Weekday/Weekend Variability and Long-Term Trends in Traffic, CO, NO_y, and Ozone for the Charlotte Metropolitan Area during the 1990's

Jennifer L. Perry
Department of Chemistry, Duke University, Durham, NC 27708

Patrick M. Owens
Department of Chemistry, Winthrop University, Rock Hill, SC 29733

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ABSTRACT

There is increasing evidence that high-growth metropolitan areas present formidable challenges for implementing effective ozone attainment strategies. Charlotte is experiencing large population growth, greater increases in vehicle miles traveled, and growing electrical power demands. This region has the highest summertime ozone readings in the Carolinas.

Comparing weekday with weekend levels of traffic, ozone precursors, and ozone shows how the region responds to short-term fluctuations in emission sources. Evaluating long-term trends provides evidence whether growth-related declines in air quality are being effectively offset by ozone attainment measures.

The objectives of this study were: 1) to compile Charlotte traffic, CO, NO_y, power plant NO_x, and ozone data; 2) to examine weekday / weekend variation for each; 3) to evaluate long-term trends; and 4) to examine correlations among traffic patterns, CO, NO_y, power plant NO_x, and ozone levels.

Hourly traffic volumes from 1990-1998 for four tachograph locations were used. Friday was the most traveled day, while Saturday and Sunday morning rush hour traffic counts were 55% and 67% below the seven-day average. Saturday and Sunday traffic totals for all sites were 18% and 31% less than the seven-day average. Traffic volumes increased 53-73% over a seven-year period.

NO_y and CO diurnal patterns showed the greatest weekday / weekend variation during AM rush hours; 7:00-8:00 AM CO levels were 8% (Saturday) and 29% (Sunday) below the seven day averages. NO_y levels (7:00-8:00 AM) were 16% (Saturday) and 49% (Sunday) below the seven day averages. These patterns emulated traffic pattern variations observed on weekends.

Ozone showed little variation in weekday/weekend maximum daily readings. Data from all three ozone monitoring sites during May through September from 1990-1998 had average Sunday and Monday levels of 98% of the 7 day average while Saturday had the highest average ozone level of 102% of the 7 day average.

INTRODUCTION

Summer tropospheric ozone is the leading air quality problem in the U.S. In 1999, over 50 million Americans resided in counties with ozone levels exceeding the 120 ppb one hour standard; over 120 million in counties exceeding the 8-hour 80 ppb standard. National trends between 1990-1999 show no change in the 8-hour ozone design values among 705 monitoring sites. While improvements during the 1990's have been made in California and the Northeast, rural sites in the Eastern U.S. and many national parks have had significant upward trends.[1]

Historically a California issue, summertime ozone is increasingly a problem in other areas, particularly Sunbelt states. Texas, North Carolina, Tennessee, Georgia, and Maryland all have counties with ozone levels among the 25 highest in the nation. In Charlotte, the number of days exceeding the 8-hour standard rose from 12 in 1989 to 26 in 1997. In 1997, for the first time ever recorded, Houston ozone levels surpassed those of Los Angeles.[2] High-growth metropolitan areas, particularly those located in sunbelt regions conducive to ozone formation, present formidable challenges for implementing effective ozone attainment strategies.

Adding to these challenges is evidence that ozone levels become more resistant to further reduction as they trend downward. A recent study[3] shows that the most rapid declines have been for sites with the highest concentrations; locations with mid-range ozone readings (above allowable standards) have responded much slower to control strategies. This increasing resistance appears to be independent of ozone precursor (VOC or NO_x) emission reductions. As urban regions move closer toward meeting attainment goals, improvements become more difficult.

Ozone control measures implemented during the 1970's and 1980's focused primarily on reducing hydrocarbon emissions; national trends indicated success with corresponding declines in summertime ozone, particularly in California (where levels were high and resistance to reduction was low). In a number of regions, in spite of significant and costly hydrocarbon emission reductions, improvement in summertime ozone levels were not achieved, leading the National Research Council and others [4,5] to call for control of nitrogen oxide emissions in addition to or in place of reactive hydrocarbon controls. California's programs to reduce both nitrogen oxides and reactive hydrocarbons continue to achieve success in lowering summertime ozone levels. Between the 1992-1994 and 1996-1998 periods, a recent study[6] has shown significant statewide ozone reductions (15-20%), possibly in part due to the statewide implementation of the California Clean Burning Gasoline program in 1995.

Effective implementation of ozone control measures requires an understanding of key regional factors. A number of measures (e.g. VOC/NO_x ratios) have been developed to assess if ozone production in a region is driven by nitrogen oxides, hydrocarbons, or a combination of both.[4, 7] Modeling has been helpful in estimating the effect of emissions reductions on predicted ozone levels.[8] To factor out meteorological variability and assess long-term trends in a region, Cox and Chu have reported ways to produce meteorologically adjusted ozone trends and to assess interannual urban ozone variation from a climatological perspective.[9,10]

One of the best ways to understand how the production of ozone within a particular region responds to major reductions in ozone precursors is to compare weekends with weekdays.

During the 1970s, research[11-13] on several urban regions showed that some sites had higher O_3 concentrations on weekends, many others had comparable weekend ozone concentrations (in spite of lower ambient precursor levels), and still others (downwind) were lower. More recently, studies[14,15] examining weekday/weekend effects in mid-Atlantic urban regions and in California have shown higher weekend ozone readings and lower weekend ozone precursor levels. A number of California locations demonstrate a significant "weekend effect" - up (from Friday) on Saturday, flat on Sunday, down on Monday. The ozone levels for many California monitoring sites are 25-30% higher on weekends than weekdays.

A number of possible causes of the weekend effect have been proposed and a major study is underway in California to examine this. Lower ambient AM NO weekend levels have been widely reported; this results in less early scavenging ($NO + O_3 \rightarrow NO_2 + O_2$) resulting in higher early morning ozone levels than on weekdays, perhaps biasing upward weekend ozone levels. Cleveland et al. during the 1970's found lower Sunday aerosol concentrations (from lower emissions)[13] and Sunday mid-quantile solar radiation and mixing heights significantly higher than on weekdays. Sunday ozone averages were markedly higher than weekdays, perhaps due to increased weekend vertical mixing (from increased radiation) with upper layers having higher ozone concentrations. Clearly weekend/weekday differences are complex. Understanding and being able to successfully model these differences is important because it may increase the confidence in evaluating and selecting effective ozone control strategies for a particular region.

This study focuses on traffic, ozone precursor, and ozone data collected during the 1990's in Charlotte, the second fastest growing U.S. city among those with a population of at least 500,000.[16] Ozone levels in Charlotte rose substantially during the second half of the 1990's. In summer 2000, the American Lung Association ranked Charlotte as the nation's eighth most ozone-polluted city--behind only Houston and Washington DC among urban areas outside of California.[1] An understanding of the within week and weekday/weekend variation of ozone and ozone precursors provides information to better understand how the Charlotte region responds to these fluctuations. The second objective is to review the impact of growth and improvements in pollution control devices to better characterize long term trends in this emerging urban center.

