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# Mid-Course Review Report for the Washington, DC-MD-VA 1-Hour Ozone Nonattainment Area

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## 1.0 Introduction

This document is the Mid-Course Review (MCR) for the Washington, DC-MD-VA nonattainment area. The states in the Washington, DC-MD-VA nonattainment area made a commitment in the State Implementation Plan ("Severe Area SIP") submitted in February 2004 to conduct a Mid-Course Review by the end of 2004. The MCR is intended to show the progress being made to improve air quality in the nonattainment area and the efforts underway to assure that all necessary steps are taken to reach the federal health standard for the one-hour ozone standard by 2005. This MCR is being prepared after completion of the 2004 ozone season. The administrative review considers all of the local, regional, and national controls implemented by 2004.

## 1.1 Background

EPA designated the Washington, DC-MD-VA nonattainment area shortly after adoption of the 1990 Clean Air Act Amendments (CAAA). EPA defined the Washington, DC region's nonattainment area as the metropolitan Washington Metropolitan Statistical Area (MSA). The nonattainment area is comprised of 10 counties; 5 from Maryland, 5 from Virginia (including 5 cities), and the District of Columbia. Table 1 lists all the counties and cities that are included in the Washington, DC-MD-VA nonattainment area.

**Table 1. Washington, DC-MD-VA 1-Hour Nonattainment Area**

| STATE | COUNTY/CITIES |
|---|---|
| District of Columbia | Washington |
| Maryland | Charles |
| | Calvert |
| | Frederick |
| | Prince George's |
| | Montgomery |
| Virginia | Arlington |
| | Alexandria (City) |
| | Fairfax |
| | Fairfax (City) |
| | Falls Church (City) |
| | Loudoun |
| | Manassas (City) |
| | Manassas Park (City) |
| | Prince William |
| | Stafford |

The plan to improve air quality in the Washington, DC region to meet the national air quality standard for ozone (one-hour ozone standard) is provided in "The Severe Area

Attainment Plan" for the nonattainment area.[1] The Plan consists of two Rate of Progress demonstrations, for the period 1999-2002 and for the 2002-2005; and an attainment demonstration for 2005. Additionally, the plan includes commitments by the states to meet requirements for severe nonattainment areas, commitments by the states to meet additional EPA requirements for the Washington, DC region including a contingency plan for 1999 rate of progress, contingency plans for the 2002 and 2005 rates of progress, and an analysis of Reasonably Available Control Measures. The plan also provides emissions inventories for 1990, 2002 and 2005.

Since designated as nonattainment, governments in the region have taken steps to reduce emissions of ozone precursors. Based on the 2002 Rate-of-Progress demonstration, occurring between 1990 and 2002, emissions were reduced by approximately 608 tons per day VOC and 258 tons per day NOx. This has caused a decline in measured ozone concentrations during episodes and a 17 percent reduction in the region's design value.

The metropolitan Washington, DC region's air quality is significantly affected by ozone and its precursors from other regions outside the Washington, DC area. Individual states and regional organizations such as the Ozone Transport Commission and Ozone Transport Assessment Group, pursued control of nitrogen oxide emissions. These efforts led to EPA's NOx SIP call which requires 21 states and the District of Columbia, including states in the Midwest upwind from the Washington, DC region, to control NOx emissions from stationary sources beginning in 2003. As a result of litigation, the implementation date was postponed to 2004 for states outside the nonattainment area. The states in the Washington metropolitan region are regulating NOx emissions from stationary sources of nitrogen oxides. EPA's analysis predicts that the reductions in regional NOx emissions will contribute to attainment of the 1-hour ozone standard in 2005.

## 1.2 Methodology for Conducting the Mid-Course Review

The MCR analysis follows the procedures outlined in EPA's March 28, 2002 memo "Mid-Course Review Guidance for the 1-Hour Ozone Nonattainment Areas that Rely on Weight-of-Evidence for Attainment Demonstration". The administrative review focuses on determining whether the area has met its obligation to reduce emissions by implementing control measures. Data required to complete the review are from the Severe Area SIP and the 2002 Periodic Emissions Inventory. Trends in air quality are determined through review of several key indicators. Data on measured ozone concentrations are available from monitors located within the nonattainment area. Statistical analyses are conducted to ascertain trends. Normalized design values, unit sensitivities, and predicted emission reductions are used to predict the attainment year design value. The statistical analyses chosen to determine air quality trends were based on EPA guidance. Transport of ozone is analyzed by evaluating measured concentrations at elevated sites upwind of the region, aircraft measurements, and through consideration of scientific studies documenting ozone transport in the eastern United States.

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[1] *State Implementation Plan ("Severe Area SIP") Demonstrating Rate of Progress for 2002 and 2005; Revision to 1990 Base Year Emissions; and Severe Area Attainment Demonstration for the Washington, DC-MD-VA Nonattainment Area,* February 19, 2004.

## 1.3 Structure of Report

The remainder of this report is organized as follows:

- Emission and Control Measures. This section presents an analysis of emissions and controls in the Washington, DC-MD-VA nonattainment area. Also provided is an evaluation of the impact of emission reduction on design values.

- Air Quality Indicator Trends Analysis. This section presents trends analyses focused on design values, monitor exceedances, maximum concentrations, effect of meteorology on ozone trends, and spatial extent of exceedances.

- Ozone Transport Analysis. This section presents information on regional transport, local transport, and transport via low-level jets.

- Summary/Conclusions. This section provides a summary of the emission/control and trends analysis. Conclusions are based on weight of evidence.

## 2.0 Emissions and Control Measures

This section presents historical and current emissions estimates for ozone precursors (VOCs and NOx) affecting air quality in the Washington, DC-MD-VA nonattainment area. An emission control analysis is presented to satisfy the Administrative Review requirements of the MCR. The analysis considers the impact of emission reduction on the region's design value.

### 2.1 Emissions

This section presents emissions data for the Washington, DC-MD-VA nonattainment area. The base year emissions inventory for the region is 1990. The most recent emissions inventory was prepared in 2002. Emissions projections for 2005 are provided in the most recent ROP, submitted to EPA in 2004.

Emissions from sources in the Washington, DC-MD-VA nonattainment area are summarized in Table 2. Nitrogen oxide (NOx) emissions from the Washington, DC region are expected to decrease by approximately 44 percent between 1990 and 2005. During this time, Volatile Organic Compound (VOC) emissions in the Washington, DC region will be reduced by more than 65 percent.

**Table 2. Emissions of Ozone Precursors in the Nonattainment Area**

| **VOC (tpd)** | | | **NOx (tpd)** | | |
|---|---|---|---|---|---|
| 1990 | 2002 | 2005 | 1990 | 2002 | 2005 |
| 955.2 | 346.9 | 325.8 | 869.3 | 611.4 | 487.5 |
| Reduction (1990-2002) - 64%<br>Reduction (1990-2005) - 66% | | | Reduction (1990-2002) - 30%<br>Reduction (1990-2005) - 44% | | |

Sources: *2002 Periodic Emissions Inventory of Ozone Precursor Emissions for the Washington, DC-MD-VA Ozone Nonattainment Area,* May 2004; and *State Implementation Plan ("Severe Area SIP") for the Washington, DC-MD-VA Ozone Nonattainment Area*, February 19, 2004.

### 2.2 Controls

The state and local governments in the nonattainment area have adopted polices and implemented programs to fulfill the requirements of the "The Severe Area SIP". The region has implemented all of the mandated Federal Programs, including regulations on NOx emissions from stationary sources of nitrogen oxides. In addition, the region has gone beyond the Clean Air Act control measures requirements for areas in severe nonattainment of the 1-hour ozone standard by implementing additional regulations and voluntary programs. These measures involved implementing the Ozone Transport Commission (OTC) model rules (AIMs, Solvent Cleaning Operations, and Portable Fuel Container Rules), and a bundle of voluntary programs including investment in renewable energy technology.[2] The region has also committed to implement more than 200 transportation emission reduction measures (TERMs).

The region has also worked to encourage control of sources of ozone outside the nonattainment area. Transport of ozone increases the challenge of meeting air quality requirements in the region. According to studies by the University of Maryland, as much as seventy percent of the ozone levels during an exceedance originate from upwind sources outside of the region.[3] Emissions from stationary sources that contribute to regional ozone transport can be mitigated through combustion and post-combustion controls. Stationary sources in areas upwind of the region are being controlled through Federal mandates -- the Acid Rain Program and NOx SIP Call. Under the Acid Rain Program, stationary sources must meet emission limits for generating units. EPA's NOx SIP call requires 21 states plus the District of Columbia, including states in the Midwest upwind from the Washington, DC region, to control NOx emissions from stationary sources beginning in 2003. The original implementation date of the NOx SIP Call was 2003, but the date was postponed to 2004 in areas outside the nonattainment area due to litigation.

