To the Graduate Council:

I am submitting herewith a dissertation written by Robert Thomas Burns entitled "Impact of Electric Vehicles on Ozone Formation in the Middle Tennessee Area." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Civil Engineering.

Wayne T. Davis

Dr. Wayne T. Davis, Major Professor

We have read this dissertation
and recommend its acceptance:

James T. Arnold

E. Ralph Dorsey

Terry L. Miller

Accepted for the Council:

Carolyn R. Hodges

Associate Vice Chancellor and
Dean of the Graduate School

IMPACT OF ELECTRIC VEHICLES ON OZONE FORMATION IN THE MIDDLE TENNESSEE AREA

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Robert Thomas Burns
August, 1995

DEDICATION

This dissertation is dedicated to my dad, Charles E. Burns, who taught me all of the important things in life (how to hunt, fish and stay honest with the world), before I ever entered a university.

ACKNOWLEDGMENTS

I wish to express my appreciation to my committee (Dr. W.T. Davis, Dr. T.L. Miller, Dr. J.L. Smoot and Dr. C.R. Mote) for their guidance and advice while completing my Ph.D. in Civil Engineering. I would especially like to acknowledge Dr. Terry Miller and Dr. Wayne Davis, who have both withstood my daily questioning (and philosophizing) not only while I completed this dissertation, but for the past five years in general.

I would also like to acknowledge the Tennessee Department of Environment and Conservation. I could not have completed this work without the experience I gained while working on the 1988 and 1990 SIP Inventories, and the UAM Modeling projects which were funded by the Tennessee Department of Environment and Conservation, Air Pollution Control Division.

Abstract

This dissertation analyzes the potential impact of electric vehicles on the formation of ozone in the southeastern United States. While the introduction of electric vehicles into an area reduces emissions of the ozone precursor pollutants, volatile organic compounds (VOCs), oxides of nitrogen (NO_X) and carbon monoxide (CO), these vehicles place an increased power production requirement on electric utilities due to the charging of the batteries used in the electric vehicles. For areas such as the Southeastern U.S. where electric power is produced predominately from coal-fired utilities, this results in increased emissions of NO_X. The objective of this dissertation was to evaluate the impact of this reallocation of NO_X emissions from mobile sources to electric utilities and the potential impact on ozone formation. Different electric vehicle scenarios for the Middle Tennessee Nonattainment area have been developed and analyzed using the Urban Airshed Model (UAM). Scenarios were chosen to reflect realistic expected conditions of electric vehicle impact. The mobile emission inventories were developed using the Environmental Protection Agency (EPA) MOBILE5A emission factor model, for the gasoline vehicle portion, in conjunction with 0 percent and 25 percent penetration rates of electric vehicles in both the light duty gas vehicle (LDGV) and light duty gas truck vehicle (LDGT1) categories, simultaneously. All modeling was conducted for the year 2010. Mobile emission inventories were developed for 2010, and used in conjunction with the 1990 State Implementation Plan (SIP) inventories of VOCs,

NO_x and CO, projected to 2010 using Bureau of Economic Analysis (BEA) factors. The SIP inventory is the basis for all emissions other than mobile sources and utility sources. The 1990 SIP emission inventory was used as the baseline inventory for projection of emissions to 2010 because it is the most current and comprehensive inventory available for the Middle Tennessee area. Coal-fired utility sources were adjusted to reflect the electric vehicle penetration of each scenario. The EPA EPS2.0 emissions preprocessing system was used to preprocess emissions data for UAM modeling. UAM modeling was conducted using high and low wind speed meteorological scenarios. The latest regulatory version of the Urban Airshed Model (UAM-IV) was used for all air quality modeling runs. The modeling domain is centered around the Nashville, Tennessee urban area, and includes 57 Tennessee and Kentucky counties. The relative impact of each electric vehicle scenario on ozone, and the ozone precursor pollutants, VOCs and NO_x, is analyzed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

AFS	Airs Facility Subsystem. The area in the U.S. EPA Airometric Information System which contains point, or facility source, air emission information.
AIRS	The U.S. EPA Airometric Information System. AIRS is the current repository of air pollutant emissions information. The AIRS system is a national database system written in the NATURAL language, and is maintained on the National Computing Center IBM Mainframe in Research Triangle Park, North Carolina.
AMS	Area and Mobile Source Subsystem. The area in the U.S. EPA Airometric Information System which contains area and mobile source air emission information.
BEA	Bureau of Economic Analysis
CAAA	Clean Air Act Amendments of 1990

CB-IV	Carbon Bond - IV is a model which simulates atmospheric photochemistry. The Urban Airshed Model uses the Carbon Bond IV mechanism in order to simulate ozone formation.
CIT	Carnegie / California Institute of Technology grid based ozone model. The CIT is based on the Caltech ozone model.
CO	Carbon Monoxide
DOE	United States Department of Energy
Domain	The geographic area simulated in an Urban Airshed Model run. The modeling domain must be rectangular in shape, and large enough to include sources/and or conditions which will effect the area of interest in the modeling study.
EHV	Electric Hybrid Vehicle
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute

EPS2.0	Emissions Preprocessing System version 2.0. Software utility written in FORTRAN 77 which processes emissions data files from the AIRS system into UAM model inputs.
EKMA	Empirical Kinetic Modeling Approach. The EKMA is a box model developed by the U.S. EPA, and is used to simulate ozone formation. The EKMA uses the Carbon Bond IV mechanism.
EV	Electric Vehicle
LDGT1	Light Duty Gasoline Trucks Class 1 (Gasoline trucks up 6,000 lb GVWR)
LDGV	Light Duty Gasoline Vehicles (Cars)
MOBILE5A	The current U.S. EPA Office of Mobile Sources mobile emission factor model. This model is used to calculate on-road vehicle emission factors in grams/mile. These factors are then multiplied by vehicle miles traveled to estimate mobile emissions.
MTMD	Middle Tennessee Modeling Domain. The MTMD is roughly centered around Nashville, Tennessee, and the five Tennessee nonattainment counties.

OTC	Ozone Transport Commission, consisting of regulators from 12 Northeastern states and initiated by the CAAA of 1990.
ROM	Regional Oxidant Model. Photochemical model which uses the Carbon Bond IV as the mechanism of photochemical ozone formation. This model is run and maintained by the U.S. EPA on a regional scale. The ROM model is intended to produce data which can be used as boundary conditions for smaller UAM domains embedded in the ROM superdomains.
SIP	State Implementation Plan. When an area is classified as nonattainment for a NAAQS pollutant, such as ozone, a SIP is required of the state. The SIP is basically a plan showing how attainment will be achieved. A major part of the SIP is an emissions inventory for the nonattainment area.
SO_X	Sulfur Oxides
TVA	Tennessee Valley Authority
UAM	Urban Airshed Model. Finite difference photochemical oxidant formation model required for ozone formation modeling by the U.S. EPA for moderate or above ozone nonattainment areas. Moderate areas may choose to use

UAM or EKMA. All nonattainment areas designated as serious or above must use the UAM model.

VAX/VMS Hardware/operating system used by the UTK Air Pollution Control workstation. The APC group at UTK operates the Urban Airshed Model on an Digital Equipment Corporation Alpha AXP VAX/VMS workstation.

VMT Vehicle Miles Traveled. VMT is calculated by multiplying the Average Daily Traffic on a given road link by the length of the road link. This gives the number of miles traveled by all vehicles on that road segment in one day.

VOC Volatile Organic Compound. Organics that evaporate at ambient temperatures into the atmosphere. For photochemical modeling purposes VOC's are categorized into photochemically reactive and nonreactive groups. These compounds must be further speciated into their components (olefins, paraffin, etc.) for input into the UAM model.

ZEV Zero Emission Vehicle. Electric cars are currently the only vehicles considered ZEV's.

Chapter 1 : Introduction

1.1 Overview

The forced implementation of electric vehicles in California beginning in 1997 is a controversial topic. The original law in California required that 2percent of annual new automobile sales by automobile manufacturers who sale over 35,000 units in California annually must be "zero emission vehicles" or ZEVs by the 1998 model year, which begins in late 1997 (USA Today, May 2, 1994). By 2001 the California law mandates that 5percent of California automobile sales must be ZEV vehicles, and by 2003 that 10percent of California automobile sales must be ZEVs. In January, 1993 the original California mandate was modified to read that the required percentages of ZEVs must be "produced and delivered for sale" as opposed to actually sold. The law was also modified to allow ZEVs to use fuel fired heaters when operating temperatures are below 41 degrees Fahrenheit (OEDC, 1993). The use of fuel fired heaters had to be written into the California law, because if fuel fired heaters are used the vehicles do not technically meet the description of "zero emission vehicle." At the present time electric vehicles are the only vehicle to meet the "zero emission" requirement (Consumer Reports, 1994). Electric vehicles which are currently available to consumers and corporate buyers, such as the Chrysler TEVan, cost approximately $100,000 per unit and

have a maximum range of 80 - 100 miles before recharging (Consumer Reports, 1994, USA Today, May 2, 1994).

The Ozone Transport Commission (OTC), a policy board created by the CAAA of 1990 composed of regulators from 12 Northeastern states, has petitioned the U.S. EPA to impose the current California ZEV regulations on the 12 states and the District of Columbia which it represents (Suris, 1994 - A). The mandated sale of electric vehicles is strongly supported by the Electric Power Research Institute (EPRI), and electric utilities in general. Utilities in California planned to use "ratepayer recovery" to pay for the power transmission and charging infrastructure which will be necessary to support electric vehicles. Consumer groups were successful in getting a bill passed in both the California House and Senate which requires that the Public Utility Commission must show that ratepayers would benefit in tangible ways, such as reliability, safety or cost reduction, before money from their monthly electricity payments could be diverted to subsidize electric vehicles (The Wall Street Journal, September 9, 1994).

The controversy over electric vehicles increased when a draft EPA report was circulated which stated that the use of electric vehicles in the Northeastern United States would actually increase some pollutant emissions, rather than reduce them due to the coal-fired utility base used to produce most of the electric power in the Northeastern United States (Suris, 1994 - B). The Northeastern States for Coordinated Air Use Management (NESCAUM), which supports the implementation of laws mandating electric vehicle sales in 12 Northeastern states, quickly charged that the EPA report was

"clearly biased" against electric vehicles and that EPA had "failed to seek technical advice from key experts in the electric vehicle field" (Alcohol Week, 1994). NESCAUM indicated that the U.S. EPA report used electric vehicle energy consumption figures generated by a computer model, rather than from real electric vehicle measurements. The NESCAUM report also stated that the EPA report "overstated NO_x emission rates by 300percent" (Alcohol Week, 1994).

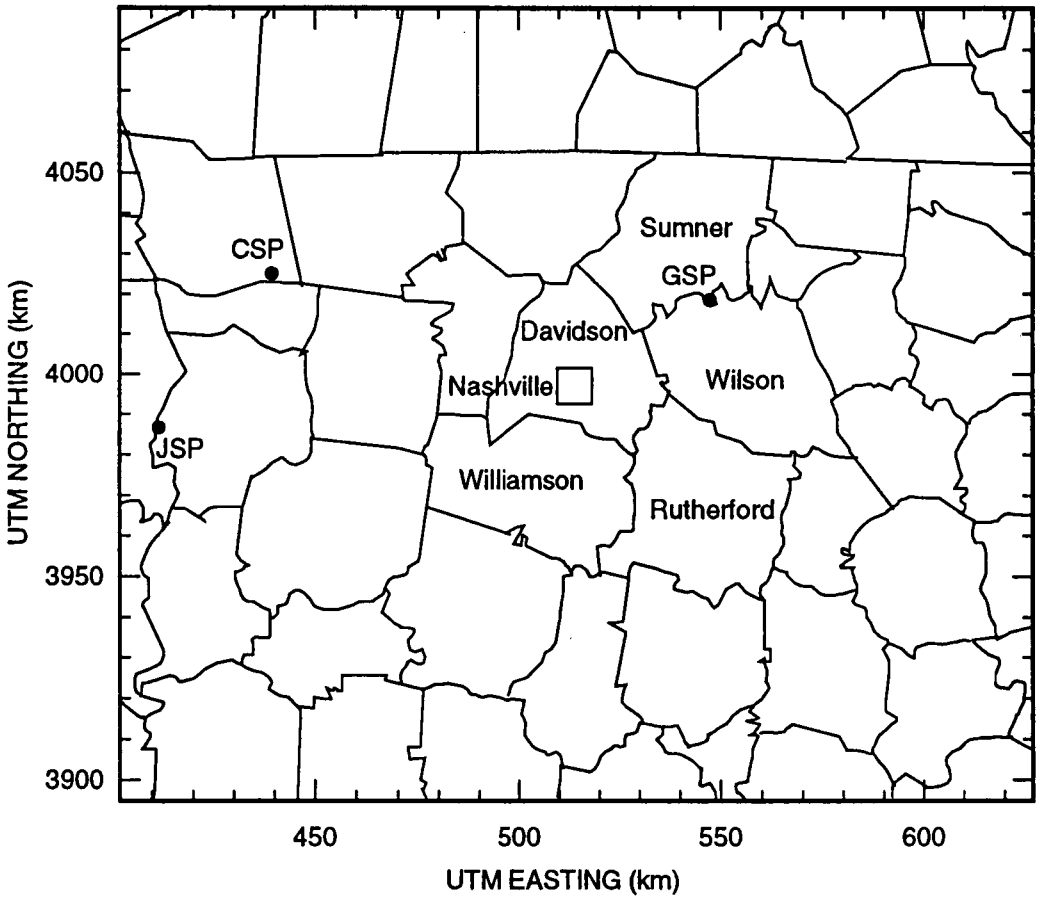
The purpose of this study is to analyze the potential impact, positive or negative, of the use of electric vehicles in the Middle Tennessee Ozone Nonattainment area, which is typical of other areas in the southeastern United States. This study utilizes electric vehicle energy consumption values consistent with those measured from current demonstration full size EVs. This study also uses projected future year utility loads provided by the Tennessee Valley Authority (TVA), and takes into account NOx reduction technology currently being installed at TVA coal-fired utility sources within the study area.

In order to determine the potential impact of electric vehicles on the formation of ozone in the Middle Tennessee Nonattainment Area, different electric vehicle scenarios were developed and analyzed using the Urban Airshed Model (UAM). Scenarios were chosen to reflect realistic expected conditions of electric vehicle impact. The mobile emission inventories were developed using the EPA MOBILE5A emission factor model, in conjunction with 0percent (base case) and 25percent EV penetration rates of electric vehicles in both the light duty gas vehicle (LDGV) and light duty gas truck vehicle

(LDGT1) categories, simultaneously. The fleet average gasoline vehicle emissions factors were adjusted to reflect sales of EVs beginning in the year 2000. All modeling was conducted for the year 2010. Mobile emission inventories developed for 2010, were used in conjunction with the 1990 State Implementation Plan (SIP) inventories of VOCs, NO_x and CO, projected to 2010 using Bureau of Economic Analysis (BEA) factors. The SIP inventory is the basis for all emissions other than mobile sources and utility sources. The 1990 SIP emission inventory was used as the baseline inventory for projection of emissions to 2010 because it is the most current and comprehensive inventory available for the Middle Tennessee area. Coal-fired utility sources were projected to 2010 using load projections provided by the Tennessee Valley Authority for the three coal-fired power plants located inside the modeling domain. The utility emissions were then adjusted to reflect the added load due to the electric vehicle penetration of each scenario. The EPA EPS2.0 emissions preprocessing system was used to preprocess emissions data for the UAM modeling. UAM modeling was conducted using both high and low wind speed meteorological scenarios. The latest regulatory version of the Urban Airshed Model (UAM-IV) was used for all air quality modeling runs. The modeling domain is centered around the Nashville, Tennessee urban area, and includes 57 Tennessee and Kentucky counties. The relative impact of each electric vehicle scenario on ozone, and the ozone precursor pollutants, volatile organic hydrocarbons (VOCs) and oxides of nitrogen (NO_x) is shown.

1.2 Background

The study area, Nashville, Tennessee, is currently a moderate non-attainment area for ozone. The modeling domain is 230 kilometers wide (east - west), and 200 kilometers deep (north - south) and is roughly centered around the metropolitan Nashville area. Figure 1 shows the Middle Tennessee Modeling Domain (MTMD), which is composed of 44 Tennessee counties and 13 Kentucky counties. The location of the three TVA power plants is also noted in Figure 1. The five Tennessee counties of Davidson, Rutherford, Sumner, Williamson and Wilson are designated nonattainment for ozone by the U.S. EPA (Davis and Miller, 1992). Three coal-fired power plants lie within the modeling domain, and are the major providers of electric power to the area. The domain is subdivided into 46 x 40 cells, 5 kilometers on a side for UAM modeling. These domain dimensions are the same as those used by the University of Tennessee for the UAM State Implementation Plan (SIP) modeling of the Nashville Nonattainment area. Previous modeling has shown that the Nashville area is sensitive to NO_x emissions (Early, 1994; Kaminski, 1994). UAM modeling of the MTMD has shown that ozone formation is more responsive to changes in NO_x emissions than changes in anthropogenic VOC emissions. The MTMD, like most areas in the southeastern U.S., has a large amount of biogenic hydrocarbon emissions from vegetation. In 1990 biogenic emissions were estimated to account for 74percent of the VOC emissions in the MTMD (Davis, *et al.*, 1993 - A). In this study area, and characteristic of the southeast, the two dominant



CSP - Cumberland Steam Plant
GSP - Gallatin Steam Plant
JSP - Johnsonville Steam Plant

Figure 1. Study Modeling Domain

NO_x source types are coal-fired power plants and mobile sources. The introduction of electric vehicles will alter the magnitude of NO_x emissions from the mobile source category and electric utilities. In this study, the emission changes associated with the introduction of electric vehicles were modeled using the UAM system to determine the net outcome on air quality in the area.

Electric vehicles (EVs) have no significant emissions of VOCs, NO_x or CO at the vehicle. Electric vehicles may generate emissions indirectly, however when the energy used to charge the batteries of the EVs is produced by a power plant with air emissions of pollutants. Mobile sources replaced by electric vehicles have their emissions replaced by increased power plant emissions caused by the need to generate electricity to power the EVs. The introduction of EVs will cause emission patterns to change both spatially and temporally.

Chapter 2 : Review of Ozone Formation

2.1 Introduction

Ozone concentrations in excess of the NAAQS (National Ambient Air Quality Standards) continue to be a prevalent national problem. Tropospheric ozone was first recognized as a problem in the 1940's due to damage to vegetables in California (NRC, 1991). The first research of significance on this subject was done in the 1960's, and 1970's when Los Angeles, California began experiencing high concentrations of ozone and other oxidants due to emissions from a rapidly expanding population. This problem is not unique to North America. Elevated ozone concentrations have been noted or studied in Australia, New Zealand, Japan, many Western European countries, and basically in all major urban areas in the world.

Ozone control strategies have historically advocated the removal of reactive hydrocarbons. Hydrocarbon or VOC (Volatile Organic Compound) controls were supported and mandated by the U.S. EPA in areas which exceed the NAAQS for ozone. This is still the case. The 1990 Clean Air Act Amendments mandate a 15 percent VOC reduction in all Moderate or above ozone nonattainment areas in the United States by 1996. The fact that 26 urban areas in the country are currently listed as moderate or above in regard to ozone nonattainment, indicates that exceedences of the NAAQS ozone standard of 120 ppb are still a problem in the United States. However, research done with gridded photochemical models now indicates that NO_x reductions may be

required to significantly reduce ozone for many areas of the country. This review will focus on the chemistry of NO_x in the atmosphere in regard to the formation and scavenging of tropospheric ozone in an effort to understand its importance in the accumulation of atmospheric oxidants.

2.2 Background

Ozone is a naturally occurring gas in both the stratosphere and the troposphere. In the stratosphere, ozone is maintained by a series of reactions referred to as the Chapman mechanism, named for Chapman who identified the reactions in 1930 (Lefohn, 1991).

In these reactions ozone is produced by the photodissociation of diatomic oxygen, and the recombination of a monatomic oxygen with a diatomic oxygen, as shown in reactions 1 and 2.

1. $O_2 + h\nu \rightarrow O + O$

2. $O + O_2 + M \rightarrow O_3 + M$

Energy from the sun is represented by $h\nu$, where h is Planks constant (6.62E-34 J*s) and ν is the wavelength of photons emitted from the sun (Wark, 1981). M represents an energy absorbing body, usually oxygen or nitrogen (NRC, 1977). It is important to note that light at wavelengths less than 242 nm (ultraviolet light) is required to photodissociate diatomic oxygen. This reaction takes place in the stratosphere, 11 to 50

km above the earth's surface. The highest ozone concentrations are found 20 - 30 km above the earth's surface (NRC, 1991). Figure 2 shows a profile of the ozone concentration vertically through the atmosphere. The highest ozone levels in the stratosphere are commonly referred to as the stratospheric "ozone bulge" (NRC, 1991). The mixing ratio defined in this figure is simply the ozone concentration expressed in molecules of O_3 / molecules of air. The mixing ratio and ozone partial pressure peak at different altitudes because the atmosphere thins exponentially with height (NRC, 1991).. Because the light energy in the ultraviolet band is filtered out in the stratosphere, tropospheric ozone does not form by photodissociation of diatomic oxygen.

Ozone in the troposphere can come from several sources. Lightning strikes, transport downward from the stratosphere and production from photochemical smog reactions are all means by which ozone enters the troposphere. Ozone is a natural trace gas in the troposphere. Ozone levels of 20 - 30 ppb are considered to be naturally occurring in the troposphere, compared with concentrations of 10,000 ppb in the highest areas of concentration in the stratosphere (NRC, 1991).

There has been concern for some time about reductions in the stratospheric ozone concentration. There is now growing concern about increases in tropospheric ozone concentrations. Ozone was measured near Paris France from 1876 to 1910 (NRC, 1991). During this time period tropospheric ozone was thought to promote health due to its disinfectant properties. Re-calibration of the ozone measurement

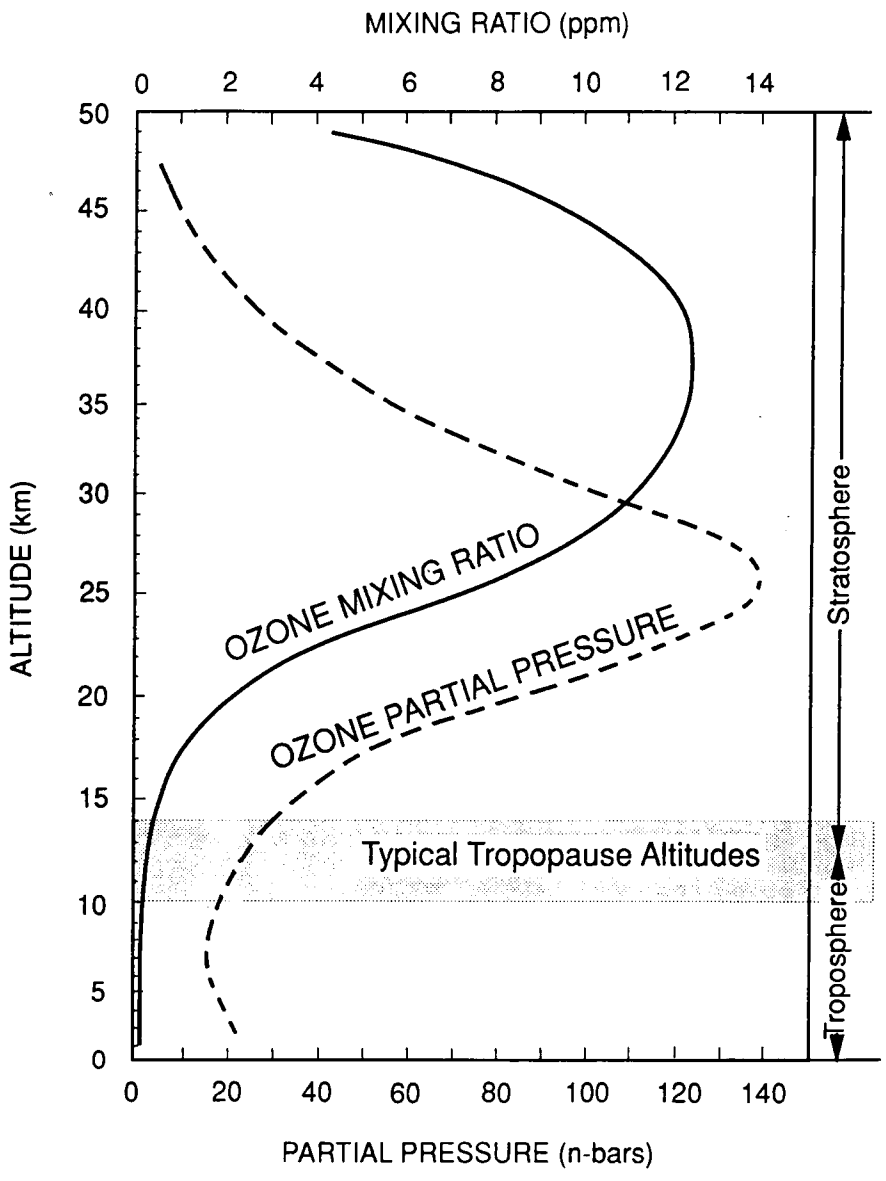


Figure 2. Vertical Ozone Distribution

method used in Paris, before the turn of the century, shows that 100 years ago concentrations of 10 ppb were common for this area. Comparing this to modern data in the area, an annual average increase of 1 to 2 percent has occurred over the last 30 years (NRC, 1991). Of the three methods listed above (lightning, downward transport and photochemistry) incursions of stratospheric ozone and tropospheric photochemistry are considered the most important. Air parcels with high ozone concentrations are injected into the lower atmosphere by events termed "tropopause folds" (Lefohn, 1991). These events are caused by large scale eddies in the jet stream during cyclonic activity. Portions of the stratosphere are forced, or folded, into the troposphere. These events are naturally occurring and can cause high ozone concentrations in localized areas.

The trend of increasing tropospheric ozone concentrations over the past 30 years is attributed to oxidant forming photochemistry fueled by anthropogenic emissions of pollutants into the atmosphere. Ozone concentrations due to tropospheric photochemical reactions can reach levels harmful to humans. In the early 1970's ozone concentrations above 600 ppb occurred numerous times in the Los Angeles area (Wark and Warner, 1981). Photochemical smog has been recognized as an increasing problem in many urban areas in the world. The chemistry which forms ozone in the troposphere is very complex, with hundreds of known reactions. A varied array of hydrocarbon compounds can yield themselves to the production of atmospheric oxidants. The critical path reactions to the accumulation of ozone always involve NO and NO_2, collectively

referred to as NO_x. Because of this dependence on NO_x, this review will look at the role of NO_x on ozone formation and destruction in the lower atmosphere.

2.3 Chemistry of Ozone Formation

The formation of ozone in the troposphere is controlled by two cyclic processes, the ozone cycle and the hydrocarbon cycle. Both of these processes are strongly dependent or interrelated to NO_x chemistry. The actual production of ozone is controlled by the availability and photodissociation of NO_2 in the atmosphere. The hydrocarbon cycle strongly influences the oxidation of NO to NO_2 in the atmosphere. The basic ozone cycle in the troposphere can be described by reactions 3, 4 and 5.

3. $NO_2 + h\nu \xrightarrow{k1} NO + O$

4. $O + O_2 + M \xrightarrow{k2} O_3 + M$

5. $NO + O_3 \xrightarrow{k3} NO_2 + O_2$

Where k3 = 0.48 (maximum sunlight intensity -1), k4 = 2E-5 ppm -2 min -1, and k5 = 23 ppm -1 min -1 (Levy, 1978). By assuming steady-state, the tropospheric ozone concentration can be described by reaction 6.

6. $$O_3 = \frac{k_5}{k_3} * \frac{NO_2}{NO} = .02 * \frac{NO_2}{NO} ppm$$

Reaction 6 (Levy and Spicer, 1978) shows that ozone production is a function of the NO_2/NO ratio and the sunlight intensity. As long as the NO_2/ NO ratio is less than 1 the ozone concentration will remain low. Ratios of NO_2/ NO from anthropogenic sources

are in the range of 9:1 to 10:1 (Wark and Warner, 1981). The light required in reaction 3 for the photolysis of NO_2, is from wavelengths of less than 430 nm. Light with a wavelength greater than 290 nm does reach the lower atmosphere, and NO_2 is a very strong absorber of sunlight. The average turnover half-life of NO_2 at a latitude of 40 ° is reported to be 1.4 minutes, meaning that in 1.4 minutes 50percent of the available lower atmosphere NO_2 can be photodissociated and reformed by equations 3 and 5 (NRC, 1991). Equations 3, 4 and 5 are the basis for ozone formation in the lower atmosphere. This set of cyclic reactions is shown graphically in Figure 3. This cycle does not explain the accumulation of high levels of ozone (hundreds of ppb) in the lower atmosphere. Reaction 5 completes the cycle by consuming ozone, and is known to be a fast reaction (NRC, 1977). A small ozone level would be reached, and as the ozone formed, NO would scavenge the ozone by forming NO_2 and O_2, and the cycle would then repeat with the photodissociation of NO_2. The rate at which NO oxidizes to form NO_2 depends on the concentration at which NO is present, and what other chemicals are present. The half-life of NO at concentrations of 1000 ppm and above is a few seconds due to the nearly stoichiometric conversion of NO to NO_2 (Wark and Warner, 1981). At normal ambient concentrations, normally less than 0.5 ppm, the atmospheric half-life of NO is around 100 hours. If NO is converted to NO_2 by this direct oxidation a small ozone concentration would appear, very quickly (reactions 3 and 4 are also fast (Wark and Warner, 1981)), and the concentration of NO_2 would decrease as ozone increases. Figure 4 shows actual data from Los Angeles on July 19, 1965 (NRC, 1977). This is a

Steady State Reaction Cycles Involving NO_2 , NO and O_3

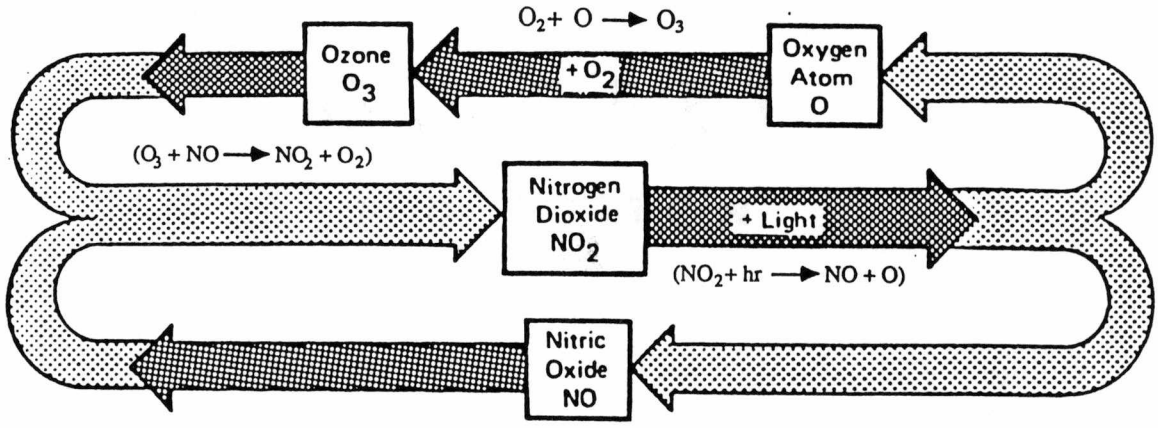


Figure 3. Steady State Ozone Reaction Cycles in an Un-Polluted Atmosphere

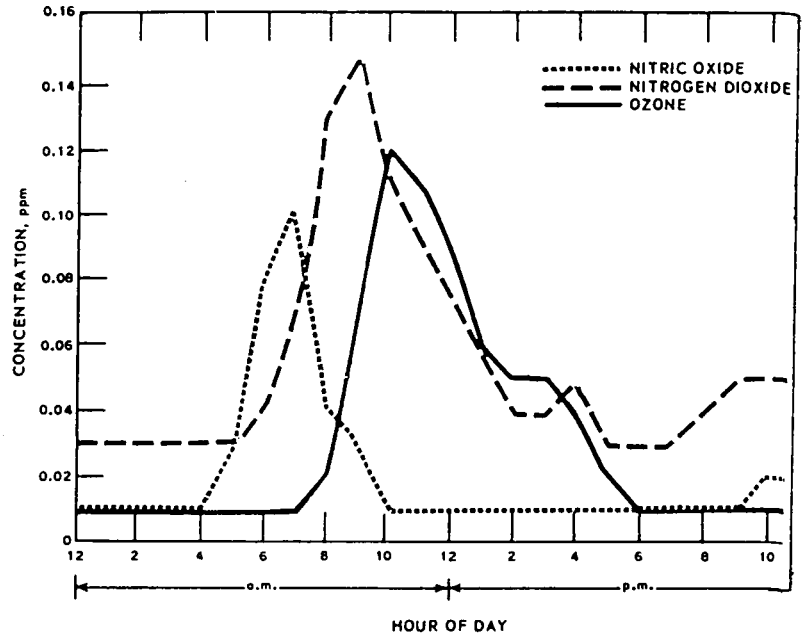


Figure 4. Diurnal Pollutant Variation in Los Angeles, 1965

classic curve found in many texts which cover photochemical oxidant formation. NO, NO_2 and ozone in ppm are plotted against time in hours. This curve shows that as the ozone increases so does the NO_2 and that NO reaches a constant value when the ozone peaks. The reason that what should theoretically happen, based on the ozone cycle, and what really happens, as shown in Figure 4 do not match is due to the oxidation rates of NO in a "real atmosphere." Direct oxidation of NO would control in an unpolluted atmosphere. This is not the case in a polluted atmosphere. The term "polluted" in this case refers to hydrocarbons in the atmosphere. If only NO_x were present, then the direct, but slow (100's of hours) oxidation would control the oxidation process. Figure 4 shows that NO is rapidly oxidized to NO_2. This rapid oxidation creates NO_2, which is needed to provide a monatomic oxygen atom for ozone formation to occur. The oxidation of NO into NO_2 also simultaneously removes NO from the cycle, which served as the natural sink for ozone and prevented large accumulations in the atmosphere. Hydrocarbons cause a rapid oxidation of NO indirectly by their reaction in the atmosphere to form peroxy radicals, designated by the form RO_2. This reaction of hydrocarbons in the atmosphere is usually referred to as the hydrocarbon cycle (Levy and Spicer, 1978).

There are hundreds of known hydrocarbons in the atmosphere which under-go chain reactions, each time forming new products and feeding other reactions. These reactions ultimately lead to the fast oxidation of NO, among other things. The ozone cycle with the addition of the peroxy radical is shown in Figure 5. This figure is a gross

Reaction Cycles Involving Organic Oxidation of NO_2 with Ozone Buildup

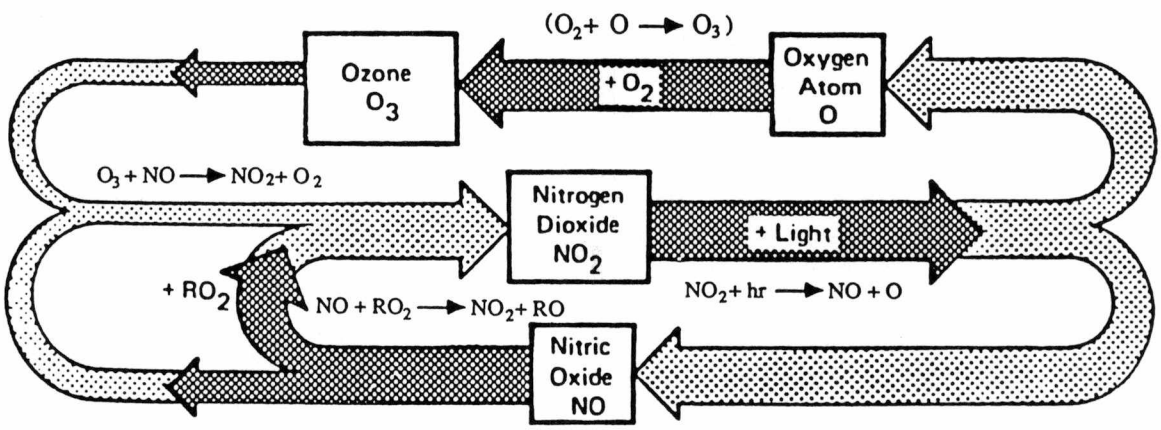


Figure 5. Reaction Cycles Involving the Organic Oxidation of NO

over simplification of free radical interactions with NO, but the general idea that these free radicals cause the removal of NO by oxidizing it into NO_2 is correct.

The methane oxidation cycle of the unpolluted troposphere is the basis for the model of the polluted troposphere. In this cycle the hydroxyl radical, OH, reacts with methane to form water and CH_3 shown in reaction number 7.

7. $$OH + CH_4 \rightarrow H_2O + CH_3$$

The generation of the OH radical needed to start this cycle in the troposphere is from the photodissociation of ozone and the combination of monatomic oxygen with water vapor, shown in the following two reactions, 8 and 9

8. $$O_3 + hv \rightarrow O_2 + O$$

9. $$O + H_2O \rightarrow 2OH$$

The photolysis of ozone occurs at wavelengths of light less than 319 nm (NRC, 1991). The methyl radical formed in reaction 7 combines with diatomic oxygen very quickly to form a methyl peroxy radical, CH_3O_2, where M is again N_2 or O_2, acting as an energy absorbing body, shown in reaction 10.

10. $$CH_3 + O_2 + M \rightarrow CH_3O_2$$

As shown in reaction 11, methyl peroxy radicals in turn oxidize NO into NO_2 and form the CH_3O radical.

11. $CH_3O_2 + NO \rightarrow CH_3O + NO_2$

The methyl peroxy radical can also react with NO_2, the hydro-peroxy radical, HO_2, and organic peroxy radicals, RO_2. In the reaction with NO_2, methyl peroxynitrate, CH_3OONO_2, is formed, shown in reaction 12.

12. $$CH_3O_2 + NO_2 \rightarrow CH_3OONO_2$$

This reaction is important because it is thermally reversible. At ambient ground level temperatures and atmospheric pressure methyl peroxynitrate has a life of approximately 1 second before it thermally dissociates back into NO_2 and the methyl peroxy radical. However, at lower temperatures and pressures which are found higher in the troposphere methyl peroxynitrate can have a life of about 2 days (NRC, 1991). Methyl peroxynitrate can act as a source of NO_2 as it thermally decomposes.

The chemistry of the hydrocarbon cycle includes hundreds of VOC compounds and multitudes of free radicals which lead to the oxidation of NO. A full treatment of organic atmospheric chemistry is beyond the scope of this review. Organic chemistry of the atmosphere and the hydrocarbon cycle are current topics of much research, because they are not yet fully understood. An understanding of the methane cycle however, yields an understanding of the role of hydrocarbons in the role of oxidant formation.

Reactivity is a term often used in text or discussions on oxidant formation. When VOCs are said to be very reactive or non-reactive, it deals with their lifetime in the atmosphere. We have used the methane cycle to base an understanding of hydrocarbon reaction upon, but methane is commonly listed as non-reactive in the oxidant formation process. The term non-reactive is misleading, because all hydrocarbon compounds are

reactive in the atmosphere. The lifetime of methane in the troposphere due to reaction with the hydroxyl radical is about 12 years (NRC, 1991). This is obviously far too slow to play any role in an ozone accumulation which occurs in hours. At the other end of the spectrum are compounds such as isoprene, which is a naturally occurring VOC compound emitted from vegetation. Isoprene has an atmospheric lifetime of approximately 1.8 hours due to reaction with the hydroxyl radical (NRC, 1991). The hydroxyl radical is only one of many which react with hydrocarbons causing their removal from the atmosphere and the oxidation of NO. Lifetimes of organic compounds are usually listed with respect to the hydroxyl reaction because it is the fastest. Table 1 lists the atmospheric lifetimes of 21 VOCs due to reaction with the hydroxyl radical, as well as NO_3, ozone and light energy. The NRC reports that the hydroxyl radical used in the hydrocarbon cycle is formed in reaction 8, the photodissociation of ozone. This statement is somewhat misleading. The photodissociation of ozone is a contributor of the hydroxyl radical, and is probably the most important source in a clean atmosphere. After VOCs show up in the troposphere and the hydrocarbon cycle begins, many of these reactions form OH radicals as a product. It should also be noted that oxidants other than ozone, such as peroxyacetylnitrate (PAN), hydrogen peroxide (H_2O_2) and PBN, are formed due to atmospheric hydrocarbon chemistry, but ozone is considered to be the most important due to the concentrations it is able to reach in the troposphere.