EXPERIMENTAL METHODS

Data Collection

This study examined 1990-1997 hourly traffic, ambient monitoring [ozone, carbon monoxide (CO), NO_x oxidation products (NO_y = NO, NO_2, NO_3, N_2O, HNO_3), hydrocarbons], and power plant emission (NO_x) data collected from four traffic location, three ambient monitoring sites, and four power plant facilities located in or near Charlotte, North Carolina. In 1995, NO_x ambient monitors were replaced by NO_y instruments to provide a better indication of total reactive nitrogen. Power plant monitors in the region have continued to measure NO_x emissions. Table 1 summarizes the monitoring locations and the specific periods of time the data were collected.

Traffic Data

Traffic volumes by hour were taken from three Charlotte City streets to characterize the traffic growth and traffic patterns in the city. The time frame from May through September 1990-1997 was used from the sites at Graham St, Wilkinson Blvd, and South Blvd. These three sites were chosen because they had the greatest amount of historical data with the most complete data sets available. In addition, the sites depict two major business thoroughfares, and one city street within the city limits. Wilkinson Blvd represents one of the six U.S. primary highways in the area while South Blvd represents one of the seven state primary highways in the area. Graham St depicts traffic flow on one of many Charlotte city streets. The rush hour volumes at 7:00-8:00 AM and 5:00-6:00 PM and the total daily traffic volume were transcribed from average daily traffic (ADT) counts provided by the City of Charlotte Department of Transportation (DOT). The rush hours were chosen as an indication of the most heavily traveled hours.

In addition, traffic volumes were taken from I-77, an interstate used by commuters just outside the Charlotte city limits to characterize the traffic growth and traffic patterns in the area. I-77 represents one of the two interstates in the region. Hourly traffic volumes for the I-77 Interstate site were provided from the South Carolina DOT in electronic format from June-August 1990-1997. The interstate site was chosen to represent the growing number of commuters that drive into Charlotte each day.

Table 1. Charlotte traffic, monitoring, and power plant data used in this study. All are hourly readings (24 hours per day) unless otherwise noted. NO_y and NO_x used due to data availability. Hydrocarbon data were from three-hour canister samples collected two-three mornings per week.

Type of Data	Monitoring Site	Selected Data
Traffic Counts	Interstate I-77	Jun-Aug, 1990-1997
	South Blvd, Wilkinson Blvd, Graham St.	May-Sep, 1990-1997 (8-9 AM, 6-7 PM, daily)
Mecklenburg County Ambient Air Monitors	Plaza, County Line	Ozone: May-Sep, 1990-2000 CO: May-Sep, 1993-2000 NO_y: May-Sep, 1995-2000 Hydrocarbons, 1995-1999
	Arrowwood	Ozone: May-Sept.1990-2000
Power Plant Continuous Emission Monitors (CEM)	Riverbend, Allen Marshall, Buck	NO_x: May-Sep, 1996-2000

Ambient Air Monitoring Data

Hourly NO_y and CO concentrations were collected in electronic format from the Plaza (in 2000 the Plaza site was relocated to Garinger, a slightly more urban site) and County Line monitors within Mecklenburg County for available years. NO_y data were available from May to September from 1995 to 2000. High Sensitivity CO data were taken from May through September of 1993 to 2000. State and local agencies maintain the monitors. The NC Division of Air Quality (DAQ) retrieved 1990-1997 and 1999-2000 data from the Aerometric Information Retrieval System (AIRS). DAQ also provided the 1995-1999 AM hydrocarbon data that was collected (canister sampling, GC analysis) two-three days weekly during early morning hours at the Plaza site. Data for the 1998 year were downloaded via the AIRS website.

Ozone data were obtained from the Plaza, County Line and Arrowwood monitors within Mecklenburg County from May through September for the years 1990-2000. State and local agencies maintain all monitors. Hourly ozone concentrations were collected electronically via the AIRS database by the NC DAQ for 1990-1997 and 1999-2000. Data for 1998 were downloaded from the AIRS website in electronic format.

Power Plant Nitrogen Oxide Emission Data

Hourly NO_x emission readings from May-September, 1996-2000, were obtained from Duke Power for the four coal-fired power plants in the Charlotte region: Allen & Riverbend (just west of Charlotte in nearby Gaston County) and Marshall & Buck (further away, northwest of Charlotte). Allen and Riverbend represent the major source of nitrogen oxide stationary source emissions near Charlotte; these two plants have nitrogen oxide emission inventories that are between 80-90% of all motor vehicles in Mecklenburg county.

Data Analysis of Parameters

Daily Distributions

Hourly data from I-77 traffic monitor, ambient air monitors and power plant monitors were used to analyze the daily distribution of mobile sources, stationary sources and pollutant emissions. Data were sorted by day of the week and then by hour to obtain average hourly values. These average hourly values were used to characterize daily variations. Ozone readings were based upon the average 1-hour daily maximums and the average 8-hour daily maximums before the values were normalized by a seven-day average of those respective daily maximums.

Yearly Patterns

Data from all traffic sites were sorted by rush hour and by daily total intervals, and then by each year to observe the yearly growth. For the secondary pollutant analysis at the County and Plaza monitoring sites, data for each available year were sorted by three different time intervals. Trends for the 7:00-8:00 AM average, the 7:00-9:00 AM average and the hourly average were found. In addition to the 7:00-8:00 AM average annual patterns for the previous parameters, yearly trends present in ozone were calculated by two different methods using data from the County, Plaza and Arrowwood monitoring sites. The maximum 1-hour ozone concentration (daily max) for each day was computed; the daily max readings from the May-September period were then averaged for each year. In a similar manner, an overall average for each year was calculated using the average of May-September daily 8-hour maximum ozone concentrations.

Nonmethane Organic Compound (NMOC) / NO_y ratios were calculated using simultaneous samples (6:00-9:00 AM). Both identified and unidentified peaks were used in calculating the total NMOC concentrations. NO_y levels used were a three hour average of hourly readings.

Correlations

To quantify the deviations present in the observed parameters, 7:00-8:00 AM data from all monitors excluding ozone were separated into Sundays, Mondays, Tuesday through Fridays and Saturdays. Mondays were separated from other weekdays due to lower readings for NO_y and for CO (Fridays were comparable to other weekdays). Data were averaged by day and then were normalized by a seven-day average. Ozone data were grouped into the same day classifications. Variances, t-tests, and p-values were found utilizing the statistical package S-Plus Version 4.5.

Missing Data Procedures

The holidays of Memorial Day, July 4th, and Labor Day were not included in the traffic analysis due to the varied traffic patterns that occurred. Days in which missing data occurred during construction or as the result of faulty equipment were not included. However, the sample size of traffic volumes that contributed to each individual day remained nearly constant, since the data were taken over eight years and the excluded data were spread across all days of the week.

Each ambient air monitor had missing hours due to instrument calibration (which normally occurred during the early morning hours in which pollutant levels are not significant to this analysis). In addition, data missing due to instrumentation failures were ignored. Data from the holidays mentioned above were included in this analysis. The number of each individual day present in the analysis was almost consistent.

RESULTS AND DISCUSSION

Weekday/Weekend Variation

Traffic Weekday/Weekend Variation

Figure 1 shows the 1990-1997 Interstate-77 hourly distribution of traffic by day of the week. Weekday patterns show two peaks that correspond to the AM and PM rush hours. Sunday and Saturday were quite different from weekdays; volumes for weekends are lower than weekday AM and PM rush hours, while the Sunday midday volumes were equivalent to the weekday volumes and Saturday midday traffic counts were slightly higher than weekday counts. Friday traffic was slightly heavier than other weekdays after morning rush hour. A 1992 July-August Atlanta traffic study by Cardelino[17] that included 47 separate traffic counters found very similar within week urban patterns to those shown in Figure 1.