EPA's analysis predicts that the reductions in NOx emissions from this regulation will contribute to attainment of the 1-hour ozone standard in 2005.[4] Based on EPA estimates, there are nearly 2,600 units in the NOx SIP call region. Of these, more than 75 coal-fired units have installed selective catalytic reduction (SCR) controls and approximately 20 have installed selective non-catalytic reduction (SNCR) controls.[5] Exhibits 1 and 2 provide an overview of SCR installation in the eastern United States. By 2005, more than 50 percent of the coal-fired capacity in Indiana, Kentucky, Ohio, Tennessee, and West Virginia will be controlled with SCR.[6] Power plants in regions upwind of the Washington, DC region will continue to install controls in 2005, leading to further reductions in emissions of nitrogen oxides and reduced ozone transport.

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[2] The Voluntary Bundle refers to nine voluntary emission reduction programs committed to in the SIP and adopted by local governments and State agencies following the EPA Voluntary Measures Guidance. These include the gasoline container replacement program; sale of reformulated consumer products in Virginia; low-VOC paints program; remote sensing device program; regional wind power purchase; diesel retrofit program; alternative fueled vehicle (AFV) purchase program; and auxiliary power units on locomotives.

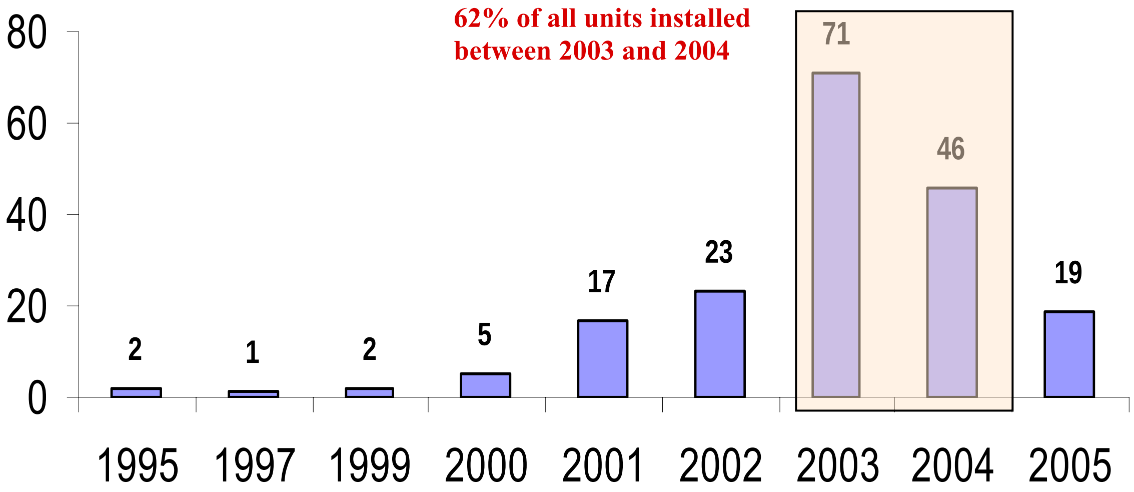
[3] *The 2003 North American electrical blackout: An accidental experiment in atmospheric chemistry*; Marufu, et. al.; Geophysical Research Letters, Vol. 31, 2004.

[4] *Ozone Transport Assessment Group Executive Report 1997*, Environmental Council of the States (ECOS) pp. 53-55.

[5] *NOx Budget Trading Program: 2003 Progress and Compliance Report.* United States Environmental Protection Agency, Clean Air Markets Program, Washington, D.C. August 2004.

[6] *The Role of Ozone Transport in the Washington, DC Area*. Presentation by Tad Aburn (Maryland Department of the Environment) and Jeff Stehr (University of Maryland), to the Metropolitan Washington Air Quality Committee. February 19, 2004.

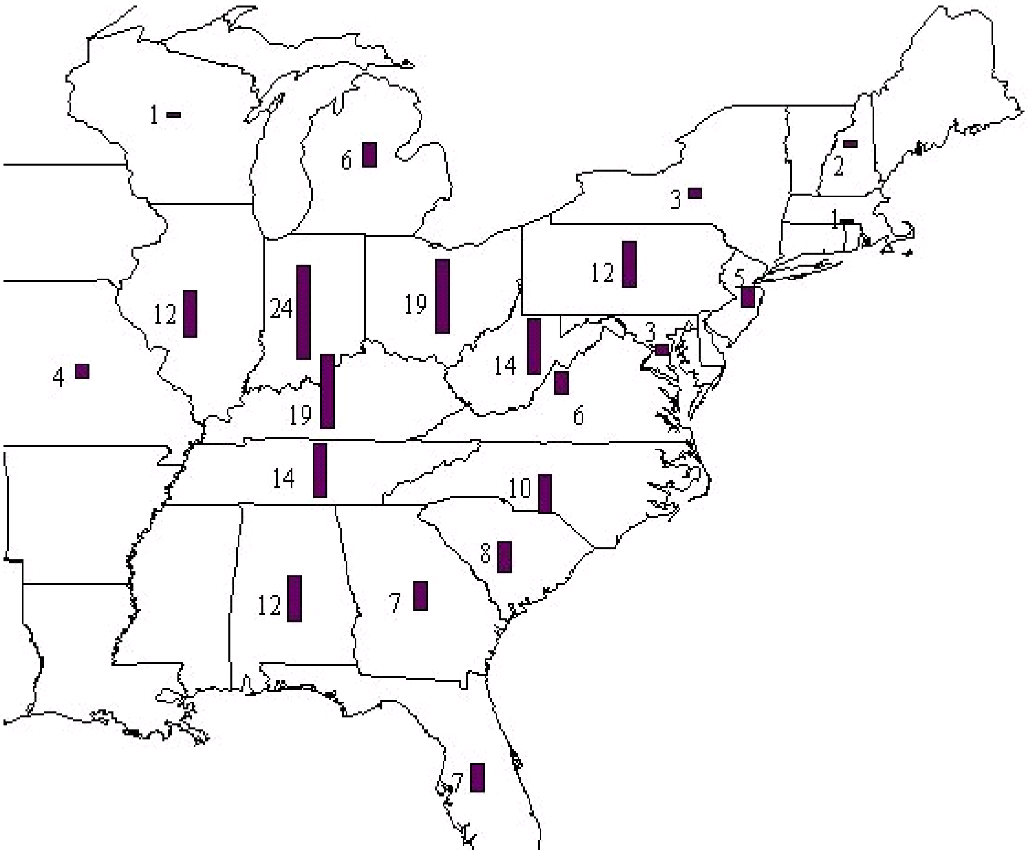
**Exhibit 1. SCR Units Installed by Year**



62% of all units installed between 2003 and 2004

Source: *The Role of Ozone Transport in the Washington, DC Area*. Presentation by Tad Aburn (Maryland Department of the Environment) and Jeff Stehr (University of Maryland), to the Metropolitan Washington Air Quality Committee. February 19, 2004.

## Exhibit 2. SCR Units by State



Source: *The Role of Ozone Transport in the Washington, DC Area*. Presentation by Tad Aburn (Maryland Department of the Environment) and Jeff Stehr (University of Maryland), to the Metropolitan Washington Air Quality Committee. February 19, 2004. Data provided by Institute for Clean Air Companies and EPA's Clean Air Markets Division.

### 2.3 Impact of Emission Reduction on the Design Value

Following the EPA guidance on using proportional extrapolations, this section presents an analysis of the predicted design value for 2005 using estimates of unit sensitivity and anticipated emission reduction.

The unit sensitivities used for the analysis are:[7]

- 0.1141 ppbv reduction in design value per ton of low-level NOx
- 0.0294 ppbv reduction in design value per ton of low-level VOC

The design value and normalized design value for 2004 is 137 and 127 ppbv, respectively. The normalized design value for 2004 was obtained by a linear regression performed on design value data for the period 1986-1988 through 2002-2004 (see Figure 1). Linear regression is one of the statistical methods used frequently for adjusting air quality data for meteorology.

Emissions for 2004 were interpolated using emissions estimates for 2002 and projections for 2005. Total emission reduction occurring between 2004 and 2005 is estimated and shown in Table 3.