Table 1. Lifetimes of Tropospheric VOCs When Reacting with OH, NO_3, and O_3

Lifetimes of Tropospheric VOCs When Reacting with OH, NO_3, and O_3			
VOC	**OH**	**NO_3**	**O_3**
Propene	7.0 Hours	4.9 Days	1.5 Days
Isoprene	1.8 Hours	50 Min	1.2 Days
Alpha-Pinene	3.4 Hours	5 Min	1.0 Days
Acetylene	19 Days	> 2.5 Years	5.8 Years
Formaldehyde	1.6 Days	77 Days	> 4.5 Years
Acetaldehyde	1.0 Days	17 Days	> 4.5 Years
Acetone	68 Days	*	> 4.5 Years
MEK	13.4 Days	*	> 4.5 Years
Methylgloxal	10.8 Hours	*	> 4.5 Years
Methanol	17 Days	> 77 Days	*

Source: National Research Council, Rethinking the Ozone Problem in Urban and Regional Air Pollution, National Academy Press, 1991.

* Expected to be of negligible importance

Table 1. (Continued)

Lifetimes of Tropospheric VOCs When Reacting with OH, NO_3, and O_3			
VOC	**OH**	**NO_3**	**O_3**
Ethanol	4.7 Days	> 51 Days	*
M- t-butal ether	5.5 Days	*	*
Benzene	12.5 Days	> 6 Years	> 4.5 Years
Tolulene	2.6 Days	1.9 Years	> 4.5 Years
m - Xylene	7.8 Hours	200 Days	> 4.5 Years
Methane	~ 12 Years	> 120 Years	> 4,500 Years
Ethane	60 Days	> 12 Years	> 4,500 Years
Propane	13 Days	> 2.5 Years	> 4,500 Years
n - Butane	6.1 Days	~ 2.5 Years	> 4,500 Years
n - Octane	1.8 Days	260 Years	> 4,500 Years
Ethene	1.8 Days	225 Days	9.7 Days

Source: National Research Council, Rethinking the Ozone Problem in Urban and Regional Air Pollution, National Academy Press, 1991.

* Expected to be of negligible importance

The simulation of ozone formation for regulatory purposes, such as EPA required modeling attainment demonstrations, currently requires the use of the Urban Airshed Model (UAM). The UAM is a finite difference gridded photochemical model. The UAM model considers advective pollutant transport, turbulent diffusion (using concentration gradients), surface removal of pollutants and the photochemistry of ozone formation. The photochemistry of ozone formation is simulated in the UAM by the Carbon Bond IV (CB-IV) mechanism.

The Carbon Bond IV mechanism is a computer algorithm which simulates the chemical kinetics of tropospheric ozone formation. The original Carbon Bond Mechanism (CBM), was initially developed by System Applications, Inc. in 1976. Since that time the Carbon Bond algorithm has been improved and updated by this group. Both the EKMA and UAM ozone formation models have utilized versions of the CBM over time. The current versions of both models utilize the Carbon Bond IV mechanism, which is the most current version of the algorithm. The CB-IV was originally introduced with 80 simultaneous chemical reactions. The current release of the CB-IV contains 98 simultaneous reactions. The Carbon Bond mechanisms were developed and tested using a number of different smog chambers (Gery, *et al.*, 1987).

2.4 Chemistry of Ozone Removal

Ozone removal is usually by one of two processes; gaseous reaction or dry deposition. Reaction 5 with NO will remove ozone from the atmosphere. In a hydrocarbon polluted atmosphere this reaction can be inhibited because of free radical reactions with NO. Ozone removal can occur by this process in the daylight when large concentrations of NO are present, as in power plant plumes. Ozone removal is usually seen in the centers of these plumes due to the scavenging action of NO (McIlvaine, 1994; Early, 1994; Altshuler, 1985). At night time this reaction is an important removal process where anthropogenic NO_x is emitted. Lower levels of NO_x emissions can scavenge at night where they could not during daylight hours because hydrocarbons are usually not emitted at night in concentrations as large as their daytime rate. Nitrogen dioxide, NO_2, can also play a role in ozone removal at night as shown in reaction 13 (Kelly, *et al.*, 1984).

13. $$NO_2 + O_3 \rightarrow NO_3 + O_2$$

During daylight hours NO_2 photodissociates so quickly this reaction is not of significance. It is estimated that this removal reaction only accounts for about 5 percent of ozone removal at night (Kelly, *et al.*, 1984).

In the absence of significant NO emissions dry deposition of ozone will control the ozone removal process. Ozone flux to the surface can be quantified using the ozone concentration by reaction 14 (Kelly, *et al.*, 1984).

14. $$F = V_d * [O_3] = kh*[O_3]$$

Where F is the ozone flux to the ground, V_d is the deposition velocity, k is the first order rate coefficient and h is the mixing height. Literature suggest that ozone deposition velocities range from 0.06 to 0.80 cm/s (Kelly, *et al.*, 1984). The rates vary over different land use patterns. Dry deposition rates include vegetative uptake of ozone. Deposition velocities are highest over vegetation such as alfalfa and juniper and low over surfaces such as sand or water (DOE, 1984).

2.5 VOC / NO_X Ratios

A VOC / NO_x ratio is often listed in SIP inventories for non-attainment areas. The VOC / NO_x ratio can be an indicator of whether an area will be VOC limited or NO_x limited, meaning that the maximum amount of ozone produced will be limited by a shortage of NO needed to be oxidized into NO_2, or a shortage of VOCs to oxidize the NO into NO_2. In either case ozone production is controlled by a shortage of NO_2 to drive the ozone cycle, but for different reasons. Since emission inventories are required in nonattainment areas, VOC / NO_x ratios would seem to be easily obtained. In reality an accurate value of this ratio is very hard to determine. The ratio which will determine which side of the cycle is limiting is a real time ambient ratio. This ratio is dynamic in both space and time. Ratios from emission inventories, even those done with the latest techniques and methodologies, are not necessarily reflective of ambient ratios for several

reasons. The methods used in inventories are many times best guesses. Many of the emissions are based on emission factors which are admittedly good within an order of magnitude. Another reason the inventory VOC / NO_x ratios can be misleading (even if the inventory was perfect) is because of the reactive chemistry occurring in the atmosphere. The term "VOC" includes many different hydrocarbon species. The atmospheric lifetimes of these species can vary from years to days. The speciation of the VOC component of the ratio is very important. Ambient measurements are sometimes used to calculated these ratios. Most areas do not have historical VOC, or ROG (Reactive Organic Gases) data, but some do. These data are available in areas of California and Michigan. The use of these data for anything more than an indicator is suspect. The Lake Michigan Oxidant Study (LMOS) has used ambient VOC/NO_x data to "correct" their inventory (UAM Modeling Convention, 1994). Hydrocarbon compounds react and disappear after they are emitted, and other loss mechanisms are present such as deposition, migration into other phases, etc. The flux of these compounds and NO_x vary temporally and spatially. The movement of these compounds is controlled by widely varying meteorological conditions. Any calculated ratio would change both temporally and spatially. Because of the different techniques used to develop these ratios, there is no clear agreement on what ratio indicates the break between NO_X or VOC limiting conditions. Research at UTK has shown negligible response to anthropogenic VOC reduction, with an inventory VOC / NO_x ratio of roughly 3:1 in the MTMD (Davis, *et al.*, 1993).

2.6 Sources of NO_X

NO_x emissions occur from both anthropogenic sources, as well as natural sources such as soil NO_x. NO_x is formed whenever fuel is burned in air. Total anthropogenic NO_x emissions in the United States are roughly evenly divided about between large stationary sources (power plants and industrial boilers) and mobile sources (Cooper and Alley, 1986). As mentioned earlier NO_x from combustion sources is 90 to 95 percent NO. There is controversy as to the importance of naturally occurring NO_x emissions. The current EPA UAM BEIS model used to predict natural emissions for EPA required regulatory ozone modeling does include soil NO_x emissions. The NO_x emissions predicted by this algorithm are a function of soil temperature and wind speed.

Power plants and mobile sources are the major contributors of NO_x emissions, but their emission patterns differ both spatially and temporally. Mobile source NO_x emissions are spread across large areas as line sources since they occur on roads. They follow distinct temporal patterns, usually with a peak in the morning and afternoon as people commute to work and back. Power plant emissions originate from large stationary sources. For many cases, power plant emission rates are nearly constant with time. Variability in power plant emissions primarily depend on the plant's use. The largest are usually run as base load plants. Base load plants are usually operated near full capacity. Smaller or less efficient plants may be used as peaking plants. Consumer

power consumption follows daily patterns of increase during the day and decrease at night.

At night, there is no energy from the sun to photodisassociate NO_2, so ozone production ceases. Most anthropogenic VOC sources do not emit at night, and the most reactive biogenic species (isoprene), is a function of light as well. The stoma of a plant must be open for isoprene to be emitted (NRC, 1991). Emissions of NO dominate during the night, as power plants continue to operate and mobile sources continue, even if at a lesser degree. During these hours any residual ground level ozone produced earlier in the day can be quickly scavenged by NO to form NO_2 and diatomic oxygen. Animation sequences developed from UAM simulations at UTK show this quick scavenging at the ground level (Burns, *et al.*, 1994). Ground level ozone monitors show that ozone levels are scavenged to well below 20 ppb at night. In the visualizations mentioned above, all of the interstate links and individual point sources of NO_x are easily discernible as the scavenging takes place.

In large power plant plumes the NO concentration is great enough to scavenge ozone in the daytime as well. Power plant plumes usually show ozone depletion in the centers of the plumes for varing distances downwind from the source (McIlvaine, 1994; Early, 1994). How extensive this scavenging is depends on the magnitude of the source as well as meteorological conditions. Farther downwind and at the edges of the plumes where the NO concentrations are lower, and mixing with hydrocarbon laden air occurs, ozone quickly forms and accumulates. Researchers indicate that the relative ozone

increase from large power plant plumes can be from 20 - 50 ppb (Altshuller, 1985; McIlvaine, 1994; Early, 1994). McIlvaine reported calculated maximum additional ozone formation of 34 ppb using an Empirical Kinetic Modeling Approach (EKMA), Early reported additions of 25 - 35 ppb using UAM, and Altshuler reported a range from 20 to 50 ppb. With background concentrations in many urban areas ranging from 60 to 100 ppb, incremental increases of the reported magnitudes could have a signifigant impact on ozone concentrations. The curves shown in Figure 6 were developed by McIlvaine, and show that there is an optimum NO concentration, past which the ozone mechanism is saturated and scavenging occurs. This makes theoretical sense. This data was developed modeling a NO_x plume interacting with a representative hydrocarbon background for the southeast. If the NO concentration is increased in a stationary plume, the optimum VOC / NO_x ratio will be found farther downwind or farther out in the edge of the plume and the maximum ozone concentration should be similar to that of the original plume. At the location of the original maximum the ozone concentration should decrease as scavenging occurs when the NO concentration reaches levels high enough to cause scavenging.

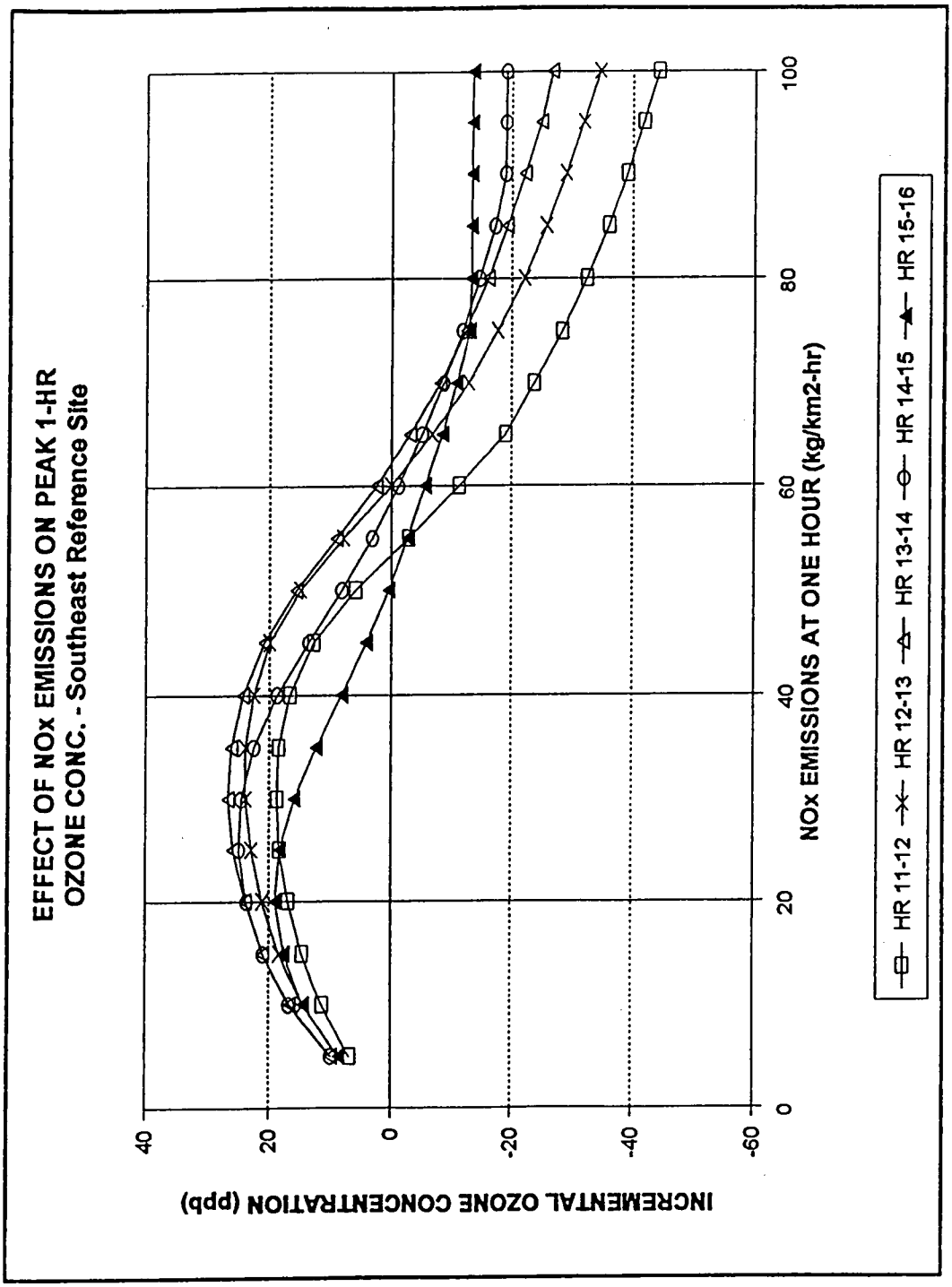


Figure 6. Effect of NOx Emissions on Ozone

2.7 Summary

NO_x chemistry is the mechanism by which photochemical ozone is formed. Ozone levels of any concern are not realized without the free radical reaction products of the hydrocarbon cycle of the polluted atmosphere. A more complete understanding of atmospheric hydrocarbon chemistry will probably improve current photochemical models. The current understanding of the importance of anthropogenic NO_x emissions is providing agencies with other control strategy options, but none appear easy to implement.

Apparent progress has been made in reducing ozone concentrations in some urban areas. For areas like Nashville Tennessee, although no long term trend in ozone concentration reductions appears to have begun, research has lead to a better understanding of the problem. In Los Angeles where ozone concentrations still exceed the standard by a factor of 3, progress must be admitted because 20 years ago the standard was exceeded by a factor of 5. This indicates that in Los Angeles VOC controls have helped, but the current standard has not been met. It should be noted that control strategies which work in one urban area may not work in another because of different mixes of NO_X and VOCs in each area.

It has been shown that in some urban areas anthropogenic VOC emissions are not required to break the ozone standard, but NO_x emissions are required to produce ozone (Smith, 1992; Kaminski, 1994). As emphasis shifts to NO_x controls a new

problem arises. Large hydrocarbon emitters are found in a large mix of source categories. The largest NO_x emission sources are found in two essential processes, transportation and power production. NOX emissions from these two source categories has traditionally been difficult and expensive to control.

Chapter 3: Review of Electric Vehicle Studies

3.1 Overview

The following review summarizes the results of reported studies, or portions of studies, which focused on predicted air quality changes from the use of electric vehicles. The review covers what EV energy consumption factors were used, and how were they arrived at. Also how the energy for the EVs was produced and the emissions from this production accounted for is summarized. Reported ozone precursor emission changes and their impact on ozone concentrations are reviewed in each study. The manner in which any predicted EV impact on ozone concentrations is arrived at is identified. A study is also included which predicts the impact of EVs on electric utility load patterns.

Nine papers describing EV studies, published from 1989 to 1994, were reviewed and included. A 1978 EPRI study on the impact of EVs on utility loads is also presented. Also a draft study and recent study, which could not be obtained, the EPA and NESCAUM studies, will be mentioned. The EPA study has not been finalized and as such has not been published. Both studies have been quoted by the media. The above listed studies will be summarized from most recently published to the oldest.

3.2 Study Summaries

3.2.1 EPA and NESCAUM Reports

Neither of these reports were available at the time of this writing. Limited information was available from published comments on the draft versions of these reports. No information was available as to specific energy consumption values or utility emissions.

The draft EPA report on electric vehicle emissions indicates that the use of electric vehicles could increase the amount of some pollutants into the atmosphere when compared to the current automobile emission standards. The Northeastern States for Coordinated Air Use Management (NESCAUM) group responded by stating that the EPA report is flawed because; 1) the utility emissions factors used were a 1992 average and NESCAUM expects power plants to be 4 times cleaner in the future, 2) that EV energy consumption was overstated from 50 percent - 130 percent by the EPA because a computer model was used rather than actual energy consumption measurements from current vehicles, and 3) that the "emissions benefits" from gasoline cars was twice that used by NESCAUM because the EPA study incorporated inspection and maintenance (I / M) programs and reformulated gasoline programs which electric vehicles would not require (Alcohol Week, 1994).

In the first comment attributed to the NESCAUM response to the EPA report there is no indication of what year the "future" is, when NESCAUM expects utilities to

be 4 times cleaner. The 10 percent increase in emissions that EPA predicts is for CO. All of the studies reviewed in this literature review agree that CO will be reduced by electric vehicles when compared to gasoline vehicles. It is unclear if the NESCAUM projected reduction of emissions at utilities by 4 times in the future applies to CO or all pollutants. As low NO_X burner technology and Selective Catalytic Reduction (SCR) are used at combustion power plants NO_X emissions can be expected to be reduced from 40percent to 90percent at these facilities (Early, 1994). Reductions in VOCs and CO would not normally be expected from these technologies.

The second comment in the NESCAUM response indicates that the NESCAUM report used projected power plant emissions and current EV consumption values. It is unclear why the future year EV energy use factors predicted in the EPA study would be as much as 150percent greater than the current values used by the NESCAUM study. The third NESCAUM comment is equally unclear. It would seem that a future year EV study would want to include expected future conditions. Reformulated gasoline and I / M programs are already a reality in some Northeastern cities.

3.2.2 MacKenzie, 1994

The Keys to the Car: Electric and Hydrogen Vehicles for the 21st Century, by James J. MacKenzie is a 128 page book which draws conclusions from a review of EV studies done by others. MacKenzie reports that current production electric Dodge

Caravans use 0.44 kilowatt hours per mile, measured at the wall outlet. These vehicles cost $100,000 per unit in 1994. The battery pack currently used in the Caravan electric, a nickel-iron battery, costs $40,000 and is expected to last 100,000 miles, which equates to a cost of $ 0.40 per mile. The Dodge Caravan electric can accelerate from 0 - 50 mph in 14 seconds and has a range of 100 - 120 miles between 4 hour charges. The Caravan electric does not have a heater or an air conditioner (MacKenzie, 1994).

MacKenzie predicts that in 2010 nearly 25percent of new automobile sales will be electric vehicles. He concludes that the use of EVs (no fleet penetration given) will "cut VOC and CO emissions to negligible levels and greatly reduce NO_X emissions, all important contributors to formation of urban smog" (MacKenzie, 1994). No modeling of ozone formation or concentration changes due to the implementation of EVs was done in this study.

3.2.3 OEDC, 1993

The Organization for Economic Co-operation and Development, based in France, published a 201 page book in 1993 entitled Electric Vehicles: Technology, Performance and Potential. The study reports the predicted percentage change in emissions in grams per mile as a result of changing from a gasoline vehicle to an EV in the year 2000. This study assumed that the gasoline vehicle displaced by an EV met the United States Tier I standards of 0.4 grams NO_X per mile, 0.25 grams VOC per mile and 3.39 grams CO per

mile. Coal-fired power plants were assumed to emit 2.8 grams of NO_X per metered kilowatt hour of electricity provided to the EV at the battery charger. A high efficiency and low efficiency EV was considered by the OEDC study. For the study year of 2000, a projected EV energy consumption of 0.65 kilowatt hours per mile was considered as the low efficiency scenario by OEDC. An electricity consumption of 0.4 kilowatt hours per mile was considered as a high efficiency scenario. The OEDC study predicted that NO_X emissions would increase by 20.4 percent in the high EV efficiency scenario, and increase by 106.1 percent in the low EV efficiency scenario. Changes in VOC emissions were predicted to be a decrease of 97.9 percent and 98.7 percent in the high and low EV efficiency scenarios, respectively. Similarly CO emissions were predicted to decrease by 98 percent and 98.7 percent for the low and high efficiency scenarios (OEDC, 1993).

The OEDC report also lists the specifications for some current production EVs. The Conceptor G-Van is built in the United Kingdom and was the first EV to meet U.S. federal safety standards for motor vehicles. This EV is a full size van with a 5 passenger capacity and a gross weight of 8600 lbs. Full size EVs may weigh more than full size gasoline vehicles because of the battery packs which weigh 1000 - 1500 lbs. The Conceptor G-Van has a range of 60 miles and consumes 1.1 kilowatt hour per mile, metered at the battery charger. The G-Van has a maximum speed of 52 miles per hour. This vehicle can be compared to the Danish built Mini-el City three wheel vehicle. This vehicle has a gross weight of 640 lbs and a maximum speed of 25 miles per hour. The

Mini-el City has a range of 22 miles and consumes 0.15 kilowatt hours per mile of electricity. The three wheel "cabin top" Mini-el has a passenger capacity of "1 adult with 1-2 children in the rear seat" (OEDC, 1993).

The OEDC study concludes that the use of EVs would "eliminate emissions of VOCs and CO and could increase or decrease NO_X emissions, depending on the fuels used at power plants." The study also states that due to VOC reductions and possible NO_X reductions urban ozone levels should decrease as well (OEDC, 1994). No modeling of ozone formation or concentration changes due to the implementation of EVs was done in this study.

3.2.4 Wang and Santini, 1993

The article "Magnitude and Value of Electric Vehicle Emissions Reductions for Six Driving Cycles in Four U.S. Cities with Varying Air Quality Problems" was published in the Transportation Research Record in 1993. In this study low speed driving cycles were used to calculate gasoline vehicle emissions, on the premise that EVs will be used for congested inner city driving only, because of their limited range and speed. EV energy consumptions from 0.32 - 0.40 kilowatt hour per mile were used, depending on which driving cycle was used. These EV energy consumption values were calculated using the MARVEL computer model developed at Argonne National Lab by Marr and Walsh (Wang, 1993). Although the study year was 2000, this study used the

MOBILE5A emission factor model to calculate emissions from 1996 model gasoline automobiles using 50,000 mile deterioration rates. This assumption traded emissions from 4 year old gasoline vehicles against projected power plant emissions in 2000. The gasoline vehicle NO_X emission factors used ranged from 0.74 - 0.95 grams per mile. The NO_X emissions from power plants for each study city were as follows: 0 grams per kilowatt hour for Chicago assumed to be generated by a nuclear plant, 1.484 grams per kilowatt hour for Denver assumed to generated predominately by coal-fired utilities, 0.156 grams per kilowatt hour for Los Angeles assumed to generated by predominately gas-fired utilities and 0.40 grams per kilowatt hour for New York, where the oil - fired utilities were considered the predominate utility source (Wang and Santini, 1993). The New York utility emission factors were taken from a separate study, and seem very low. Wang concludes that VOC and CO emissions will be reduced by more than 98 percent in all four cities using any of the studied driving cycles on a per mile basis comparing an EV to a 1996 model gas vehicle in 2000. The study also predicts that NO_X emissions will be eliminated in Chicago on the assumption that nuclear power plants will be used to provide EVs with power. Reductions in NO_X of 10 percent - 40 percent are forecast for Denver, greater than 90 percent in Los Angeles and 80 percent in New York (Wang and Santini, 1993). In regards to ozone Wang predicts that "in VOC / NO_X lean areas, where control of HC (the predominate class of VOCs) helps reduce ozone formation, use of EVs alleviates the ozone pollution problem" (Wang and Santini, 1993). No

modeling of ozone formation or concentration changes due to the implementation of EVs was done in this study.

3.2.5 DOE prepared by EPRI, 1993

This study "Utility Emissions Associated with Electric and Hybrid Vehicle (EHV) Charging" is a draft interim of a planned joint DOE / EPRI report of the same title which was never completed. The U.S. Department of Energy published this draft with the following forward.

"In the course of finalizing this report, differences of opinion developed regarding some of the assumptions used by DOE and the implications of the utility emissions analysis. Many uncertainties exist with respect to EHVs at this stage of technological development. DOE believes that the scenarios used in this report bracket those uncertainties. EPRI believes that the less favorable EHV energy use assumptions used in the analysis are out of date. EPRI also believes that marginal energy use and emissions due to EHV electricity demand can not be accurately projected past 1995 and therefore should not be used to describe future EHV emissions. Finally, EPRI believes that the increase of sulfur oxides (SO_X) emissions projected in this report should be discounted because SO_X emission caps, required by 1990 Clean Air Act Amendments, will ensure that electricity use by EHVs does not lead to SO_X increases in the future. We believe that the marginal energy use and emissions have to be the basis for assessing EHV impacts, even if uncertainties exist. We also believe that EHV SO_X emission impacts are relevant since they would require other mitigating actions in order to meet the Clean Air Act requirements.

Because we have not been able to resolve these differences of opinion, we will not be producing a joint DOE / EPRI report on the emissions of EHVs as originally intended. However, in order to make the technical analysis available to interested parties, DOE is releasing the September 1992 draft of the report that contains complete documentation of the technical analysis and results. This report does not reflect the views of EPRI concerning EHV emissions.

While neither we nor EPRI are endorsing the results of this report, DOE nonetheless believes that it will contribute to a fuller understanding of alternative fuel vehicle emissions. DOE will continue to address the uncertainties indicated in the enclosed report" (DOE, 1993).

The above is signed Kenneth L. Heitner, Manager, Advanced Battery Systems, Electric and Hybrid Propulsion Division, Conservation and Renewable Energy. This forward was included as it indicates the current state of knowledge when predicting EV performance 15 years into the future. It also indicates the strong vested interest that most "EV experts" and electricity oriented research groups have when working on EV studies.

In this interim report all EV charging was assumed to be in the off-peak hours from 10:00 p.m. to 6:00 a.m.. Lead-acid battery powered vans and nickel-iron battery powered vans, trucks and cars were considered, and an energy use factor assumed for a conservative and optimistic case for each. The optimistic case for 2010 resulted from projecting increases in battery efficiency over 1992 technology. In the conservative scenario vans with lead-acid batteries were assumed to require 0.7 kilowatt hours per mile in 2010. In the optimistic scenario lead-acid battery equipped vans were assumed to use 0.39 kilowatt hours per mile. Nickel-iron battery powered vans and trucks were assumed to use 0.9 kilowatt hours per mile and nickel-iron powered cars 0.6 kilowatt hours per mile in the conservative scenario. In the optimistic scenario nickel-iron battery equiped vehicles were assumed to use 0.39 kilowatt hours per mile for vans and trucks and 0.16 kilowatt hours per mile for cars (DOE, 1993).

The results from this report were calculated for all regions of the country, for a large number of scenarios concerning power mix and differing numbers of EVs in use in 101 specific cities in the U.S., which were classified as nonattainment for ozone. The

scenarios bracket such a wide range that predicted NO_X changes are shown as both increasing and decreasing depending on which scenario is chosen. Since this DOE report is an unfinished interim version no clear conclusions were presented.

3.2.6 Bentely et al., 1992

The report entitled "The Impact of Electric Vehicles on CO_2 Emissions", published in 1992, did not deal with changes in VOC, NO_X or ozone concentrations. The article is included in this review because it had a more in-depth calculation of future year (2010) EV emission factors than any other article reviewed.

This study utilized predicted performance parameters or goals set by battery manufacturers to calculate EV energy consumption for future years. Included in the EV energy consumption calculations were consumption due to vehicle accessories and air conditioning loads. This is the only study reviewed which incorporates these energy consumptions. In 2010 Bentley predicts that an electric minivan will consume 0.81 kilowatt hours per mile of electricity. In comparison he predicts a "small commuter" EV will require 0.56 kilowatt hours per mile in 2010 (Bentely, *et al.*, 1992).

To calculate changes in CO_2 emissions Bentely used the correct approach of considering the entire fleet. In this study an EV sales penetration equal to that required under the California mandate was assumed for each year. By doing this each EV sold displaced a new gasoline vehicle of that year model. This modified fleet mix was then used to generate the gasoline emission factor used in the CO_2 emission comparison.

3.2.7 Russell et al., 1992

The article "Electric Vehicles and the Air Pollution in Los Angeles" was published in Energy and Environment in 1992. The year of study used by Russell is 2010, and the location is Los Angeles. The electric vehicle energy consumption was based on a Chrysler TEVan powered by a nickel-iron battery. All EVs were assumed to use 0.5 kilowatt hours per mile, which Russell reports as consistent with current nickel-iron battery technologies in the demonstration phase (Russell, *et al.*, 1992).

A EV penetration of 15 percent of both light duty autos and light duty trucks was used. A 15percent penetration means that 15 percent of all light duty gasoline vehicles (LDGV) and 15 percent of all light duty gasoline trucks (LDGT1) on the road in 2010 would be electric. Emission factors of 0.42 grams NO_X per mile was used for LDGVs and 0.51 grams NO_X per mile for LDGT1s (Russell, *et al.*, 1992). In this study the fleet average emission factor was not adjusted to reflect the removal of new vehicles by the sale of EVs.

Additional power needed to meet a 15 percent EV penetration was assumed to be provided at different locations. A large natural gas power plant was assumed to meet 50 percent of the required load increase. This hypothetical plant was assumed to be located on the coast and have a NO_X emission factor of 0.27 grams per kilowatt hour. The remaining 50 percent required load increase was assumed to be met by a mix of existing sources located through the basin. The were assumed to have a combined NO_X emission factor of 0.52 grams per kilowatt hour of electricity generated (Russell, 1992).

In this study changes in ozone concentrations were addressed using the CIT (Carnegie / California Institute of Technology) model, a gridded photochemical model. The CIT model predicted a maximum ozone concentration for the 2010 base case run of 196 ppb NO_X over a 3 day simulation. The 15 percent EV penetration scenario predicted an ozone peak of 188 ppb when additional power demands were met by local supplies, as described above. The CIT model again predicted a ozone maximum of 188 ppb over a three day period when all additional power was imported from outside the area. A statistical study predicted that the number of annual ozone exceedence days, days when a concentration of 120 ppb or more, would be reduced from 12.3 days per year with the base case scenario to 9.8 days per year with a 15 percent EV penetration and power supplied from inside or outside the area (Russell, *et al.*, 1992). Russell concluded that "this analysis shows for Los Angeles, EVs would provide significant air quality benefits over conventional gasoline fueled vehicles". Russell also contended that EVs would displace emissions "far from urban centers" and "displace emissions temporally away from day-light hours when the impact of mobile emissions is most pronounced" (Russell, *et al.*, 1992).

3.2.8 Dowlatabadi et al., 1990

Electric Vehicles and the Environment: Consequences for Emissions and Air Quality in Los Angeles and U.S. Regions, is a 119 page softbound volume published by

Resources for the Future as a "Discussion Paper". It should be noted that Dowlatabadi is the third author listed on the previous paper "Electric Vehicles and the Air Pollution in Los Angeles" published in Energy and Environment in 1992. Russell is listed as the third author on this study, Electric Vehicles and the Environment: Consequences for Emissions and Air Quality in Los Angeles and U.S. Regions, and both papers have the same second author, A. J. Krupnick. This paper covers the same study as the previous paper, but in greater detail. This research was sponsored by EPRI.

The long version of this report (Dowlatabadi) includes information on the number of grid-hours greater than 120 ppb over the three day simulation. The number of grid-hours greater than 120 ppb is simply the total number of grids over the 72 hour period which exceeded 120 ppb. In the 2010 base case CIT simulation 1593 grid-hours in excess of 120 ppb were reported. In the 15 percent EV penetration scenario 1436 grid-hours over 120 ppb were reported. Dowlatabadi states that "localized increases in ozone concentrations" were seen because of NO_X reductions due to the implementation of EVs, which reduced NO_X scavenging effects in some areas (Dowlatabadi, *et al.*, 1990).

In conclusion it was reported that coal-fired utilities were the only power production source in current use which causes an increase in NO_X emissions when EVs replace gasoline vehicles. This conclusion is based on the gasoline NO_X emission factors listed in the above Russell paper and assumed coal-fired utility emissions of 0.738 grams NO_X per mile of EV travel. Dowlatabadi concluded that these results can be

extrapolated to other regions in the United States, and that EVs would improve air quality in urban regions throughout the United States. This report indicates that changes in ozone formation due to the implementation of EVs would be small, and could be positive or negative (Dowlatabadi, *et al.*, 1990).

3.2.9 Wang et al., 1990

The paper entitled "Emission Impacts of Electric Vehicles" was published in the Journal of Air and Waste Management in 1990. This study used the California EMFAC7D model to calculate gasoline vehicle emission factors and considered two years, 1995 and 2010. This model corresponds to the EPA MOBILE3 model and did not include current emission standards for current vehicles. Two EV efficiencies were assumed a high and low scenario. In the high efficiency scenario EVs which could replace passenger cars were assumed to use 0.3 kilowatt hours per mile in 2010 and 0.4 kilowatt hours per mile in 1995. Low efficiency passenger EVs were assumed to consume 0.4 kilowatt hours per mile in 2010 and 0.5 kilowatt hours per mile in 1995. Light duty electric trucks were assumed to use 0.5 kilowatt hours per mile in 2010 and 0.7 kilowatt hours per mile in 1995 in the high efficiency scenario. The low efficiency light duty electric trucks were assumed to use 0.7 and 0.9 kilowatt hours per mile in 2010 and 1995 respectively. These values are said to be based on a "previous analysis" (Wang, 1990). Automobiles replaced by EVs were assumed to emit 0.791 grams of NO_X

per mile and light trucks 0.837 grams of NO_X per mile in this study for 2010. The 1995 NO_X emission factors used were 0.416 grams of NO_X per mile and 0.613 grams of NO_X per mile for cars and trucks, respectively. The 2010 factors increase due to the assumed deterioration of the vehicles over time. This study, like most of those reviewed, replaces old cars with new EVs in a future year and looks at emission reductions on a per mile basis.

For 2010 NO_X reductions of - 56 percent and - 76 percent were reported for the maximum and minimum EV impact scenarios. The NOX changes in 1995 were calculated to be increases of 55 percent and 145 percent for the maximum and minimum impact scenarios. The maximum and minimum scenarios included the above listed ranges in EV energy consumption and low and high power plant emission scenarios. Wang states that the use of a photochemical model would be required to predict changes in ozone concentrations, but "in practice ozone models are inaccurate and highly sensitive to detailed emission and meteorological data and ambient air pollution input data which are rarely available in sufficient detail" (Wang, *et al.*, 1990).

3.2.10 Wang et al., 1989

The paper "Air Pollutant Emissions and Electric Vehicles", published by the Transportation Research Group, University of California at Davis in 1989 is a more complete version of the above paper re-published in the Journal of Air and Waste

Management in 1990. The conclusions in this version of the paper acknowledge that although the per mile reductions calculated by displacing gasoline automobiles with EVs are very large, real reductions in emissions will not occur until EVs have a large market penetration (Wang *et al.*, 1989).

3.2.11 EPRI, 1978

The report entitled "The Impact of Electric Passenger Automobiles on Utility System Loads, 1985 - 2000" was published by EPRI in 1978. This report uses multiple computer databases and utility forecasting programs to generate load curves with and without the impact of EVs for several U.S. cities. In each case both load curves are very similar. The following conclusion follows pages of near identical curves for with and without EV impact. "Once again, the conclusions to be drawn from these figures seems clear: electric vehicles are unlikely to have much of an impact on utility loads. What impact they have, however, will be favorable because much of the added load will occur at night. Moreover because the impact is so small, these conclusions are more or less independent of our projections of vehicle demand, electricity consumption, or the diurnal pattern of charging activity" (EPRI, 1978). This work is very old in comparison to all of the other work reviewed, but the only report which spoke specifically to how utility loads could change due to EV use, and was prepared by the research arm of the utility industry itself. If the conclusion that EV impact is independent of vehicle demand,

electricity consumption, or the diurnal pattern of charging activity is correct then the conclusion should still be valid.

3.3 Summary

The EV papers reviewed were consistent in using emission factors from gasoline vehicles which would be 5 - 15 years old in the study year. At the same time many studies try to predict power plant emissions which will occur in future, supposedly cleaner, generation scenarios. In some studies, predicted EV energy consumption values from EVs which do not meet the performance requirements of the gasoline vehicles they were assumed to replace, are used in the calculations which compare emissions from older gasoline powered cars.

With the exception of one study, the fact that EVs will always replace new vehicles was overlooked. In the study which did adjust the fleet mix input into the MOBILE model, to correct for this fact, the MOBILE3 model was used. The MOBILE3 model did not have future year emission factors, years beyond 1990, incorporated into it. Although many authors predicted decreases in ozone concentrations and mentioned the benefits of moving emission releases to night-time hours, only one study incorporated the use of an ozone model. This study only considered emissions released at night and showed very small ozone reductions, and indicated increases occurred, although the magnitude of those increases was not given.

When considering EV energy consumption factors it should be noted that not all electric cars are created equal. Table 2 shows a summary of energy consumption and vehicle type. If a plot of EV energy consumption verses vehicle weight, where both weight and EV energy consumption were given in Table 2 is constructed a linear relationship between EV weight and energy consumption is noted. Many of the prototypes which have the smallest energy consumption values can not pass the federal motor safety vehicle standards, and as such could not be sold in the United States. It is clear that EVs which could possible replace gasoline vehicles are the largest energy consumers. The higher energy consuming vehicles have multiple passenger capacity and can at least nearly reach the speed limit. It should also be noted that only one study considered the energy consumption of accessories and air conditioning, items which consumers consider necessities on current production gasoline vehicles. It has been recognized that in order to see real benefits from EVs a considerable percentage of vehicles on the road will have to be electric. In order to achieve a large EV penetration on the road, EVs which will perform to consumer expectations must be offered for sale, and in reality these vehicles have the larger of the listed energy consumptions.

