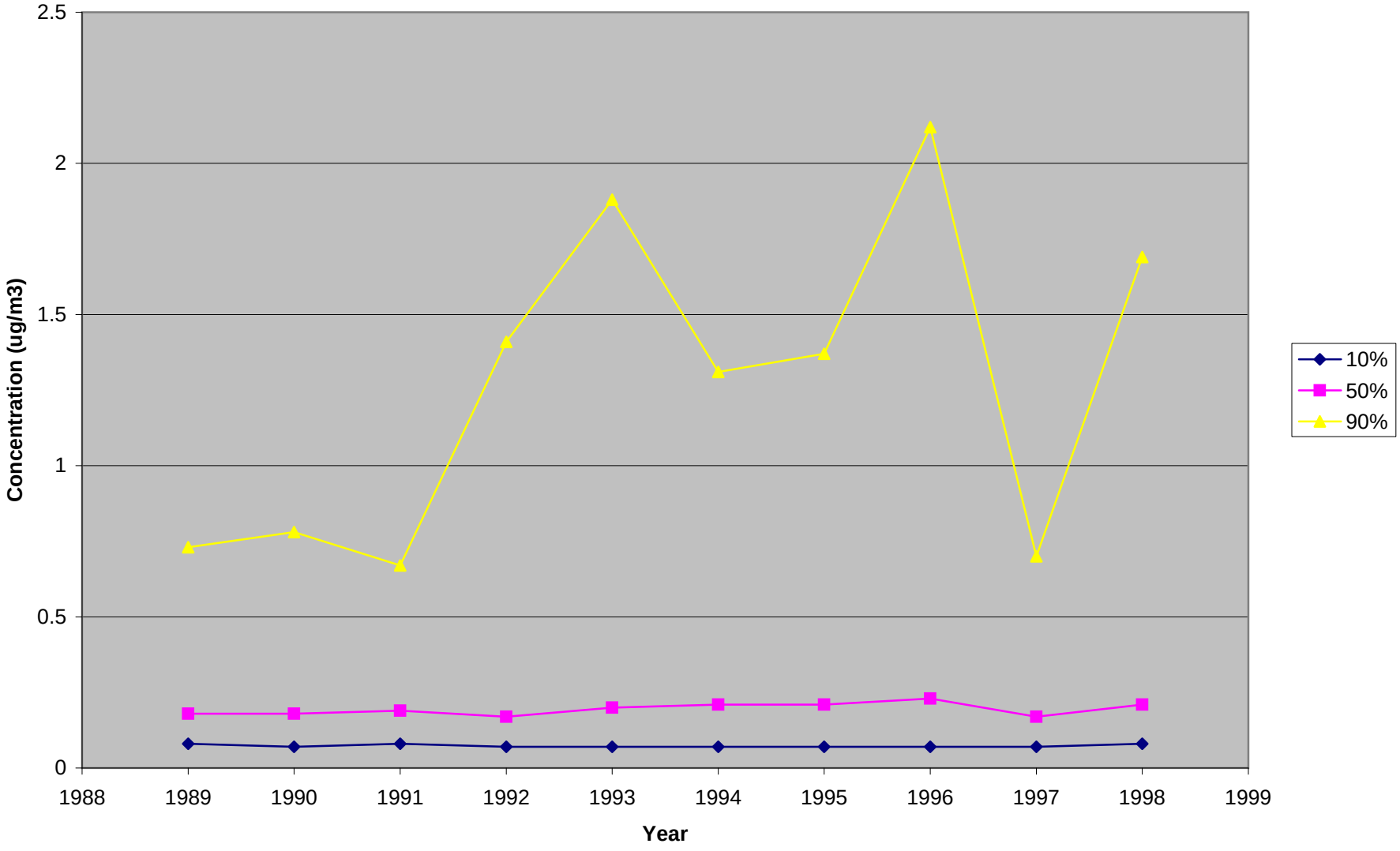
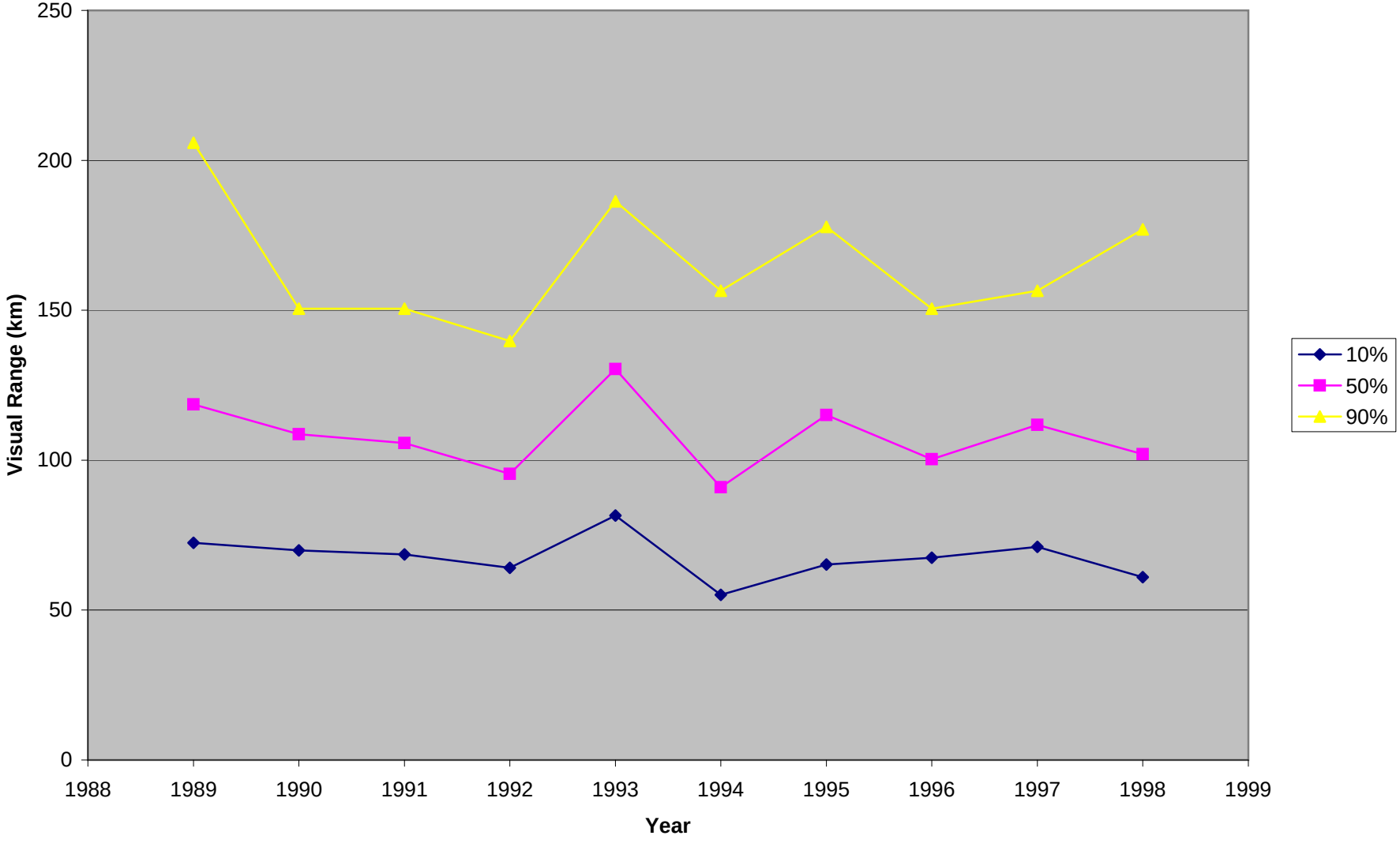
**Figure 4-7: BNP NP Visual Range (1989-1998) - Validity Codes 0 Only**