**Table 3. Estimated Emission Reduction**
**(MCR Year - Attainment Year) (tpd)**

| | 1990 | 2002 | 2005 | 2004 (interpolated) | Emission Reduction (2004-2005) |
|---|---|---|---|---|---|
| VOC | 955.2 | 346.9 | 325.8 | 332.8 | 7.0 |
| NOx | 869.3 | 611.4 | 487.5 | 528.8 | 41.3 |

Sources: *2002 Periodic Emissions Inventory of Ozone Precursor Emissions for the Washington, DC-MD-VA Ozone Nonattainment Area,* May 2004; and *State Implementation Plan ("Severe Area SIP") for the Washington, DC-MD-VA Ozone Nonattainment Area*, February 19, 2004.

Ozone response is determined by multiplying the total emission reduction by the unit sensitivities. The result is 4.9 ppbv.

Predicted attainment year ozone concentration is determined by subtracting the ozone response from the 2004 normalized design value.

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[7] *State Implementation Plan ("Severe Area SIP") Demonstrating Rate of Progress for 2002 and 2005; Revision to 1990 Base Year Emissions; and Severe Area Attainment Demonstration for the Washington, DC-MD-VA Nonattainment Area,* February 19, 2004.

**Table 4. Predicted 2005 Design Value**
**(all in ppbv)**

| 2004 Normalized Design Value | Ozone Response | 2005 Design Value |
|---|---|---|
| 127 | 4.9 | 122 |

Based on the results presented in Table 4, the design value in 2005 will be below 125 ppbv. This conclusion is further supported by photochemical modeling results presented in the "Severe Area SIP". Based on the controlled emissions inventory for 2005, the 2005 design value was found to be 115 ppbv, which is below the 1-hour standard of 124 ppbv. The methodology for this calculation has been described in detail in Section 11.13.1 in pages 11-43 through 11-47 in the “Severe Area SIP, February 19, 2004” submitted to EPA.

## 3.0 Air Quality Indicator Trend Analyses

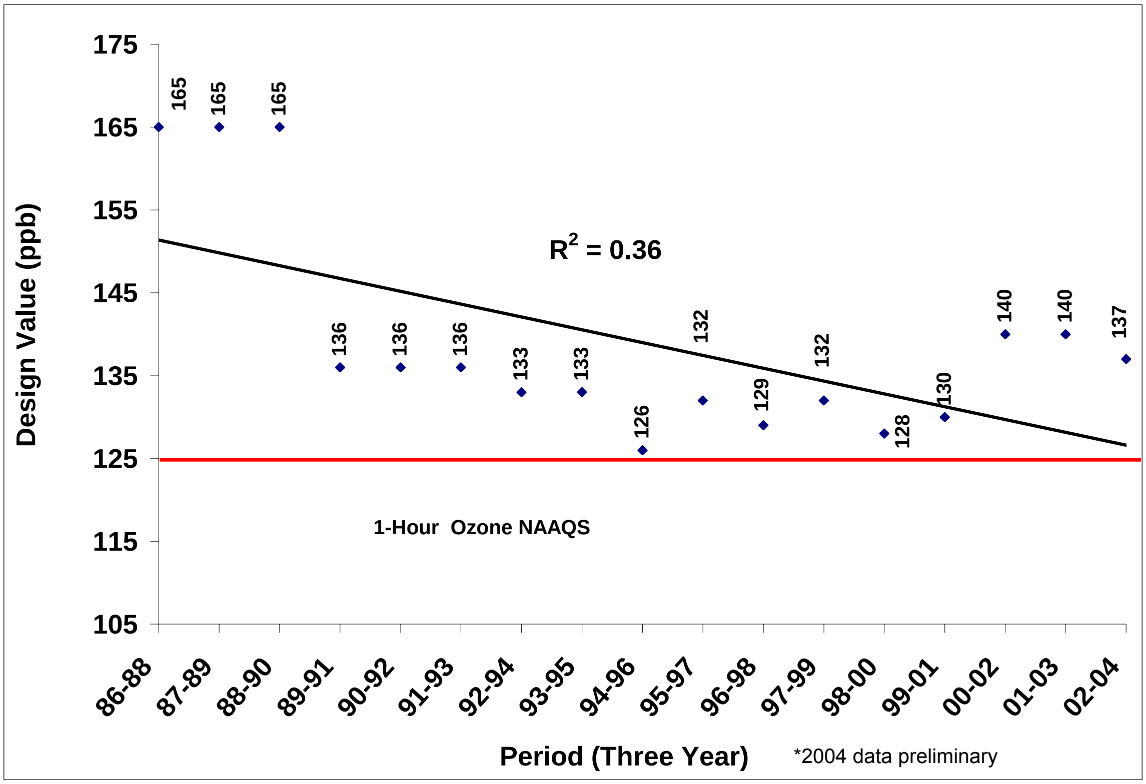
Various trends are analyzed to determine if the Washington, DC-MD-VA nonattainment area is likely to reach attainment by 2005. A number of analyses are conducted including trends in the region's 1-hour ozone design values, high running average ozone concentrations, numbers of exceedances, and meteorology-adjusted 1-hour maximum ozone levels. Trends are analyzed from 1988 through 2004 using the Linear Regression method, allowing for a comparison of pre-1990 Clean Air Act conditions to post-1990 Clean Air Act conditions.

### 3.1 Trend in One-Hour Design Value

Figure 1 displays the 1-hour ozone design value trend for the Washington nonattainment area. This is the maximum monitor design value for all monitors within the Washington, DC-MD-VA 1-hour ozone nonattainment area.

1-hour ozone design values in the Washington nonattainment area have declined since 1986-1988 from 165 ppbv to 137 ppbv in 2002-2004. Average design values from 1991-2004 have declined 19 percent from average design values from 1986-1990 (pre-1990 Clean Air Act). The trend line in Figure 1 also shows a downward trend.

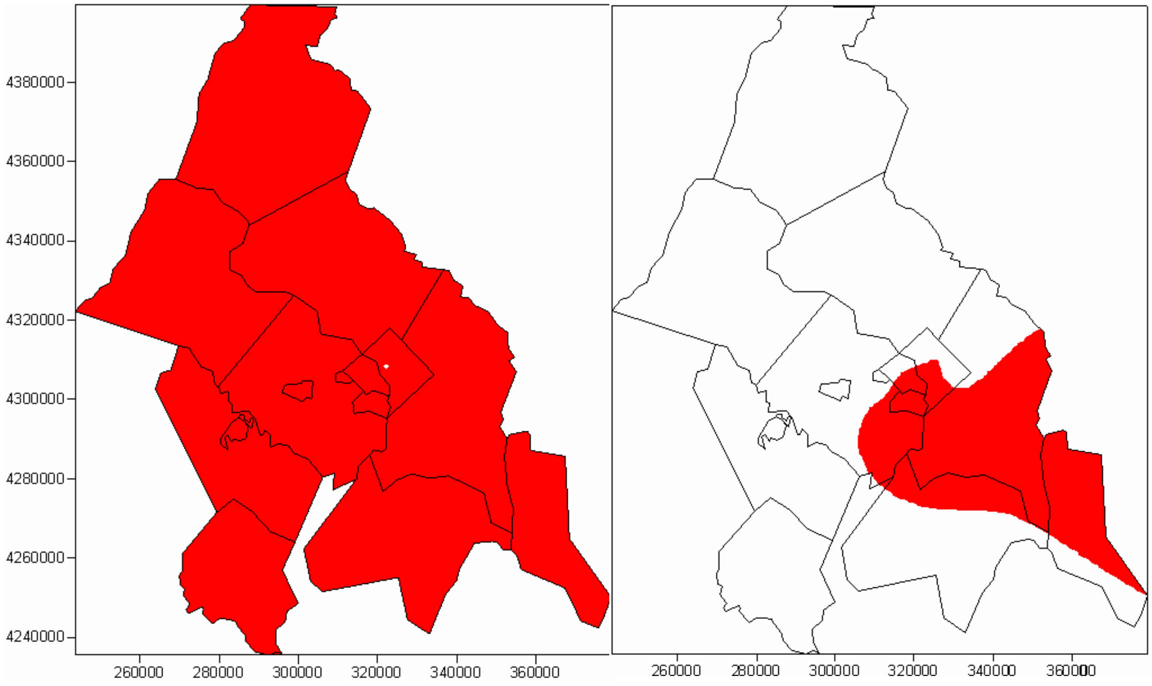
**Figure 1. Trend in Washington Nonattainment Area 1-Hour Design Value**



### 3.2 Spatial Extent of NAAQS Violations

The Washington, DC-MD-VA nonattainment area's geographical extent of violation has been decreasing in size since 1990. Figure 7 shows a decrease in the spatial extent of the nonattainment zone within the Washington, DC-MD-VA nonattainment region between 1990 and 2004. The actual nonattainment geographical area exceeding 1-hour ozone design value of 124 ppbv has been shown in red color in the figure. It is clear that almost the entire Washington, DC metropolitan region was in nonattainment during 1988-1990. The 2002-2004 data show that the geographical extent of this area has reduced in size to portions of the District of Columbia, the city of Alexandria, and Arlington, Fairfax, Charles, and Prince George's counties.