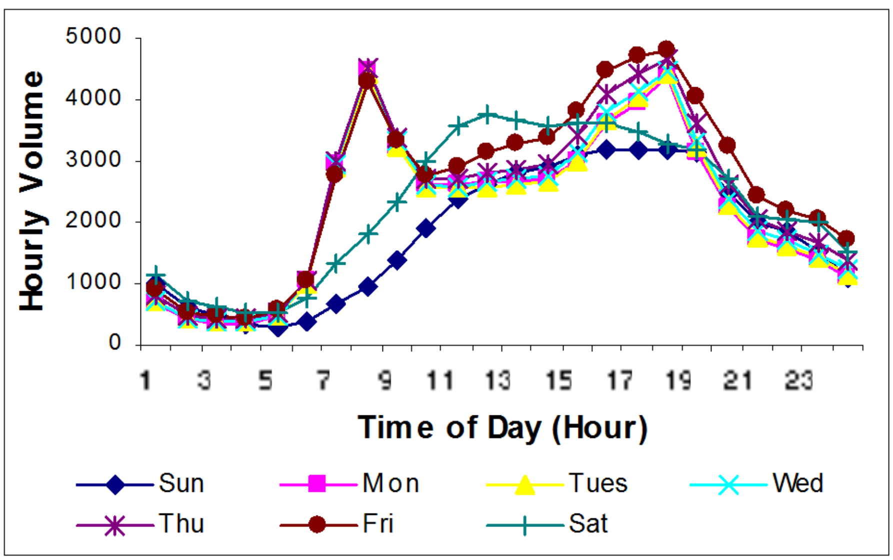


Figure 1. Average hourly traffic counts for Interstate-77, June-August, 1990-1997. The I-77 traffic counts illustrate nearly identical weekday patterns and deviating weekend patterns. Traffic count data used did not include information on the vehicle types represented by the counts.

Weekday/Weekend Variation in Ambient Monitoring NO_y and CO Levels

The 24-hour concentration plots of NO_y and CO for the County Line and Plaza sites show similar bimodal diurnal patterns; the patterns for the Plaza (an urban) site are depicted in Figure 2. Weekdays overlap one another while Saturdays and Sundays each display distinct patterns. The morning peak, between 6:00-8:00 AM, shows the clearest weekday/Saturday/Sunday deviations in pollutant concentrations. Saturdays are noticeable lower than weekdays while Sundays have by far the lowest CO and NO_y AM concentrations. These results are very comparable to an August-September, 1991, Aneja study[18] conducted in downtown Raleigh, NC. In Figure 2, Plaza had weekday and weekend AM CO levels of 900 and 550 ppb (vs 900 and 400 ppb in Aneja) and AM NO_y weekday and weekend levels of 35 and 20 ppb (vs. 34.4 and 4.8 ppb in Aneja). It is not apparent why NO_y weekend levels were so much lower in the Raleigh study. Similar trends for CO and NO_y are also evident at the County Line monitoring site.

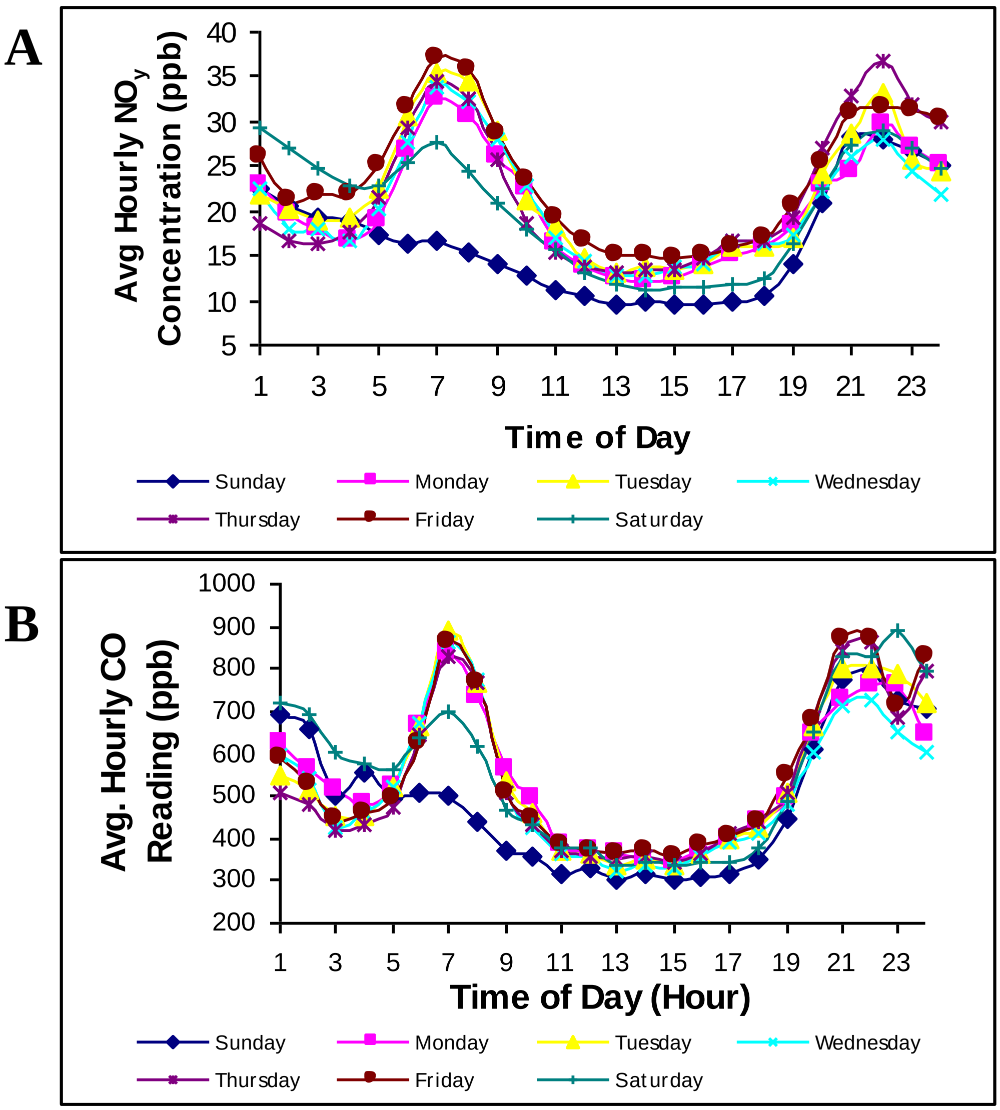


Figure 2. (A) May-Sep 1995-1998 NO_y and (B) May-Sep 1993-1998 CO distributions from the Plaza monitoring site. A diurnal pattern is present during each day. Sundays and Saturdays deviate from the similar weekday pattern primarily during the morning traffic rush hours.