Table 2. Summary of Electric Vehicles Energy Consumption

Summary of Electric Vehicles Energy Consumption (Kilowatt hours / mile) metered at the Battery Charger		
Source	kW / mile Required	Vehicle type and Description
MacKenzie, 1994	0.44	Dodge Caravan
OEDC, 1993	1.10	Conceptor G-Van, 8600 lb. Van
OEDC, 1993	0.15	Mini-el City, 640 lb. "Car"
OEDC, 1993	0.40 - 0.65	Small electric van value used in 2000 study
Wang, 1993	0.32 - 0.40	4 Passenger EV (2750 lbs.) used in 2000 study*
DOE, 1993	0.39 - 0.70	Pb - Acid Vans used in 2010 study
DOE, 1993	0.39 - 0.90	Ni - Fe Vans used in 2010 study
DOE, 1993	0.16 - 0.60	Ni - Fe passenger EVs used in 2010 study
Bentely, 1992	0.81	Minivan, in 2010 study
Bentely, 1992	0.56	Small commuter EV, in 2010 study
Russell, 1992	0.50	Demo Chrysler TEVan, used in 2010 study.
Wang, 1990	0.30 - 0.40	Passenger EVs, used in 2010 study
Wang, 1990	0.50 - 0.70	LDGT1 electric trucks, used in 2010 study

* Generated using the MARVEL computer model

Chapter 4: Mobile Source Emissions

4.1 Baseline 2010 Mobile Source Emissions

The 2010 base case on-road mobile source inventory was developed using the same methodology used in preparing the 1990 SIP on-road mobile source inventory for the Nashville Ozone Nonattainment area. The procedure used in the 1990 SIP is documented in full detail in Volume 4 of the report entitled SIP BASE YEAR 1990 EMISSIONS INVENTORY FOR PRECURSORS OF OZONE FOR THE NASHVILLE NONATTAINMENT AREA AND MIDDLE TENNESSEE MODELING DOMAIN, which is listed as a reference to this study. The 1990 SIP on-road mobile source inventory was used as the basis for the 2010 inventory. The 1990 on-road mobile source inventory was adjusted to 2010 using the EPS2.0 emissions preprocessing system.

4.1.1 MOBILE5A Emission Factor Calculations

The MOBILE5A model was used to calculate average emission factors for the on-road fleet in 2010. These emission factors were used in conjunction with the EPS2.0 MVADJ processor which adjusted the 1990 emission factors currently in the EPS workfile to 2010 levels.

The study area was divided into 7 sub-regions, each with a separate MOBILE5A scenario. The 7 sub-regions were allocated as follows; Davidson County, TN, which includes the metropolitan Nashville area, Rutherford County, TN, Sumner County, TN, Williamson County, TN, Wilson County, TN, the remaining Tennessee counties and Kentucky counties. The 5 ozone nonattainment counties were considered as individual sub-regions in the MOBILE5A modeling. The remaining Tennessee counties constituted another mobile sub-region as did the Kentucky counties in the study area. The Tennessee Department of Transportation (TDOT), provided vehicle miles traveled (VMT) mix data and speed data for each road type in each Tennessee sub-region. The Kentucky Transportation Cabinet provided this information for the region in Kentucky. Sub-regions contained up to 10 road types each. The Inspection and Maintenance (I / M)programs which are in place, or required to be implemented in the near future in the nonattainment counties, were also included. The MOBILE5A input file for each sub-region is included in the Appendix to this document. Following these input files the MOBILE5A output for the attainment counties in Tennessee for 2010 with the default fleet mix and the fleet mix adjusted for EV penetration are shown.

4.1.2 Projected 2010 VMT

The VMT values used in preparing the 1990 SIP on-road mobile source inventory were provided by the TDOT and the Kentucky Transportation Cabinet, for the Tennessee and Kentucky areas respectively. These VMT values were based on real

traffic counts. In Tennessee the TRIMS model was used to extrapolate county wide VMT from the traffic counts (Davis, *et al.*, 1995). For the 1996 Attainment Demonstration UAM modeling, the 1990 VMT was projected to 1996, using growth rates provided by TDOT for the 5 nonattainment counties of Davidson, Rutherford, Sumner, Williamson and Wilson. Growth factors for the remaining Tennessee and Kentucky mobile sub-regions were derived by regressing the most recent 6 years of federal Highway Performance Monitoring System (HPMS) data.

The 2010 VMT growth factors were obtained by ratioing the 1990 - 1996 VMT growth factors by 20/6. These factors were then used to project the 1990 VMT to 2010. These growth factors were applied by road-type and county, and are included in the Appendix to this document listed by mobile sub-region.

The annual growth rates ranged from a high of 10 percent per year on some Wilson county roads to a low of 0.115 percent per year on some Sumner county roads. Although a large range does exist in the VMT growth factors, most factors were on the order of 3 percent growth per year. The total study area 1990 VMT, calculated in the 1990 SIP inventory for this area, is 66.6 million miles per day in ozone season. The 2010 projected VMT is 109 million miles per day in ozone season. This reflects an average growth over 20 years of 63.7 percent, or 3.18 percent per year. The average VMT growth rate for Tennessee and the nation has been about 3 percent for the past several years, so this value appears in line.

4.1.3. Emission Totals

Table 3 shows the projected 2010 base case emissions totals for VOCs, NO_X, and CO for on-road mobile sources, and list the 1990 SIP on-road mobile emissions for comparison as well (Davis, *et al.*, 1994). The base case represents a scenario where all on-road mobile vehicles are conventionally fueled automobiles.

Table 3. Base case 2010 On - Road Ozone Mobile Season Emissions

Base case 2010 Ozone Season On - Road Mobile Emissions (Tons / Day)		
VOC	**NO_X**	**CO**
216.34	284.08	1595.11
SIP 1990 Ozone Season On - Road Mobile Emissions (Tons / Day)		
VOC	**NO_X**	**CO**
253.19	262.36	2075.78

4.2 Adjusted 2010 Mobile Source Emissions with 25 percent EV Penetration

4.2.1 Fleet Mix Adjustment Due to EV Sales

In order for 25 percent of the both the light duty gasoline vehicles (LDGV), or cars, and light duty gasoline trucks (LDGT1), on the road to be electric, in 2010, EVs must be assumed to integrate the fleet in years prior to 2010. In this study EVs were

assumed to begin to be sold in 2000. Initial EV sales were assumed to be 2 percent of annual new vehicle sales. This corresponds to the required sales percentage for 1997 under the California mandate. In order to reach a 25 percent penetration of both the LDGV and LDGT1 vehicle classes by 2010 an annual increase in EV sales of 4.15 percent was projected for both categories of vehicles.

In Figure 7, the assumed annual percentage of EV sales, as a fraction of total sales is shown from 2000 through 2010. This sales rate was assumed for both LDGV and LDGT1 class vehicles. The MOBILE5A fleet mix was then adjusted to reflect the EVs now in the fleet. This was accomplished by subtracting the fraction of EVs sold each year from the default MOBILE5A fraction of new gasoline vehicles in that year, for both the LDGV and LDGV1 classes of vehicles. The adjusted fleet mix for each vehicle category was then normalized back to 1. In Figure 8 the fleet mix, by year, for the LDGV class is shown before and after the introduction of EVs. Figure 9 shows the fleet mix, by year for the LDGT1 class before and after the introduction of EVs. The year 1986 actually represents all vehicles in the fleet sold in 1986 or before. This category represents vehicles 25 years old or older from the MOBILE5A model scenario year, in this case 2010.

Each time an EV is sold new, it is assumed to replace a new gasoline vehicle which would have been purchased, if the EV had not. As shown in Figure 8 and Figure 9, this reduction in new gasoline automobile sales, over the most recent 11 years of the 25 year fleet average, weights the fleet average heavier in older vehicles. This in turn

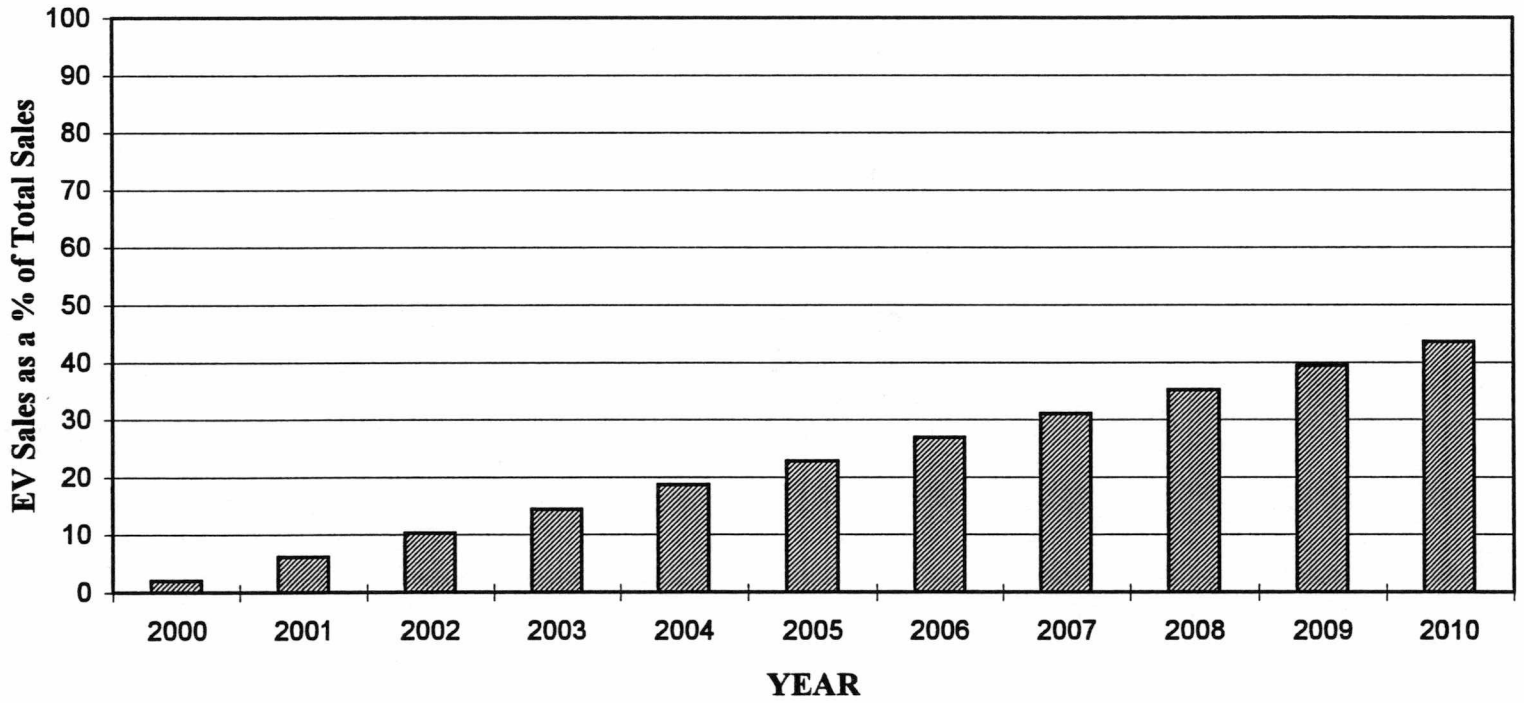


Figure 7. EV Sales in LDGV & LDGT1 Vehicle Class.

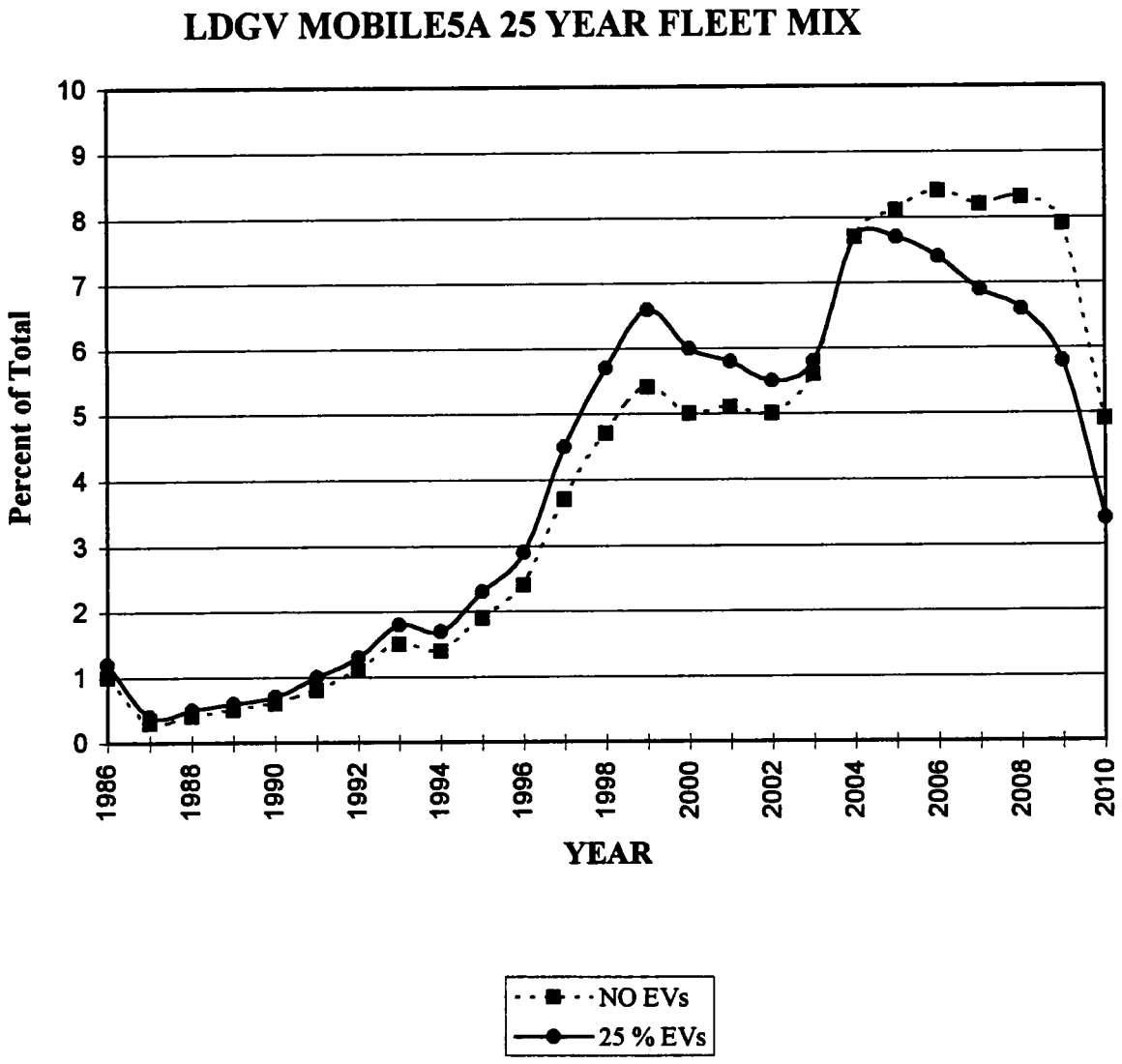


Figure 8. LDGV MOBILE5A 25 Year Fleet Mix

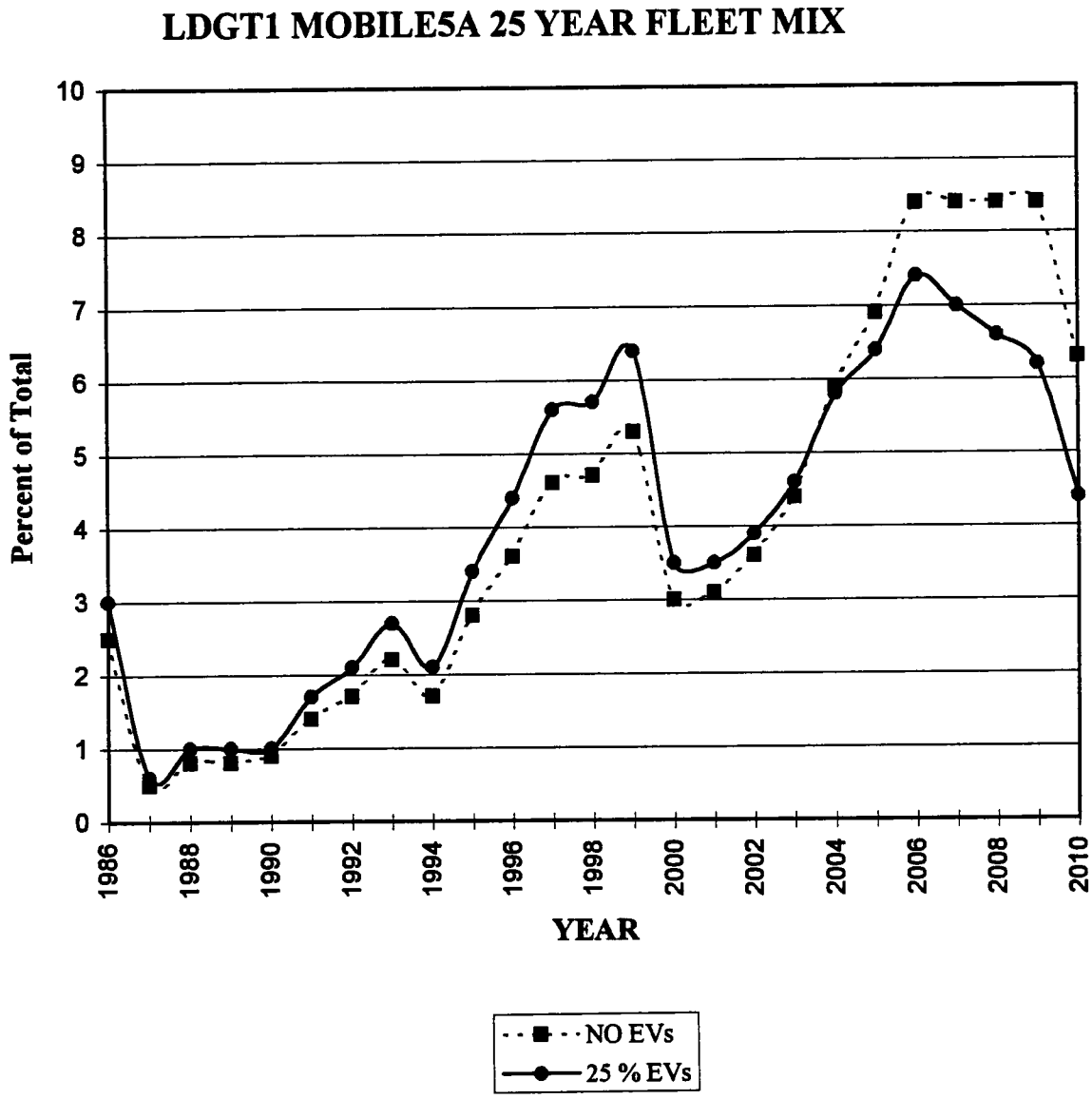


Figure 9. LDGT1 MOBILE5A 25 Year Fleet Mix

causes the MOBILE5A emission factors, which are fleet age average factors, for LDGV and LDGT1 gasoline vehicles to increase. In Table 4 the fleet average NO_X emission factors for LDGV and LDGT1 vehicles with the base case fleet mix, and the 25 percent EV penetration fleet mix predicted by the MOBILE5A model, at an average speed of 19.6 miles per hour, are shown.

Table 4. 2010 MOBILE5A NO_X Emission Factors

MOBILE5A 2010 FLEET AVERAGE NO_X EMISSION FACTORS (grams / mile)		
Vehicle Type	NO EV Penetration	25 percent EV Penetration
LDGV	1.26	1.41
LDGT1	1.49	1.69

The average fleet NO_x emission factors for LDGV and LDGT1 vehicles in a 2010 fleet with a 25 percent penetration of these classes are 10 percent to 12 percent higher than those for a 2010 fleet without any EV penetration, due to the heavier weighting of older gasoline vehicles in the 25 percent EV fleet. The factors shown in Table 4 are average factors for the entire fleet of LDVG and LDGT1 gasoline vehicles, respectively. Each of these fleet emission factors represents a mix of each vehicle type which includes all ages of each vehicle type (adjusted for, but excluding EVs in the 25 percent EV scenario) on the road. For this reason, and due to increasing emissions over time due to deterioration, these factors are higher than the NO_X emission factor for a vehicle which

would be sold new in 2010. For example beginning in 1995 the CAAA require LDGVs to meet a NO_X emission standard of 0.4 grams per mile from 0 - 50,000 miles and 0.6 grams of NO_X per mile from 50,000 to 100,000 miles. Vehicles which meet the proposed Clean Fuel Vehicle standards by 2001, will have further lowered LDGV NO_X emissions of 0.2 and 0.3 grams per mile for vehicles with 0 - 50,000 miles and 50,000 - 100,000 miles, respectively (U.S. House of Representatives, 1990).

4.2.2 Emission Totals

In order to calculate the mobile source emissions from on-road gasoline vehicles in conjunction with a 25 percent penetration of EVs in the LDGV and LDGT1 categories, the VMT for these categories must be adjusted to reflect the EV usage. Table 5 shows the spreadsheet used to project the 2010 VMT from the 1990 VMT. The spreadsheet shown in Table 5 also shows the percentage of LDGV and LDGT1 vehicles in each road type in each county. These values were provided by TDOT. No VMT mix data were available from the Kentucky counties within the study area, so the VMT mix for similar Tennessee counties was used for the Kentucky counties.

When weighted and averaged the LDGV and LDGT1 categories together constitute 82.7 percent of the total VMT in the study area. A 25 percent penetration rate of EVs equates to a 20.68 percent (0.827 x 0.25 = 0.2068) reduction in total VMT (all on-road vehicle miles traveled per day regardless of vehicle type) within the study

Table 5. 2010 VMT Projection Spreadsheet

County	Road Type	1990 VMT	2010 Growth		2010 VMT	LDGV	LDGT1	Total (LDGV + LDGT1	VMT
47000	Urban	5,448,529	1.766		9,622,102	0.589	0.201	0.79	3.58E+07
47000	Rural	2.49E+07	1.433		3.57E+07				
TN Total	3.03E+07			4.53E+07					
21000	Urban	2,767,416	1.814		5.02E+06	0.589	0.201	0.79	1.37E+07
21000	Rural	6,932,609	1.771		1.23E+07				
KY Total	9,700,025			1.73E+07					
Davidson	Urban Interstate	5,743,742	1.74		9,994,111	0.671	0.224	0.895	8,944,729
Davidson	Urban Expressway	847,585	2.21		1,873,163	0.668	0.239	0.907	1,698,959
Davidson	Urban Major Arterial	4,767,360	1.225		5,840,016	0.735	0.212	0.947	5,530,495
Davidson	Urban Minor Arterial	906,706	1.225		1,110,715	0.735	0.212	0.947	1,051,847
Davidson	Urban Collector	846,428	3.629		3,071,687	0.73	0.195	0.925	2,841,311
Davidson	Urban Local	1,048,947	1.278		1,340,554	0.856	0.044	0.9	1,206,499
Davidson Total	1.42E+07			2.32E+07					
Rutherford	Urban Interstate	216,535	2.504		542,204	0.564	0.121	0.685	371,409
Rutherford	Rural Interstate	957,613	1.615		1,546,545	0.552	0.119	0.671	1,037,732
Rutherford	Urban Major Arterial	626,253	2.466		1,544,340	0.741	0.16	0.901	1,391,450
Rutherford	Rural Major Arterial	165,336	1.535		253,794	0.7	0.15	0.85	215,725
Rutherford	Urban Minor Arterial	263,078	2.166		613,147	0.728	0.157	0.885	542,635
Rutherford	Rural Minor Arterial	329,268	1.912		629,560	0.734	0.158	0.892	561,568
Rutherford	Urban Collector	330,982	3.049		1,009,164	0.749	0.161	0.91	918,339
Rutherford	Rural Collector	435,401	2.466		1,073,699	0.725	0.156	0.881	945,929
Rutherford	Urban Local	263,871	1.356		357,809	0.769	0.166	0.935	334,551
Rutherford	Rural Local	363,284	1.283		466,093	0.755	0.162	0.917	427,408
Rutherford Total	3,971,623			8,036,355					
Sumner	Urban Interstate	87,798	1.612		141,530	0.568	0.122	0.69	97,656
Sumner	Rural Interstate	141,992	1.67		237,127	0.56	0.12	0.68	161,246
Sumner	Urban Major Arterial	765,976	1.966		1,505,909	0.732	0.158	0.89	1,340,259
Sumner	Rural Major Arterial	32,997	1.703		56,194	0.678	0.146	0.824	46,304
Sumner	Urban Minor Arterial	62,213	1.023		63,644	0.722	0.155	0.877	55,816
Sumner	Rural Minor Arterial	448,633	1.807		810,680	0.705	0.152	0.857	694,753
Sumner	Urban Collector	216,933	1.978		429,093	0.718	0.155	0.873	374,599
Sumner	Rural Collector	509,185	1.806		919,588	0.713	0.153	0.866	796,363
Sumner	Urban Local	245,600	1.053		258,617	0.769	0.166	0.935	241,807
Sumner	Rural Local	376,594	1.083		407,851	0.755	0.162	0.917	374,000
Sumner Total	2,887,921			4,830,233					
Williamson	Urban Interstate	398,213	2.63		1,047,300	0.653	0.14	0.793	830,509
Williamson	Rural Interstate	563,834	1.953		1,101,168	0.555	0.119	0.674	742,187
Williamson	Urban Major Arterial	303,965	2.399		729,212	0.734	0.158	0.892	650,457
Williamson	Urban Minor Arterial	103,015	3.519		362,510	0.741	0.16	0.901	326,621
Williamson	Rural Minor Arterial	610,475	1.786		1,090,308	0.728	0.157	0.885	964,923
Williamson	Urban Collector	149,455	2.189		327,157	0.741	0.159	0.9	294,441
Williamson	Rural Collector	326,912	1.453		475,003	0.72	0.154	0.874	415,153
Williamson	Urban Local	70,727	1.618		114,436	0.769	0.166	0.935	106,998
Williamson	Rural Local	427,180	1.209		516,461	0.755	0.162	0.917	473,594
Williamson Total	2,953,776			5,763,555					
Wilson	Rural Interstate	907,262	2.1		1,905,250	0.588	0.127	0.715	1,362,254
Wilson	Urban Major Arterial	258,362	1.488		384,443	0.729	0.157	0.886	340,616
Wilson	Rural Major Arterial	196,579	2.796		555,227	0.698	0.15	0.848	470,832
Wilson	Urban Minor Arterial	76,887	1.889		145,240	0.737	0.159	0.896	130,135
Wilson	Rural Minor Arterial	258,159	1.62		418,218	0.721	0.155	0.876	366,359
Wilson	Urban Collector	148,551	3.685		547,410	0.744	0.16	0.904	494,859
Wilson	Rural Collector	272,149	1.266		344,541	0.737	0.159	0.896	308,708
Wilson	Urban Local	42,674	1.045		44,594	0.769	0.166	0.935	41,696
Wilson	Rural Local	457,759	1.02		466,914	0.755	0.162	0.917	428,160
Wilson Total	2,620,382			4,811,836					
							% of VMT (LDGV & LDGT1)		
	6.66E+07	6.66E+07		1.09E+08	1.09E+08		0.827345	82.70%	9.04E+07
							% of Total VMT		
									EV VMT
							0.206836	20.70%	2.26E+07

area. This represents 22.6 million conventionally fueled vehicle miles traveled per day, replaced by EVs.

In Table 6 the 2010 on-road mobile source emissions of VOCs, NO_X and CO are shown for the baseline and 25 percent EV penetration scenarios.

Table 6. 2010 On - Road Mobile Source Emissions.

2010 On - Road Mobile Source Emissions (Tons / Day)			
Scenario	VOC	NO_X	CO
No EVs	216.34	284.08	1595.11
25 percent EV	172.13	247.05	1383.27
percent Change	- 13.87 percent	- 13.03 percent	- 13.28 percent

The implementation of a 25 percent penetration of EVs in the LDGV and LDGT1 class of vehicles results in a predicted reduction in on-road mobile source VOCs of 13.87 percent. The on-road mobile source NO_X emissions were reduced 13.03 percent and on-road mobile source CO emissions by 13.28 percent. These reductions assume no increase in power plant loads. This could be accomplished if all additional power were supplied by a source which does not emit VOCs, NO_X , or CO, such as nuclear or hydro-electric power, or if the needed electricity were produced outside of the study area. In previous modeling studies of the MTMD ozone transport into the area and additional ozone production in the area has been noted from coal-fired utility emission plumes

located to the east and north of the study area (Davis, *et al.*,1995). The emissions totals for the all source categories in the MTMD, by pollutant, are shown for the 2010 base case, or no EV scenario, and the 25 percent EV penetration scenario, without additional power plant loads in Tables 7, 8 and 9. These tables show the total change in each pollutant on a domain wide basis, as well as by source category.

When considered as a change in the domain total of each pollutant type the percentage reduction achieved by the introduction of EVs in the 25 percent penetration scenario used in this study is small. The 25 percent EV penetration scenario without utility emission increases, which equates to a total VMT reduction of 20.68 percent, is the maximum air quality benefit scenario presented in this study. All other scenarios modeled will include the emissions increases associated with the increased power production needed to support 22.6 million miles of daily EV use.

Table 7. 2010 MTMD VOC Emissions by Source Category

2010 MTMD VOC Emissions by Source Category (Tons / Day)					
Scenario	Point	Area & NR Mobile	On - Road Mobile	Biogenics	Total
No EVs	131.70	352.65	216.34	1883.60	2584.29
25 percent EVs	131.70	352.65	172.13	1883.60	2540.08
Change	0	0	- 13.87 percent	0	- 1.71 percent

Table 8. 2010 MTMD NO_X Emissions by Source Category

2010 MTMD NO_X Emissions by Source Category (Tons / Day)					
Scenario	Point	Area & NR Mobile	On - Road Mobile	Biogenics	Total
No EVs	358.10	176.52	284.08	negligible	818.70
25 percent EVs	358.10	176.52	247.05	negligible	781.67
Change	0	0	- 13.03 percent	0	- 4.5 percent

Table 9. 2010 MTMD CO Emissions by Source Category

2010 MTMD CO Emissions by Source Category (Tons / Day)					
Scenario	Point	Area & NR Mobile	On - Road Mobile	Biogenics	Total
No EVs	191.16	826.81	1595.11	N/A	2613.08
25 percent EV	191.16	826.81	1383.27	N/A	2401.24
Change	0	0	- 13.28 percent	N/A	- 8.12 percent

This study assumes that the trip length of EVs will be identical to the LDGV and LDGT1 vehicles which they replace. In some studies EVs are considered to have much shorter trip lengths than conventional gasoline vehicles, because of their limited range, between recharges. In reality, if EV trips were shorter than the original trip length of the vehicles they replaced, the difference in VMT would have to be made up by conventional gasoline vehicles. Although other studies do not include the required gasoline vehicle VMT increase, if shorter EV trips are assumed, it would have the effect of decreasing calculated emission gains from EVs. For this reason this study assumes that EVs will be capable of replacing LDGV and LDGT1 vehicles on a trip per trip basis in 2010. This assumption would indicate that the EVs considered in this study be ones which are most able to truly replace gasoline vehicles. The EVs which are most capable of this replacement are the larger vehicles which have standard passenger capacities and larger, and heavier, battery packs capable of a greater range. These EVs have the highest kilowatt per mile energy consumption rate.

Chapter 5 Power Plant Emissions

5.1 Electric Vehicle Energy Consumption

5.1.1 Study Assumptions

For this study an electricity use of 0.5 kilowatt hours per mile, metered at the battery charger, was assumed for EVs which replace both LDGV and LDGT1 class vehicles. Although 2010 is the specific year used in this study, EVs are introduced into the fleet from 2000 through 2010 at the linear growth rate described in section 4.2.1 of this document. The EV energy consumption of 0.5 kilowatt hours per mile was used for all EVs, regardless of year of introduction.

The 0.5 kilowatt per hour EV electricity use represents a value consistent with recent studies with projected years of interest of 2000 and 2010, as reported in section 3.3 of this document. For those studies which assumed ranges, the 0.5 kilowatts per hour assumption also falls within the assumed range of EV energy consumption values for 6 of these studies. One study, (Wang and Santini, 1993) assumed a lower range of values, 0.3 - 0.4 kilowatt hours per mile. It should be noted that only the study by Bentely, which predicted 0.56 kilowatt hours per mile for small commuter EVs, and 0.81 kilowatt hours per mile for minivans in the year 2010, tried to account for additional air conditioning and vehicle accessory electricity consumption. These items would be

expected on any vehicle capable of achieving the projected sales rates of this study, outlined in section 4.3.2.

5.1.2 EV Emissions at the Utility

Electricity consumption values, metered at the battery charger only include power transfer efficiencies from the battery charger to vehicle use. These values do not consider the efficiencies involved with distributing power through the transmission infrastructure to the charging location. Table 10 shows the efficiencies associated with power consumption from the power plant to the EV. These values, with the exception of the utility thermal efficiency were reported by Wang and Santini in 1993. The 0.5 kilowatt per hour EV energy consumption figure accounts for all losses shaded in the table. This is the quantity of electricity (0.5 Kwh/mile), which must be purchased by the consumer.

Table 10. Power Generation and Transfer Efficiencies for EV Use

Power Generation and Transfer Efficiencies for EV Use						
Process	Utility *	Power Lines	Battery Charger	Battery	Electric Motor	Drive Train
Efficiency	0.35	0.92	0.90	0.80	0.85	0.85

Source: Wang and Santini, 1993, * calculated

In order to calculate emissions of pollutants from increased loads due to EV energy requirements, the thermal efficiency of each of the three TVA power plants in the MTMD was calculated using maximum load heat rate provided by TVA for these plants for the year of 1988. The thermal efficiencies should not change appreciably, if the plants continue to fire with the same fuels. Maximum load heat rate was expressed in BTUs input per kilowatt hours output. The efficiencies were calculated for each plant as follows:

Cumberland $$\frac{3413\,BTU}{Kwh} * \frac{KwH\,Out}{9747\,BTU\,In} = 0.35$$

Gallatin $$\frac{3413\,BTU}{Kwh} * \frac{KwH\,Out}{9327\,BTU\,In} = 0.37$$

Johnsonville (Units 1-6) $$\frac{3413\,BTU}{Kwh} * \frac{KwH\,Out}{11217\,BTU\,In} = 0.30$$

Johnsonville (Units 7 - 10) $$\frac{3413\,BTU}{Kwh} * \frac{KwH\,Out}{10400\,BTU\,In} = 0.33$$

Assuming an average thermal efficiency of 0.35 for these coal-fired utilities, the resulting NO_x emissions from electric vehicles energy usage can be calculated for each plant in grams of NO_X per mile. Since VOC and CO emissions from power plants are negligible, on a per mile basis from EVs, only NO_X emissions are calculated and shown in this manner. Power plant emission increases of VOCs and CO from EV use are accounted for in all UAM modeling and are shown in the emission totals later in this report.

A NO_X emission factor of 0.43 lbs per 10^6 BTUs input was provided by TVA for the Gallatin Steam Plant (TVA, 1994-A). This emission factor reflects the low NO_X burner system which is currently installed at the Gallatin plant. Using this factor, and the appropriate efficiencies, the following NO_X emissions on a per mile basis can be calculated for an EV. The NO_X emissions generated by an EV using power generated at the Gallatin Steam plant are 1.03 grams per mile, shown in the following calculation.

$$\frac{0.43\,lb\,NOx}{10^6\,BTU} * \frac{3413\,BTU}{Kwh} * \frac{453.6\,g}{lb} * \frac{1}{0.35} * \frac{1}{0.92} * \frac{0.5\,kWh}{Mile} = \frac{1.03\,g\,NOx}{Mile}$$

Unlike the Gallatin plant, which utilizes 4 tangentially fired boilers, and the Johnsonville plant, which has 6 tangentially fired and 4 front fired boilers, the Cumberland Steam Plant uses 2 cell fired units (Early, 1994). Cell fired units are subject to NO_X emissions limits in 1998. At the present time these limits have not been established. The current NO_X emission factor provided by TVA for the Cumberland Steam plant is 1.2 lbs NO_X per10^6 BTU input (TVA, 1994-A). By the study year of 2010 the Cumberland plant will have been required to have the 1998 low NO_X burner limits in place. A cell fired low NO_X burner was assumed to be consistent with current tangentially fired low NO_X burner technology. An assumed NO_X reduction of 40 percent was applied to the current Cumberland NO_X emission rate of 1.2 lbs per 10^6 BTUs input, which results in a calculated future NO_X emission rate of 0.72 lbs per 10^6 BTUs input for this pant. The following calculation gives the NO_X emission per EV mile from the Cumberland Steam plant using this factor.

$$\frac{0.72\,lb\,NOx}{10^6\,BTU} * \frac{3413\,BTU}{Kwh} * \frac{453.6\,g}{lb} * \frac{1}{0.35} * \frac{1}{0.92} * \frac{0.5\,kWh}{Mile} = \frac{1.73\,g\,NOx}{Mile}$$

A NO_X emission factor of 0.51 lbs per 10^6 BTUs input was provided by TVA for the Johnsonville Steam Plant (TVA, 1994-A). This emission factor reflects the low NO_X burner system which will be installed at the Johnsonville plant by 1996. Using this factor the following NO_X emission on a per mile basis can be calculated for an EV.

$$\frac{0.51\,lb\,NOx}{10^6\,BTU} * \frac{3413\,BTU}{Kwh} * \frac{453.6\,g}{lb} * \frac{1}{0.35} * \frac{1}{0.92} \frac{0.5\,kWh}{Mile} = \frac{1.23\,g\,NOx}{Mile}$$

Table 11 summarizes the utility NO_X emissions on a per mile basis from EV use in the MTMD, by power plant. Emission factors of 1.03, 1,73, and 1.23 grams per mile of NO_X emissions are calculated for the Gallatin, Cumberland and Johnsonville steam plants, respectively. Also included in Table 11 are the LDGV NO_X emission limits required for new vehicles after 1995, and the LDGT1 NO_X emission limits for new trucks after 1996. The LDGV class of vehicles is defined as vehicles with a weight less than 3750 lbs. This can be compared to the predicted weight of 3600 lbs. for an EV which consumes 0.5 kilowatt hours per mile of electricity. The EV weight of 3600 lbs can be estimated from the linear relationship between weight and energy consumption, described in section 3.3 of this document.

5.2 Utility Emissions

5.2.1 Projected 2010 Utility Emissions

The 2010 TVA power plant emissions of VOCs, NO_X and CO were calculated using projected power production figures for each plant provided by TVA for the ozone season months of June, July and August (TVA, 1994-B). These power production predictions are included in the Appendix of this document. The NO_X emissions were calculated by using NO_X emission factors provided by TVA for the Gallatin and Johnsonville plant and by using 60 percent of the current NO_X emission factor value provided by TVA for the Cumberland plant. This reduced factor was used for the Cumberland plant to approximate the NO_X limits to be imposed by the U.S. EPA on cell

Table 11. Utility NO_X per Mile of EV VMT compared to Vehicle Emission Limits

Utility NO_X per Mile of EV VMT compared to Vehicle Emission Limits				
Utility	Utility NO_X Emissions (lbs/Million BTUs)	EV NO_X at the Utility (grams/mile)	LDGV NO_X Limit After 1995 (grams / mile)	LDGT1 NO_X Limit After 1996 (grams / mile)
Gallatin	0.43	1.03	0 - 50,000 mile 0.4 0- 100,000 mile 0.6	0 - 50,000 mile 0.7 0-100,000 mile 0.98
Johnsonville	0.51	1.23	0 - 50,000 mile 0.4 0- 100,000 mile 0.6	0 - 50,000 mile 0.7 0-100,000 mile 0.98
Cumberland	0.72	1.73	0 - 50,000 mile 0.4 0- 100,000 mile 0.6	0 - 50,000 mile 0.7 0-100,000 mile 0.98

fired units in 1998. AP-42 emission factors were used to calculate the VOC and CO emissions from each boiler type using the appropriate AP-42 factor (Davis, *et al.*, 1993).