**Figure 2. Washington 1-Hour Ozone Nonattainment Zone Comparison of 1-Hour Design Values Exceeding 124 ppbv**

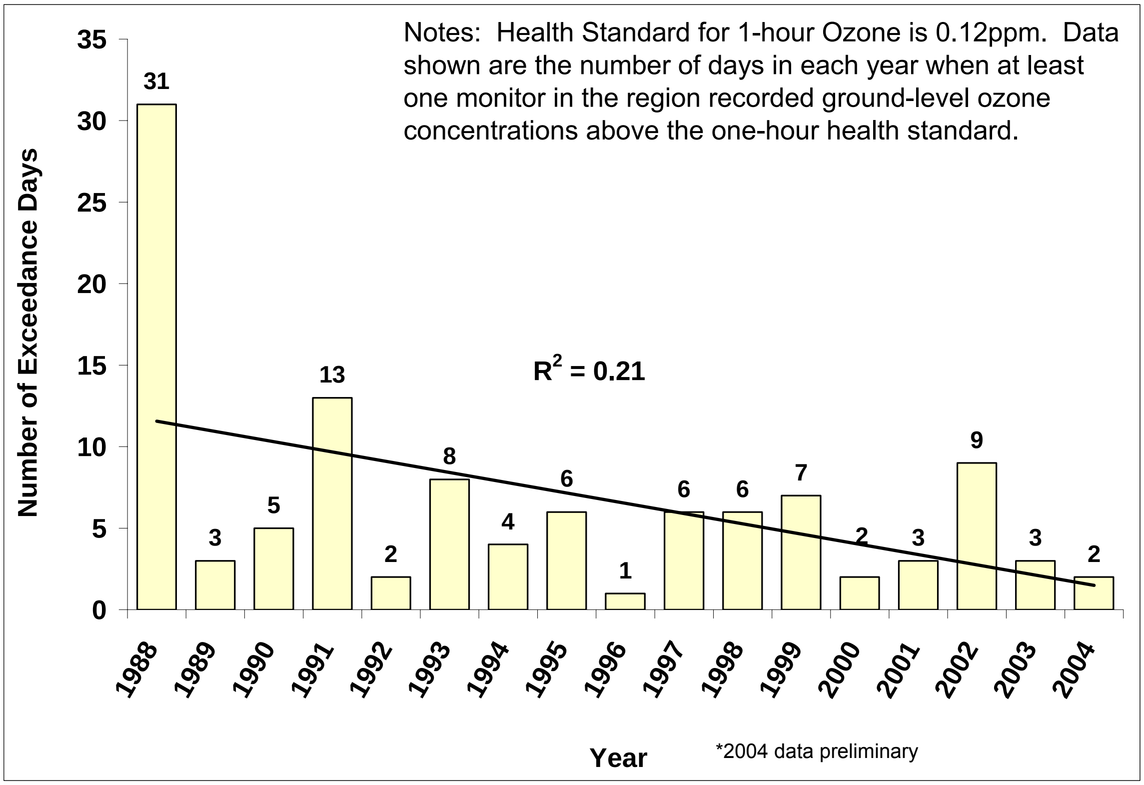


**1988-1990** **2002-2004**

### 3.3 Trend in Exceedance Count across All Monitors

The trend in total number of monitor exceedances between 1988 and 2004 is shown in Figure 2. Monitor exceedances occur whenever a monitor's 1-hour ozone concentration is greater than or equal to 0.12 ppm. The number of monitors in the Washington, DC-MD-VA 1-hour nonattainment area has actually increased by approximately one-third, from 12 monitors in 1988 to 17 monitors in 2004. However, there has been a significant decrease in the number of monitored exceedances since 1988 from 31 to just 2 in 2004.

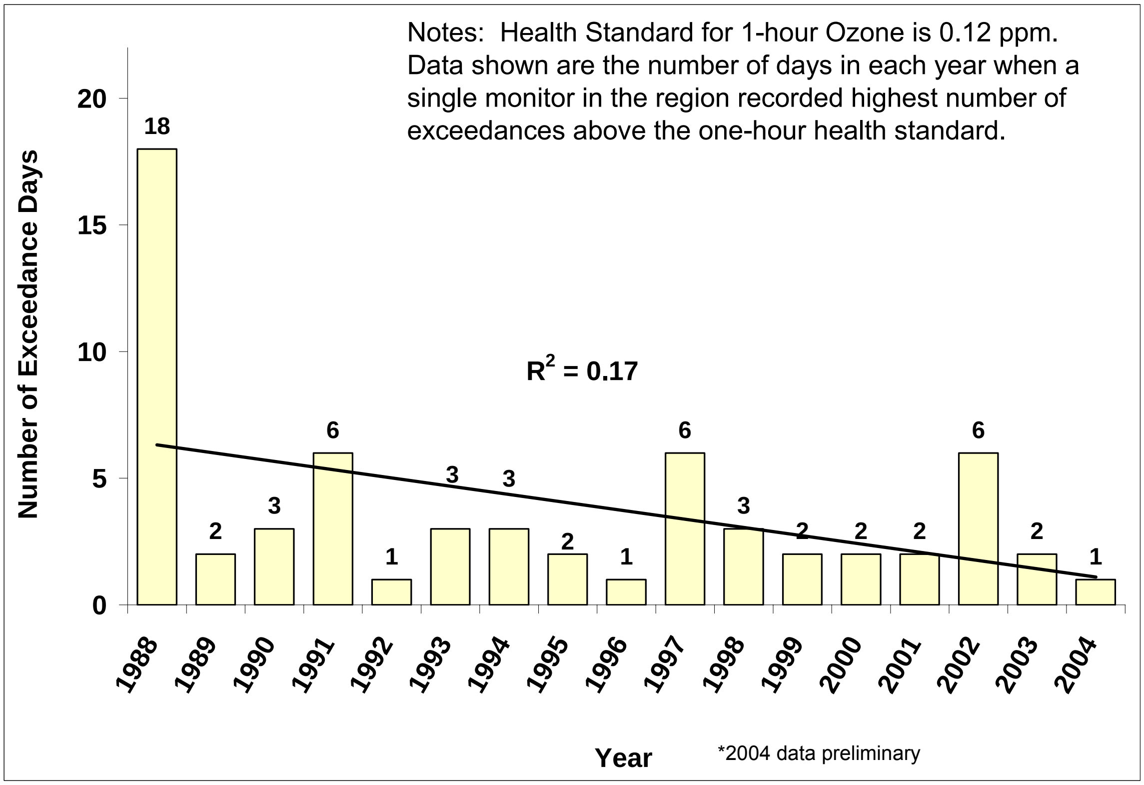
**Figure 3. Trend in Monitored Exceedances across All Monitors in the Washington Nonattainment Area**



### 3.4 Trend in Exceedance at the Monitor with Most Exceedances

The trend in the total number of exceedances at the monitor recording the highest number of exceedances between 1988 and 2004 is shown in Figure 3. There has been a significant decrease in the number of monitored exceedances since 1988 from 18 to just 1 in 2004. Focusing at the most recent three years, the number of exceedances has declined from 6 to only 1 in 2004.