Weekday/Weekend Variation in Ambient Ozone Levels

Similar 24-hour concentration plots from 1990-1998 were created for ozone concentrations at the three ambient air monitors. Plots were based upon hourly average concentrations and maximum 1-hr concentrations. The overall pattern was unimodal with an increase from 8:00 AM to 2:00 PM followed by a decrease and leveling off into the late evening and early morning hours. Unlike ambient CO and NO_y concentrations, there were no discernable visible differences between weekday and weekend ozone levels. For ozone, the Charlotte results are somewhat different from Aneja's Raleigh study that showed lower peak ozone (28 ppb weekend vs 38 ppb weekday) weekend levels. The Charlotte data are comparable to a 1978 study that found sites in New York City to have comparable weekday/weekend ozone levels, while precursor weekend levels were lower than weekdays.[12] Similarly, there are a number of sites in California where there are comparable weekend/weekday ozone levels and lower weekend precursor levels.[19]

Weekday/Weekend Variation in Power Plant NO_x Emissions

According to the North Carolina DAQ, power plants and motor vehicles account for 75% of the nitrogen oxide emissions in the Charlotte region. Within week variation of power generation NO_x emissions is shown in Figures 3A and 3B. The day of week pattern clearly shows mid-week (Tuesday-Friday) emissions for all four facilities are 5-15% above 7-day averages, with weekend (Saturday-Monday) emissions 5-24% lower than 7-day averages.

As can be seen from the hourly trends in Figure 3B, Monday AM power plant emissions are the lowest of anytime during the week. Monday emissions increase sharply during the day, reaching mid-week emission levels by midnight. End of week emissions decrease slower with downward trends Friday, Saturday and Sunday to weekly lows achieved early Monday morning.

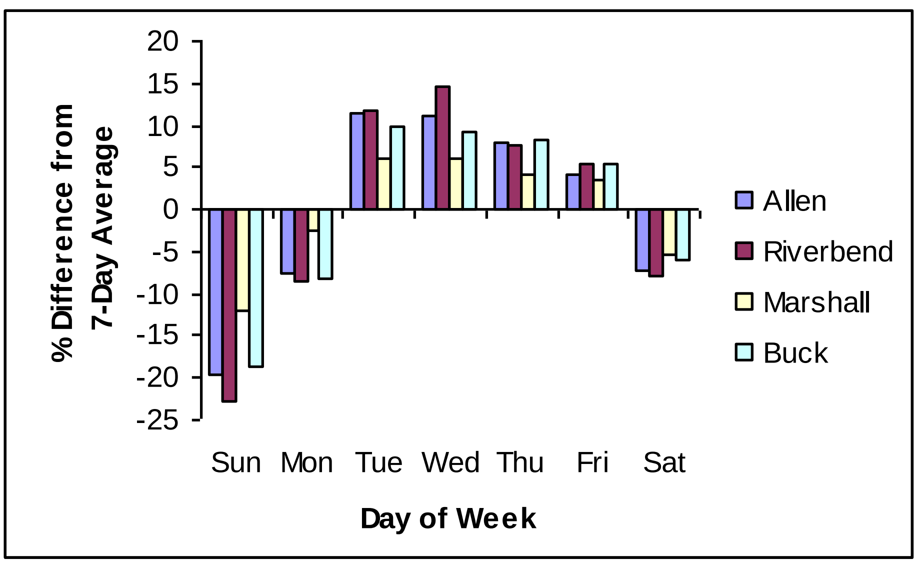


Figure 3A. Day of week and hourly variations in NO_x emissions from the four coal-fired power plants (Allen, Riverbend, Marshall, and Buck) near Charlotte NC. Nitrogen oxide emissions are clearly the highest during mid-week.

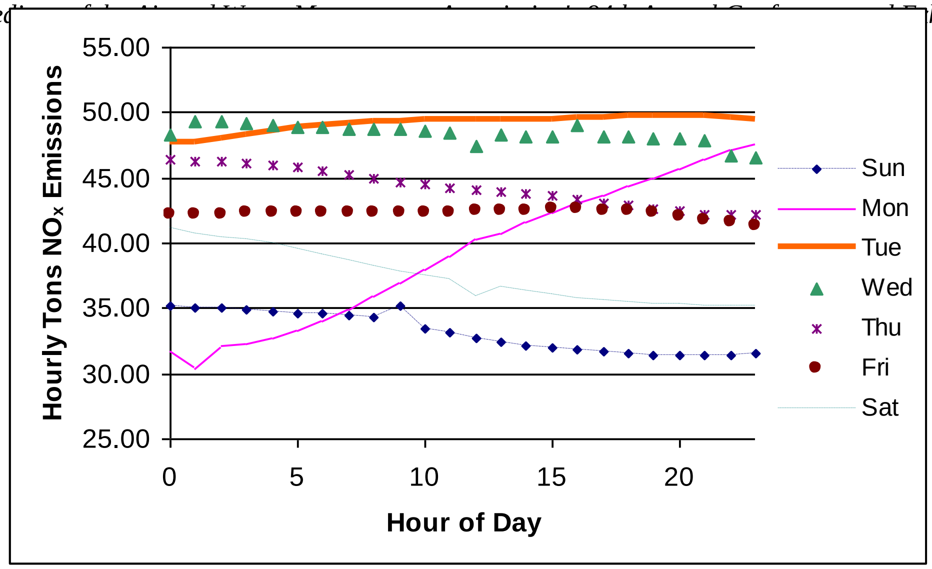


Figure 3B. Coal-fired power plant hourly variations in NO_x emissions by day of the week during a recent summer season. Note Monday's sharp rise in emissions during the day.

Trends during the 1990s

Traffic Long-Term Trends

Figure 4 depicts hourly traffic volumes for the I-77 and South Blvd from 1990-1997. The I-77 site increased regularly while the South Blvd. site was more variable. Trends from the other two sites were not included due to missing data between 1992-1995. At both sites depicted in Figure 4, the evening rush hour traffic appeared to be increasing the most rapidly. For I-77, 5:00-6:00 PM traffic volumes increased 55%, while South Blvd volumes increased 92%. Daily average hourly volumes increased 52% and 76% respectively, while 7:00-8:00 AM volumes increased 36% and 52%. Some of the variability may be attributed to changing traffic patterns because of the opening of the southern Charlotte beltway (I-485) in 1995. The increase in average daily traffic volume is evident. The Vehicle Miles Traveled (VMT) is increasing at a faster rate than the population. Between 1990 and 1997, according to information provided to the authors by the North Carolina DAQ, VMT in Mecklenburg County increased by an annual rate of 4.4%; the I-77 traffic show an annual increase of 5.9%, not surprising since commuter traffic increases at a faster rate than overall VMT. In support of these trends, Mecklenburg County mobile emissions are higher than average for VOC, NO_x and CO pollutants according to EPA standards.[20]