Table 12 shows the calculated VOC, NO_X and CO emissions for the Gallatin, Cumberland and Johnsonville Steam plants, during the 2010 ozone season, without increases due to the implementation of EVs. The NO_X values listed here are significantly less than those reported in the MTMD 1990 SIP inventory due to the introduction of low NO_X burners at these facilities by the year 2010.

Table 12. Base case 2010 Power Plant Emissions Before Load is Increased

Base case 2010 Power Plant Emissions (Tons / Day)			
Plant	VOCs	NO_X	CO
Gallatin	0.14	34.92	1.29
Cumberland	0.77	193.82	7.12
Johnsonville	0.19	48.62	1.79
Total	1.1	277.36	10.2

5.2.2 Calculated Utility Emissions Increases from EVs

Two main scenarios were considered in this study, the first assumed that the use of EVs did not result in any increase on VOC, NO_X, or CO emissions inside the MTMD. The second scenario assumes that all additional electricity consumption, due to the

implementation of EVs will be supplied by the TVA coal-fired utilities located inside the MTMD. This scenario is further sub-divided into scenarios where 100 percent of the needed additional power is provided by each plant individually, and in combination. This scenarios are implemented in order to identify the utility location where increased emissions will have the most negative impact upon ozone formation in the MTMD.

In the second scenario the implementation of EVs in the MTMD will result in an increased power use in the MTMD. Using the EV VMT of 22.6 million miles per day calculated for the 2010 ozone season in section 4.2.1 of this document, and the NO_X emission factors shown in section 5.1.2 on a per EV mile basis, the increased NO_X emissions due to EV use can be calculated. In a similar manner the VOC and CO emissions can be calculated as well from AP-42 emission factors. The calculations for NO_X emissions due to a 25 percent EV penetration in the LDGV and LDGT1 vehicle classes at each TVA steam plant are shown below.

NO_X increase for 100 percent EV load at the Gallatin Steam Plant:

$$22.6.E^6\ VMT * \frac{1.03\,gram\ NOx}{mile} * \frac{1\,lb}{453.6\,grams} * \frac{1\,ton}{2000\,lbs} = 25.66\ tons\,NOx\,/\,day$$

NO_X increase for 100 percent EV load at the Cumberland Steam Plant:

$$22.6.E^6\ VMT * \frac{1.73\,gram\ NOx}{mile} * \frac{1\,lb}{453.6\,grams} * \frac{1\,ton}{2000\,lbs} = 43.10\ tons\,NOx\,/\,day$$

NO_X increase for 100 percent EV load at the Johnsonville Steam Plant:

$$22.6.E^6\ VMT * \frac{1.23\,gram\ NOx}{mile} * \frac{1\,lb}{453.6\,grams} * \frac{1\,ton}{2000\,lbs} = 30.64\ tons\,NOx\,/\,day$$

In Table 13 the base case 2010 TVA Steam plant NO_X emissions are shown as well as the increase which would occur at each plant if it alone, were to provide the additional power requirements due to a 25 percent EV penetration in the LDGV and LDGT1 class of vehicles.

In a similar manner, VOC and CO emission increases were calculated using AP-42 emission factors and the additional EV power load. The 2010 TVA Steam plant VOC

Table 13. Coal-Fired Utility NO_X Emissions with and without EV Load Increase

Utility NO_X Emissions with and without EV Load Increase (Tons / Days)			
Scenario	Gallatin	Cumberland	Johnsonville
2010 Base case	34.92	193.82	48.62
Emissions from EV Load Increase	25.66	43.10	30.64
25 percent EV Scenario *	60.58	236.92	79.26

* During UAM modeling only 1 plant was input at 100 percent EV load per simulation.

and CO emissions are shown in Tables 14 and 15 respectively. These values represent the emissions increase which would occur at each plant, if it alone, were to provide the additional power requirements due to a 25 percent EV penetration in the LDGV and LDGT1 class of vehicles.

For a UAM modeling scenario where 100 percent of the EV emissions load was placed at one plant, all three pollutants, VOC, NO_X and CO, were increased to represent the increased load. The remaining two plant's emissions were left at the base case levels, unless a combination scenario, where more than one plant carried the load, was being simulated.

Table 14. Coal-Fired Utility VOC Emissions with and without 100 Percent EV Load Increase

Utility VOC Emissions with & without 100 percent EV Load Increase (Tons/Day)			
Scenario	Gallatin	Cumberland	Johnsonville
2010 Base case	0.14	0.77	0.19
Emissions from EV Load Increase	0.10	0.10	0.10
25 percent EV Scenario *	0.24	0.87	0.29

* During UAM modeling only 1 plant was input at 100 percent EV load per simulation.

Table 15. Coal-Fired Utility CO Emissions with and without 100 percent EV Load Increase

Utility CO Emissions with & without 100 percent EV Load Increase (Tons/Days)			
Scenario	Gallatin	Cumberland	Johnsonville
2010 Base case	1.29	7.12	1.79
Emissions from EV Load Increase	0.95	0.95	0.95
25 percent EV Scenario *	2.24	8.07	2.74

* During UAM modeling only 1 plant was input at 100 percent EV load per simulation.

Chapter 6: Urban Airshed Model Simulations

6.1 Overview

The UAM model was used to simulate the ozone precursor emission changes in both the on-road mobile source category and the TVA Steam plants due to the calculated impact of EV penetration in the MTMD. Two meteorological scenarios were used. These scenarios are representative of dates used by the University of Tennessee in the 1988 UAM Model Performance Evaluations and 1996 UAM Ozone Attainment Demonstrations for the MTMD. These dates were chosen for several reasons. Both of these days have been modeled extensively by the UTK, and day specific inventories were available for 1996. Four day specific meteorological scenarios were simulated using the UAM model for the MTMD for both the 1988 UAM Model Performance Evaluations and 1996 UAM Ozone Attainment Demonstrations (Davis, *et al.*, 1995). Two of these dates, August 1, 1988 and August 3, 1988, were relatively low windspeed days where ozone production was predominately centered around the Nashville metropolitan area. A third date, June 24, 1988, was a higher windspeed day where the highest ozone concentration predicted occurred downwind of the Cumberland power plant. The fourth date, July 09, 1988, was dominated by transport into the region from north of the MTMD.

For this study the meteorological conditions on August 3, 1988 and June 24, 1988 were simulated. The UAM model has been validated and EPA statistical

performance measures met for simulation results compared to measured ozone data on these dates in 1988. The 1990 SIP ozone season inventory for the MTMD was projected to 2010 using BEA factors for all point sources other than TVA utility sources. The BEA projection factors were also used for area and non-road mobile sources. The on-road mobile source category was developed using MOBILE5A emission factors and projected 2010 VMT values.

All times reported in the following analyses are in the form Central Daylight Savings Time clock time.

6.2 August 3, 2010 UAM Results (Low Wind Speed Scenario)

6.2.1 Modeling Scenarios

For this study, using the meteorological conditions for August 3, 1988 the following series of 2010 simulations were made using the UAM.

August 3, 2010

- Base case August 3, 2010 Conditions (No EV Penetration)
- 25 percent EV Penetration (LDGV & LDGT1), no EV load at Utilities
- 25 percent EV Penetration (LDGV & LDGT1), 100 percent EV load at Gallatin, with emissions increases distributed proportionally over 24 hours.
- 25 percent EV Penetration (LDGV & LDGT1), 50 percent EV load at Gallatin & 50 percent at Cumberland, distributed proportionally over 24 hours.

- 25 percent EV Penetration (LDGV & LDGT1), 100 percent EV load at Gallatin, with all emissions increases from 6 p.m. to 7 a.m., applied as a level load.

The bulk flow direction of the wind on August 3, 1988 was from the east to the west. The impact of emissions from all source categories were simulated under these conditions. Emissions from the Nashville Urban area, including mobile source emissions, were transported from east to west producing a maximum ozone concentration just west of Davidson County, in Cheatham County, Tennessee. Emissions from the Gallatin plant were transported across the Nashville urban area, while emissions from the Cumberland and Johnsonville plants were transported westward, out of the modeling domain. Emissions increases due to EV loads at the Gallatin plant were simulated, distributed proportionally over 24 hours of the day, and over the 12 hour night-time period of 6 p.m. to 7 a.m., applied as a level load. The maximum ozone concentrations predicted for the August 3, 2010 UAM simulations are shown in Table 16 The grid-cell location and time of maximum concentration are also given as well.

6.2.2 Data Analysis

The base case 2010 simulation predicted an exceedence of the current 1 hour average ozone standard of 120 ppb. All 25 percent EV penetration scenarios, regardless

Table 16. August 3, 2010 UAM Predicted Ozone Maximum Concentrations

August 3, 2010 UAM Predicted Ozone Maximum Concentrations (ppb)			
Simulation	Ozone (ppb)	Time	Grid-Cell
Basecase (No EV Penetration)	130.7	4 p.m.	985
25 percent EV, no EV load increase in MTMD	127.1	4 p.m.	985
25 percent EV, 100 percent EV load at Gallatin, distributed over 24 hours	128.0	4 p.m.	985
25 percent EV, 50 percent EV load at Gallatin, 50 percent at Cumberland	127.6	4 p.m.	985
25 percent EV, 100 percent EV load at Gallatin, from 6 p.m. - 7 a.m.	128.4	4 p.m.	985

of where the EV power was generated, were predicted to exceed the 1 hour ozone standard. For regulatory purposes the U.S. EPA currently requires all ozone control strategies simulated with the UAM model to be judged on the single highest predicted grid-cell concentration of ozone over the entire day simulated at any location in the modeling domain. Using this definition, and considering only the current ozone standard, none of the EV usage scenarios would be considered successful. The ozone profile for the base case 2010 (No EVs) and the 25 percent EV penetration with no EV load at utilities, scenarios, at the grid-cell of highest predicted concentration, are shown in Figure 10. This represents the maximum ozone reduction EV scenario, when looking only at a single cell maximum value. A daily ozone maximum reduction of 3.6 ppb was

August 3, 2010 Ozone Profiles

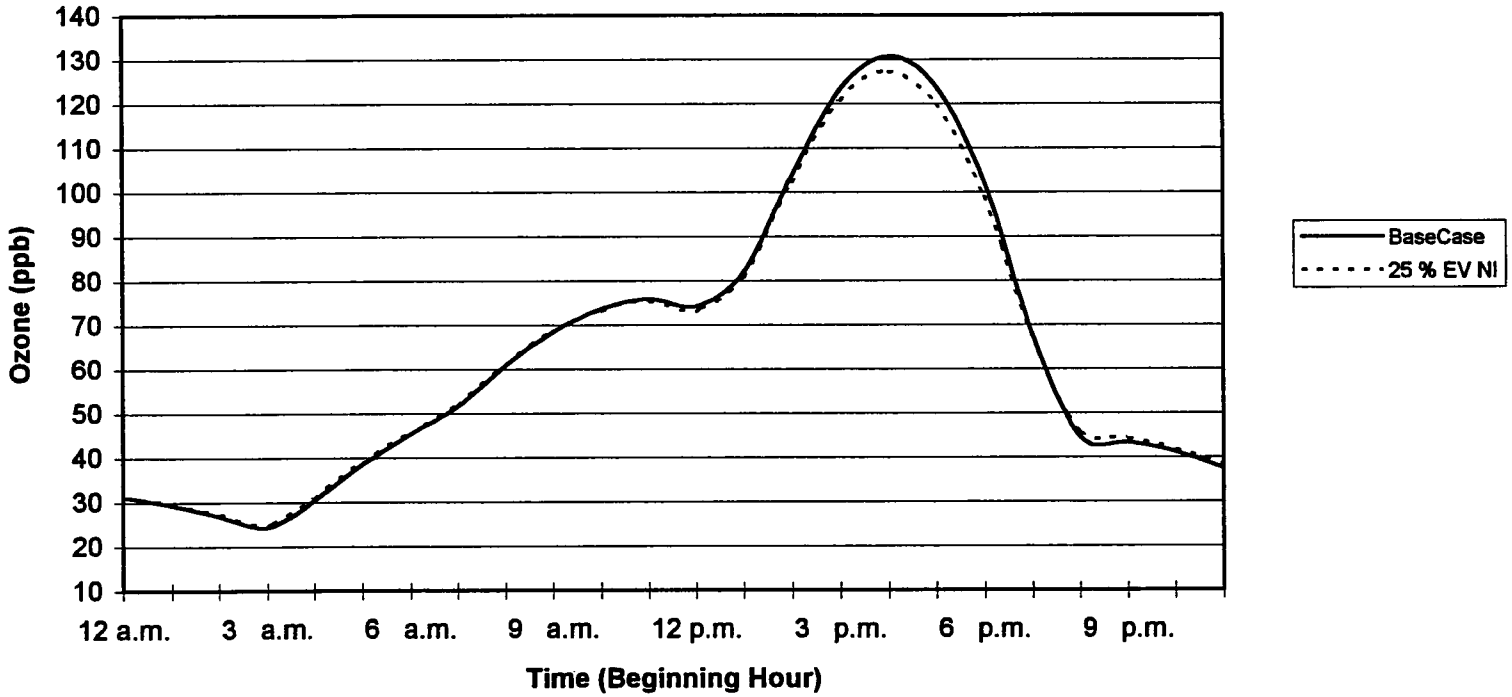


Figure 10. August 3, 2010 Ozone Profiles

predicted from the implementation of 25 percent EVs in the LDGV and LDGT1 vehicle classes, without the EV utility load in the MTMD, when compared to a 2010 base case with no EVs. The base case simulation predicted a maximum ozone concentration of 130.7 ppb, while the 25 percent EV scenario, without additional EV utility load resulted in a predicted maximum ozone concentration of 127.1 ppb. All other simulation profiles for this grid-cell, for the August 3, 2010 scenarios fall within the ranges established by the base case and 25 percent EV, no utility load increase profiles.

The adoption of an 8 hour average ozone standard is currently under debate. The 8 hour average standard has been suggested as 80 or 100 ppb. A more detailed analysis was conducted for both the 25 percent EV scenario with no EV load at the utilities, and the 25 percent EV scenario where 100 percent of the EV load was distributed proportionally over 24 hours at the Gallatin Steam plant. Since the remaining scenarios have very similar results only these two scenarios will be presented here with an expanded analysis.

Figure 11 shows a color isopleth map of August 3, 2010 base case scenario ground level ozone concentration for the 4 p.m. hour, when the maximum predicted ozone concentration occurred. The maximum ozone concentration of 130.7 ppb was located about 25 kilometers west of the Nashville urban area, in the base case simulation.

Several color isopleth maps were prepared for the expanded analysis. Each color map has the name of the data file which was used to generate the map listed at the top. This file name starts with an abbreviated date, such as AG0310, for August 3, 2010.

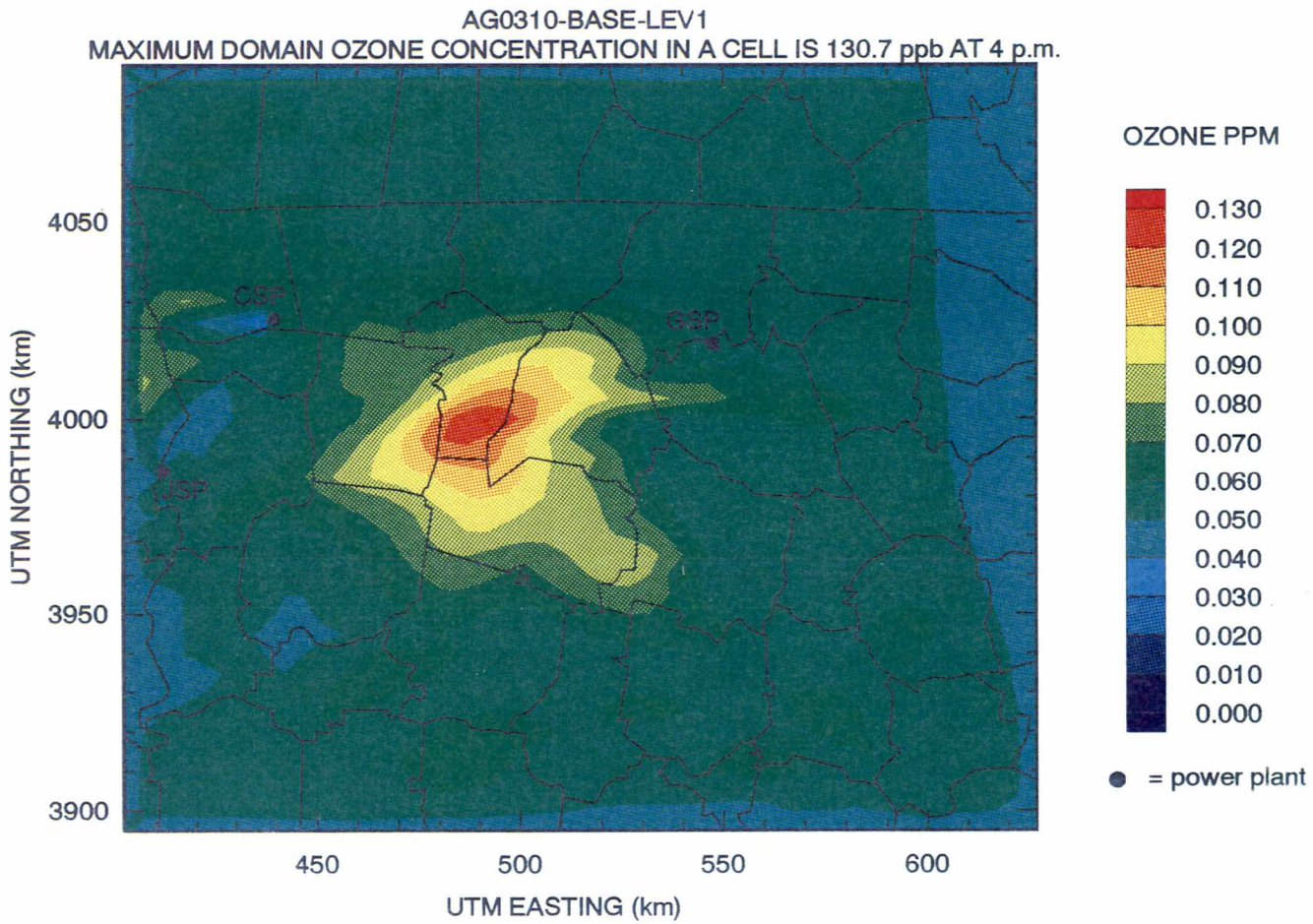


Figure 11. August 3, 2010 Base case Maximum Predicted Ozone Concentration

The scenario, or two scenarios used if the plot is a difference map of two runs is listed next. If two runs were used to generate a difference plot the second scenario was always subtracted from the first. The second scenario in this case will always be the appropriate base case scenario. This methodology insures that negative numbers indicate a decrease in ozone from the base case scenario, while positive values indicate an ozone increase over base case conditions. The use of difference plots in this manner allows one to see the change in ozone concentrations, across the entire domain due to the implementation of each scenario. This method provides much more information than simply looking at single cell maximum concentrations. Figures 12, 13, 14 and 15 show the effect of implementing a 25 percent EV penetration, with no utility load increases; with 100 percent of the required EV load distributed proportionally to the 1988 load pattern, over 24 hours at the Gallatin Steam plant; with 50 percent of the required EV load placed at the Gallatin Steam plant; and 50 percent of the EV load at the Cumberland Steam plant; and with 100 percent of the required EV load placed at the Gallatin Steam plant during the night-time hours from 6 p.m. through 7 a.m. applied as a level load, respectively. In Figure 16., the Gallatin August 3, 1988 emissions profile provided by TVA is shown, adjusted to the 2010 base case level, the 24 hour EV load level and the adjusted profile used when the required EV loads were added during the 6 p.m. through 7 a.m. period, applied as a level load.

Although all August 3, 2010 EV scenarios have similar maximum single cell ozone concentrations, the difference plot shown in Figures 12, 13, 14 and 15 show

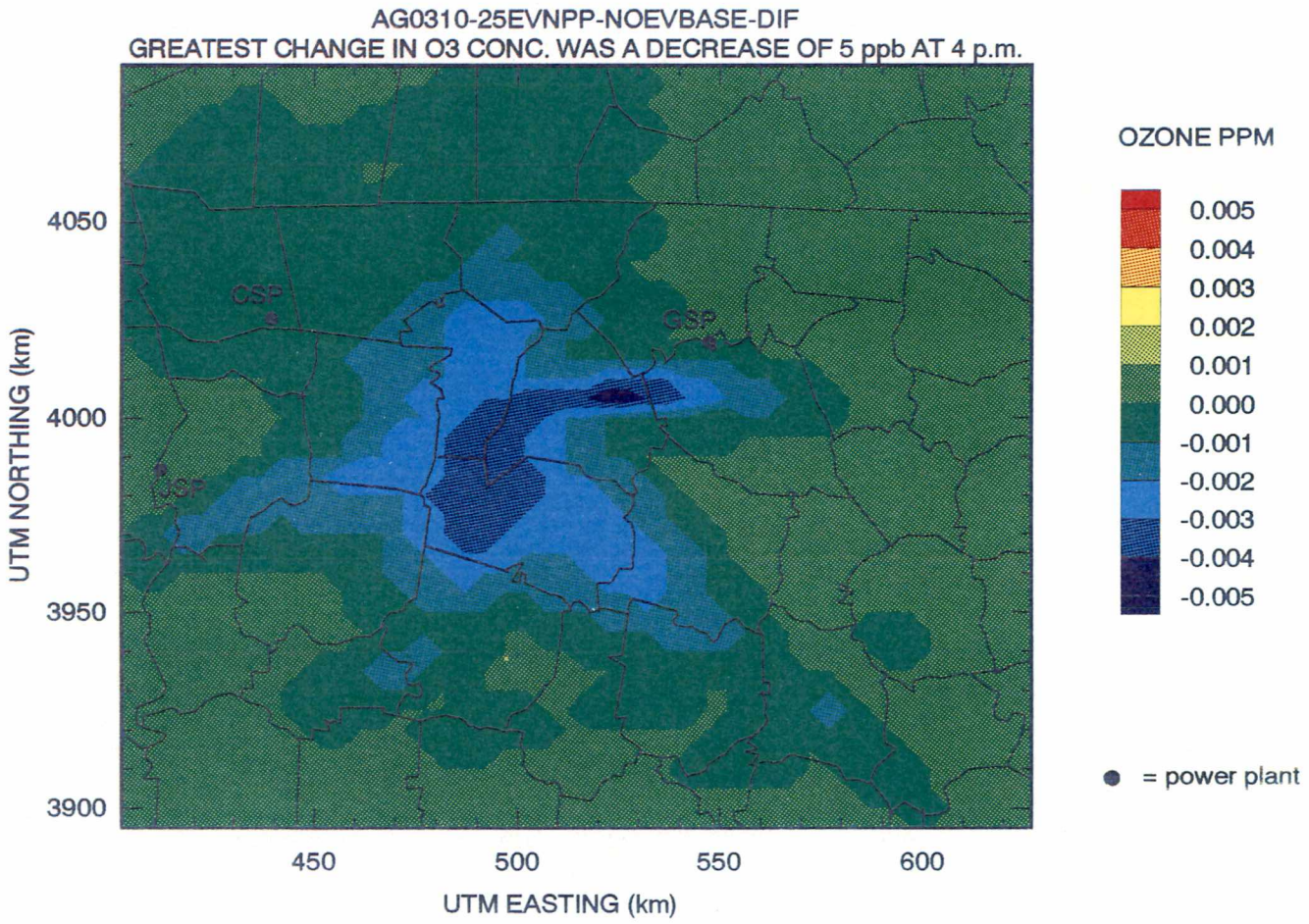


Figure 12. August 3, 2010 25 % EV, No Utility Load Increase Difference Plot

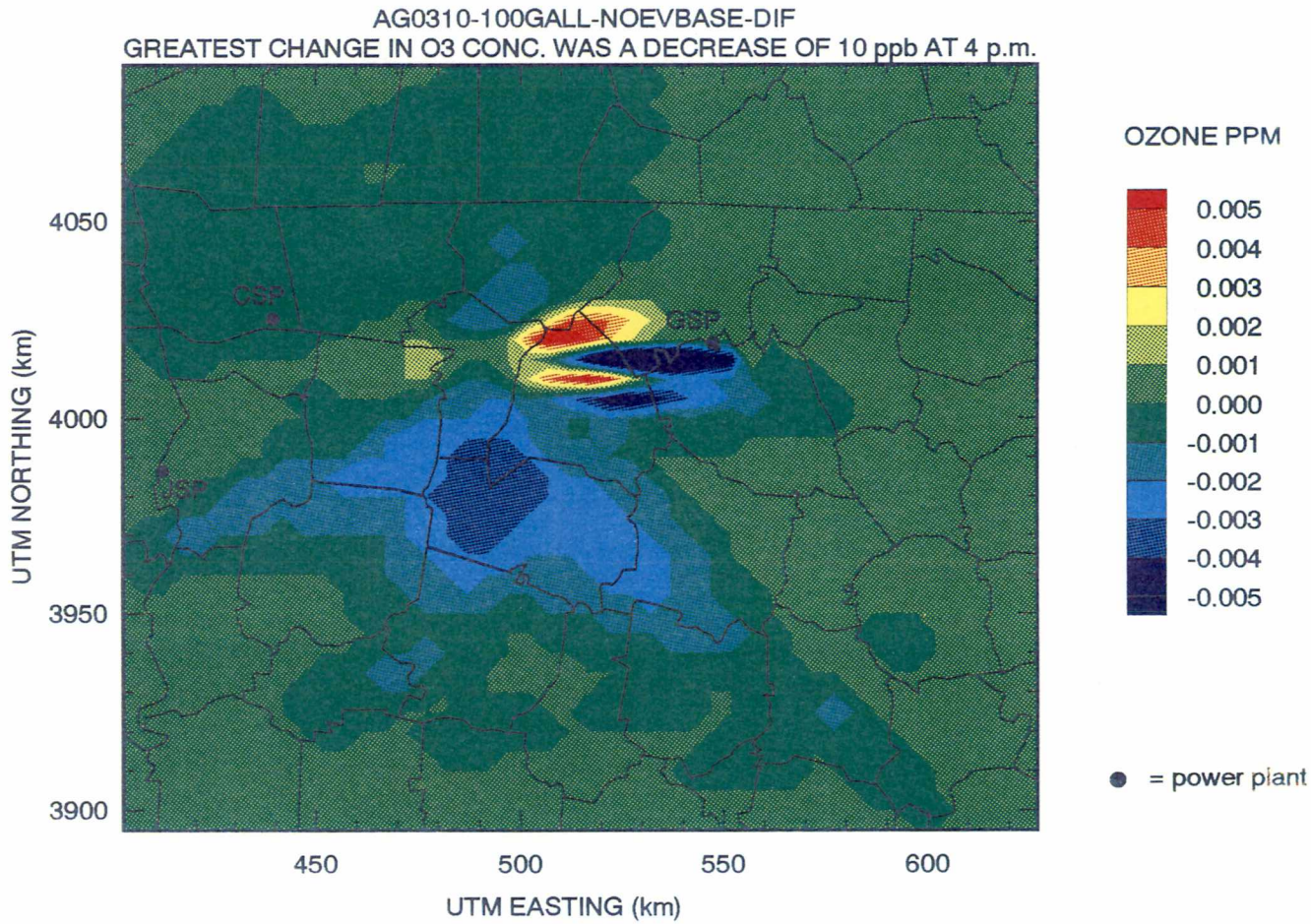


Figure 13. August 3, 2010 25 % EV, Load at Gallatin Difference Plot

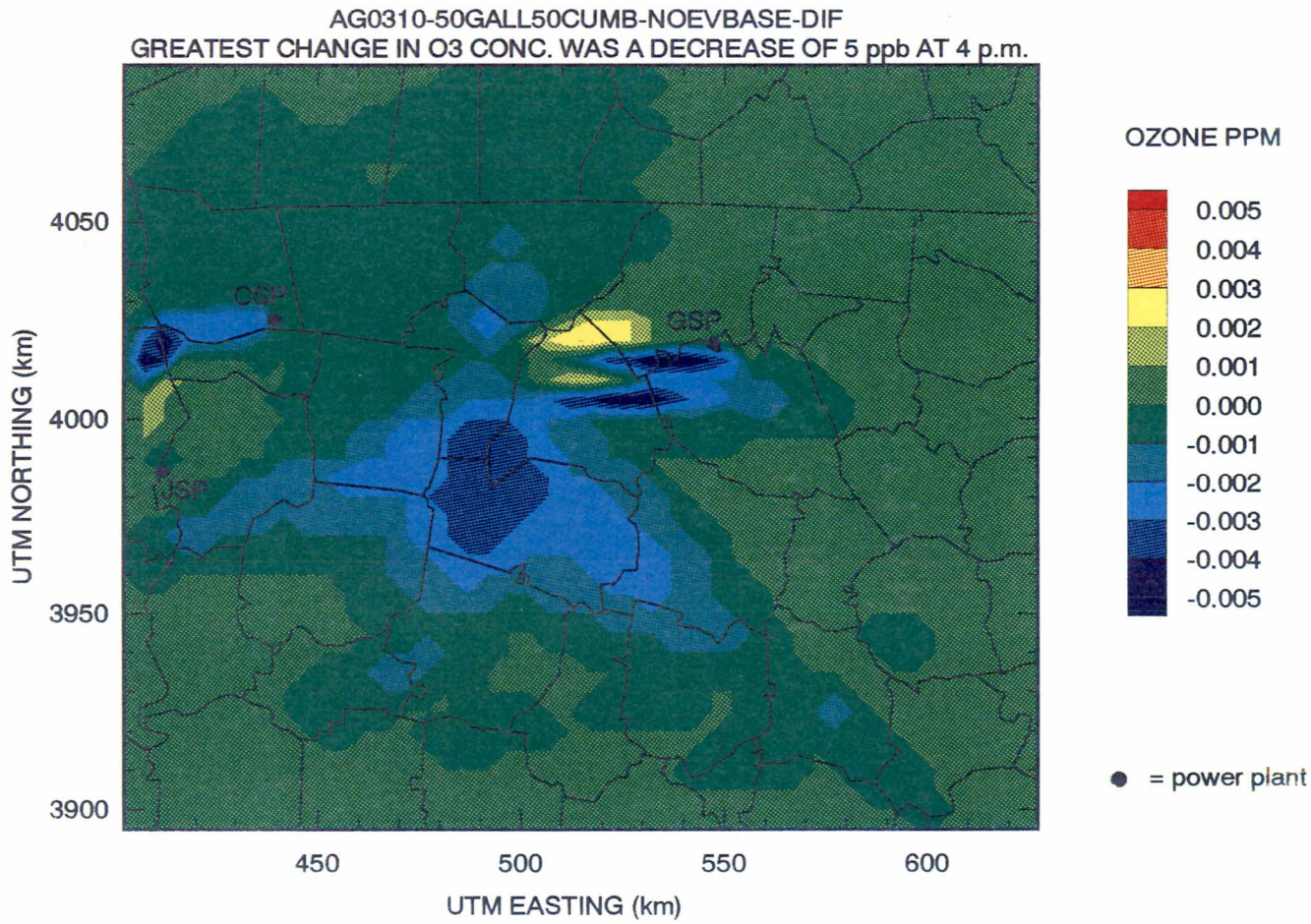


Figure 14. August 3, 2010 25 % EV, Load Split Gall. - Cumb. Difference Plot

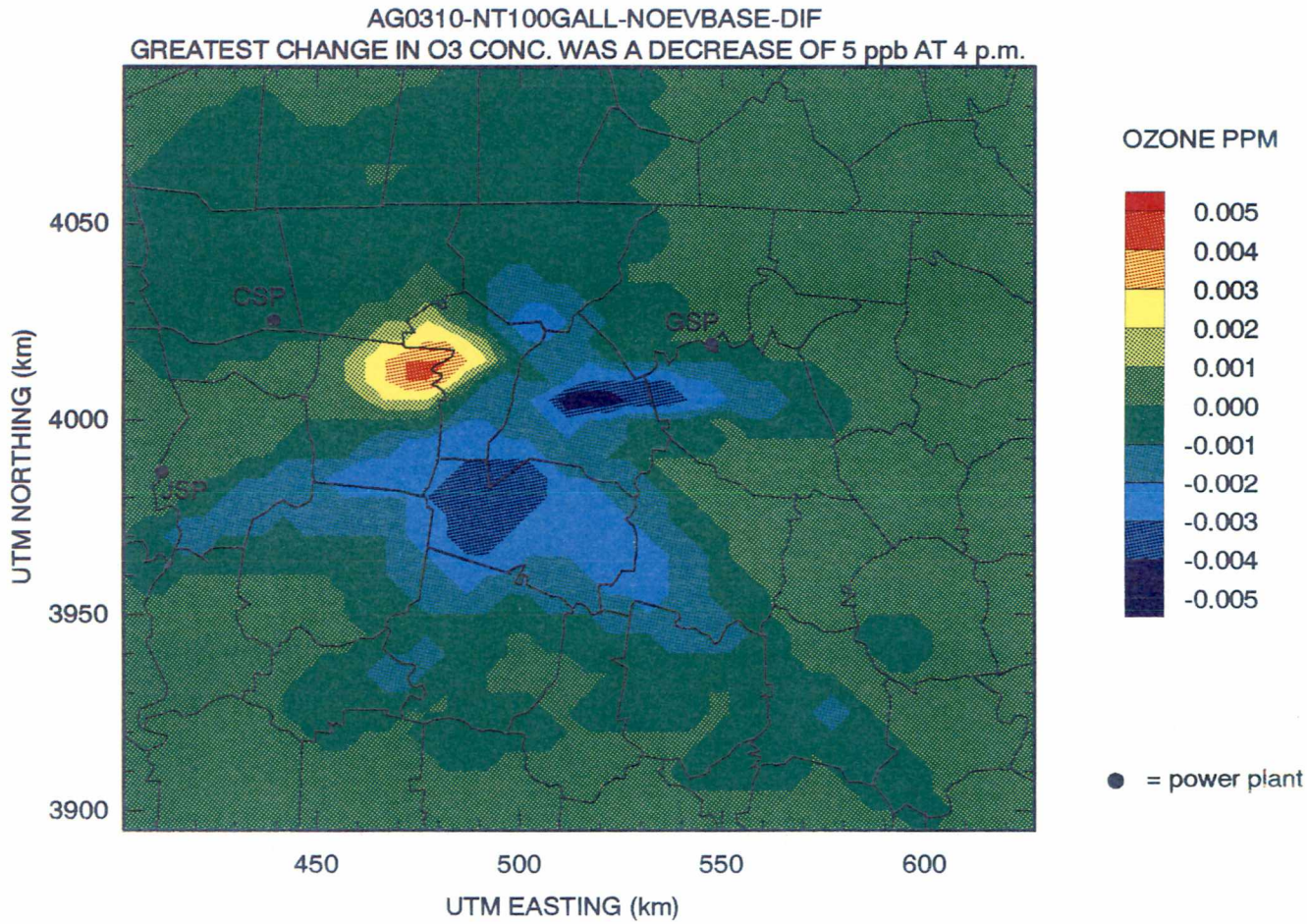


Figure 15. August 3, 2010 25 % EV, Night Load at Gallatin Difference Plot

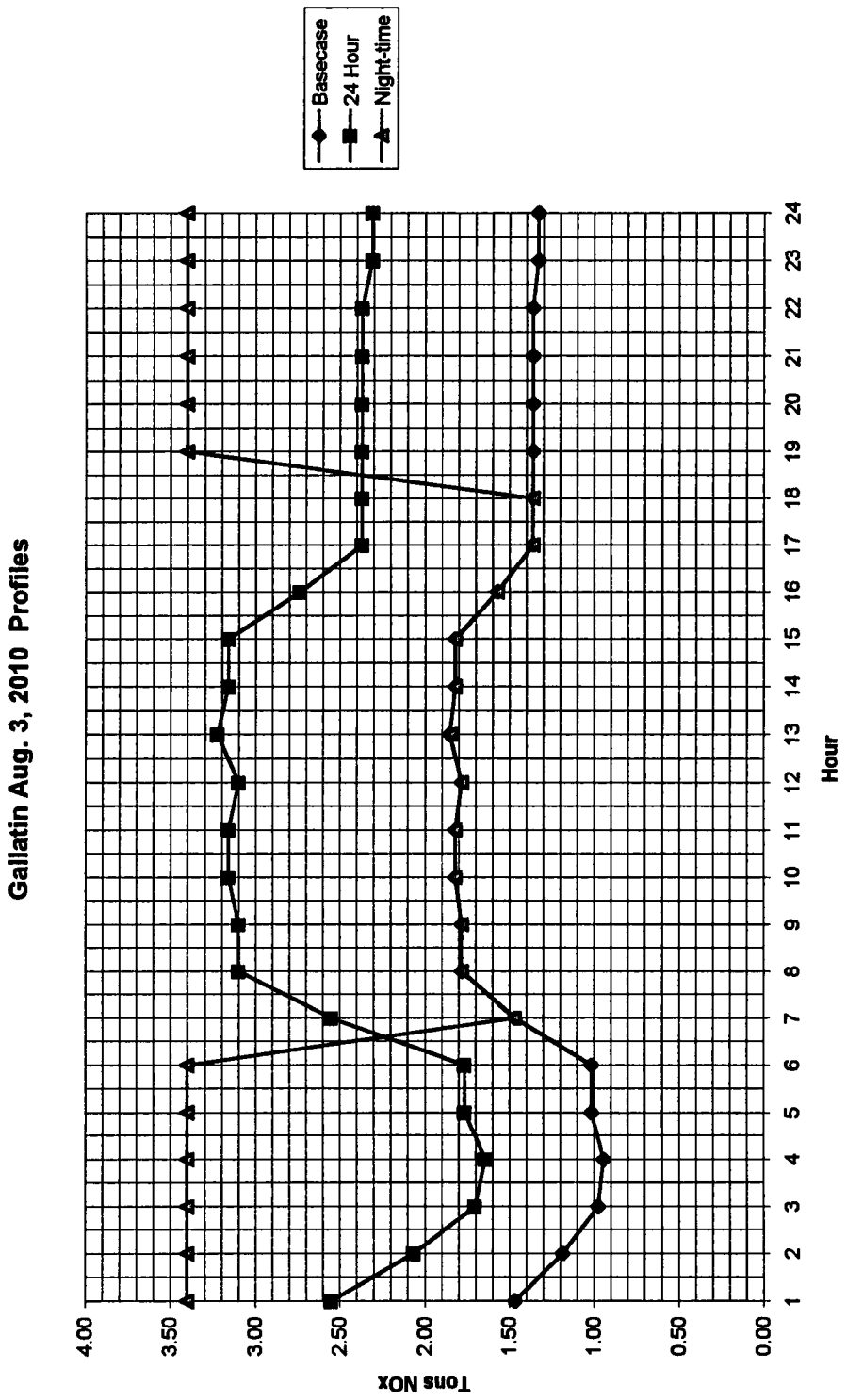


Figure 16. Gallatin Steam Plant Emissions Profile

greater variation at locations other than the maximum ozone concentration cell location. Figure 13 shows that a large area experienced an ozone reduction in the 3 - 5 ppb range during the hour when the daily ozone maximum was predicted. When emissions are increased at the Gallatin plant in an amount appropriate to support the 25 percent EV penetration, an increase in the Gallatin plants contribution to ozone is noted, near the edges of the plume. The centerline of the plume shows increased scavenging due to the increased NO_X emissions. Figure 14 shows similar results where the Gallatin plume influence is lessened due to 50 percent rather than 100 percent of the additional power being generated at The Gallatin plant. The result of the additional 50 percent EV power requirement added at Cumberland in this simulation, cannot be seen due to meteorological conditions which transport the Cumberland plume westward out of the modeling domain on this date. The largest area of ozone increase predicted from increased emissions at Gallatin is shown in Figure 15. The intensity of this increase is between 4 and 5 ppb, as shown in Figure 15, at 4 p.m. due to increased emissions in the early morning hours. In the scenario shown here, 100 percent of the additional power requirements were met by Gallatin from 6 p.m. to 7 a.m. The increased NO_X emissions stop at the beginning of the 7 a.m. hour, but the plume from this release remains in the domain for several hours, and its effect is seen in Figure 15.