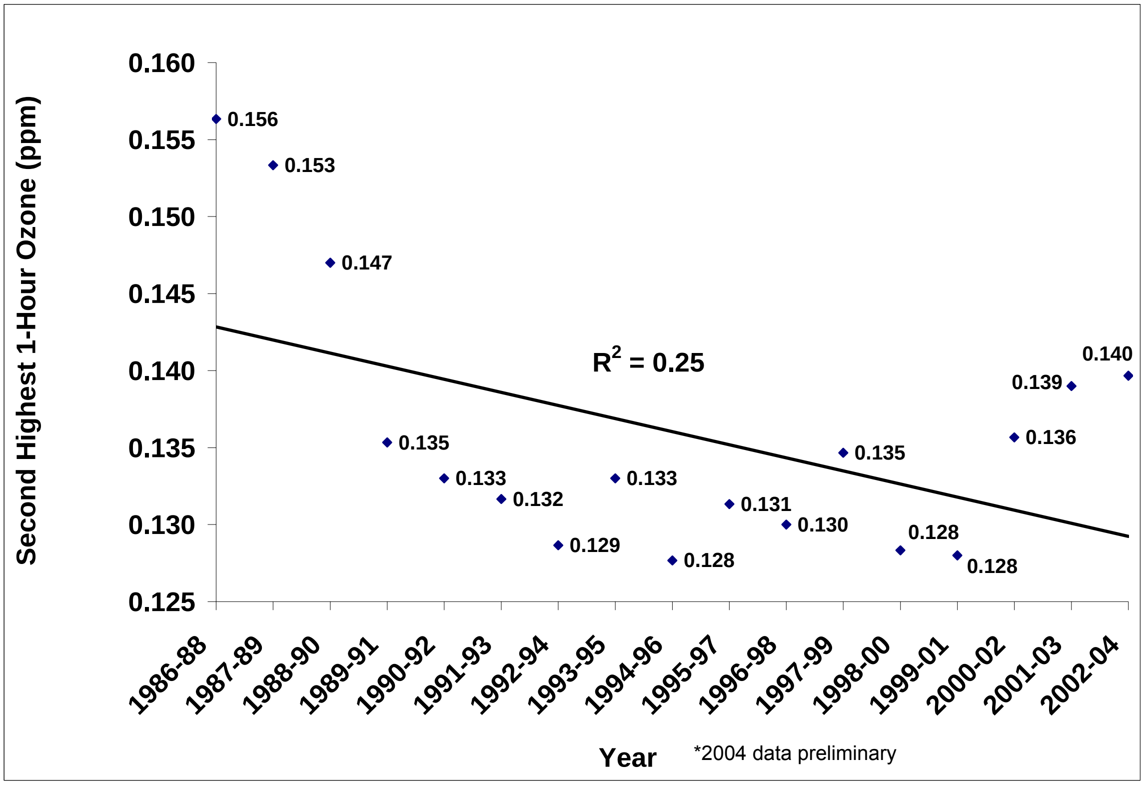
**Figure 4. Trend in Monitored Exceedances at the Monitor with Most Exceedances in the Washington Nonattainment Area**



### 3.5 Trend in Highest Running Average $2^{nd}$ High Daily Maximum Ozone Concentration

The trend in the highest running average $2^{nd}$ high daily maximum ozone concentration between 1988 and 2004 is shown in Figure 6. There has been a significant decrease in the highest running average $2^{nd}$ high daily maximum ozone concentration since 1988. Between 1998-2000 and 2002-2004, the highest $2^{nd}$ high daily maximum ozone concentration has ranged from 0.128 to 0.140 ppm.

Figure 5. Trend in Highest Running Average $2^{nd}$ High Daily Maximum Ozone Concentration in the Washington Nonattainment Area



*2004 data preliminary

### 3.6 Effect of Meteorology on Ozone Trend

Ozone concentrations are quite dependent on meteorological conditions. Ozone is formed by a chemical reaction between Volatile Organic Compounds (VOCs) and Oxides of Nitrogen (NOx). Sunlight and warm temperatures are generally needed to drive ozone production. Correlations can be made between ozone concentrations and meteorological variables such as the number of 85ºF days, average temperature, and average winds during crucial hours. Hot dry summers can produce long periods of elevated ozone concentrations while ozone production can be limited during cool and wet summers.

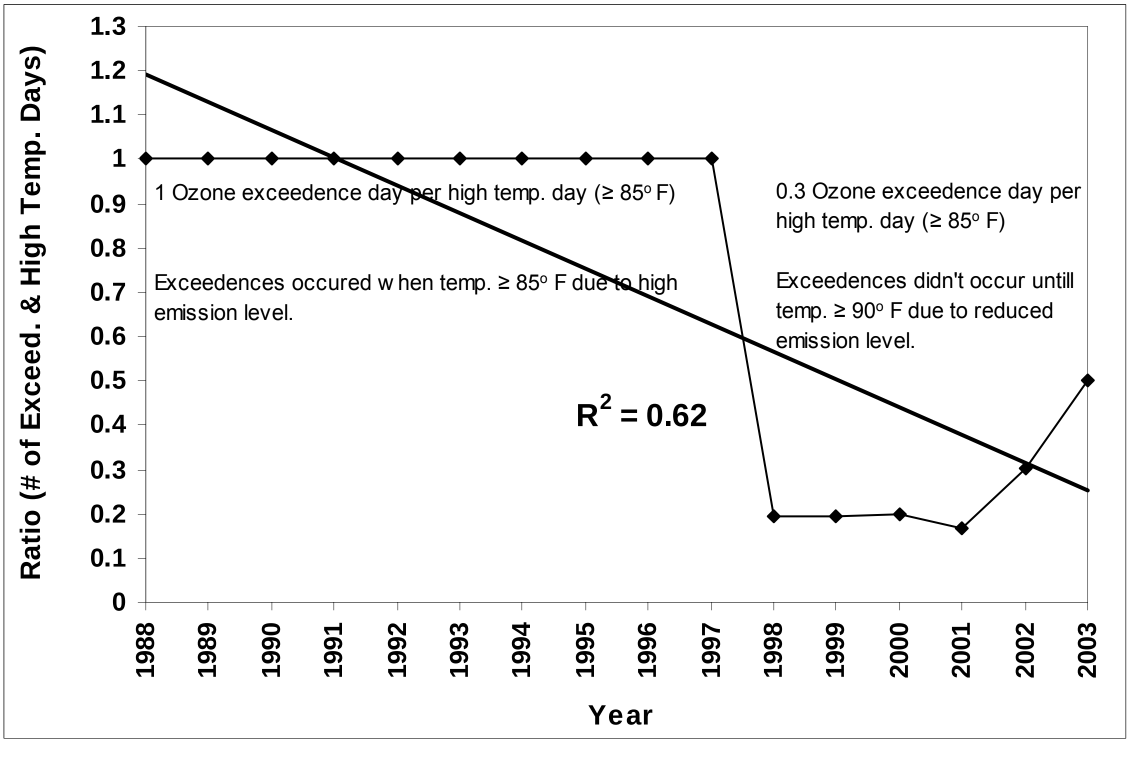
Meteorological data from the Reagan National Airport was reviewed to determine any trends between 1-hour ozone values and summertime weather conditions. Table 4 lists meteorological data for all years from 1988 through 2003 along with the average 1-hour maximum ozone concentration and the number of exceedance days within the Washington, DC-MD-VA nonattainment area on 1-hour exceedance days. There were strong correlations found between number of 1-hour exceedance days and warm days (≥ 85ºF) (R = 0.48), average maximum 1-hour ozone and average maximum temperature (R = 0.68), and 1-hour exceedance days and average maximum temperature (R = 0.69). Since 1988, there have been 3 years with more than 20 days with temperatures ≥ 85ºF (1998, 1999, and 2002). In comparing these years to 1988, there has been a decline of 65 to 75 percent in the number of 1-hour exceedance days and 5 to 10 percent in the average maximum ozone concentrations.

**Table 5. Meteorological and Exceedance Data for the Washington Nonattainment Area at Reagan National Airport 1988-2003**

| Year | Avg 1-Hour Max Ozone Concentration (ppbv) | 1-Hour Exceedance Days | Avg Max Temperature (ºF) | Avg Wind (2 pm) | Temp ≥ 85ºF (# of Days) |
|---|---|---|---|---|---|
| 1988 | 146 | 28 | 95 | 5.1 | 28 |
| 1989 | 134 | 3 | 90 | 5.3 | 3 |
| 1990 | 135 | 5 | 88 | 4.2 | 5 |
| 1991 | 137 | 9 | 93 | 6.1 | 9 |
| 1992 | 128 | 2 | 87 | 6.5 | 2 |
| 1993 | 135 | 10 | 94 | 4.7 | 10 |
| 1994 | 134 | 8 | 92 | 4.8 | 8 |
| 1995 | 138 | 7 | 92 | 4.3 | 7 |
| 1996 | 125 | 1 | 90 | 0 | 1 |
| 1997 | 140 | 7 | 94 | 5.5 | 6 |
| 1998 | 131 | 7 | 90 | 5.6 | 36 |
| 1999 | 133 | 7 | 91 | 6.1 | 36 |
| 2000 | 136 | 2 | 90 | 4.9 | 10 |
| 2001 | 130 | 3 | 88 | 3.9 | 18 |
| 2002 | 138 | 10 | 91 | 5.7 | 33 |
| 2003 | 135 | 3 | 89 | 6.6 | 6 |

The data in Table 5 are analyzed using MDE's technique[8] for any relationship between the number of exceedances and the days with maximum temperature ≥ 85ºF. The trends in the ratio between the number of one-hour exceedance days and the number of days with maximum temperature ≥ 85ºF are shown in Figure 6. A close look at the graph reveals that while on an average there was 1.0 one-hour ozone exceedance day per high temperature days (≥ 85ºF) during 1988-1997, they were only 0.3 one-hour ozone exceedance days per high temperature days after 1997. The reason behind fewer ozone exceedance days after 1997 can be attributed to lower emission levels. While during 1988-1997 temperatures around 85ºF or more caused an exceedance, beginning 1998 exceedences occurred only when temperature reached 90ºF or more due to lower emission levels. Thus it is clear that the emission levels have been decreasing over the years and since 1998 it has been reduced to such a level that it now required the temperature to be 90ºF or more in order to exceed. After the Clean Air Act came into force, a number of control measures were implemented leading to a sharp drop in emission levels. This resulted in a significant reduction in the number of 1-hour ozone exceedance days after 1990. Additionally beginning 1996, a number of control measures were implemented by Maryland, Virginia, and the District of Columbia, full benefits of which began in 1998. Emission reductions from these measures further decreased the number of ozone exceedance days since 1998.