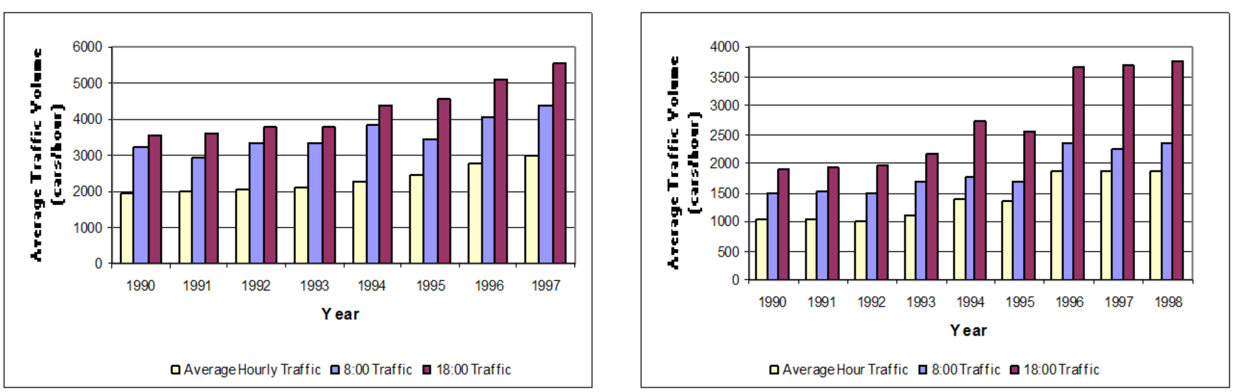
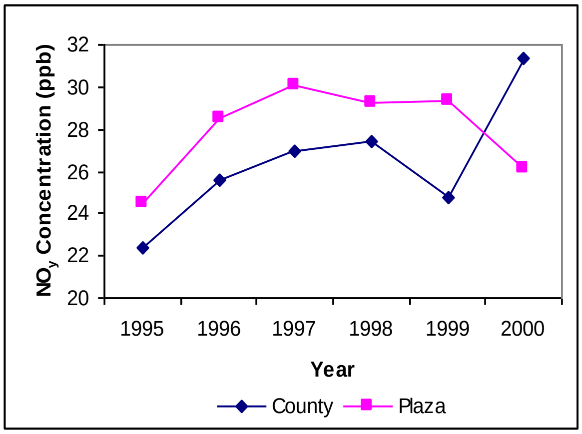


Figure 4. Traffic growth trends for the I-77 and South Blvd sites categorized by daily hourly average, AM rush hour, and PM rush hour traffic volumes.

Ambient NO_y and CO Long-Term Trends
Long-term trends in average AM ambient concentrations of NO_y and CO concentrations are shown in Figure 5. Trends for both monitors were somewhat similar; the Plaza site consistently had a considerably higher CO concentration and a slightly higher NO_y concentration (except for 2000) than County Line. From 1995-1998 there appears to be an upward trend at both sites for both CO and NO_y. Since 1998, the overall trend in CO is sharply downward at both sites. For NO_y, the pattern is mixed with a large increase at the County Line site and a smaller decrease at Plaza. A review of the County Line 2000 NO_y AM data did not provide any reason for the increase—the numbers seem to be consistently high throughout the summer at this site. The size of the increase (20-25%) at County Line in 2000 clearly warrants further scrutiny.

In addition to the 7:00-9:00 AM averages shown in Figure 5, 7:00-8:00 AM averages and hourly average concentrations for each day were evaluated for long-term growth trends. These averages showed the same trends that are indicated in Figure 5.



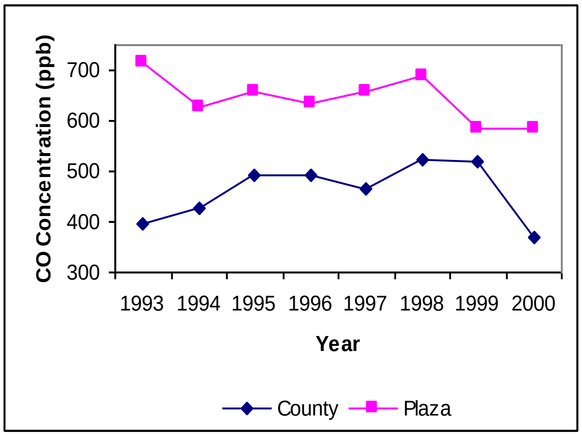


Figure 5. Yearly trends in May-September average 7:00-9:00 AM NO_y and CO levels at County Line and Plaza sites. High 1993 Plaza CO may be due to high sensitivity CO startup. A review of the data did not show why NO_y levels rose sharply at County Line in 2000.

In addition to studying the average yearly concentration growth, CO and NO_y average May-September concentrations for each day of the week were found. From 1993-1998, Saturday CO concentrations indicated the greatest increase, followed by Sunday and weekday averages at both monitoring sites. For NO_y during the 1995-1998 period, Plaza and County Line weekday concentrations showed steady increases while weekend NO_y concentrations varied from year to year.

Ambient Ozone Long-Term Trends
Ozone concentration trends between 1990-2000 at the three monitoring sites were determined using the average daily 1-hour maximum and average daily 8-hour maximum for each year. Figure 6 shows long-term trends in average ozone 8-hour concentrations over the years for all three sites (nearly identical trends were observed for the average 1-hour daily maximum). For the average daily 8-hour maximum concentration, County Line, Arrowwood and Plaza sites illustrated increases of 29%, 35%, and 29% respectively between 1994 and 1998. An analysis of variance for each of the three locations indicates that the between year differences are significant

(p is negligible). For both 1999 and 2000 at all three sites, May-September ozone averages were less than the previous year, an encouraging sign. It also appears the long-term ozone trends are quite similar for each of the sites, the ozone monitors also appear to be somewhat redundant.

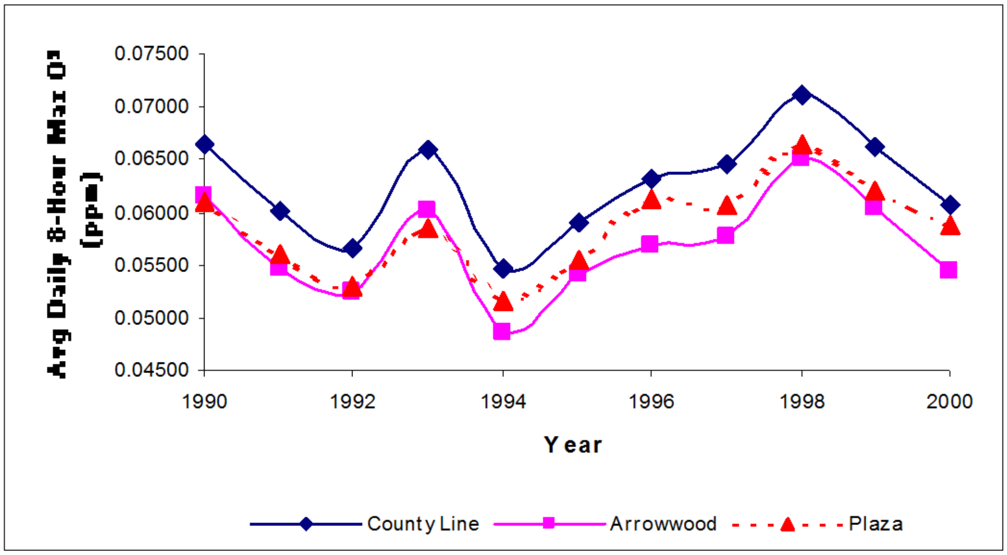


Figure 6. Yearly trends in the average daily 8-hour maximum ozone concentrations for three Charlotte ambient air monitors. 1993 and 1998 were unusually hot summers.