For the 25 percent EV scenario with no utility load increase, and the 100 percent EV power requirements supplied by Gallatin Steam plant distributed proportionally over a 24 hour period scenario, a more detailed analysis was conducted. The previous plots

show the increases and decreases of ozone concentrations for the maximum hour only. In an effort to gain a better understanding of the ozone concentration changes over time, an 8 hour analysis was performed on these scenario results. The 8 hours of highest predicted ozone concentration for the August 2010 scenarios was identified from the profiles shown previously in Figure 10. This period was identified as 11 a.m. to 7 p.m.. A series of FORTRAN programs were written which identify the maximum ozone increase in each grid-cell over the selected 8 hour period due to the implementation of each of the two selected scenarios when compared to the base case. A similar FORTRAN program was written to find the largest ozone decrease in each cell over the same 8 hour period. A program was also written which calculates the 8 hour average ozone concentration change from base case conditions in each cell, over the selected 8 hour period.

Figures 17 and 18 show the maximum and minimum ozone concentration difference tileplots for the August 3, 2010 25 percent EV, no utility load increase scenario, as compared to the August 3, 2010 base case scenario. Figure 17 indicates that while some cell locations always experience an ozone decrease due to the implementation of this scenario, that others have ozone increases up to 3.6 ppb during this 8 hour time period. The cells which increase are located in the Nashville urban area. The ozone increase in the cells is due to a reduction in NO_X emissions by the introduction of EVs. The mobile NO_X in this area was great enough to cause ozone

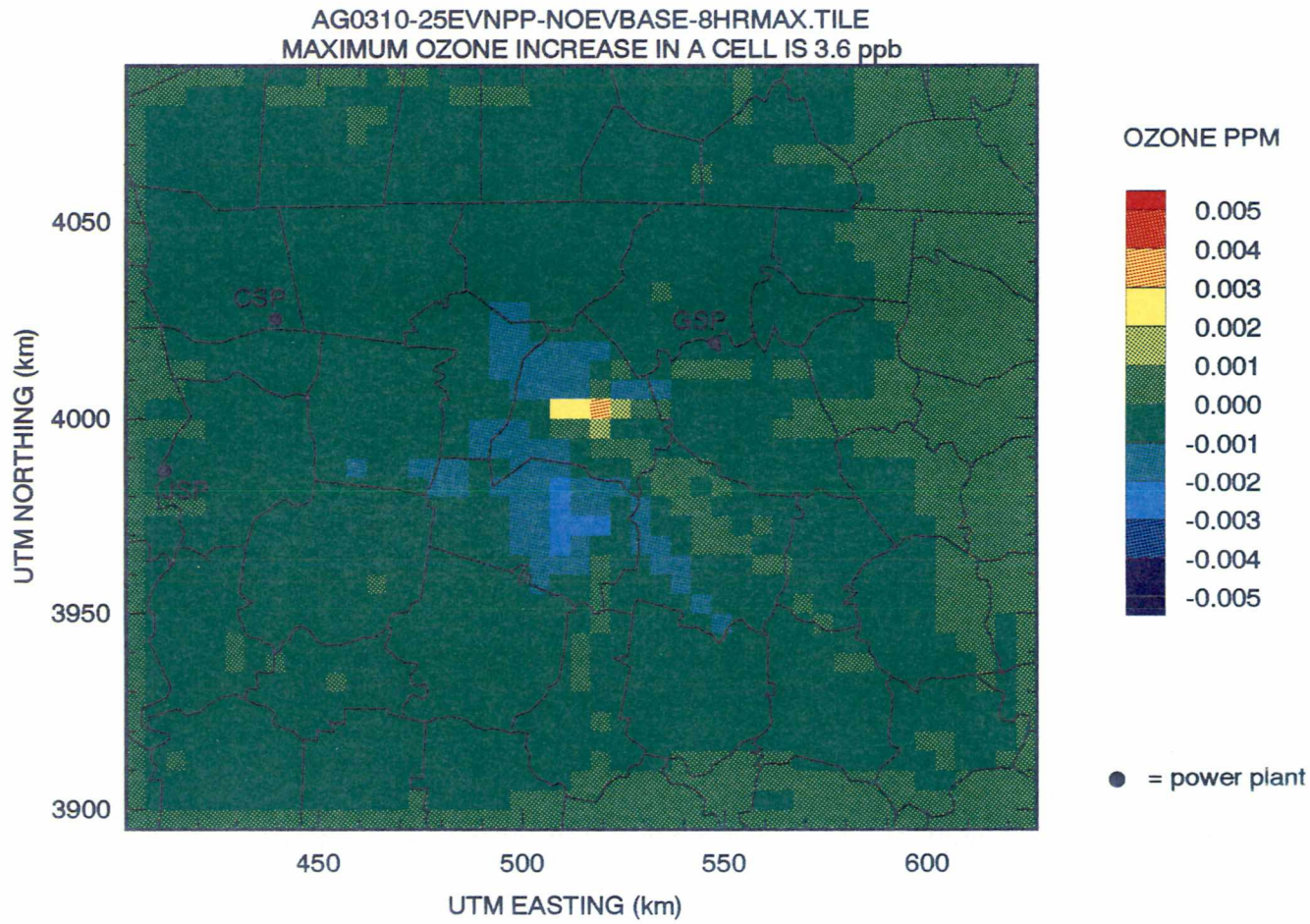


Figure 17. August 3, 2010 25 % EV, No Utility Load 8 Hour Max Plot

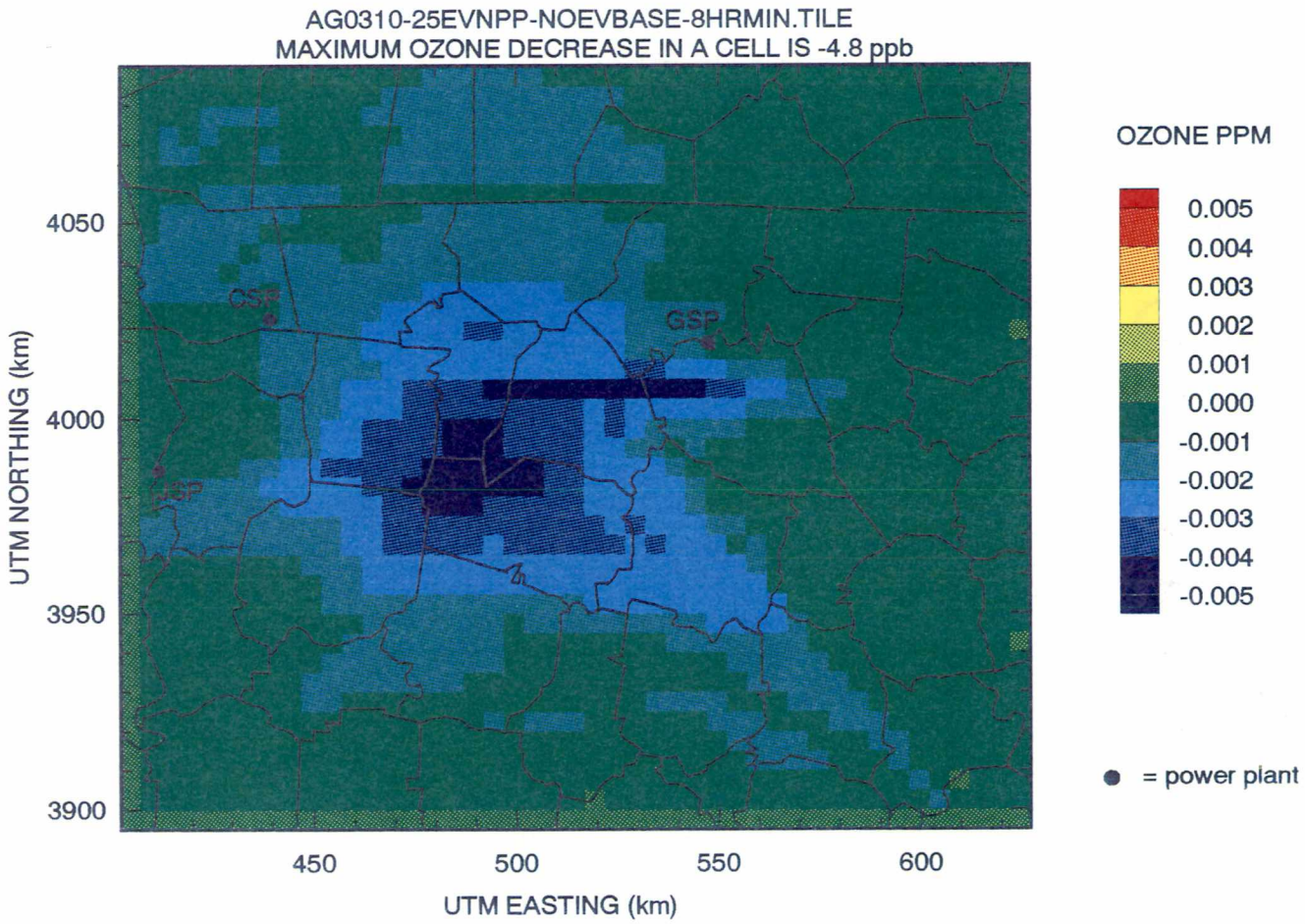


Figure 18. August 3, 2010 25 % EV, No Utility Load 8 Hour Min Plot

scavenging to occur in the 5 cell area shown in Figure 17. The removal of a portion of this NO_X reduced the scavenging effect, and shows up as an ozone increase in the difference tile plot. Figure 18 further indicates that this increase did not occur during all 8 hours between 11 a.m. to the 7 p.m. hour, as it shows that all cells decreased in ozone concentration, in reference to the base case, at some point during this time. A large area with ozone reductions of up to 4.8 ppb is noted in Figure 18. To further quantify these changes a bar chart is shown in Figure 19 which indicates the total number of grid-hours which increased and decreased in ozone concentration, over the 8 hour period of interest. The domain contains 1840 grid-cells. The total number of grid-hours over any 8 hour period would be 8 x 1840, or 14,720 grid-hours. The graph in Figure 19. indicates how many grid-hours changed (increased or decreased), and by what magnitude. The bar labeled as "0" represents the number of grid-hours with no change when compared to the base case scenario results. The "1 ppb" bar indicates cells which increased any amount greater than 0 and less than or equal to 1 ppb. In a similar manner each bar number represents grid-hour totals over the 8 hour period which changed more than the next lesser bar value up to or equal to the bar value. For the 25 percent no EV load increase scenario analyzed in Figure 19, the overall change is clearly shifted to the left, indicating a general decrease in ozone concentrations due to the implementation of this scenario. For this case 12,523 grid-hours, or 85.1 percent of the total grid-hours analyzed, decreased in ozone concentration. A total of 9.1 percent of the grid-hours had no change in ozone concentration, and 5.8 percent of the grid-hours increased in ozone

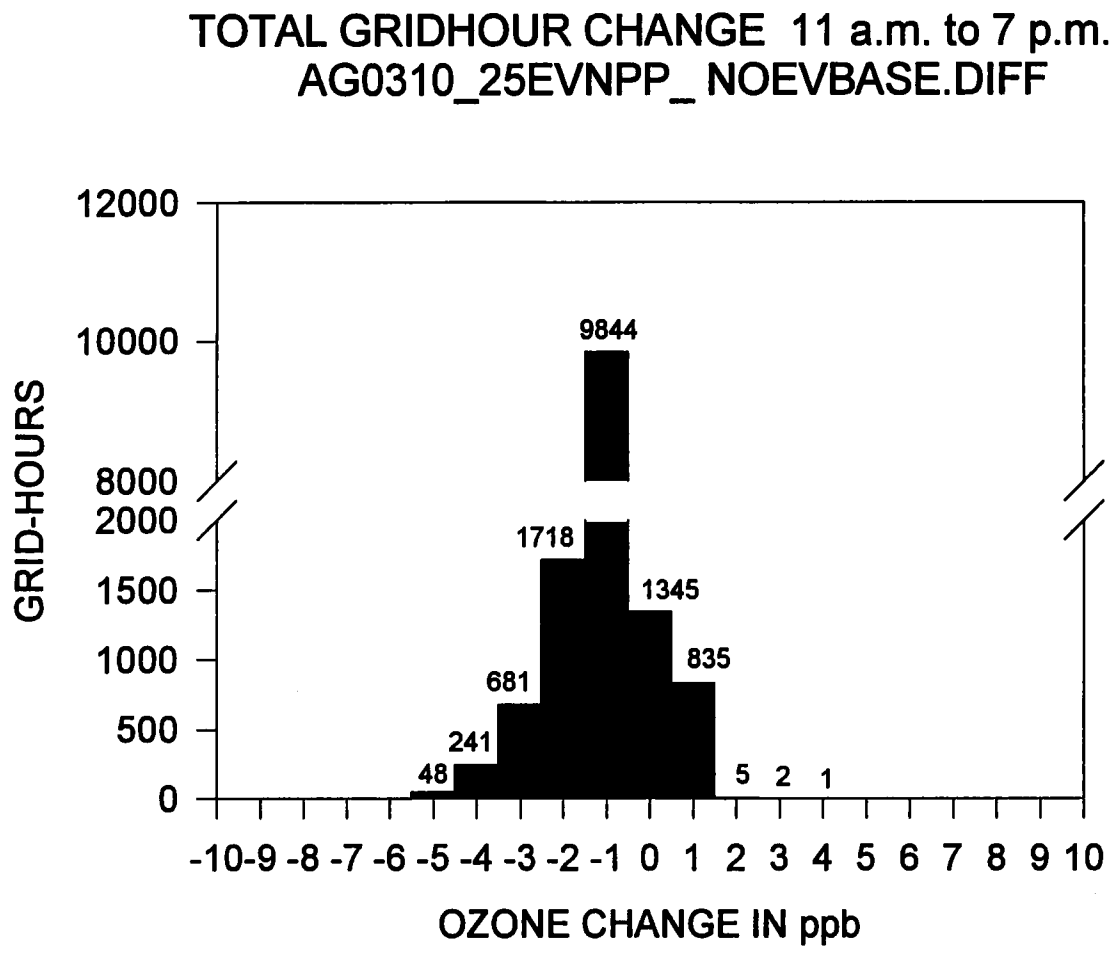


Figure 19. August 3, 2010 25 % EV, No EV Load Grid-Hour Distribution

concentration. Of the 12,523 grid-hours which decreased, 9844 or 78.6 percent decreased by 1 ppb or less. The percentage of grids which showed no change, 9.1 percent, remains relatively constant for all simulations using the same meteorological conditions. The cells which do not change are primarily located on the upwind side of the domain, and represent the in-flux of static boundary condition ozone values.

The average 8 hour change in ozone concentrations, with respect to the base case, is shown in Figure 20. This plot indicates that on the average in the 8 hour period of most concern, with respect to ozone formation, that nearly all changes in ozone were decreases. This plot is quantified in Figure 21 where a bar plot indicating the distribution of the 8 hour average grid difference values. Figure 20 shows the 8 hour average grid-cell difference value, where Figure 19 showed the distribution of all grid-cell difference values over the 8 hour period (i.e. total grid-hours over 8 hours). The distribution in Figure 21 is similar to the Figure 19 distribution, indicating most cells decreased, 89.3 percent, and that the largest portion of this decrease, 80.8 percent was less than or equal to 1 ppb.

An identical analysis was carried out for the 25 percent EV penetration, with all additionally required power supplied by the Gallatin Steam plant over 24 hours scenario. The 11 a.m. to the 7 .p.m. hour maximum and minimum tile plots are shown in Figure 22 and Figure 23. In Figure 22 ozone increases greater than 5 ppb are shown as a result of the increased NO_X emissions from the Gallatin plant. In Figure 23 the area of ozone decrease from the EV penetration is noted as well as areas of ozone scavenging due to NO_X rich areas of the Gallatin plume. The noted scavenging shows decreases in ozone

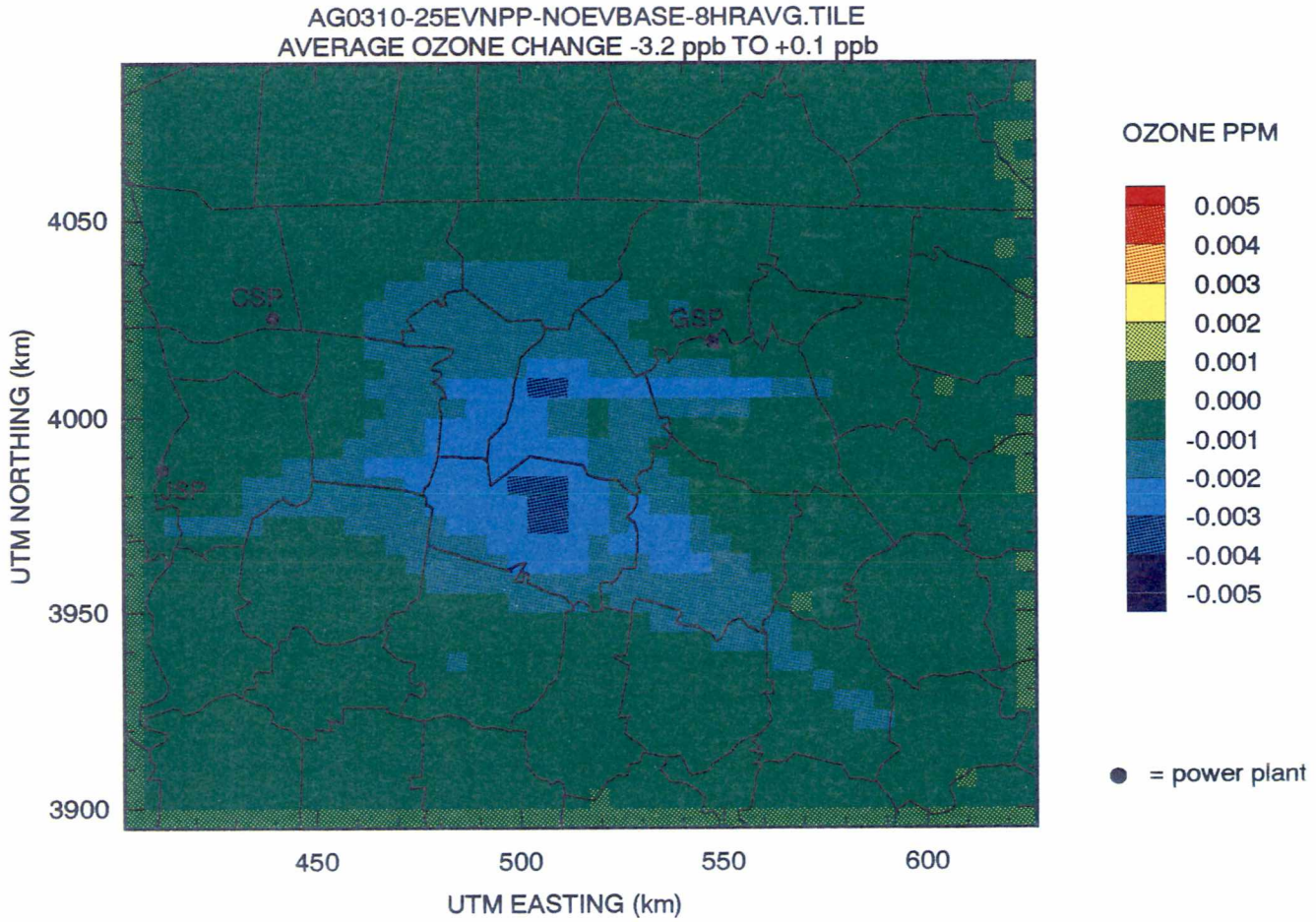


Figure 20. August 3, 2010 25 % EV, No EV Load 8 Hour Average Plot

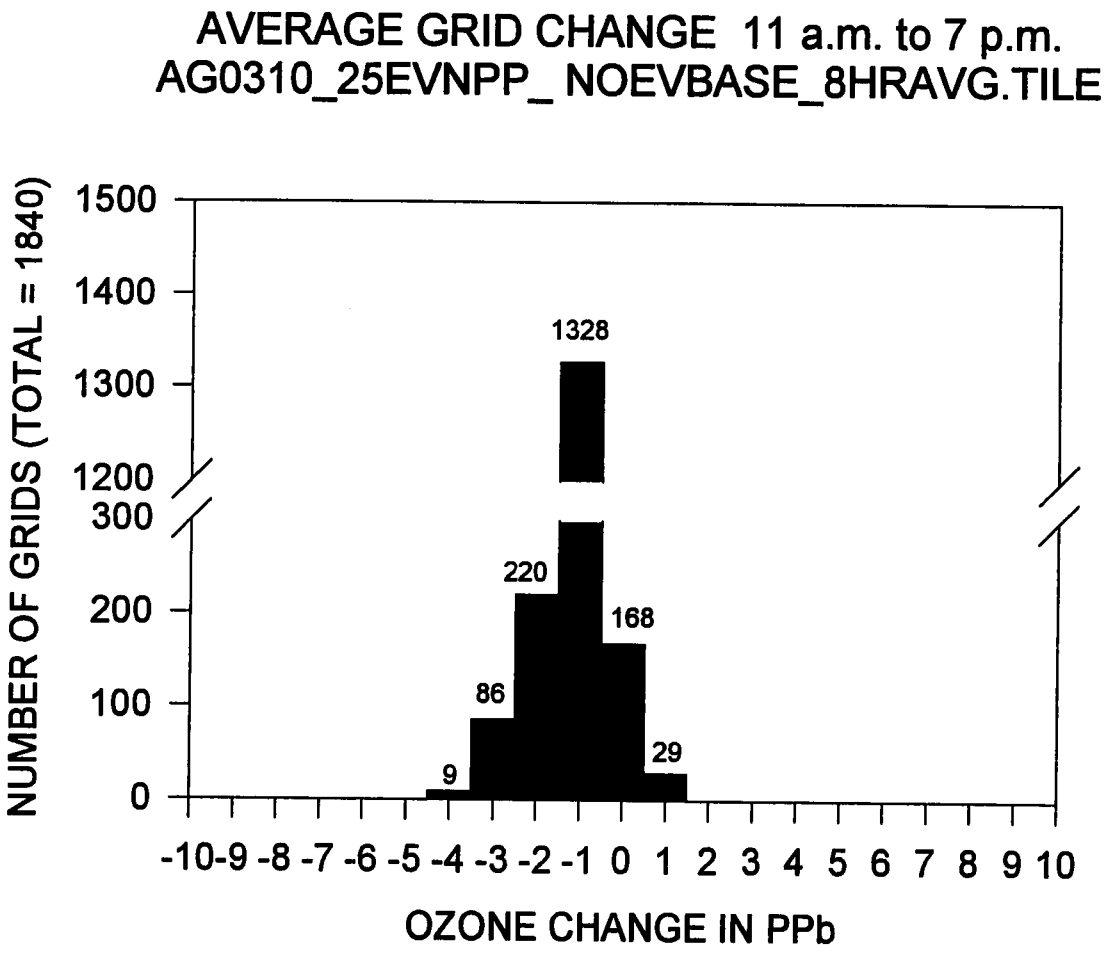


Figure 21. August 3, 2010 25 % EV, No EV Load 8 Hour Average Distribution

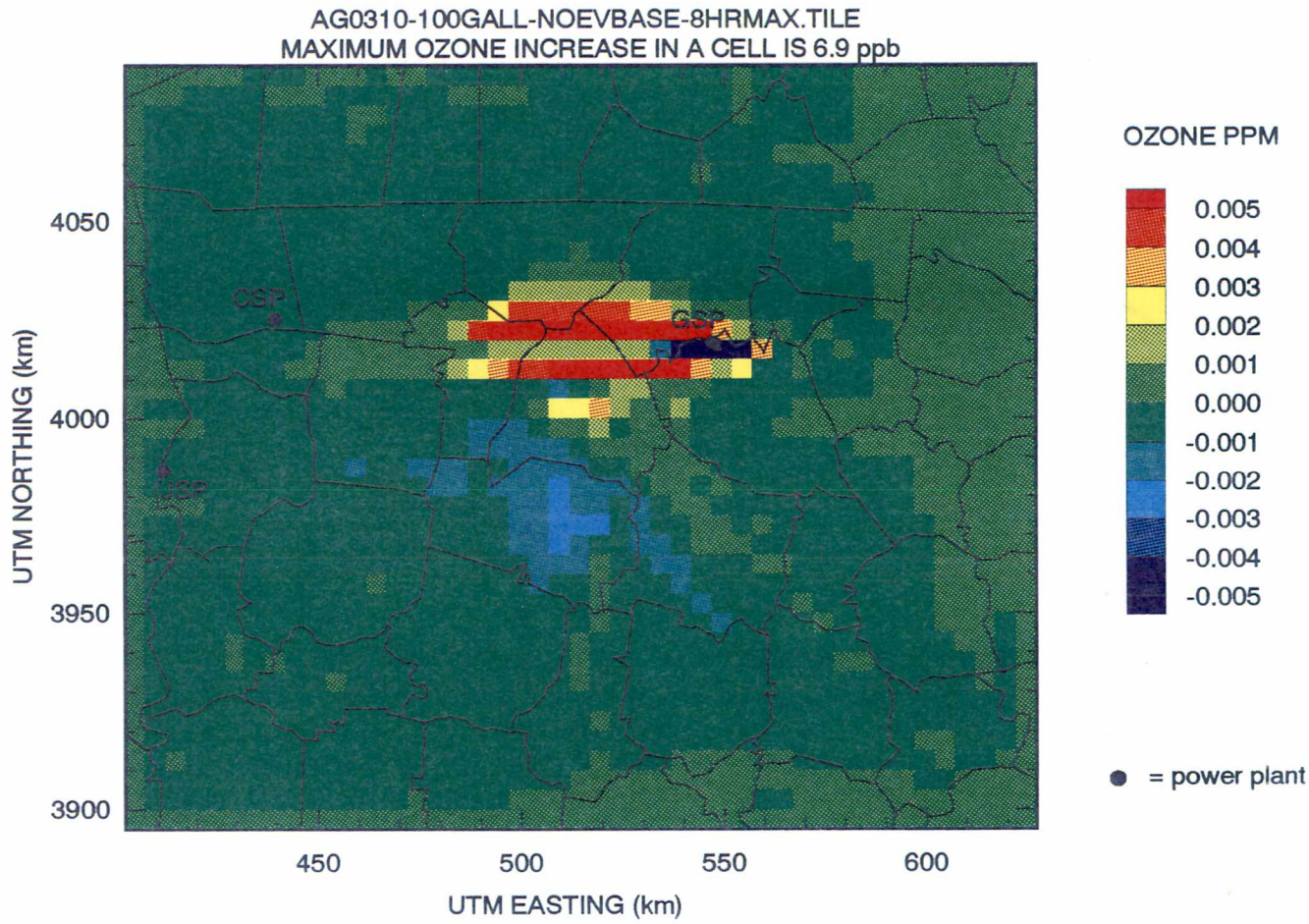


Figure 22. August 3, 2010 25 % EV, 100 % Gallatin 8 Hour Max Plot

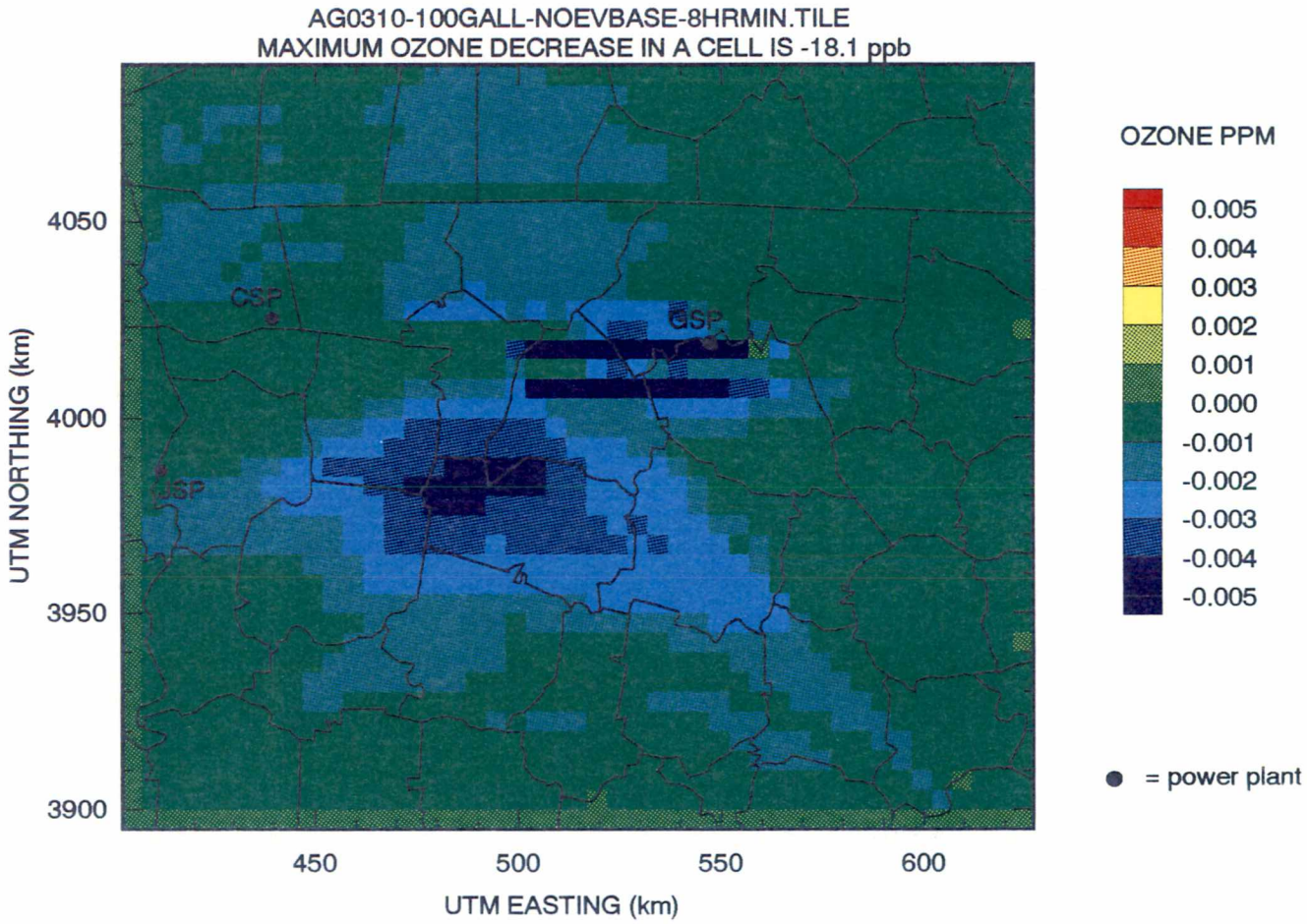


Figure 23. August 3, 2010 25 % EV, 100 % Gallatin 8 Hour Min Plot

up to 18.1 ppb. As shown in the bar plot in Figure 24, although the distribution is still shifted to the left, a greater number of grid-hours increased, 8.4 percent as compared to 5.8 percent with no EV utility load increase, due to the emissions increase at Gallatin. The 8 hour average grid cell ozone concentration in Figure 25, as well as the 8 hour grid-cell average bar plot in Figure 26 indicate that the overall effect of adding both EVs and the increased utility loads associated with EVs, results in a greater number of grid-hour ozone reductions than increases. The effect of increased ozone concentrations due to the increased utility loads at the Gallatin Steam plant, under the August 3, 2010 meteorological conditions is more localized, than the effect of decreased ozone concentrations by a 25 percent EV penetration in the LDGV and LDGT1 mobile source vehicle classes. However, the noted increases and decreases in ozone are generally small when compared to the maximum concentration predicted in the base case scenario.

Table 17 shows the largest ozone increase and decrease noted over the 8 hours of interest from the 25 percent EV, no EV load increase, and the 25 percent EV, 100 percent EV load increase at Gallatin scenarios described above.

Table 17. Largest Ozone Increases and Decreases noted by Scenario (August 3, 2010)

Largest Ozone Increases and Decreases noted by Scenario (August 3, 2010)		
Scenario	Largest Increase	Largest Decrease
25 percent EV, no Utility Load Increase	3.6 ppb	4.8 ppb
25 percent EV, 100 percent of Utility Load Increase at Gallatin over 24 hours	6.9 ppb	18.1 ppb

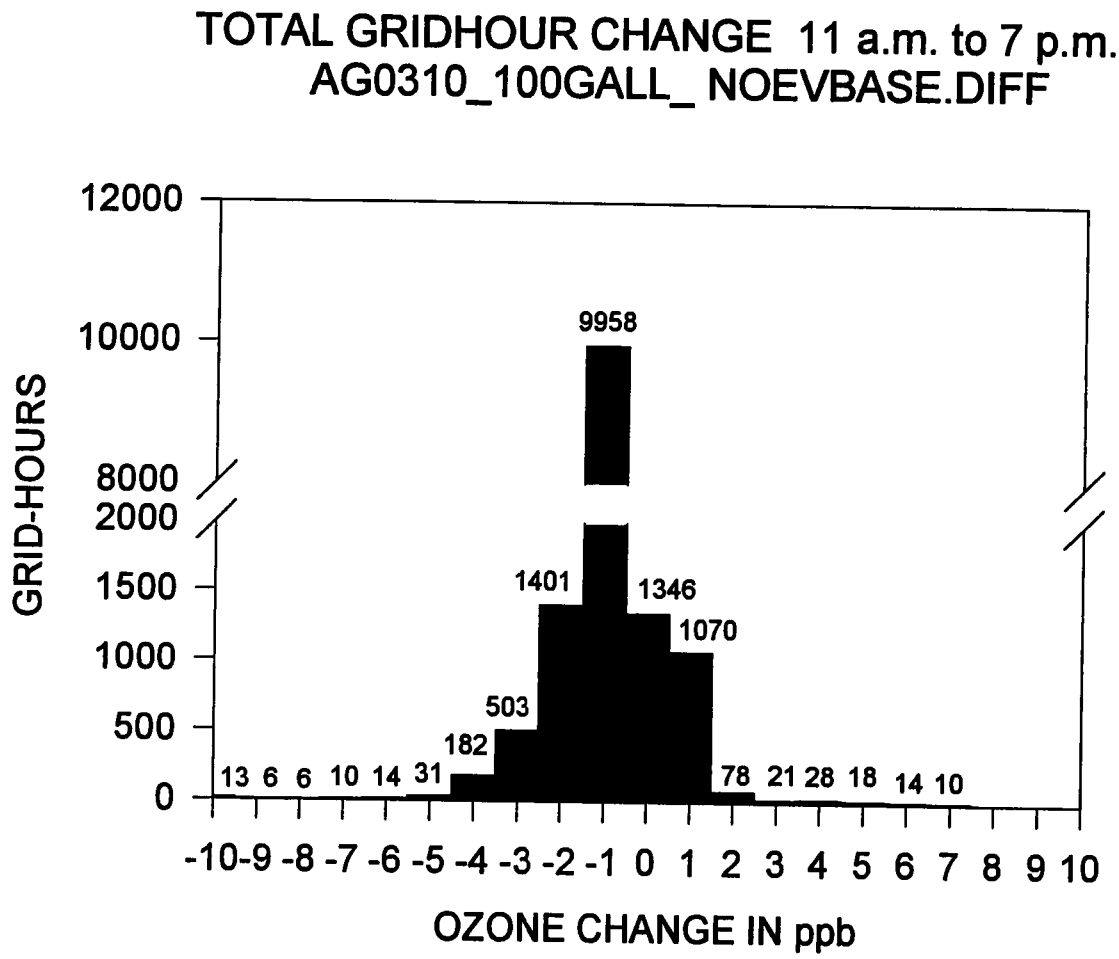


Figure 24. August 3, 2010 25 % EV, 100 % Gallatin Grid-Hour Distribution

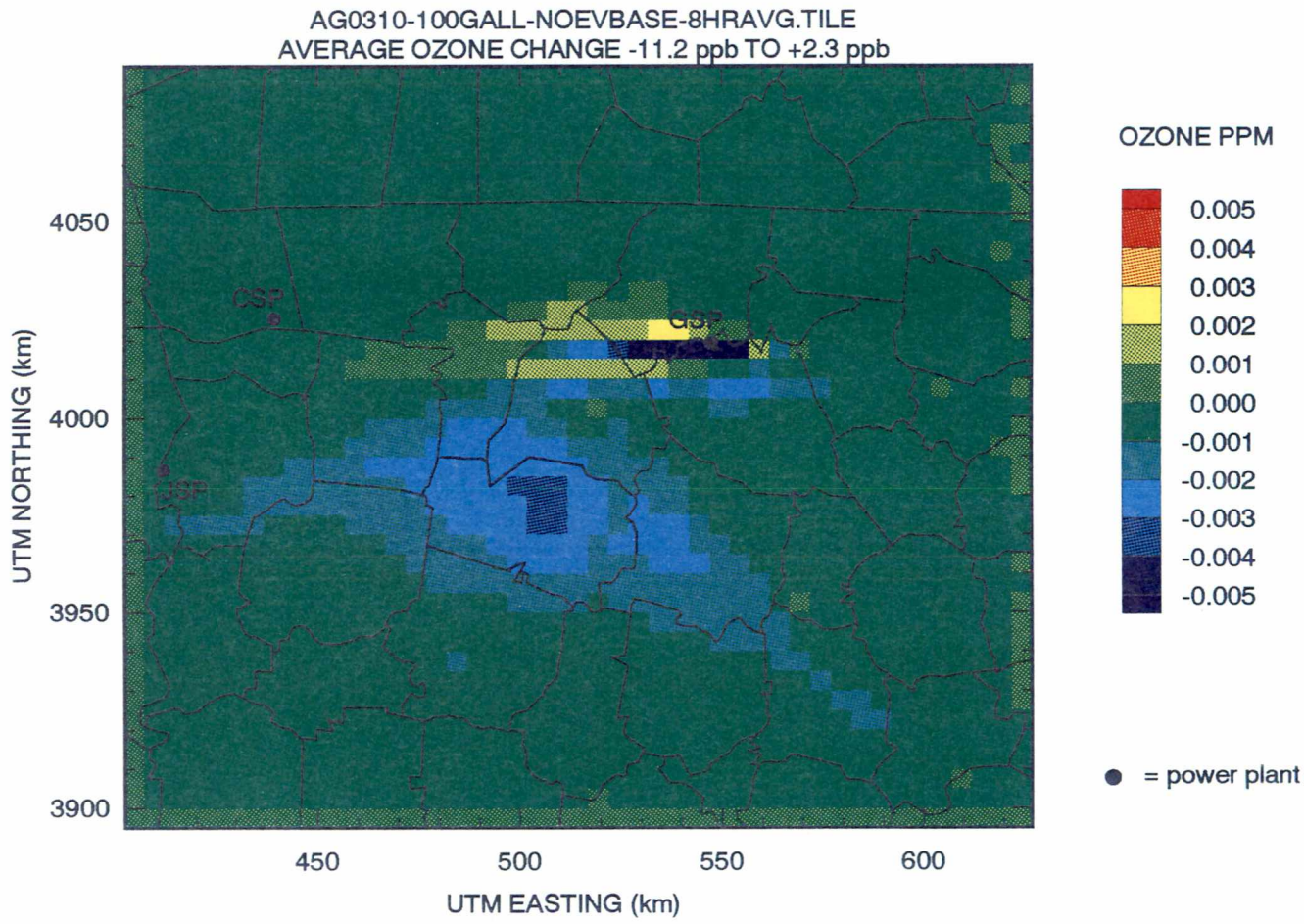


Figure 25. August 3, 2010 25 % EV, 100 % Gallatin 8 Hour Average Plot

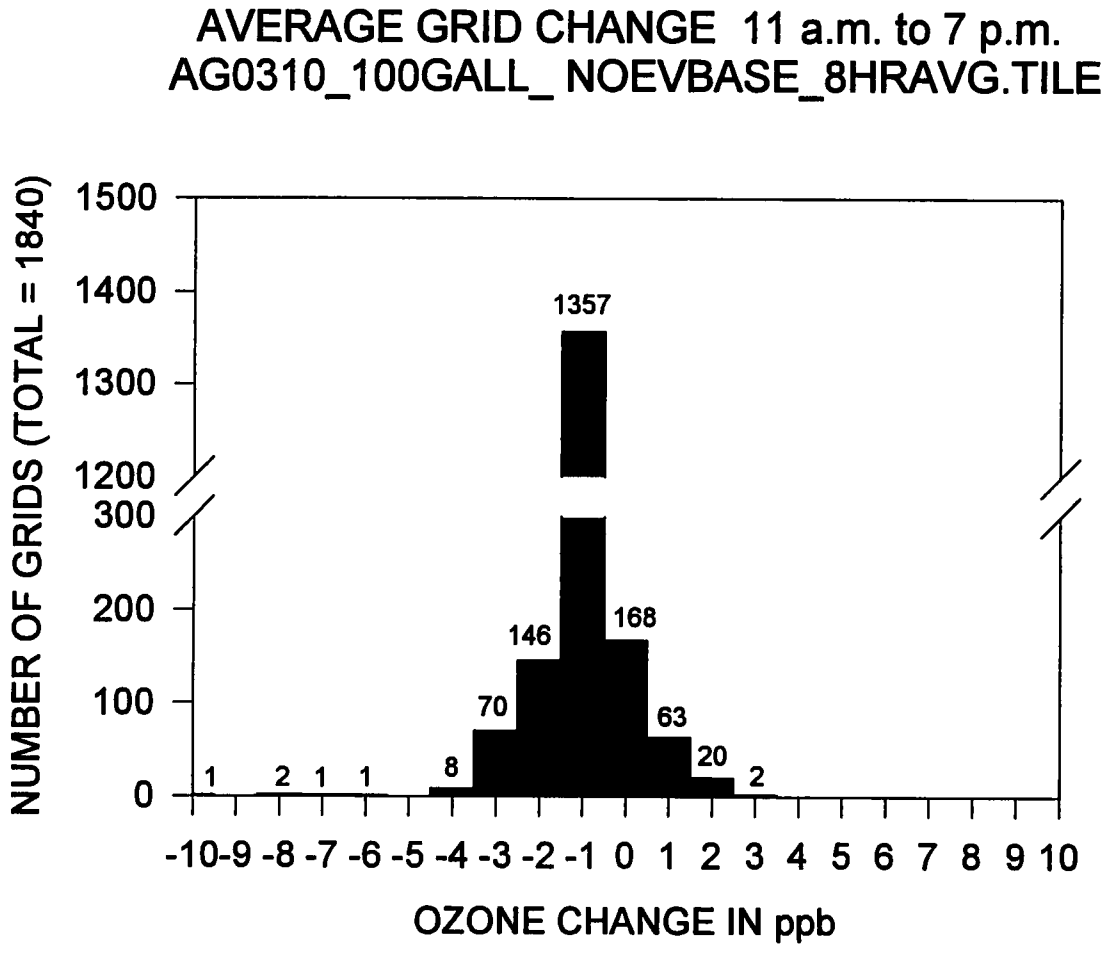


Figure 26. August 3, 2010 25 % EV, 100 % Gallatin 8 Hour Average Distribution

The addition of the increased utility load results in increased NO_X emissions which cause higher ozone concentrations in some cells. The maximum cell ozone reduction value also increases when EV loads are applied at the TVA plants due to localized ozone scavenging from NO_X emissions. The magnitude of the ozone reduction increased from 4.8 to 18.1 ppb due to NO_X scavenging near the Gallatin steam plant.