**Figure 6. Trend in Ratio of 1-Hour Ozone Exceedance Days and High Temperature Days (≥ 85ºF) in the Washington Region**



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[8] *2002 Maryland Air Quality Report - Status Report and Long-Term Trends, pp. 17*, December 3, 2003.

After finding a strong relationship between meteorological variables and the 1-hour maximum ozone trend, an advanced statistical technique called KZ filter was used to adjust the 1-hour maximum ozone trend for meteorology in order to study the meteorology-free ozone trend. Figure 7 shows the 1-hour maximum ozone trend free from the effect of temperature. This technique has been described fully by Zurbenko, I.G.[9]

Daily maximum temperature and 1-hour maximum ozone concentration data used in this analysis were acquired from the National Weather Service station at the Reagan National Airport and EPA, respectively.

The temporal variations of ozone measurements were analyzed using moving average filters and a linear least squared regression model to reduce the influence of both short-term variation and meteorological fluctuation in the ozone trends. The moving average filters, also called KZ filters were used to remove the high-frequency (short-term) variations from the ozone and temperature time series. The KZ filters are based on the premise that ozone and temperature time series can be expressed as:

$$X(t) = W(t) + S(t) + e(t)$$

where $X(t)$ is the original time series, $W(t)$ is the short-term variation, $S(t)$ is the seasonal variation, $e(t)$ is the long-term trend, and $t$ is time.

Two specific filters were used in this study. One was the KZ (15,5) filter, with a window length of 15 days and 5 iterations, used to remove the components with periods less than about 33 days. The other was the KZ (183,3) filter, with a window length of one "ozone year" (from April 1 to September 30), which is capable of removing all components with periods less than about 500 days (or two "ozone years"). Using these two filters, the time series of ozone concentrations were separated into (1) a short-term component representing the influence of fluctuating synoptic meteorological conditions and random processes, (2) a seasonal component representing the influence of earth's rotation around the sun, and (3) a long-term component representing the influence of changes in emissions and climate.

After the short variations in daily maximum ozone were removed by filter KZ (15,5), the ozone baseline had both seasonal and meteorological effects. A linear least-squared regression model then was used to remove the meteorological effect from the ozone baseline. In this study, the influence of meteorology on ambient ozone was moderated using surface temperature as a surrogate for all meteorological conditions that affect ozone. The filtered ozone baseline can be expressed as

$$\mathrm{KZ}(15,5)\ \mathrm{ozone}(t) = \alpha + \beta \mathrm{KZ}(15,5) T(t+\Delta t) + \varepsilon(t)$$

where KZ(15,5) ozone($t$) are filtered ozone concentrations, KZ(15,5)$T(t+\Delta t)$ are filtered corresponding surface temperatures, $\alpha$ and $\beta$ are regression coefficients, $\Delta t$ is the lag time between the ozone and temperature annual cycles that maximize the regression

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[9] *Spectral Analysis of Non-Stationary Time Series,* Zurbenko, I. G.; Int. Stat. Rev., 1991, Vol. 59, pp. 163.

determination $R^2$, $\alpha + \beta KZ(15,5)T(t+\Delta t)$ represents the seasonal and long-term variation explained by the temperature, and $\varepsilon(t)$ is the residuals of the regression, consisting of the seasonal and long-term variations unexplained by the temperature. Finally, by applying the filter KZ (183,3) on the residuals, $\varepsilon(t)$, to remove the seasonal component, the long-term trend in remaining residuals can be attributed to changes in emissions caused by regulatory actions.

The regression analysis was performed using data from the Arlington, VA monitor for the period of 1994–2004 to evaluate the 1-hour maximum ozone trend during this period. Figure 7 shows the ozone trend after the effect of temperature has been removed. The residual trend can be regarded as the ozone trend caused by changes in emissions. The magnitude of both the increase and the decrease is about 0.2 in log scale, which is about 1.6 ppbv in ozone concentration. This is in agreement with studies performed by other researchers for the mid-Atlantic region such as Yang & Miller.[10] The trend increased between 1996 and 1998 and again slightly between 2001 and 2002, and decreased during 1998–2001 and 2002-2004. Overall it appears that after 1998 ozone levels have been declining since 1998.

However, there are other factors such as short and long-distance transport that have not been accounted for in this trends analysis. Since it is not possible to quantify and remove the effect of transport from the ozone trend analysis, transport may be affecting the long-term ozone trend.

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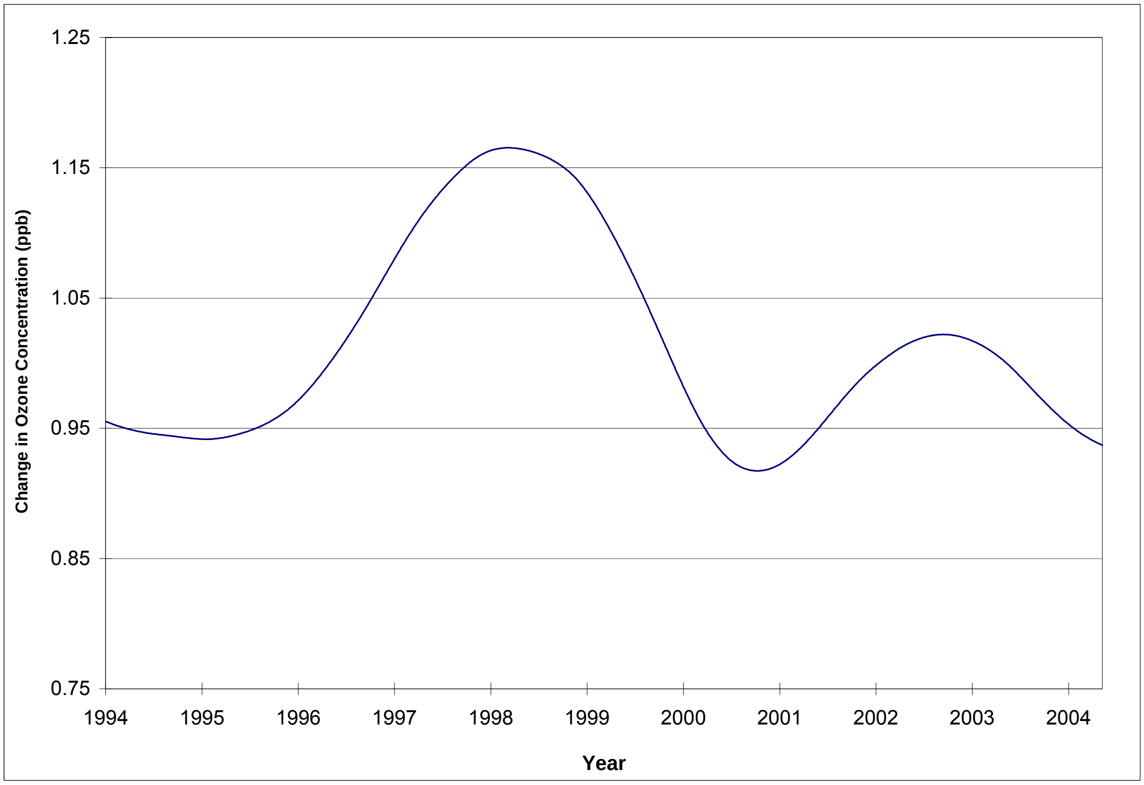
[10] Trends and Variability of Ground-Level ozone in Connecticut over the Period 1981–1997; Yang & Miller; Vol. 52, Dec. 2002, pp. 1354.