Coal-Fired Power Plant NO_x Emissions Long-Term Trends

Figure 7 shows the 1996-2000 average May-September NO_x emissions from the two Gaston County coal-fired power plants. These facilities are in the process of implementing NO_x controls while also meeting the increasing electrical demands due to rapid economic growth in the Charlotte region. Unlike traffic patterns, power plant emissions appear to be holding steady. Improved NO_x controls appear to somewhat be offsetting the greater demands for electricity.

Plotting the emission time series for each of the years brought to light that the low 1997 NO_x emissions readings were attributable to several weeks of operating at less than full capacity at one of the plants. This was apparently necessary for installation of pollution abatement controls. The May-September 1999 period had limited down-time and low emissions. From this, it appears evident that power plant NO_x emissions are stable. Power plant emissions trends would be expected to trend downward further in the future with the recently announced commitment by Duke Power to substantially reduce NO_x emissions over the next five years.

It is interesting to note that the fluctuations in power plant emissions do not appear to fit the observed NO_y patterns in Figure 5. Between 1997 and 1998, there was a significant increase (~15%) in power plant emissions, but there was little to no increase at the two NO_y monitors. Between 1996 and 1997, power plant NO_x emissions decreased significantly (~10%), yet during that period, ambient NO_y levels increased 5-10% at both Plaza and County Line. The 1999-2000 increase (~10%) in NO_x power plant emissions occur during a period when there is a sharp increase at County Line and a large decrease at Plaza.

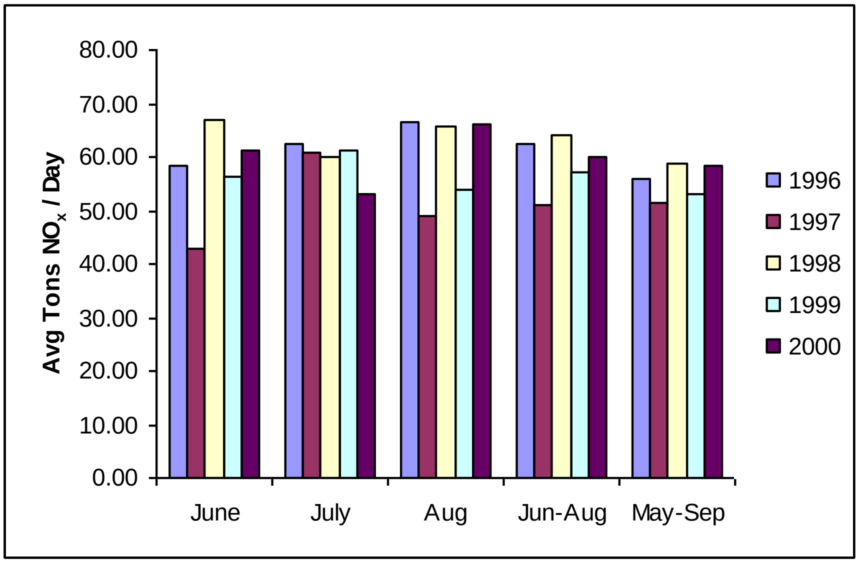


Figure 7. NO_x emissions for the two coal-fired power plants, Allen and Riverbend, near Charlotte. Low 1997 emissions are partially attributable to shutdowns.

Figure 8 portrays the tradeoffs between power generation and emissions. Power generated by the two plants increased 27% between 1996 and 2000, while NO_x emissions increased only 4%. There is a clear downward trend in emissions per unit of electrical power. Economic growth has increased the demand for power; improved pollution control systems have offset this growth. Total power plant NO_x emissions have remained relatively stable in recent years.

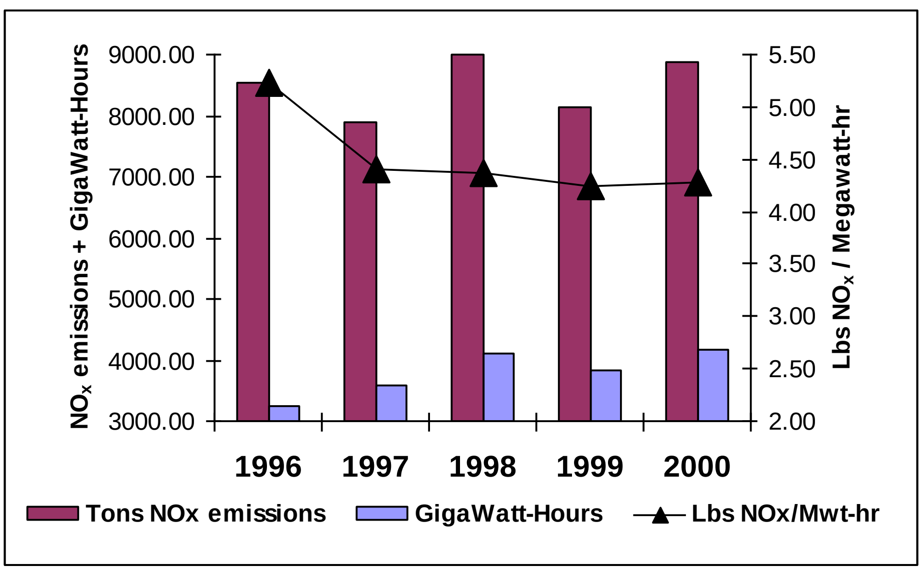


Figure 8. Long-term trends for NO_x emissions, power generation, and emissions per megawatt-hour for Allen and Riverbend, the two coal-fired power plants near Charlotte.

It is also interesting to note that the observed 1994-1998 increases in Charlotte ozone readings (Figure 6) occurred during a period of essentially no change and probably a decrease in summertime power plant NO_x emissions. There are no indications from the data presented that reducing these emissions near Charlotte would necessarily lower ozone concentrations.

Long-term Trends in Reactive Hydrocarbons and NMOC/NO_y Ratios

Figure 9 shows long-term trends in early morning reactive hydrocarbons and NMOC / NO_y ratios at the Plaza monitoring site. There appears to be a downward trend in hydrocarbon reactivity in recent years. It is also very noticeable that Charlotte's NMOC / NO_y ratios are predominantly below 10. Ratios in this range are indicative of a hydrocarbon limited environment.[4] These data point to the need to reduce hydrocarbon emissions in Charlotte to limit ozone production..