6.3 June 24, 2010 UAM Results (High Wind Speed Scenario)

6.3.1 Modeling Scenarios

For this study, using the meteorological conditions for June 24, 1988 the following series of 2010 simulations were made using the UAM.

June 24, 2010

- Base case June 24, 2010 Conditions (No EV Penetration)
- 25 percent EV Penetration (LDGV & LDGT1), no EV load at Utilities
- 25 percent EV Penetration (LDGV & LDGT1), 100 percent EV load at Gallatin, with emissions increases distributed proportionally over 24 hours.
- 25 percent EV Penetration (LDGV & LDGT1), 100 percent EV load at Cumberland, with emissions increases distributed proportionally over 24 hours.
- 25 percent EV Penetration (LDGV & LDGT1), 100 percent EV load at Johnsonville, with emissions increases distributed proportionally over 24 hours.

- 25 percent EV Penetration (LDGV & LDGT1), 50 percent EV load at Gallatin & 50 percent at Cumberland, distributed proportionally over 24 hours.
- 25 percent EV Penetration (LDGV & LDGT1), 100 percent EV load at Cumberland, with all emissions increases from 6 p.m. to 7 a.m., applied as a level load.

The bulk flow direction of the wind on June 24, 1988 was from the northwest to the southeast. The impact of increased utility loads due to EVs from each of the three steam plants was considered under these conditions. The Gallatin Steam plant emissions are downwind of the Nashville urban area, but impact the area of highest ozone concentration, which is also downwind of Nashville to the southeast. Emissions from the Cumberland plant are transported through the Nashville urban area before interacting with the Gallatin and Johnsonville emissions.

The increased utility load at the Cumberland Steam plant resulted in the smallest reduction of ozone maximums when considered with the 25 percent EV penetration, as compared to placing the EV load at the other TVA plants when using June 24, 1988 meteorology. Placing the utility load increase, due to EVs, over 12 nighttime hours, in conjunction with the 25 percent EV penetration, resulted in a domain wide maximum of 90.0 ppb, while distributing the EV load increase over 24 hours at the Cumberland plant resulted in a domain wide ozone maximum of 89.8 ppb.

The maximum ozone concentrations predicted for the June 24, 2010 UAM simulations are shown in Table 18 The grid-cell location and time of maximum concentration are also given as well.

6.3.2 Data Analysis

The base case June 24, 2010 scenario and 25 percent EV scenario without additional power plant load scenario predicted ozone profiles are shown in Figure 27. A daily ozone maximum reduction of 1.8 ppb was predicted with the 25 percent EV

Table 18. June 24, 2010 UAM Predicted Ozone Maximum Concentrations

June 24, 2010 UAM Predicted Ozone Maximum Concentrations (ppb)			
Simulation	Ozone (ppb)	Time	Grid-Cell
Base case (No EV Penetration)	90.2	4 p.m.	905
25 percent EV, no utility load increase in MTMD	88.4	4 p.m.	905
25 percent EV, 100 percent EV load at Gallatin, distributed over 24 hours	88.4	4 p.m.	905
25 percent EV, 100 percent EV load at Cumberland, distributed over 24 hours	89.8	4 p.m.	905
25 percent EV, 100 percent EV load at Johnsonville, distributed over 24 hours	88.4	4 p.m.	905
25 percent EV, 50 percent EV load at Gallatin, 50 percent at Cumberland	89.1	4 p.m.	905
25 percent EV, 100 percent EV load at Cumberland, from 6 p.m. - 7 a.m.	90.0	4 p.m.	905

penetration scenario with no utility load increases from EVs, when compared to the base case scenario. The windspeed on this date was approximately 4 times that of the August 3 conditions. The bulk flow wind direction was from the northwest to the southeast, for the entire day. A maximum ozone concentration of 90.2 ppb was predicted for the base

June 24, 2010 Ozone Profiles

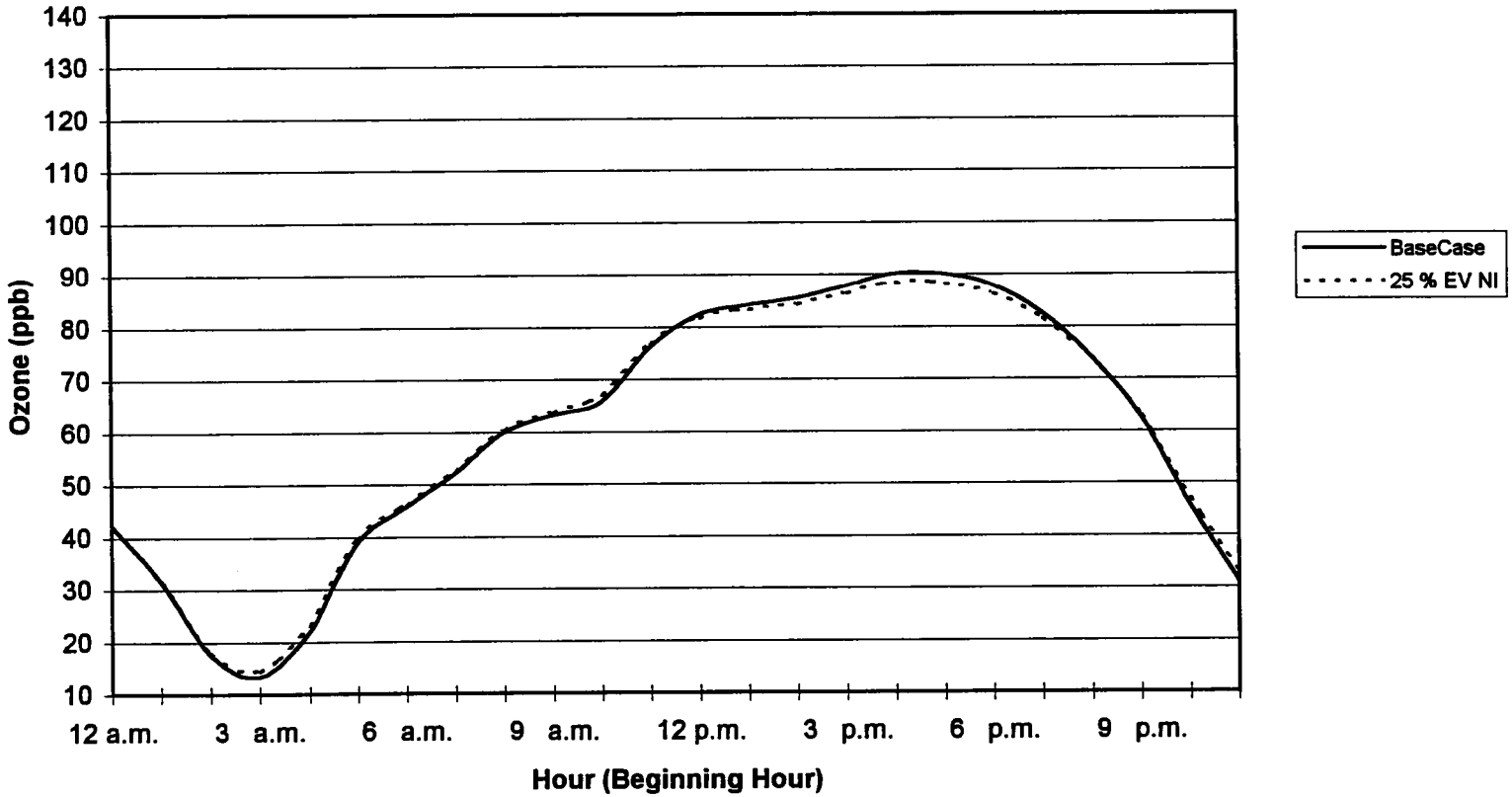


Figure 27. June 24, 2010 Ozone Profiles

case scenario, and a maximum of 88.4 ppb was predicted for the 25 percent EV, no increased utility load scenario.

Figure 28 shows a color isopleth map of August 3, 2010 base case scenario ground level ozone concentration for the 4 p.m. hour, when the maximum predicted ozone concentration occurred. The maximum ozone concentration of 90.2 ppb was located about 50 kilometers southeast of the Nashville urban area in the base case simulation.

Figures 29, 30, 31 and 32 show the effect of implementing a 25 percent EV penetration with no utility load increases; with 100 percent of the required load distributed over 24 hours at the Gallatin Steam plant; with 100 percent of the required load distributed over 24 hours at the Johnsonville Steam plant and with 100 percent of the required load distributed over 24 hours at the Cumberland Steam plant; respectively. The 25 percent EV penetration with no utility load increase scenario, resulted in the greatest ozone reduction. This scenario results in an ozone decrease of up to 4 ppb slightly south of the region where the maximum ozone concentration occurred in the base case scenario. The area of reduction is down the corridor of Interstate 24 which connects Nashville and Chattanooga Tennessee. For the 25 percent EV penetration with 100 percent of the EV load increase at the Gallatin Steam plant a similar ozone decrease is noted down the I-24 corridor, and an ozone increase, of approximately 2 - 3 ppb to the north of this area from the increase in NO_X in the Gallatin plume, as seen in Figure 30. Figure 31 shows the 25 percent EV load placed at the Johnsonville Steam plant.

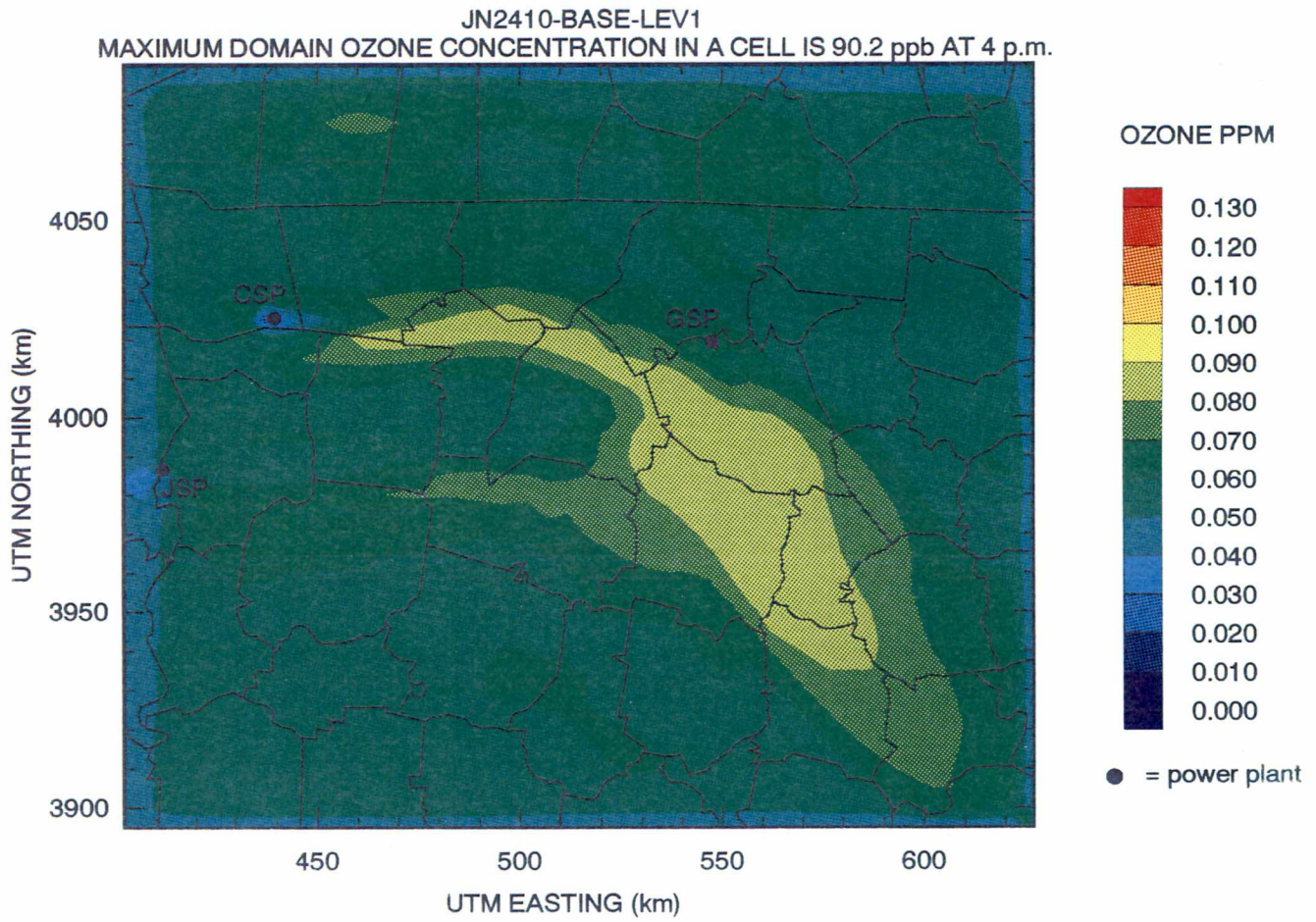


Figure 28. June 24, 2010 Base case Maximum Predicted Ozone Concentration

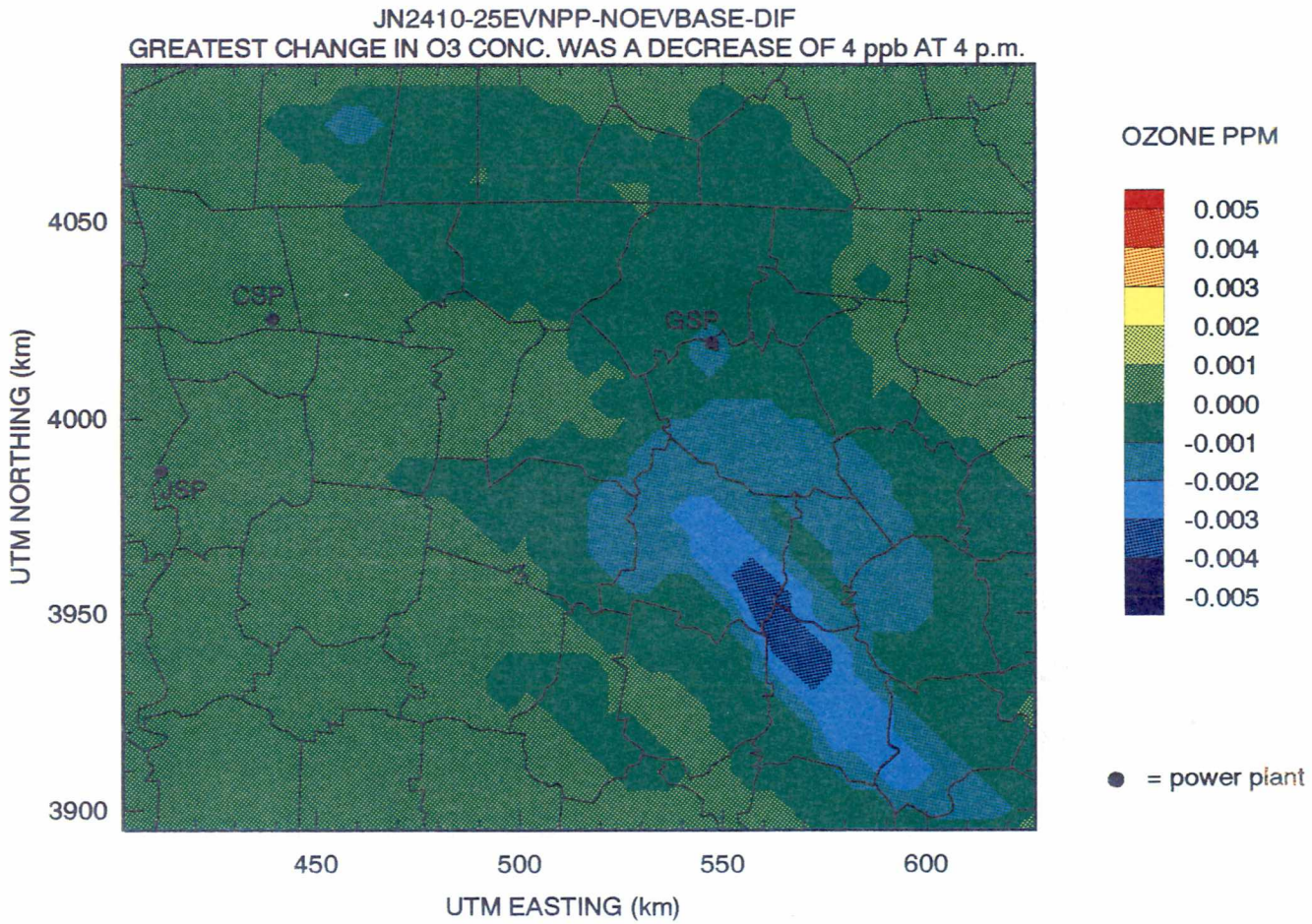


Figure 29. June 24, 2010 25 % EV, No Utility Load Difference Plot

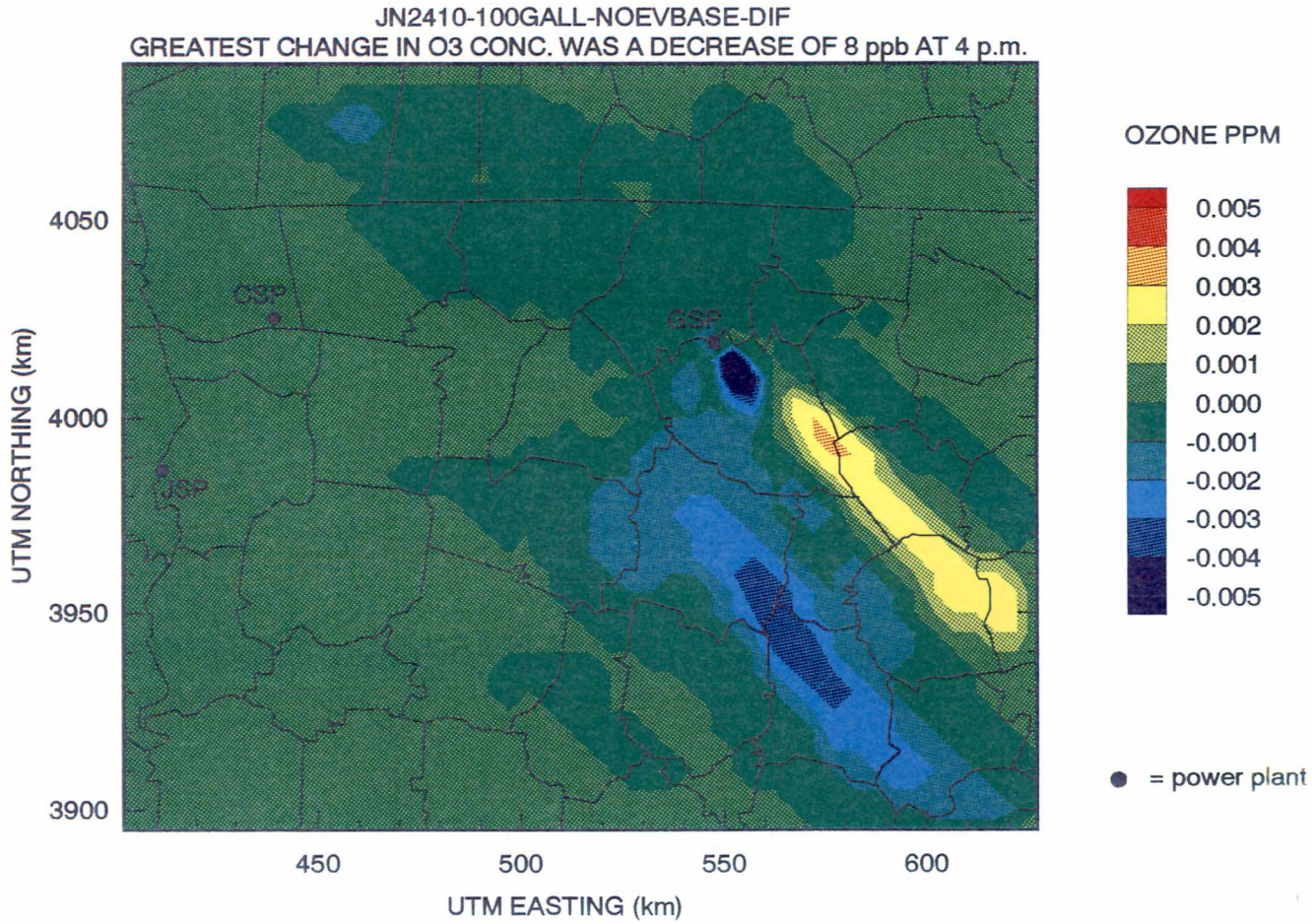


Figure 30. June 24, 2010 25 % EV, Load at Gallatin Difference Plot

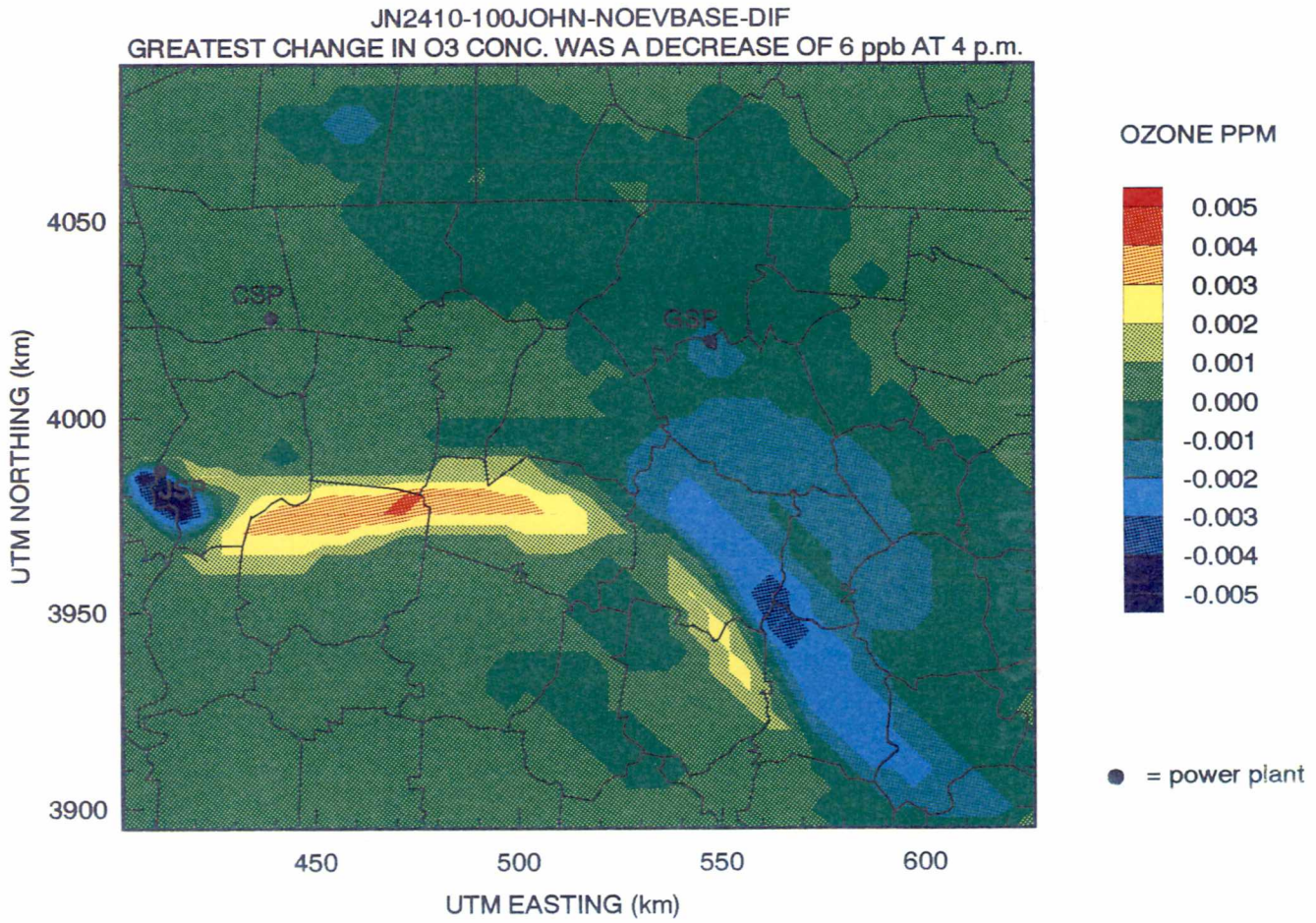


Figure 31. June 24, 2010 25 % EV, Load at Johnsonville Difference Plot

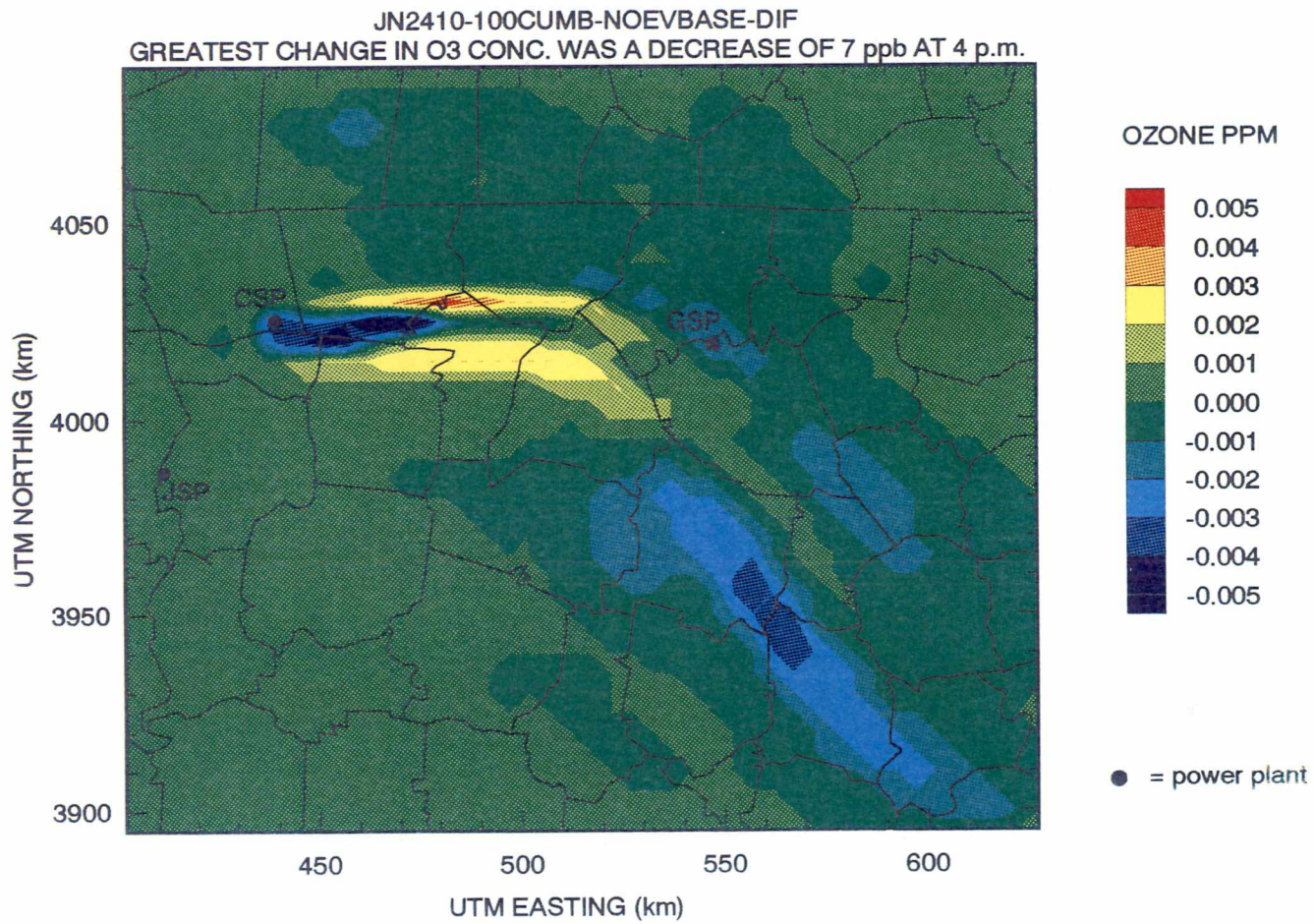


Figure 32. June 24, 2010 25 % EV, Load at Cumberland Difference Plot

Again a decrease in ozone is seen down the I-24 corridor while an ozone increase of up to 5 ppb is noted to the south of Nashville resulting from the NO_X increase at the Johnsonville plant. In Figure 32 the EV load from the 25 percent EV penetration is placed at the Cumberland Steam plant. In this scenario the same decrease in ozone is noted down I-24, and an ozone increase is seen at the northern edge of the Nashville Urban area. The Cumberland plume shows an ozone increase of between 4 and 5 ppb at the edges with scavenging up to 7 ppb in the plume center. Each of these plots represents the change in ozone concentrations at the maximum ozone concentration hour of 4 p.m., for the June 24 conditions, due to the implementation of each scenario when referenced to the base case. Figure 33 shows the 25 percent EV load with 50 percent of the required load placed at the Gallatin Steam plant, and 50 percent of the load at the Cumberland Steam plant. In this scenario an ozone increase of about 2 ppb is seen from both the Cumberland and Gallatin plants, with the similar decrease down I-24.

All of the EV load increases described above for the June 24 scenarios were distributed proportional to the June 24, 1988 load pattern to the power plants over a 24 hour time period. Figure 34 shows a 25 percent EV penetration with 100 percent of the required load placed at the Cumberland Steam plant during the night-time hours from 6 p.m. to 7 a.m. In Figure 35, the June 24, 1988 Cumberland Steam plant emissions profile provided by TVA is shown, adjusted to the 2010 baseline emissions. The adjusted profile used when the required EV loads were added during the 6 p.m. to 7 a.m. period is also shown, as well as the profile marked 24-Hour which represents the June 24, 2010 EV load increase distributed over 24 hours. In Figure 34, it is interesting to note that