## Figure 7. Temperature Adjusted 1-Hour Maximum Ozone Trend

(Arlington, VA Monitor)



## 4.0 Ozone Transport Analysis

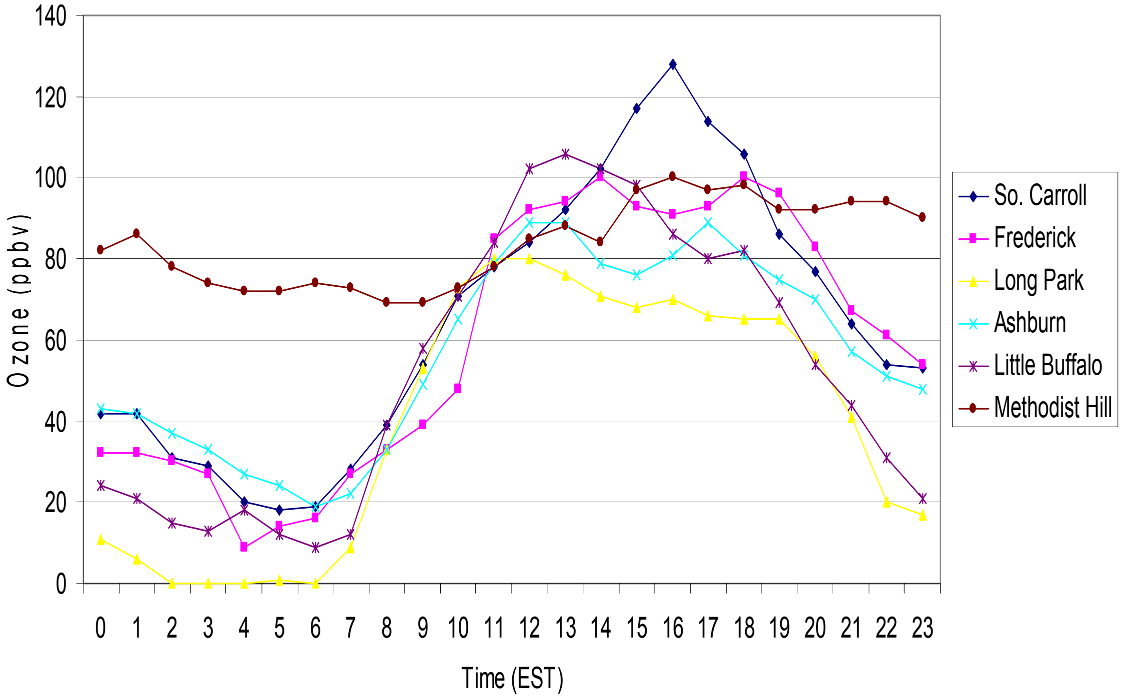
Ozone transport has a significant effect on ozone concentrations within the Washington, DC-MD-VA nonattainment area. Ozone transport is highly variable and assessing the effects on design values, exceedances and peak concentrations is quite difficult because it would necessitate an analysis of large amounts of data, some of which may no longer be easily accessible. A qualitative assessment will be made on large-scale regional transport, short-term local transport, and transport via low-level jets into the Washington, DC-MD-VA nonattainment area using evidence from elevated monitors placed in rural areas to the south and west of the nonattainment area.

### 4.1 Regional Ozone Transport Assessment

Large-scale regional transport occurs when ozone is trapped within the lower boundary layer over a wide area (e.g., several hundred square miles). These regional-scale ozone plumes become embedded within the large-scale atmospheric flow affecting areas well away from their source regions. These regional plumes are often observed at ozone monitors located in elevated terrain. Ozone from these regional plumes can drift across regions and then mix down to the surface affecting monitors over a large area.

The Washington, DC region has a number of elevated monitoring sites with historical data to determine the effects of such long-range ozone transport. One is an elevated ozone monitor at Methodist Hill on South Mountain (~1900 ft) in Pennsylvania, operated since the mid 1990s by the Pennsylvania Department of Environmental Protection (PA DEP). The effects of these regional ozone plumes on regional ozone concentrations have been observed on several occasions. Figure 8 demonstrates what happens when these regional plumes enter southcentral Pennsylvania. Ozone concentrations at the elevated monitor, Methodist Hill, remain high during the overnight hours. Ozone concentrations at the surface monitors remain low until the morning temperature inversion breaks. Then atmospheric mixing allows the elevated regional pool of ozone to mix down to the surface and surface ozone concentrations rise rapidly to match those of the elevated monitor.

**Figure 8. Effect of Urban Ozone Plumes (July 1999 Episode)**



Source: *The Role of Ozone Transport in the Washington, DC Area*. Presentation by Tad Aburn (Maryland Department of the Environment) and Jeff Stehr (University of Maryland), to the Metropolitan Washington Air Quality Committee. February 19, 2004.

Ozone data from Virginia's Shenandoah National Park monitor was also used to assess regional ozone transport. This particular monitor has been operating since 1987 by the Virginia Department of Environmental Quality (DEQ). The monitor is located in a National Park surrounded by rural areas between West Virginia and Virginia.

Changes in design values, peak values and 4th-high values were examined over the 1988-1990 and 2002-2004 time period. The results of this analysis as well as the average values for the Washington, DC region are presented in Table 6.

**Table 6. Regional Transport Analysis using Shenandoah National Park**

One-Hour Design Values
Shenandoah National Park vs. Washington, DC-MD-VA Nonattainment Area

| Monitor | 1988-1990 (ppm) | 2002-2004 (ppm) | % Change |
|---|---|---|---|
| **Shenandoah National Park** | 0.106 | 0.102 | **-3.8%** |
| **Washington, DC** | 0.165 | 0.137 | **-17%** |

Peak & 4th High One-Hour Ozone Concentrations
Shenandoah National Park vs. Washington, DC-MD-VA Nonattainment Area

| | Peak Value (ppm) | | | 4th High (ppm) | | |
|---|---|---|---|---|---|---|
| **Monitor** | **Average 1988-1990** | **Average 2002-2004** | **% Change** | **Average 1988-1990** | **Average 2002-2004** | **% Change** |
| **Shenandoah National Park** | 0.111 | 0.105 | **-5.4%** | 0.094 | 0.088 | **-6.4%** |
| **Washington, DC** | 0.159 | 0.146 | **-8.2%** | 0.133 | 0.117 | **-12.0%** |

The data presented in Table 6 indicate two trends. First, there has been limited reduction of regional ozone being transported into the Washington, DC-MD-VA nonattainment area, suggesting that emission reductions in regions upwind of the Washington, DC region have not yet had a major impact on reducing large-scale regional ozone transport. Second, the data indicate that local measures implemented in the nonattainment area have been successful in reducing ozone concentrations in the region.

A recent study by Marufu *et al*. provides further evidence of regional ozone transport into the Washington, DC region.[11] This paper discusses the August 2003 North American electrical blackout, which provided a unique opportunity to quantify directly the contribution of power plants emissions located in northeast US and southeastern Canada to ozone levels in the Pennsylvania and Washington, DC regions. Ozone levels decreased by ~38 ppbv in response to about 34 percent and 20 percent reductions in $SO_2$ and $NO_X$ emissions from power plants during that period. While ozone levels were forecasted to be 115 ppbv on August 15, 2003, they actually reached only 84 ppbv. Historically the forecasting error is 10 ppbv, so the bulk of this overestimation was attributed to reduced emissions from power plants during electrical blackout. The improvement in air quality provides evidence that transported pollutant emissions from power plants hundreds of kilometers upwind play an important role in ozone production in the Washington, DC-MD-VA nonattainment area.

### 4.2 Short Term Local Ozone Transport Assessment

Ozone transport within the lower boundary layer into the Washington, DC-MD-VA nonattainment area is another important process. Unlike regional transport, local transport occurs over shorter distances and affects a smaller area. This process includes the low-level ozone plumes that emanate from the large metropolitan areas in the south. Ozone from Central Virginia have been observed migrating downwind towards

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[11] *The 2003 North American electrical blackout: An accidental experiment in atmospheric chemistry*, Marufu, *et al.*; Geophysical Research Letters, Vol. 31, 2004.

Washington, DC region and further into Baltimore.[12] Surface ozone concentrations will decrease shortly after sunset during the night due to the loss of sunlight, decreasing temperatures, dry deposition, and NOx titration by NO. The next day all the precursors will be available further downwind to start the ozone production process again.

Transported ozone can affect design values immediately downwind of the large metropolitan areas. This explains why design values in Prince George's and Anne Arundel counties are at times higher than other monitors inside the Washington, DC-MD-VA nonattainment area.