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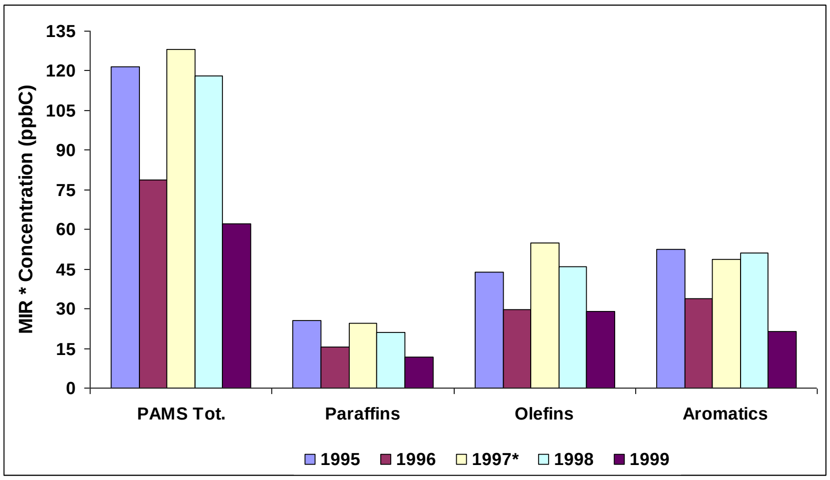

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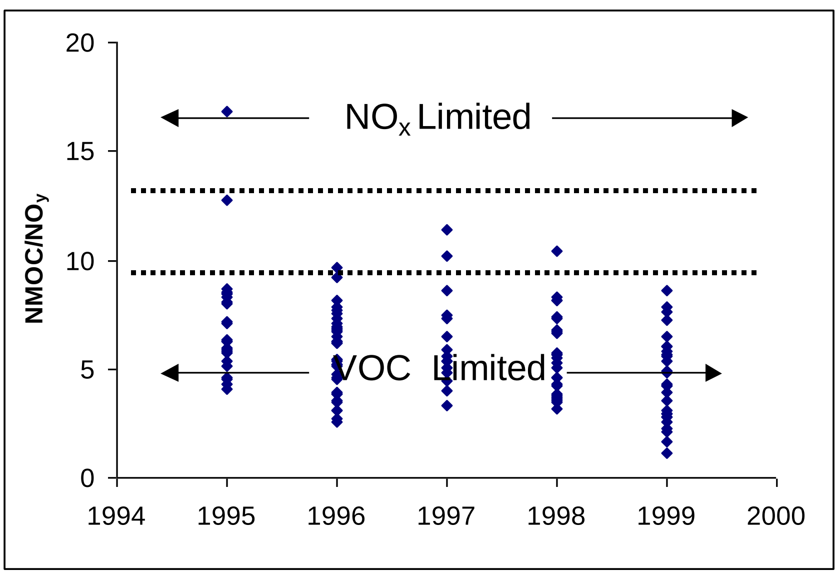

Figure 9. Long-term trends in 6:00 –9:00 AM: **(A)** Hydrocarbons and **(B)** NMOC / NO_y ratios at the Plaza Monitoring Site in Charlotte. Hydrocarbon levels shown are weighted by reactivity. NMOC / NO_y ratios appear to be primarily in the VOC limited region.

Relationships Among Traffic, Ambient Monitoring, and Power Plant Data

Figure 10 illustrates the 7:00-8:00 AM traffic volume as a percentage of the average day (7-day week). Calculations for the 5:00-6:00 PM and total daily traffic volume were also determined. For all these time intervals, traffic volumes were at least 31% lower on Sundays and 18% lower on Saturdays (comparing well to Cardelino's Atlanta study[17] showing Sunday reductions of 35-41% and Saturday reductions of 14-26%). The 7:00-8:00 AM traffic volumes illustrated in Figure 8 give the most striking deviations from the average day. A 67% reduction is observed at all sites on Sunday and a 55% reduction at all sites on Saturday.

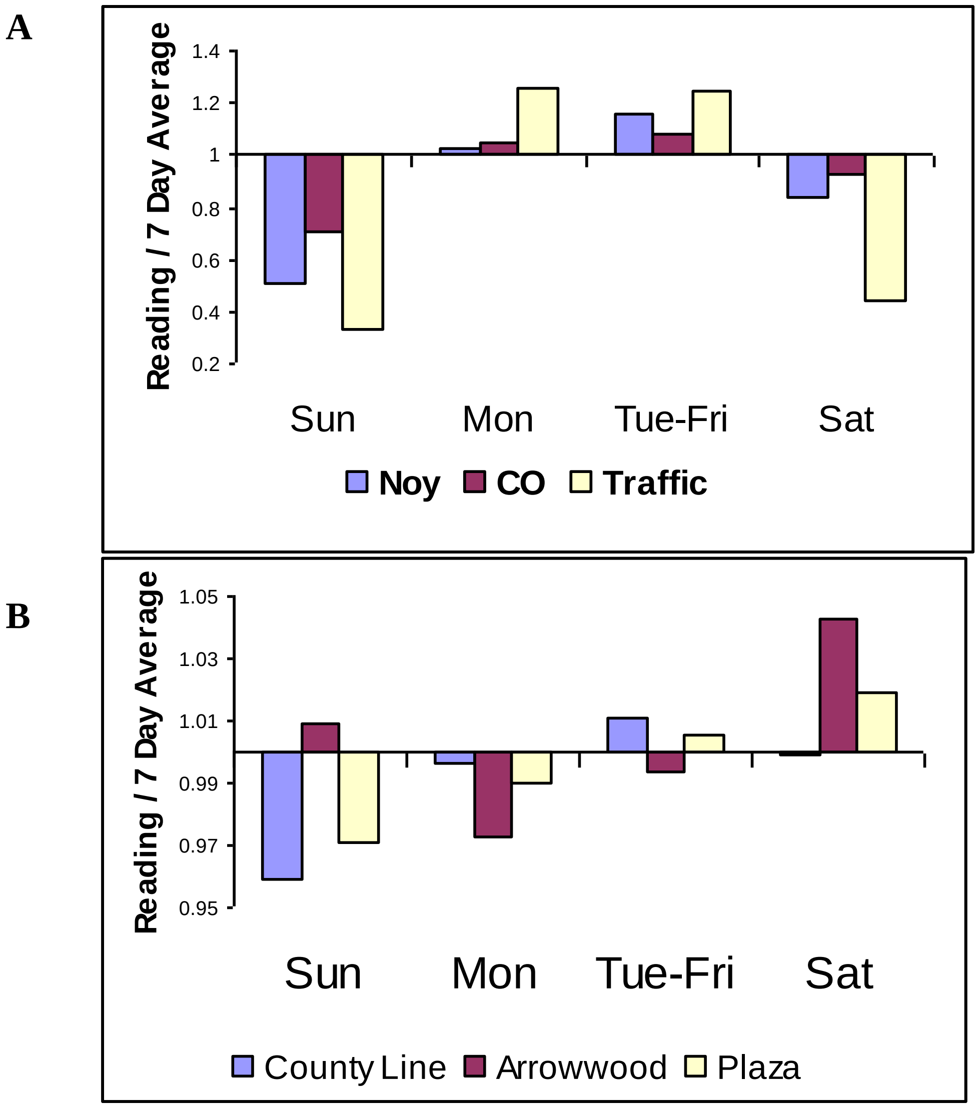

Figure 10. (A) Within week (Mon, Tues-Fri, Sat, Sun) fluctuations for all **(A)** NO_y, CO, traffic, and **(B)** ozone data. Ozone data are graphed separately due to the minor deviations among days.

Figure 10 also shows that at least a 10% decrease in CO concentrations and a 7% decrease in NO_y concentrations occur on weekends at the County and Plaza sites. These reductions in CO and NO_y correspond to the reductions present in traffic on weekends. The collective daily fluctuations for the primary pollutants are compared to the variability in traffic as a percentage of the average day (7-day week) in Figure 9. Not only is there a significant difference in the CO and NO_y concentrations during the weekend compared to weekdays, but there also appears to be a significant difference in the concentrations that are present on Mondays.