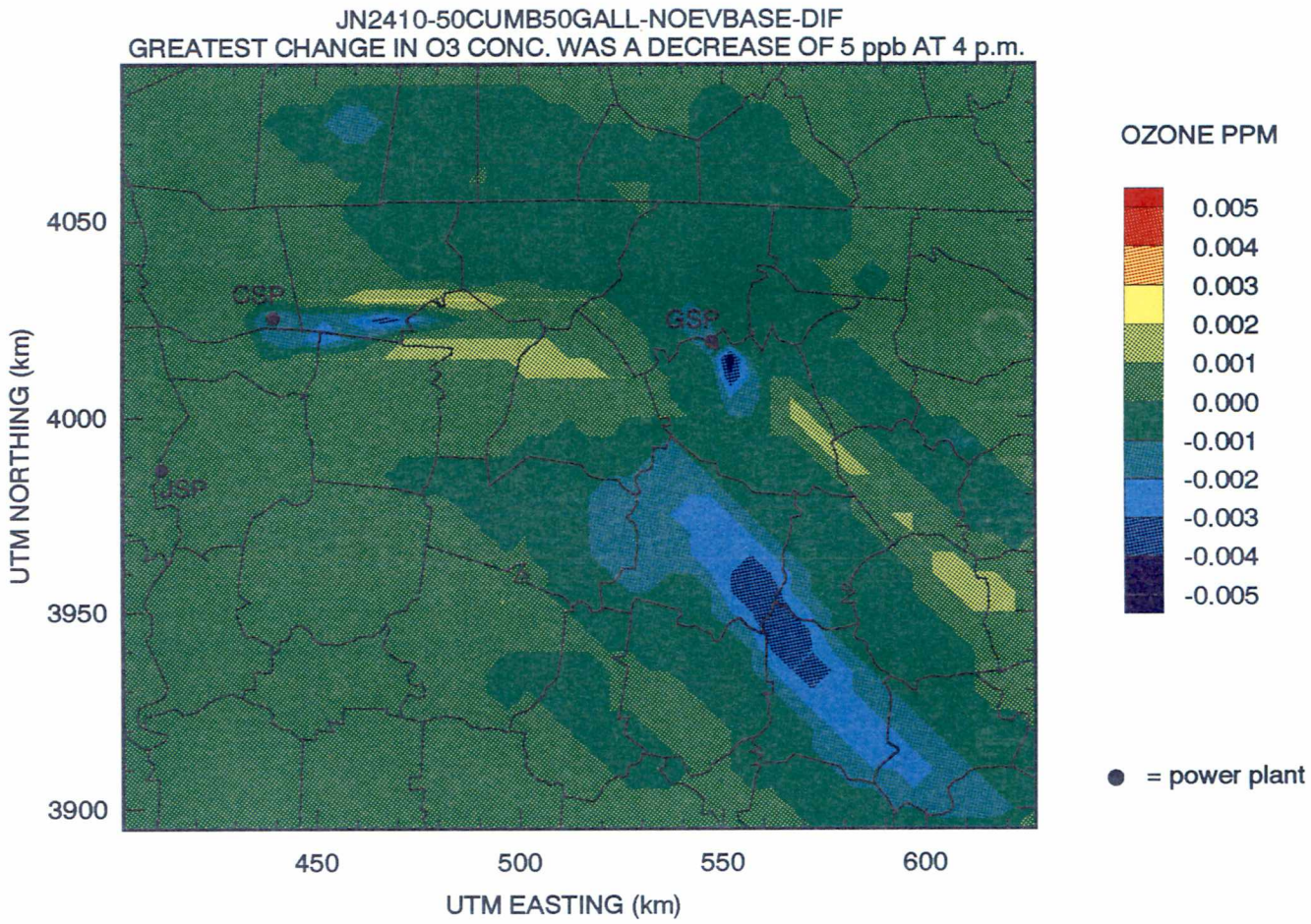


Figure 33. June 24, 2010 25 % EV, Load Split Gall.-Cumb. Difference Plot

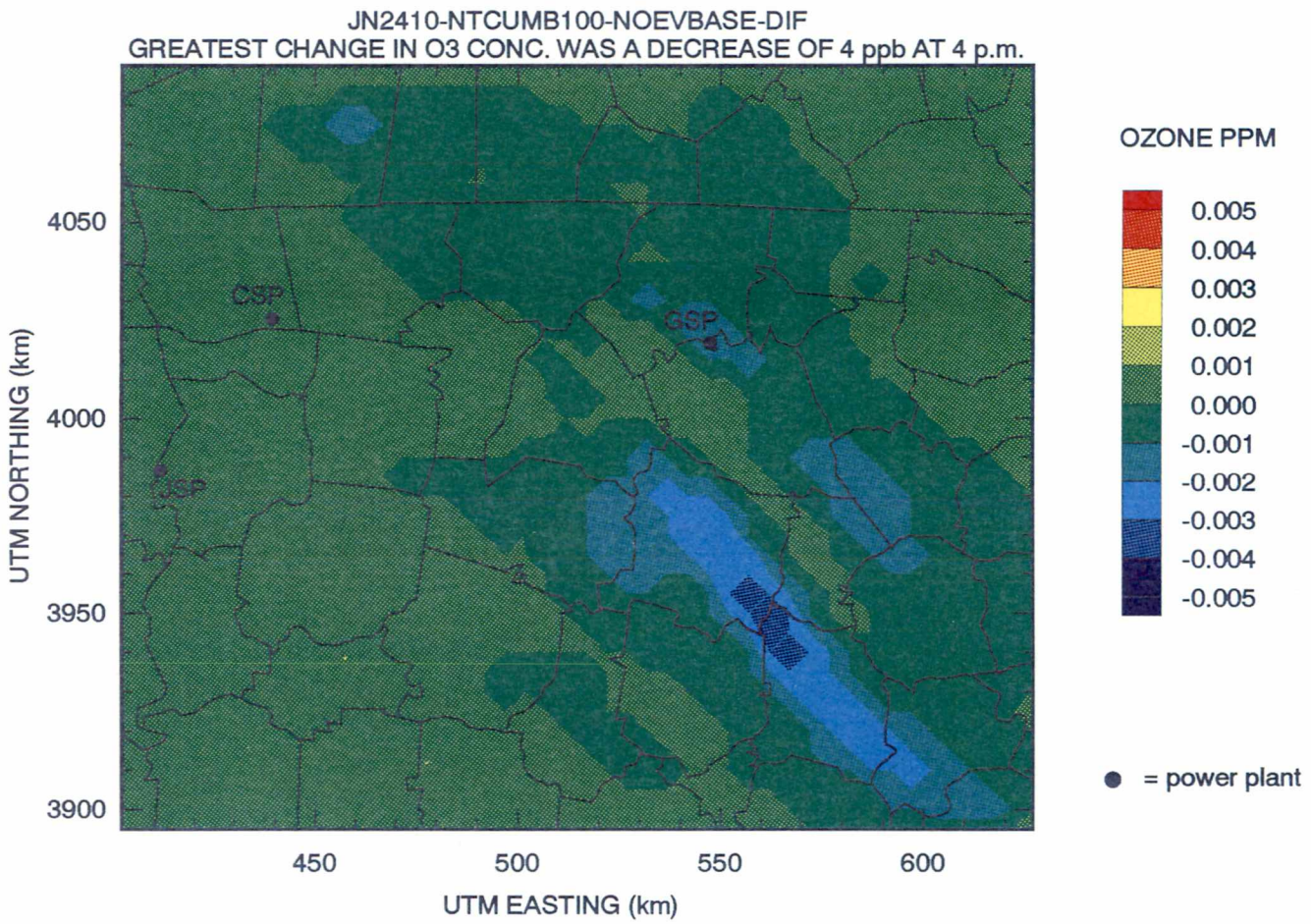


Figure 34. June 24, 2010 25 % EV, Night Load at Cumberland Difference Plot

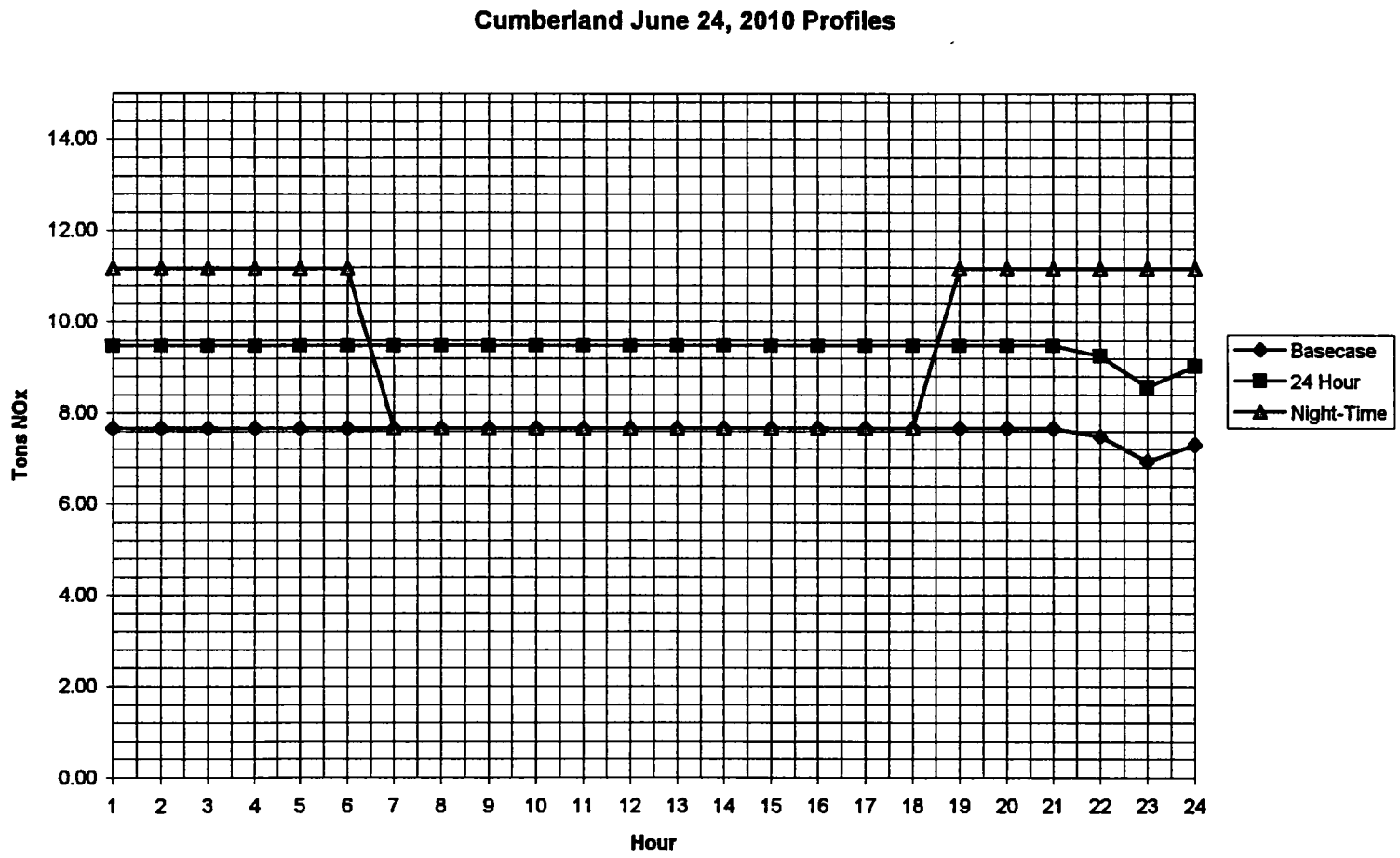


Figure 35. Cumberland Steam Plant Emissions Profile

ozone increases of less than 1 ppb occur, but at the location of the base case maximum. Although the magnitude of the ozone increase was greater when the 100 percent EV load was placed at the Cumberland plant over 24 hours, the absolute maximum is slightly lower in the 24 hour distribution scenario, 88.4 ppb, than in the night-time scenario which had a simulation maximum of 90.0 ppb. This is due to the differing locations of the increases, one where the daily maximum was, and the other several kilometers to the northwest of this location. An ozone decrease is seen to the north of this area, from the increased NO_X emissions which ceased at 7 a.m.

Like the August 3, 2010 simulations all June 24, 2010 EV scenarios have similar maximum single cell ozone concentrations. The difference plot shown in Figures 29, 30, 31, 32, 33 and 34 show greater variation at locations other than the maximum ozone concentration cell location. When emissions are increased at each power plant in an amount appropriate to support the 25 percent EV penetration, an increase in the plants contribution to ozone is noted, as well as some increased scavenging due to the increased NO_X emissions in the centerlines, or close to the stacks of the plants.

For the 25 percent EV scenario, with no EV utility load increase, and the 100 percent EV power requirements supplied by Cumberland Steam plant over a 24 hour period scenario, a more detailed analysis was conducted. The previous plots show the increases and decreases of ozone concentrations for the maximum hour only. The 8 hours of highest predicted ozone concentration for the June 2010 scenarios were identified from the profiles shown previously in Figure 27. This period was identified as

12 a.m. to 8 p.m. for this date. Using the same series of FORTRAN programs which were used for the preceding August 3 analysis the following plots were generated.

Figures 36 and 37 show the maximum and minimum ozone concentration difference tileplots for the June 24, 2010 25 percent EV, no utility load increase scenario, as compared to the June 24, 2010 base case scenario. Figure 36 indicates that while some cell locations always experience an ozone decrease due to the implementation of this scenario, that others have ozone increases up to 1.3 ppb during this 8 hour time period. The cells which increase are located east of the Nashville urban area. The ozone increase in the cells is due to a reduction in NO_X emissions by the introduction of EVs. The mobile NO_X in this area was great enough to cause ozone scavenging to occur in the Nashville Urban area, apparently along the I-40 corridor. implementation of the 25 percent EV scenario without utility load increases. This analysis again uses the same domain which contains 1840 grid-cells. The removal of a portion of this NO_X reduced the scavenging effect, and shows up as an ozone increase in the difference tile plot. Figure 37 indicates that although some cells experienced a slight ozone increase over this 8 hour period, all cells experienced a decrease in ozone concentrations for some portion of the 8 hour period, in reference to the base case scenario.

The bar graph shown as Figure 38 shows the distribution of grid-hours of ozone change, both positive and negative, over the 8 hour period of interest. The total number

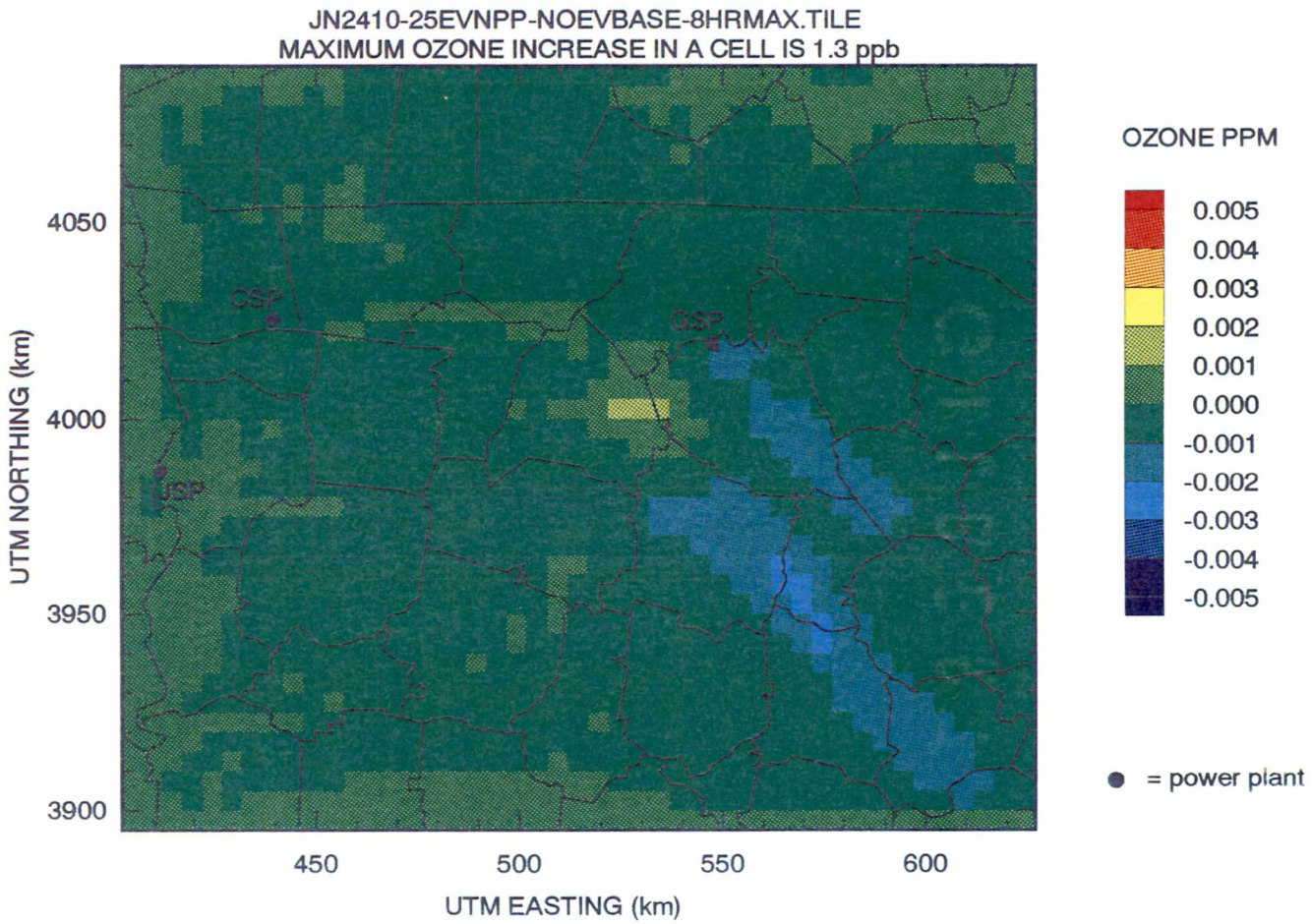


Figure 36. June 24, 2010 25 % EV, No Utility Load 8 Hour Max Plot

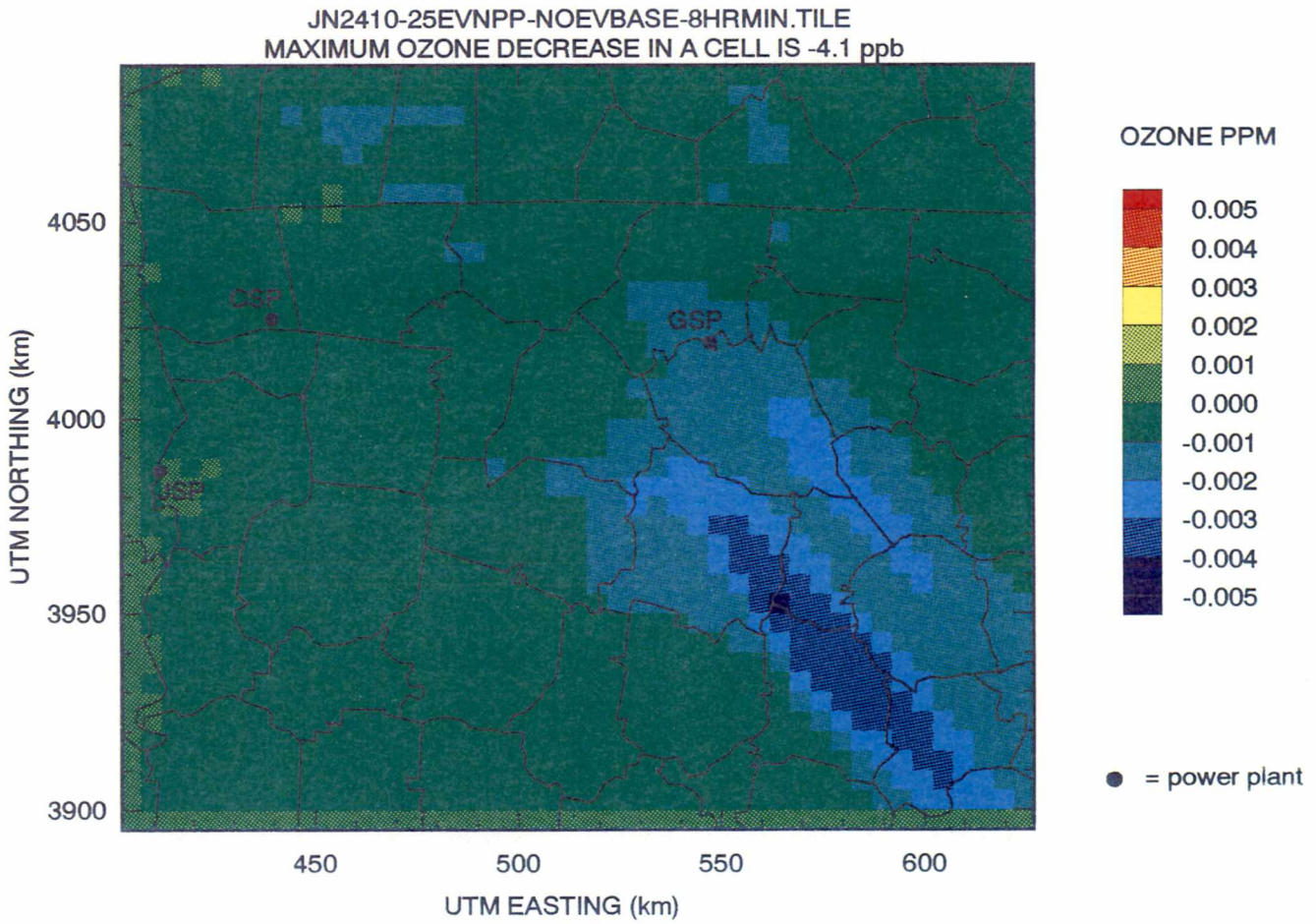


Figure 37. June 24, 2010 25 % EV, No Utility Load 8 Hour Min Plot

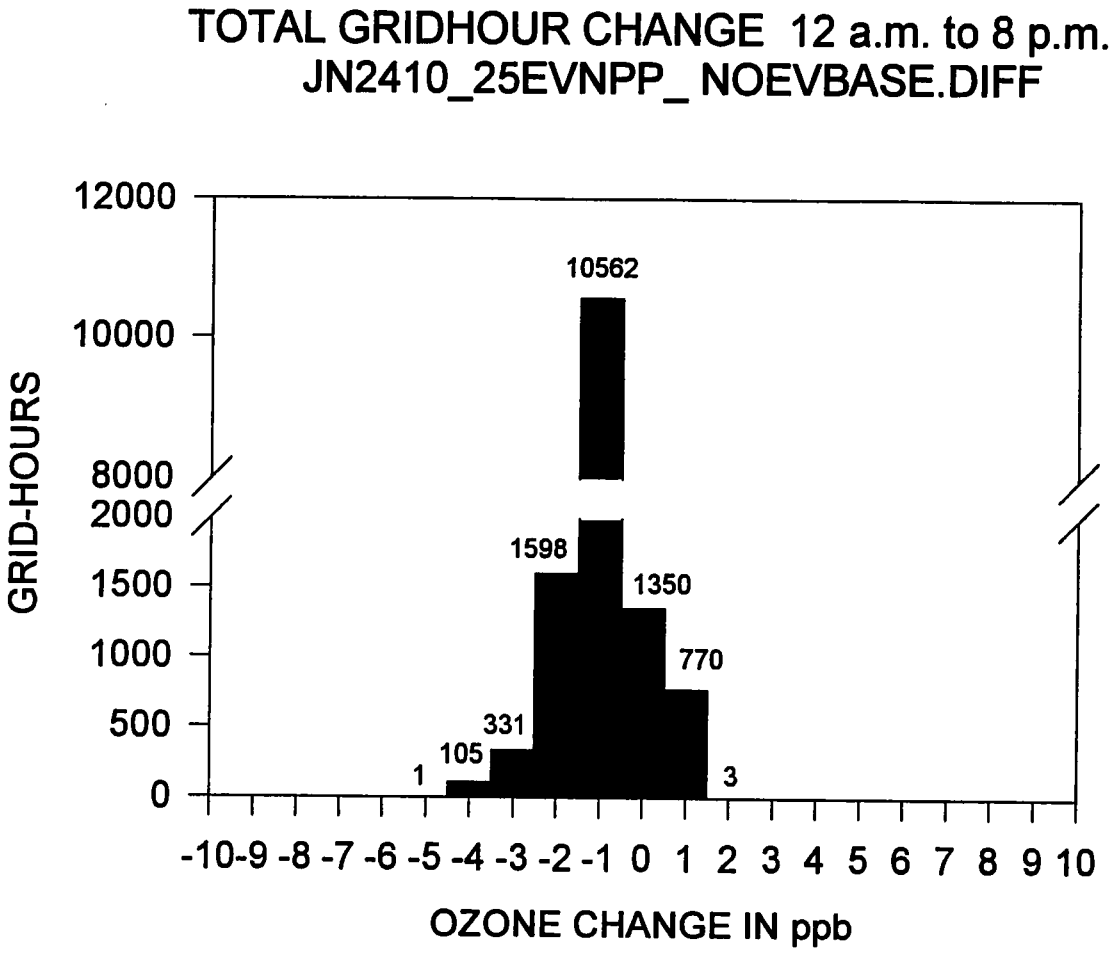


Figure 38. June 24, 2010 25 % EV, No EV Load Grid-Hour Distribution

of grid-hours over any 8 hour period would be 8 x 1840, or 14,720 grid-hours. The overall change is clearly shifted to the left, indicating a general decrease in ozone concentrations. For this case 12,597 grid-hours, or 85.6 percent of the total grid-hours analyzed, decreased in ozone concentration. A total of 9.1 percent of the grid-hours had no change in ozone concentration, and 5.3 percent of the grid-hours increased in ozone concentration. Of the 12,597 grid-hours which decreased, 10,562 or 83.8 percent decreased by 1 ppb or less.

The average 8 hour change in ozone concentrations, with respect to the base case, is shown in Figure 39. This plot indicates that on the average in the 8 hour period of most concern, with respect to ozone formation, that greatest percentage of all changes were ozone decreases. This plot is quantified in Figure 40 where a bar plot indicating the distribution of the 8 hour average grid difference values. The distribution in Figure 40 is similar to the distribution shown in Figure 38, indicating that on the average most of the cells decreased in ozone concentration. A total of 87.9 percent of the 8 hour average grid-cell difference values were ozone decreases. The largest portion of this decrease, 83.9 percent, was less than or equal to 1 ppb.

An identical analysis was carried out for the 25 percent EV penetration, with all additionally required power supplied by the Cumberland Steam plant over 24 hours scenario. The 12 a.m. to 8 .p.m. maximum and minimum tile plots are shown as Figure 41 and Figure 42. In Figure 41 ozone increases as high as 4.6 ppb are shown as a result of the increased NO_X emissions from the Cumberland plant. In Figure 42 the area of

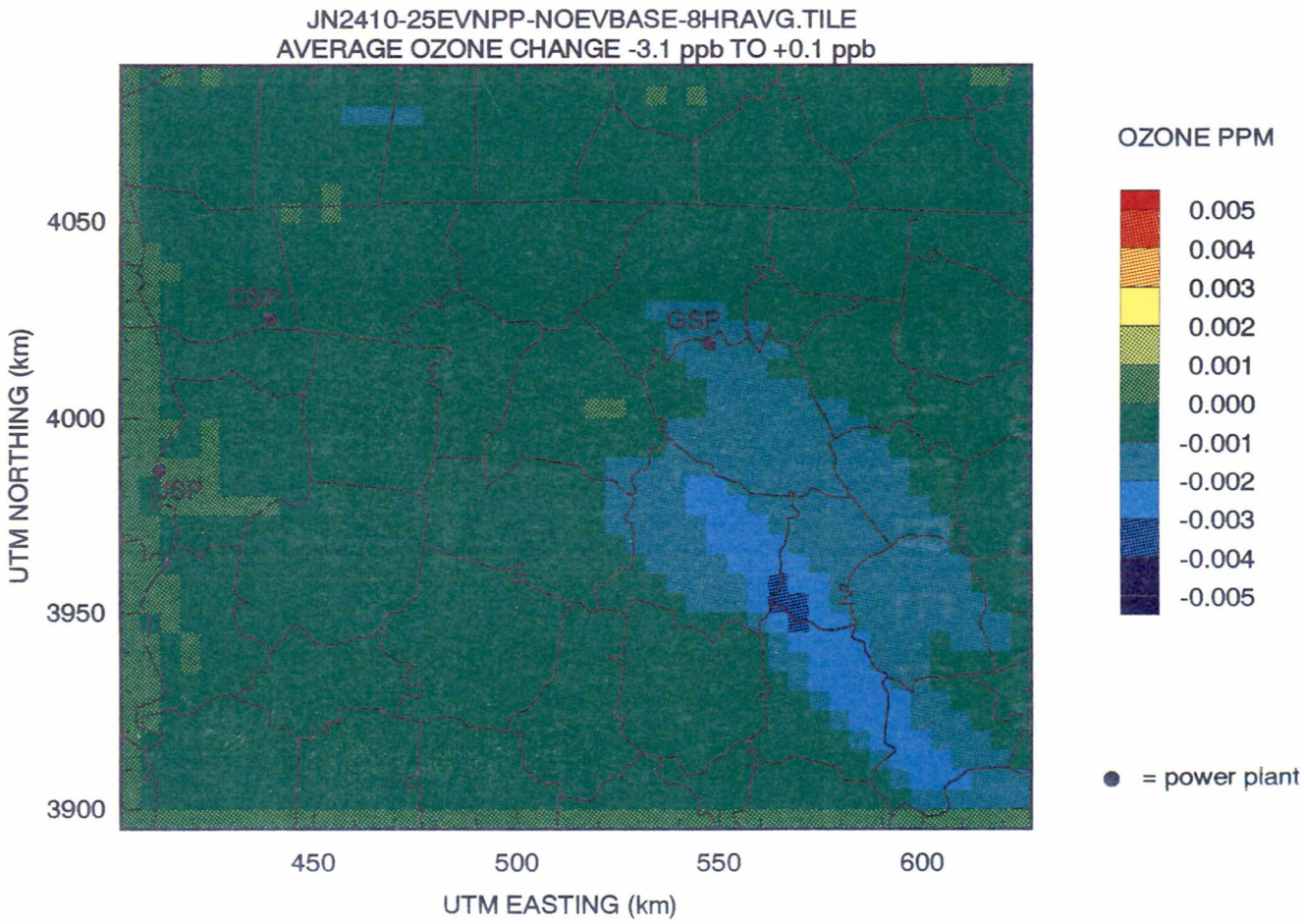


Figure 39. June 24, 2010 25 % EV, No EV Load 8 Hour Average Plot

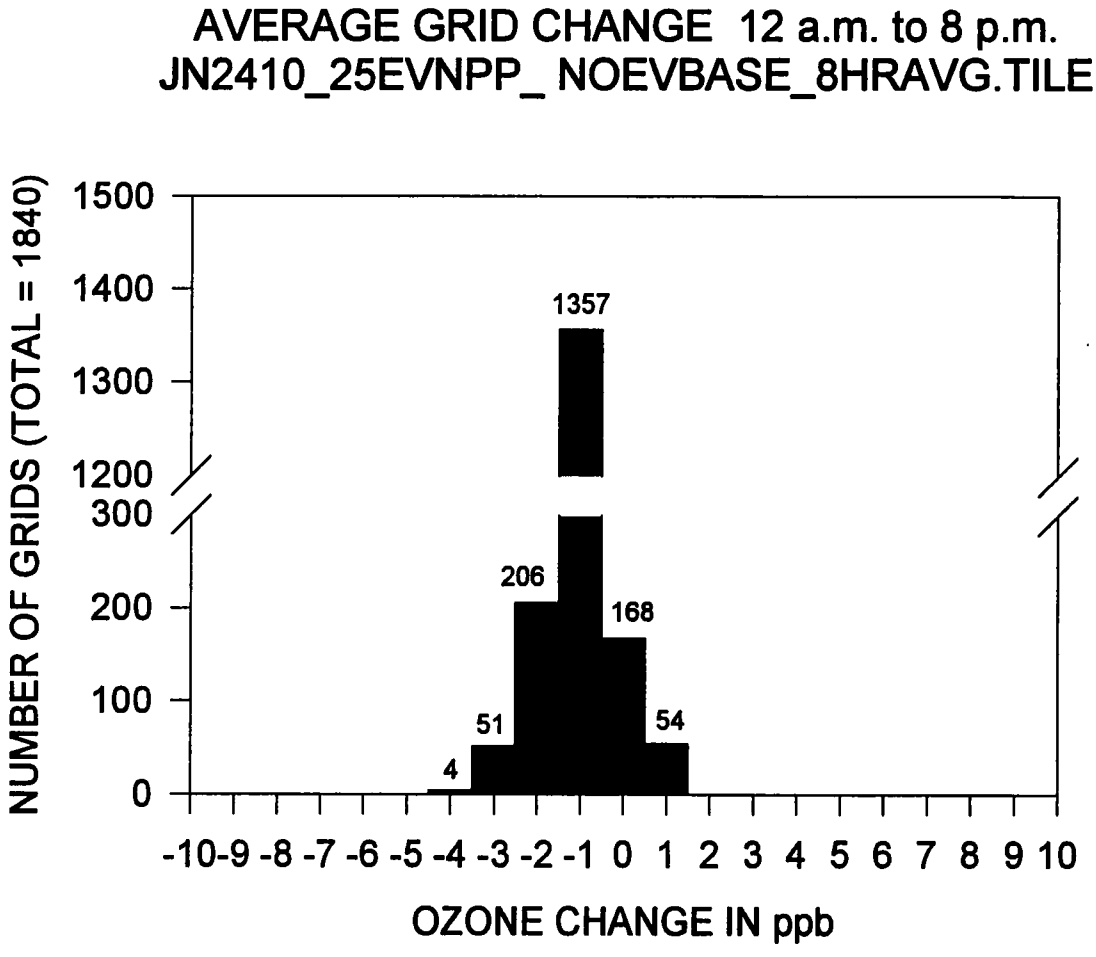


Figure 40. June 24, 2010 25 % EV, No EV Load 8 Hour Average Distribution

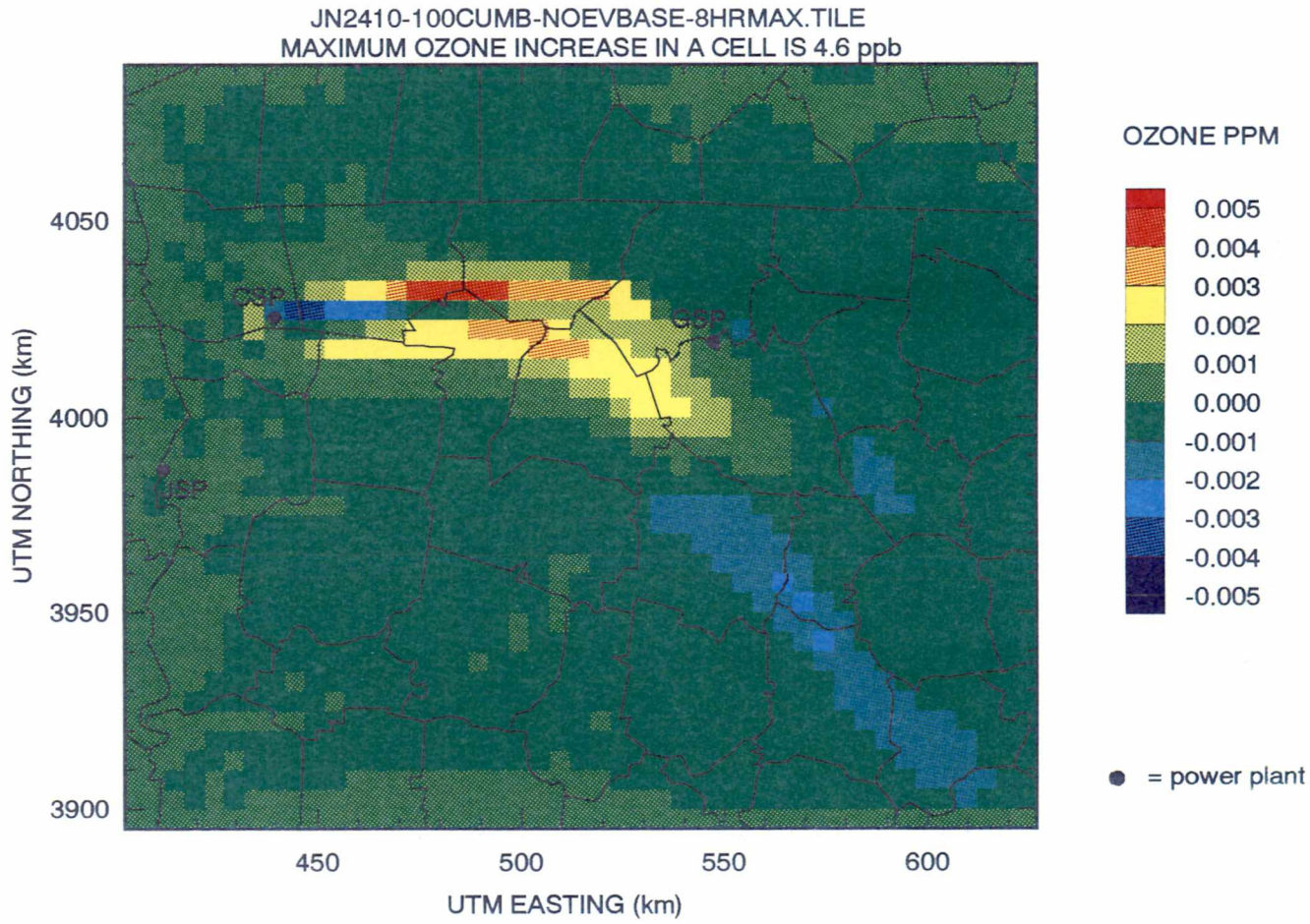


Figure 41. June 24, 2010 25 % EV, 100 % Cumberland 8 Hour Max Plot

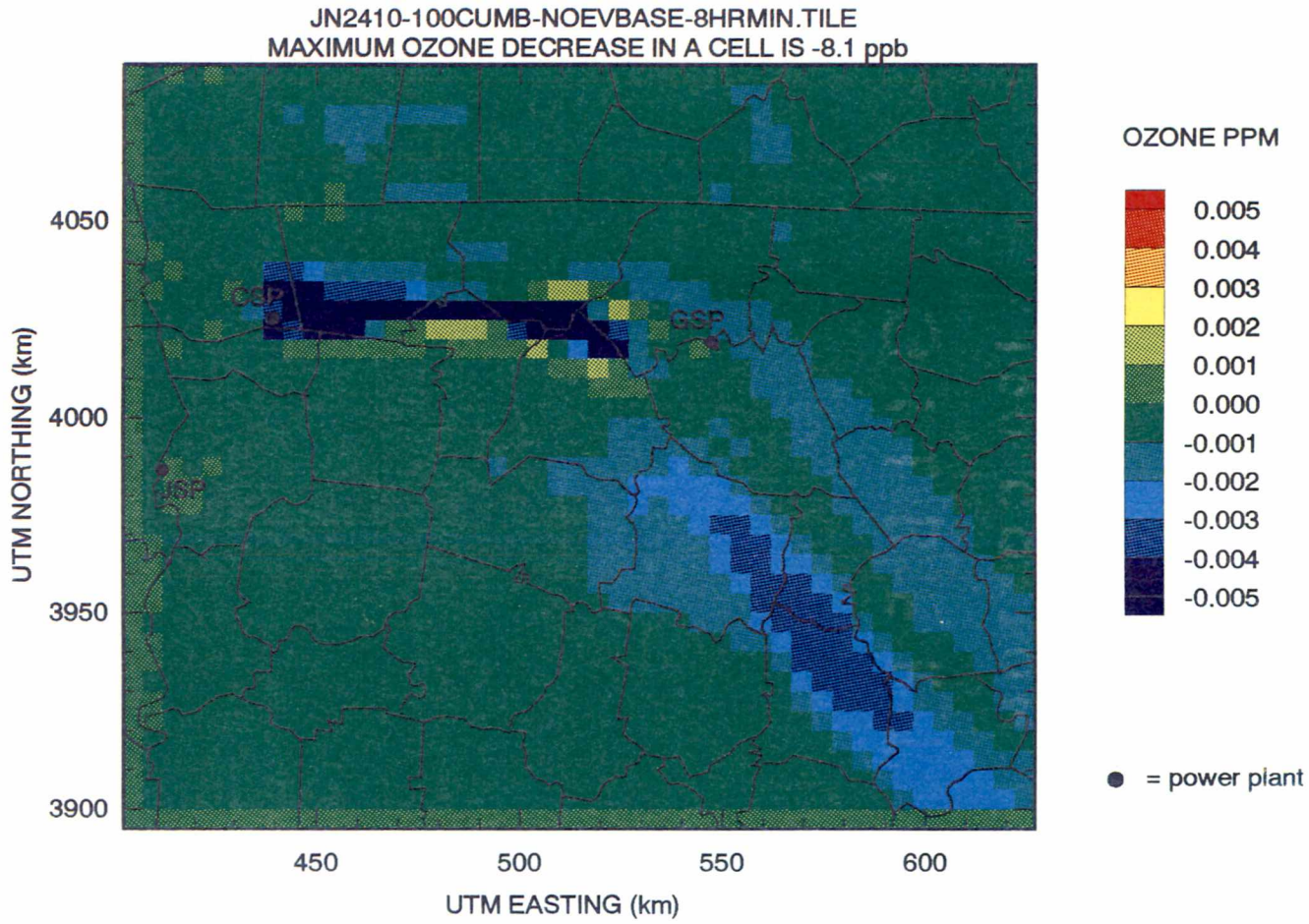


Figure 42. June 24, 2010 25 % EV, 100 % Cumberland 8 Hour Min Plot

ozone decrease from the EV penetration is noted as well as areas of ozone scavenging due to areas with the greatest NO_X concentrations in the Cumberland plume. The noted scavenging shows decreases in ozone up to 8.1 ppb. As shown in the bar plot in Figure 43, the distribution is still shifted to the left, indicating that the ozone concentration decreased over more grid-hours than it increased, due to the implementation if this scenario. The ozone concentration in 79.8 percent of the grid-hours decreased. The percentage of grid-hours which increased in the scenario was 11 percent compared to the no utility load increase scenario, in which 5.3 percent increased. The 8 hour average grid cell ozone concentration in Figure 44, as well as the 8 hour average difference grid-cell bar plot in Figure 45 indicate that the overall impact of adding both EVs and the increased utility emissions associated with them reduces ozone concentrations in the domain on a grid-hour basis, i.e. more cells decreased than increased in ozone concentration. Again the noted increases and decreases in ozone are generally small when compared to the maximum concentration predicted in the base case scenario.