### 4.3 Ozone Transport via Low-Level Jets

Ozone transport via low-level jets is a relatively recent discovery. Low-level jets are nocturnal phenomena that have the potential for moving large pools of ozone in the lower boundary layer. Low-level jets (LLJ) are similar to large-scale regional transport with ozone moving above the surface then mixing down to the surface once the nocturnal inversion breaks shortly after sunrise. The vertical wind profiler at Fort Meade has observed low-level jets during the summer (see Figures 9&10).[13] Low-level jets form during the late night and early morning hours. The LLJ forms between the Appalachian Mountains to the west and the Atlantic Ocean to the east, and moves the air from the south to the north. Typically the LLJ will have wind speeds of 15 meters/second (or approximately 35 mph) and thus have the potential of transporting ozone and ozone precursors hundreds of miles during the night time hours. The nature of low-level jets makes it difficult to quantify their contribution to ozone transport into the Washington, DC-MD-VA nonattainment area. However, according to the study, these jets can routinely transport approximately 80 to 90 ppbv ozone.[14]

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[12] *The Role of Ozone Transport in the Washington, DC Area*. Presentation by Tad Aburn (Maryland Department of the Environment) and Jeff Stehr (University of Maryland), to the Metropolitan Washington Air Quality Committee. February 18, 2004.

[13] Ibid.

[14] Ibid.

**Figure 9. Low Level Jet Recorded above Fort Meade, Maryland**

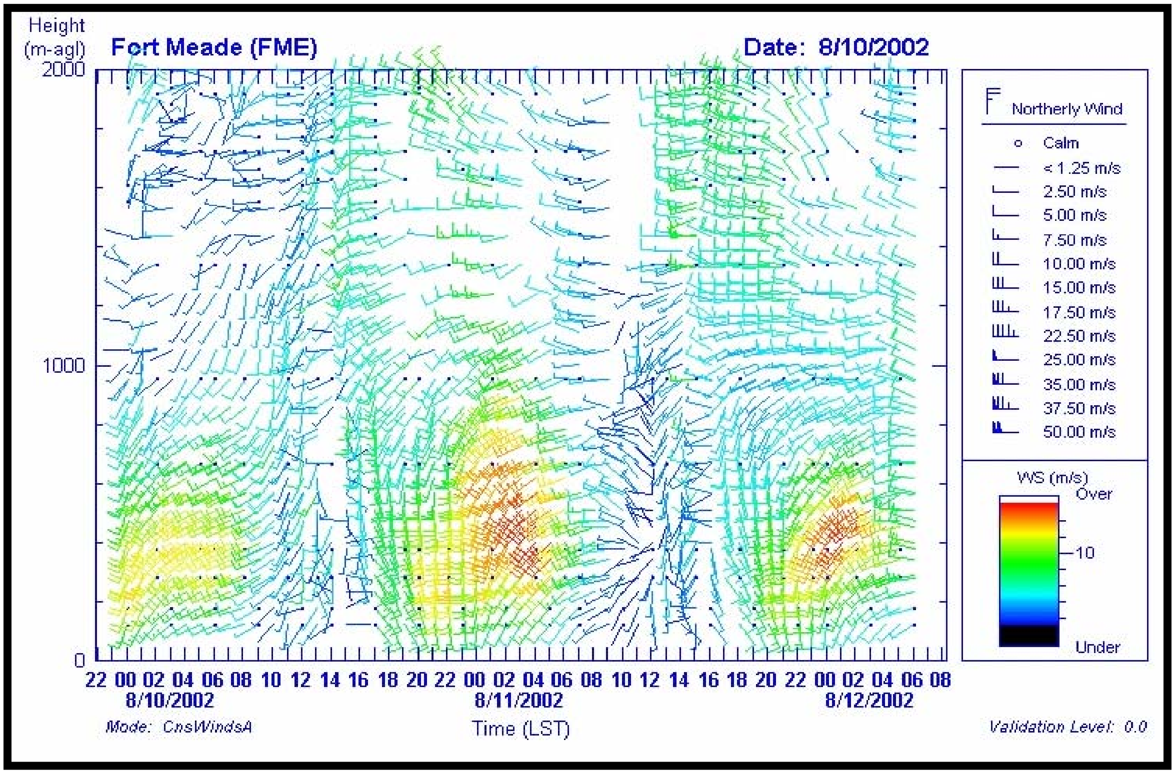
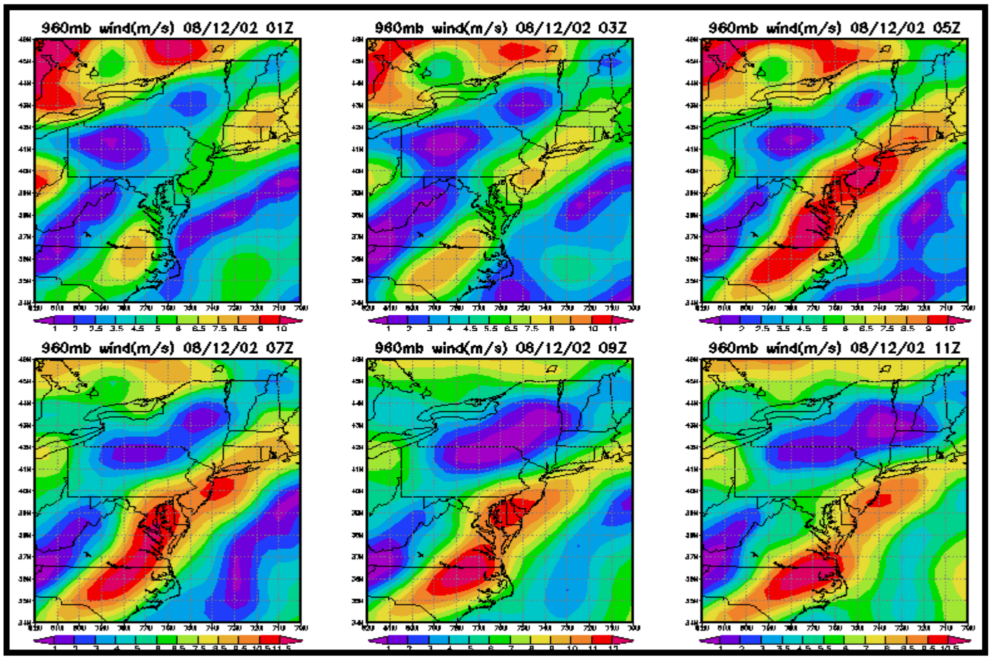


**Figure 10. Model Depiction of the Low Level Jet**

(High Wind Speeds in Red)



## 5.0 Summary and Conclusion

The midcourse review evaluates progress made in the Washington, DC-MD-VA area toward meeting the 1-hour ozone standard in 2005. The analysis considered emission reduction, status of control program implementation, air quality trends, and transported ozone. The analysis relies on photochemical modeling results and proportional extrapolation to assess whether anticipated emissions in 2005 will enable the region to attain the 1-hour ozone standard.

There have been significant reductions in ozone precursor emissions in the Washington, DC-MD-VA nonattainment area since adoption of the Clean Air Act. Nitrogen oxide emissions from the Washington, DC region decreased by approximately 30 percent between 1990 and 2002. During this time, Volatile Organic Compound (VOC) emissions were reduced by more than 60 percent. All of the mandated programs in the region's "Severe Area SIP" are being implemented so that emissions in 2005 are at or below the levels required to reach attainment based on photochemical modeling.

Air quality in the region has improved. Design values and monitor exceedances are decreasing over time even when weather conditions are favorable for ozone formation (hot and dry summers). Additionally, the number of exceedances has declined and the number of monitors compliant with the 1-hour ozone standard has increased. This improvement is expected to continue into the region's attainment year of 2005.

While local emission reduction has reduced ozone pollution, the region’s air quality is significantly affected by ozone and its precursors transported from areas outside of the nonattainment area. States upwind of the region began to increase control of NOx emissions from stationary sources in 2004 as a result of EPA's NOx SIP call. Additional controls are being installed in 2005. Together with local emission reduction, the reductions in NOx emissions from these regional controls should contribute to attainment of the 1-hour ozone standard in 2005.

Using proportional extrapolations based on the normalized design value for 2004, unit sensitivities for both NOx and VOC, and predicted emission reduction between 2004 and 2005, the predicted design value for 2005 is 122 ppbv, which is below the 1-hour ozone standard.

Based on the weight of this evidence, this analysis concludes that the Washington, DC-MD-VA 1-hour ozone nonattainment area is on track to meet its emission reduction targets and should comply with the 1-hour ozone standard by the 2005 attainment date.

## Appendix 1: Washington , DC-MD-VA 1-Hour Nonattainment Area Ozone Monitors