P-values for day of week combinations with various parameters are given in Table 2. P-values correspond to the 7:00-8:00 AM averages of traffic, NO_y and CO and the maximum 1-hour ozone average for each day comparison. P-values for Saturday and Sunday traffic counts are significantly different from Tuesday-Friday counts, while Monday patterns are similar (p= 0.7488) to other weekdays.

Table 2. P-values for daily fluctuations in traffic, ambient levels, and power plant NO_x emissions

Day Comparison	Traffic	CO	NO_y	Ozone	Power NO_x
Sun/Tue-Fri	0	0	0	0.3373	0
Mon/Tue-Fri	0.7488	0.9473	0.0381	0.3484	0.0023
Sat/Tue-Fri	0	0.0012	0	0.4683	0.0025

Comparable results are seen for ambient CO concentrations. Interestingly enough, while Monday CO levels are similar (p=0.9473) to other weekdays, Monday NO_y concentrations are significantly different (p=0.0381) from Tuesday-Friday weekday readings. One possible explanation for statistically significant lower NO_y Monday readings than other weekdays is due to lower power plant Monday emissions (p=0.0023) from Tuesday-Friday NO_x outputs. This is particularly true when considering that early Monday morning NO_x emissions from power plants are lower than any other time during the week. For ozone, there is little difference between Tuesday-Friday readings and Saturday, Sunday or Monday. This follows from earlier discussions.

Aspects that were not taken into account when determining these relationships include wind conditions, temperature conditions and biogenic levels of VOC, NO_x due to forests and agriculture activity in the area. From 1990 EPA estimations, Mecklenburg county has greater than 50 Mg/day of VOCs emissions and less than 3 Mg/day of NO_x emissions from biogenic sources.[20] Anjea et al. recently studied ozone patterns for three metropolitan areas in North Carolina including Charlotte. Their study took into account background ozone formation in a rural area from biogenic sources and noticed Charlotte ozone readings were almost double rural background concentrations.[21, 22] In addition they incorporated meteorological statistical averages into their calculations. For Charlotte, they found only southwest winds created significant ozone deviations between a downwind monitoring site and the total area average from neighboring monitors. They attributed the deviations, the number of high ozone days to local mobile sources from nearby highways instead of regional transport.

CONCLUSION

Growth rates (~ 5% annually) in traffic counts from four locations in or near Charlotte, NC, during the 1990's were comparable to those predicted by VMT growth in Mecklenburg county. Observed within week traffic patterns were similar to patterns found on urban roads in Atlanta. Friday and Thursday were the most heavily traveled days having average counts 18% and 12%

higher than 7-day averages. Sunday and Saturday were the least traveled days having average counts 31% and 18% lower than 7-day averages.

For May-September, 1996-2000, power plant NO_x emissions from the four major coal-fired facilities near Charlotte, North Carolina remained stable. During this period, electrical power generated by the two Gaston County plants near Charlotte increased 27%, emissions per unit of power decreased nearly 20% and overall NO_x emissions increased only 4%. Greater power demands from strong economic growth are being offset by improvements in pollution control technology. This is resulting in stable emissions from coal-fired facilities in the region.

Within week variation of NO_x emissions from four coal-fired plants showed peak emissions Tuesday-Thursday that were 10% above the 7-day average. Sundays had the least NO_x emissions, 19% below the daily average, with Mondays and Saturdays having comparable emissions 7.5% below the average. Monday AM emissions from power plants are the lowest within each week; a sharp increase in emission rates occurs during Mondays.

Ambient CO and NO_y readings appeared to be rising in Mecklenburg County between 1994 and 1998. Since 1998, CO AM averages have decreased at both monitoring sites, while NO_y levels have increased at one and decreased at the other. The year-to-year changes in ambient NO_y averages do not appear to reflect changes that occurred in power plant NO_x emissions in the region.

Ambient CO and NO_y readings were significantly lower on weekend days than on Tuesday-Friday. The greatest difference in weekday/weekend CO and NO_y levels occurs during the early morning rush hour period. Monday CO readings were found to be comparable to other weekdays, while Monday NO_y levels were significantly lower than other weekdays. Since Monday traffic patterns were similar to other weekdays, lower Monday NO_y levels may be attributable to the lower Sunday PM and Monday AM NO_x emissions from power plants.

Unlike NO_y and CO, weekday and weekend ozone levels in Mecklenburg County were comparable. For the 1990-1998, May-September period, individual day of week average ozone readings were all within 5% of the 7-day average for each of the three monitoring sites; many were within 2% of the 7-day average. For the three monitoring sites combined, Saturdays had the highest ozone readings with an average that was 2% above the 7-day average; Sundays and Mondays had the lowest ozone readings, with means that were approximately 2% below the 7-day average.

It is not clear why Charlotte ozone levels are not lower on weekends than on weekdays. Traffic is much less, power plant emissions are much lower, and ambient NO_y and CO concentrations are lower. Similar and quite different weekday / weekend effects have been found in other studies. The fact that Charlotte weekend ozone levels are comparable to weekday readings makes it apparent that decreased commuting, fueling, power usuage, and other activities on a given day would appear to have no discernible effect on reducing ozone on that particular day. Policies to encourage voluntary measures by citizens, businesses and government organizations would be better served to focus on lifestyle changes and business practices that are to be implemented throughout an entire summer ozone season rather than on a particular day.

After decreasing during the early 1990's, ambient ozone 1-hour and 8-hour daily maxima steadily increased between 1994 and 1998. For the three Mecklenburg County ozone monitoring sites, ozone average 8-hour concentrations rose between 29% and 34%. Year to year increases in ozone were found to be statistically significant. Long-term trends in ozone were remarkably similar for all three Mecklenburg county sites. Ozone levels decreased in both 1999 and 2000 for all three sites from the previous year.

The 1994-1998 increase in ozone does not appear to be attributable to power plant NO_x emissions that have stabilized in recent years as pollution controls have been installed and as ozone levels have risen. There is no recent evidence from data in the Charlotte region that lower power plant NO_x emissions would necessarily lower ambient ozone levels.

An analysis of hydrocarbon to nitrogen oxide ratios for Mecklenburg County indicates that Charlotte's ozone production appears to be primarily governed by reactive hydrocarbons. During the past five years, nearly all NMOC / NO_y AM ratios have been below 10 with summer median values near five and trending downward. This points to the primary need to lower hydrocarbon emissions—in place of or in addition to reducing NO_x emissions--in Charlotte as the most prudent strategy to lower summertime ozone levels. This conclusion is consistent with a number of studies indicating that ozone production in urban areas depends primarily on hydrocarbons while rural ozone production tends to be more dependent on nitrogen oxides.

The decrease in ozone that occurred during the early 1990's (Figure 6) occurred during a period in which lower fuel vapor pressure requirements were implemented. California has seen a statewide 15-20% decrease in ozone levels between 1992-1994 and 1996-1998, perhaps as a result of the 1995 implementation of a clean fuels program in conjunction with NO_x reductions. Given the uncertainty concerning how the Charlotte's ozone production responds to changes in precursor concentrations and the fact that 1995-1999 median NMOC / NO_y AM ratios in Charlotte were near 5, current policies to focus primarily on reducing NO_x emissions to lower ozone levels in Charlotte may need to be reexamined. Simultaneous reduction of both reactive hydrocarbons and nitrogen oxides would appear to be a more prudent approach, particularly in light of what has occurred in recent years.

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