Table 19 shows the largest ozone increase and decrease noted over the 8 hours of interest from the 25 percent EV, no utility load increase, and the 25 percent EV, 100 percent EV load increase at Cumberland scenarios described above. The addition of the EV utility load results in areas of increased ozone formation and areas of increased ozone scavenging. The greatest decrease of ozone in a single cell changes from 4.1, in the 25 percent EV, no utility load increase scenario to 8.1 ppb in the 25 percent EV, 100

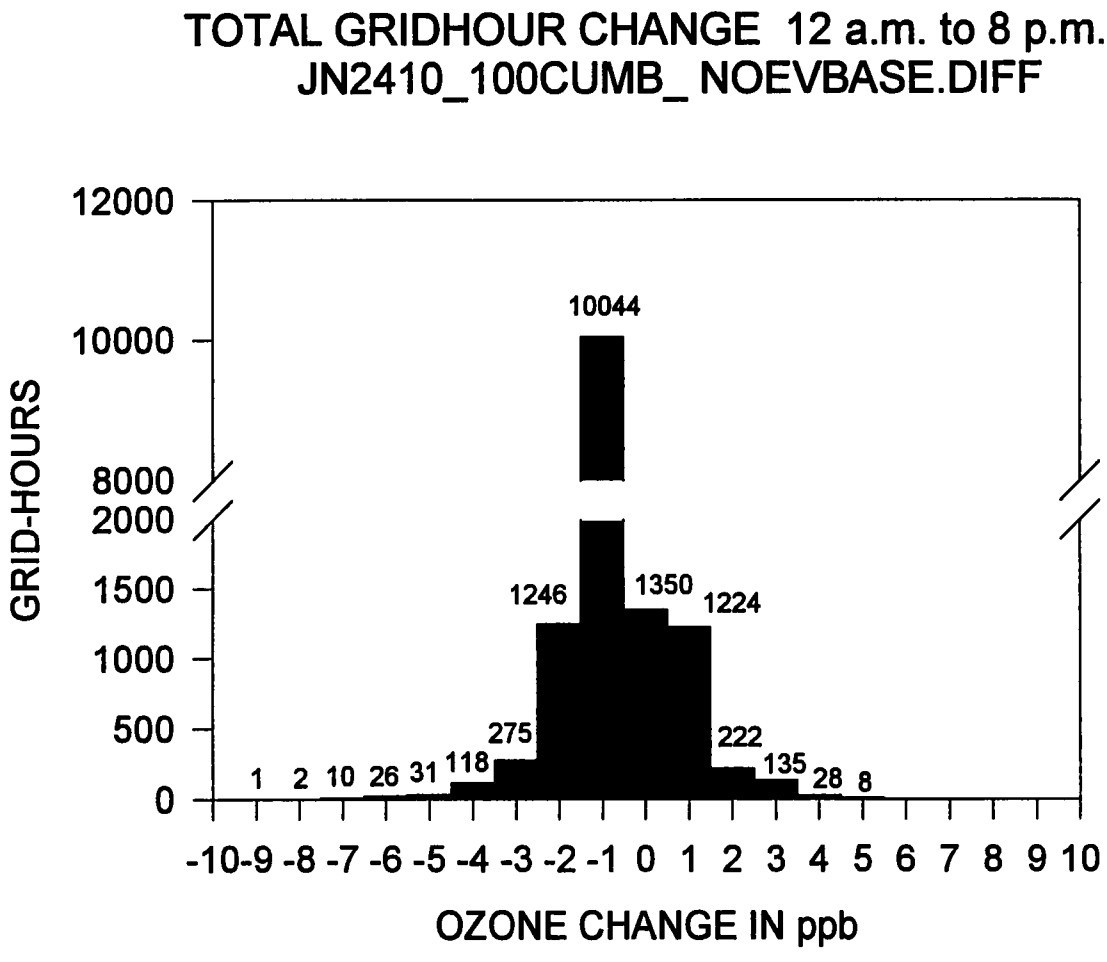


Figure 43. June 24, 2010 25 % EV, 100 % Cumberland Grid-Hour Distribution

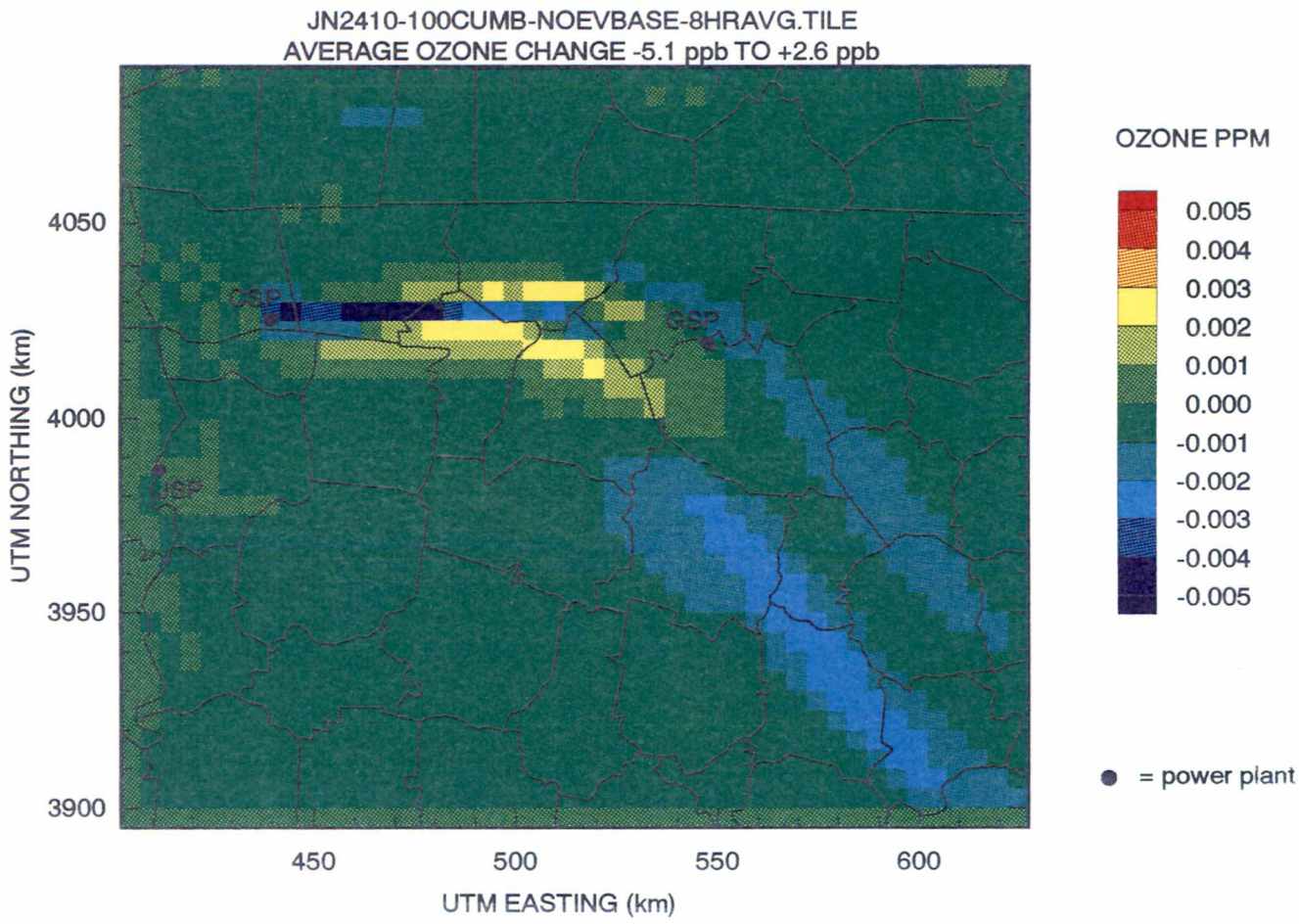


Figure 44. June 24, 2010 25 % EV, 100 % Cumberland 8 Hour Average Plot

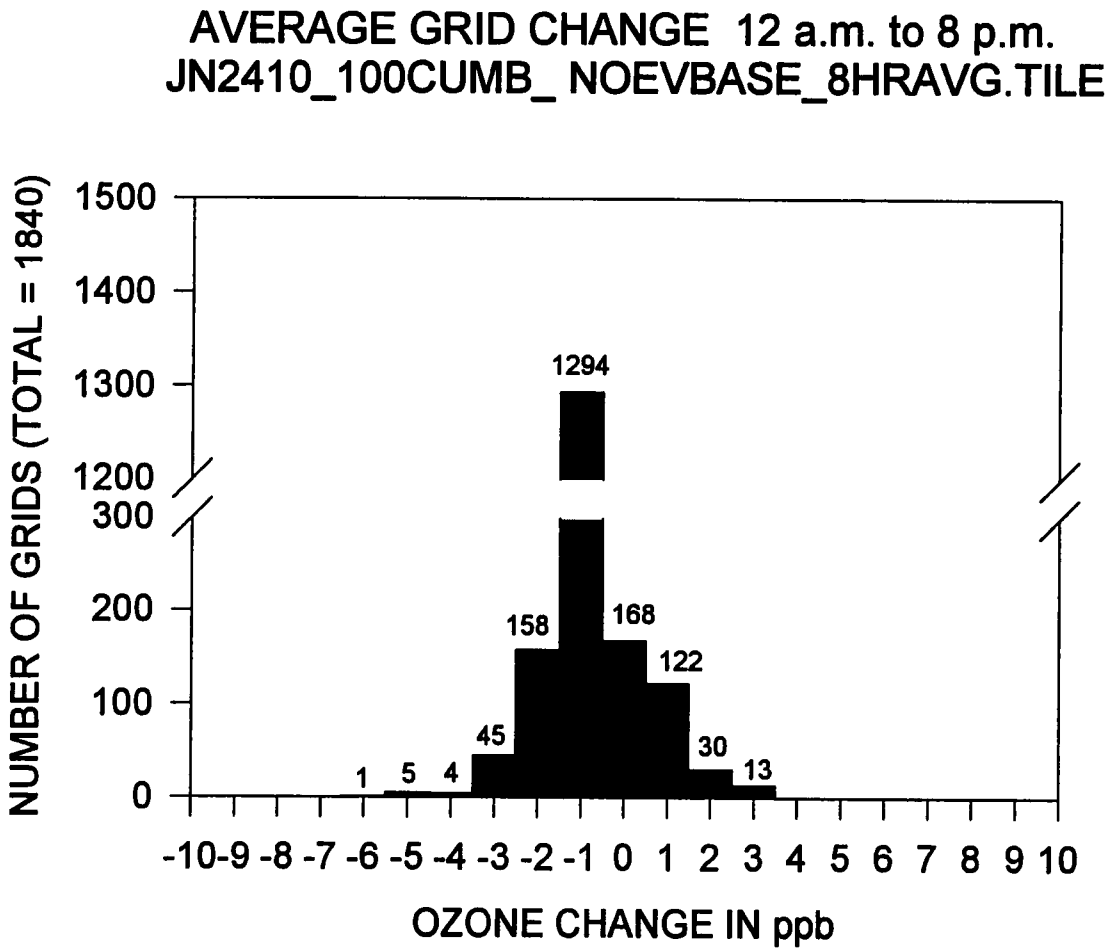


Figure 45. June 24, 2010 25 % EV, 100 % Cumberland 8 Hour Average Distribution

Table 19. Largest Ozone Increases and Decreases noted by Scenario (June 24, 2010)

Largest Ozone Increases and Decreases noted by Scenario (June 24, 2010)		
Scenario	Largest Increase	Largest Decrease
25 percent EV, no Utility Load Increase	1.3 ppb	4.1 ppb
25 percent EV, 100 percent of Utility Increase at Cumberland over 24 hours	4.6 ppb	8.1 ppb

percent EV load at Cumberland scenario due to NO_X scavenging near the Cumberland steam plant.

6.4 Ozone Response to On-Road Mobile Source Emissions Changes

The UAM modeling results shown in this study are specific to the MTMD, and the Nashville Urban area. However, other urban areas in the southeast are very similar to the Nashville area in several ways. Southeastern urban areas would be expected to have similar, high biogenic emission fluxes. In addition electric power is predominately generated by coal-fired utilities. The total mobile source category emissions, however, would be directly related to the total VMT in a given urban area. Other factors could also cause mobile source category emissions to vary, such as fleet age mix and facility speeds.

In an effort to provide a broader inference to the results presented in this study, simulations were conducted using the August 3 meteorological conditions with varying percentages of the MTMD mobile source category emissions in the inventory. Since differing percentages of EV usage only vary the emission reduction from the on-road mobile source category, the curves generated from these simulations can also be used to quickly consider differing EV penetration rates in the Nashville area, and possibly other urban areas in the Southeastern U.S., when utility emissions increases are not considered.

The curve, shown in Figure 46 , shows the maximum domain ozone concentration using the August 3, 2010 base case scenario with varing on-road mobile source category emissions. The 100 percent on-road mobile source VMT scenario is identical to the August 3, 2010 base case scenario presented in section 6.2 of this document. The Figure 46 curve shows that the domain maximum ozone concentration increases in a non-linear fashion until it decreases slightly between the 250 percent and 300 percent VMT increase scenarios. The noted ozone decrease represents a point where the mobile source category NO_X emissions reach a level where ozone scavenging begins to occur. Animation sequences of these runs have shown that the area of ozone scavenging which causes the domain maximum to decrease is localized in the center of the mobile source contribution area.

Table 20 shows the domain maximum ozone concentration predicted using differing VMT percentages, which are directly proportional to differing on-road mobile

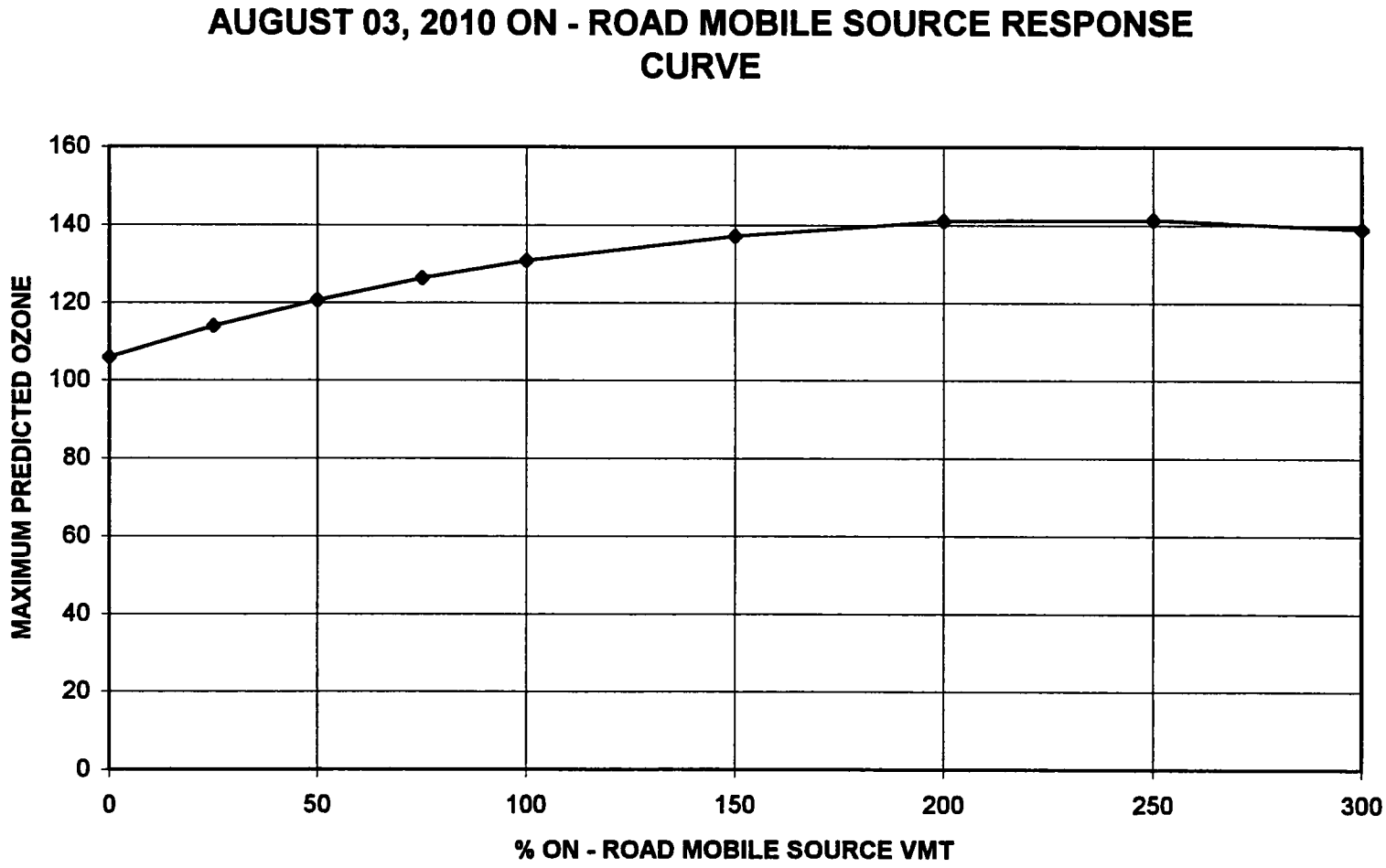


Figure 46. Maximum Predicted Ozone - Mobile Source Response Curve

Table 20. Maximum Predicted O_3 Concentrations vs. On-Road Mobile Emissions

August 3, 2010 Max Predicted O_3 Concentrations vs. On-Road Mobile Emissions									
Percent Mobile Emissions	0	25	50	75	100	150	200	250	300
Ozone (ppb)	105.9	113.9	120.6	126.2	130.7	137.1	141.0	141.3	138.9

source emissions. The curve shown in Figure 47, is the same data presented in Figure 46, but in a slightly different format. Figure 47 shows the ozone increase in ppb above the domain maximum ozone concentration predicted, with no on-road mobile source emissions, for each percentage of on-road mobile emissions simulated. A domain maximum ozone concentration of 105.9 ppb was predicted without any on-road mobile source emissions, using a boundary condition of 40 ppb ozone for 2010 emissions, with August 3, 1988 meteorology.

Using Figure 46, or Table 20 it can be seen that the UAM analysis predicts that a reduction in on-road mobile source emissions of more than 50 percent would be required to meet the current 1 hour ozone standard of 120 ppb for the forecast 2010 base case using August 3, 1988 meteorological conditions. A EV penetration larger than 50 percent would be required to attain a 50 percent on-road mobile source emissions reduction, not allowing for any EV utility load increase emissions occurring. For comparison purposes the on-road mobile emissions flux of Orange County, California

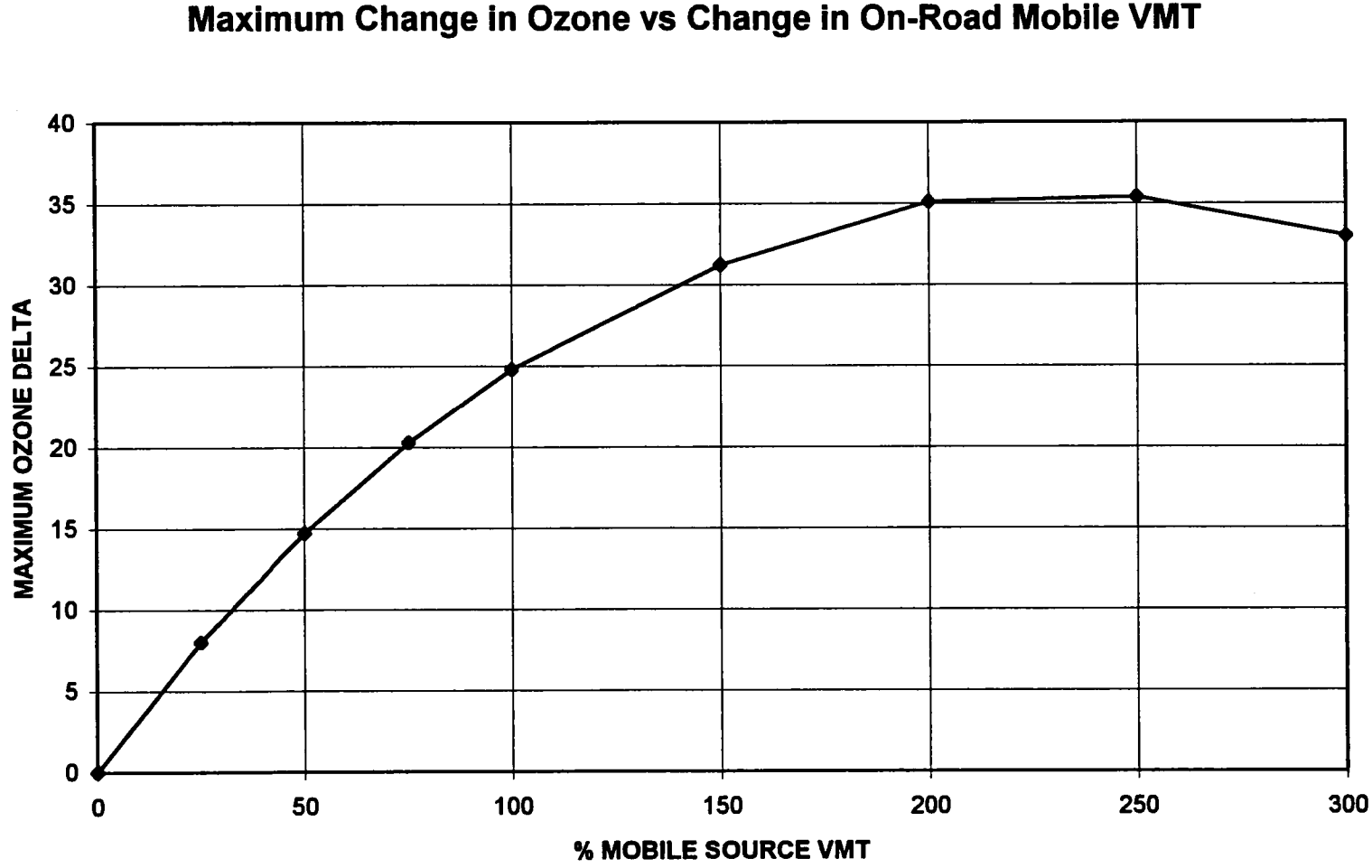


Figure 47. Maximum Ozone Delta - Mobile Source Response Curve

(Los Angeles Urban area), was calculated to be approximately 200 percent that of the Davidson County, Tennessee (Nashville Urban area), using Orange County emissions data reported by Lents and Davidson County emissions data reported by Davis (Lents and Kelly, 1993: Davis, *et al.*, 1994).The following series of color ozone concentrations plots were generated by subtracting the simulation results from the August 3, 2010 UAM scenario with no on-road mobile source emissions from the simulations with increasing percentages of on-road mobile sources in place. These figures show the ozone contribution from differing percentages of on-road mobile source emissions. These plots do not represent ozone maximums, or even increments between the maximums in different runs, due to the fact that the location of maximum mobile source contribution may not be the location of the overall domain ozone maximum. Figure 48 represents the no on-road mobile "base case" scenario, and shows a domain maximum concentration of 105.9 ppb. Figures 49, 50, 51, 52, 53, 54 and 55 represent the ozone contribution from 50 percent, 75 percent, 100 percent, 150 percent, 200 percent, 250 percent and 300 percent of the projected 2010 Nashville on-road mobile source emissions using August 3, 1988 meteorological conditions. These figures show that the ozone contribution grows in both the area effected and the magnitude of the concentration, with increasing on-road mobile source category emissions.

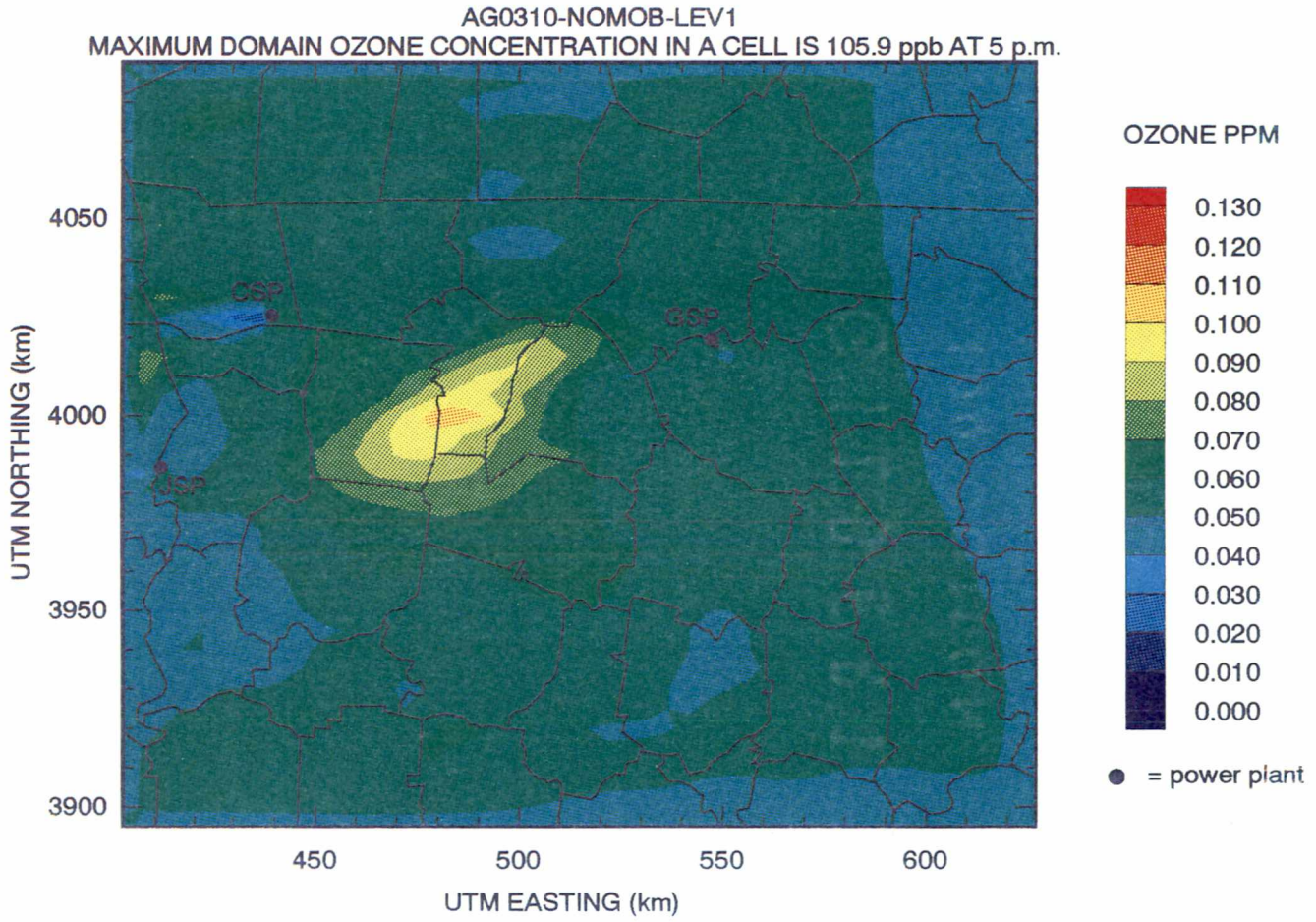


Figure 48. August 3, 2010 No Mobile Source Emissions - Base case

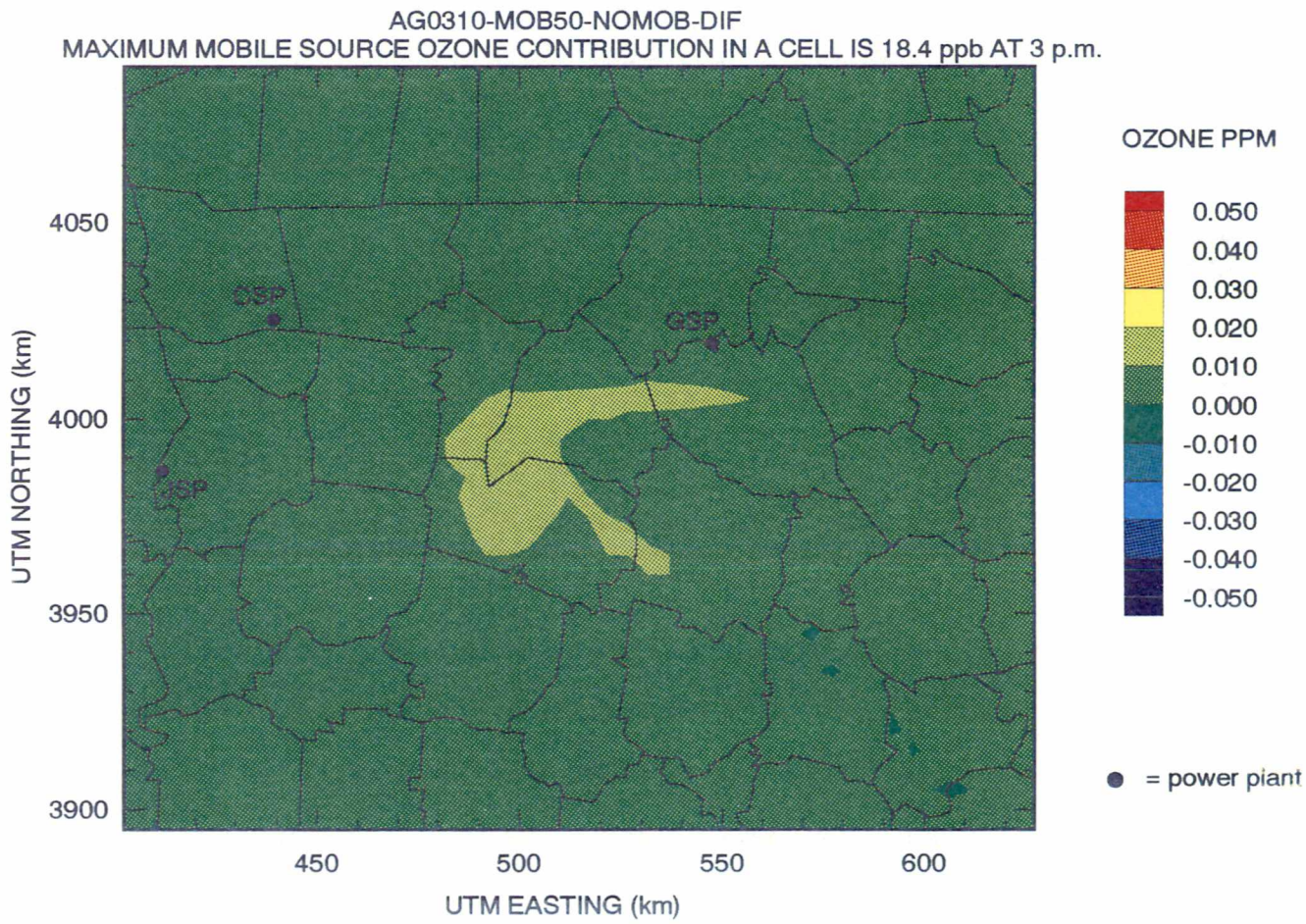


Figure 49. August 3, 2010 50 % Mobile Source Difference Plot

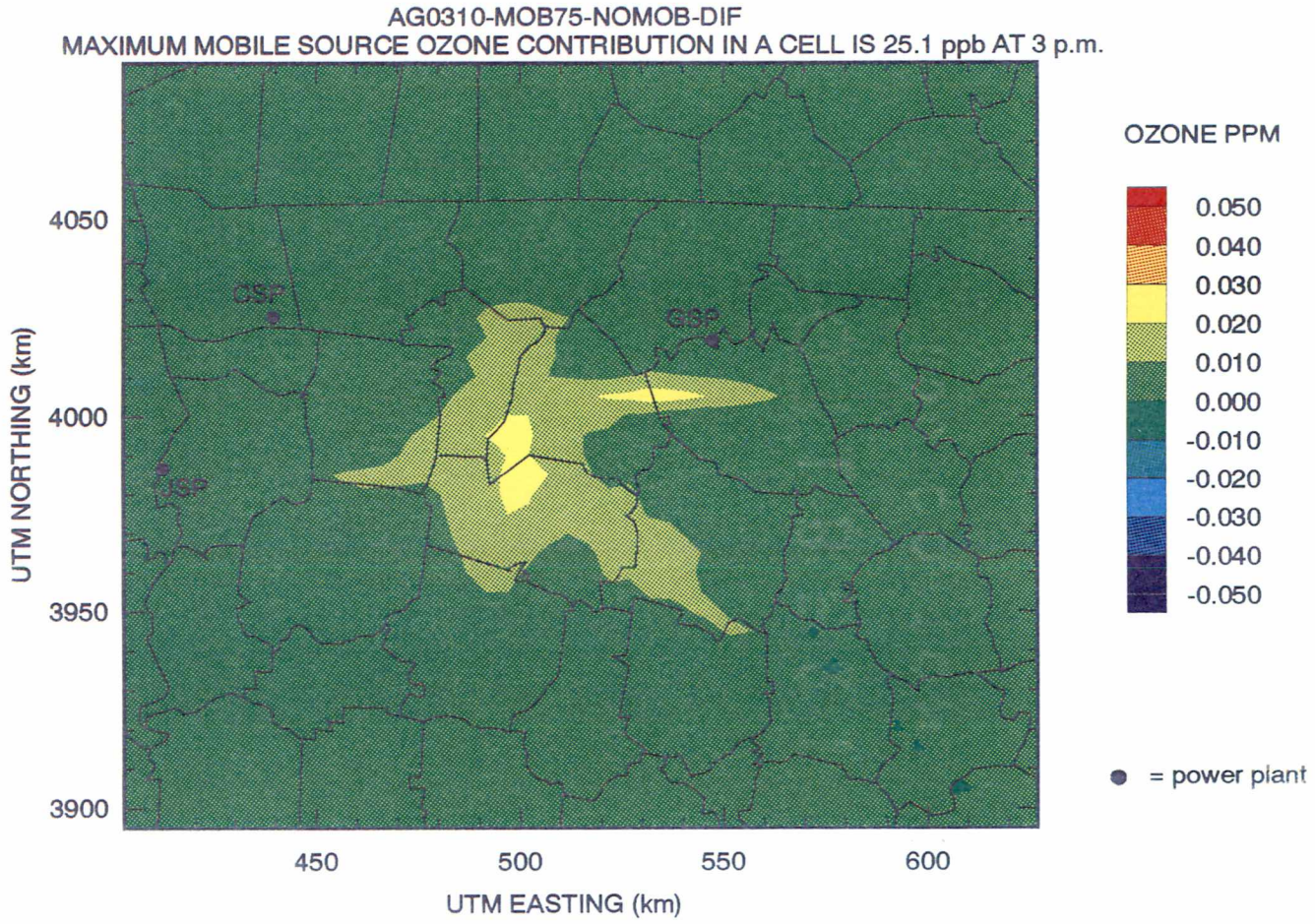


Figure 50. August 3, 2010 75 % Mobile Source Difference Plot

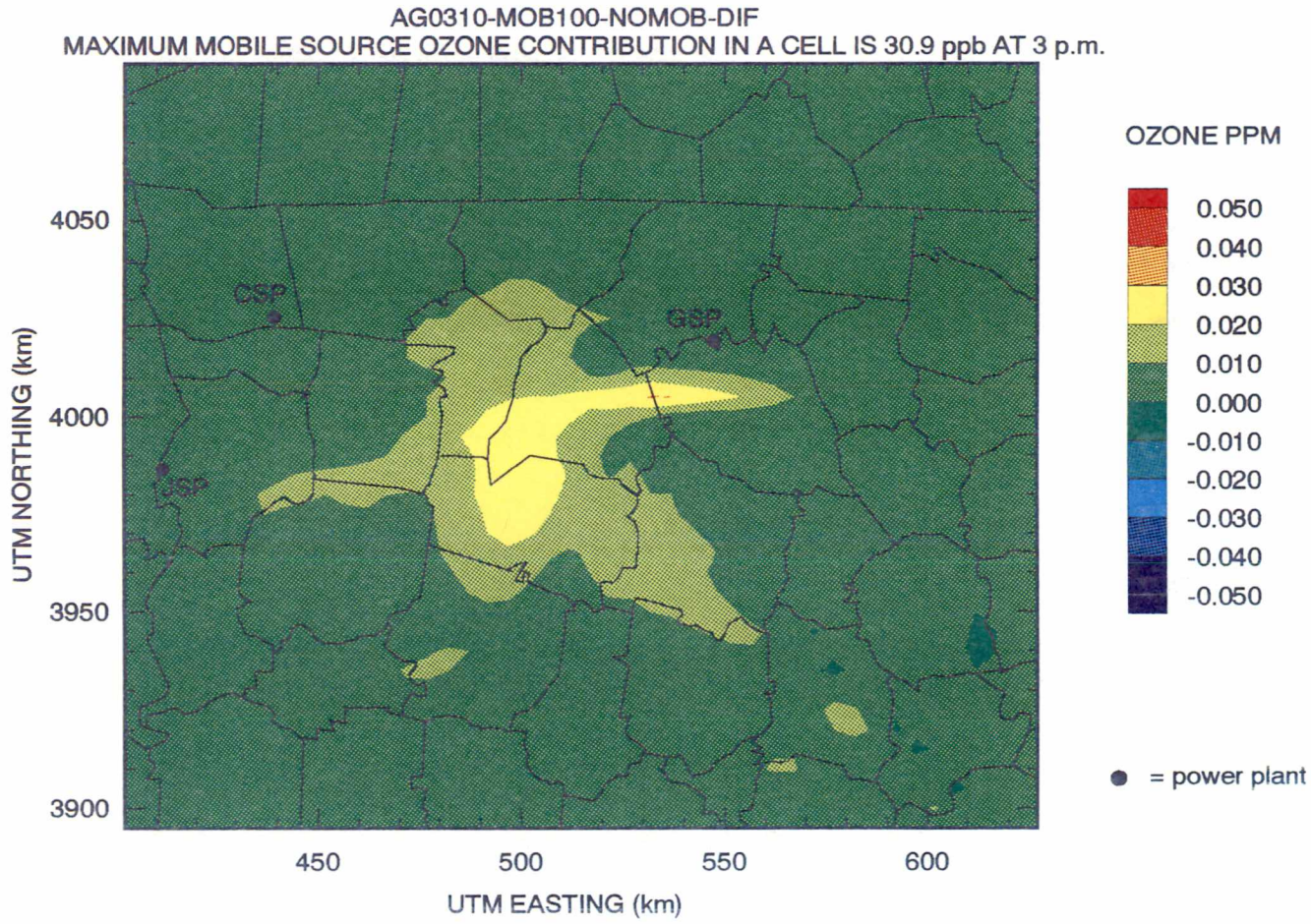


Figure 51. August 3, 2010 100 % Mobile Source Difference Plot

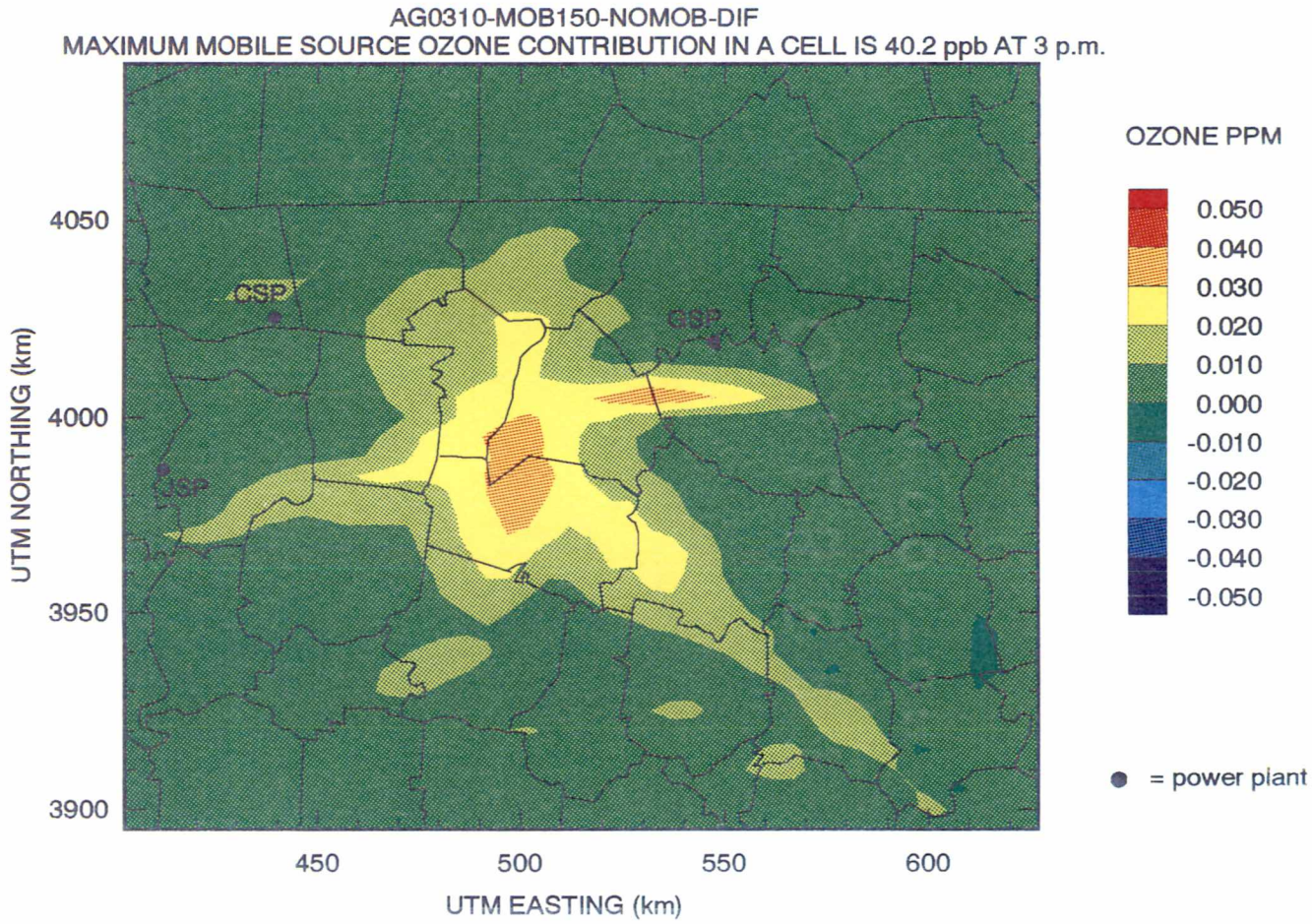


Figure 52. August 3, 2010 150 % Mobile Source Difference Plot

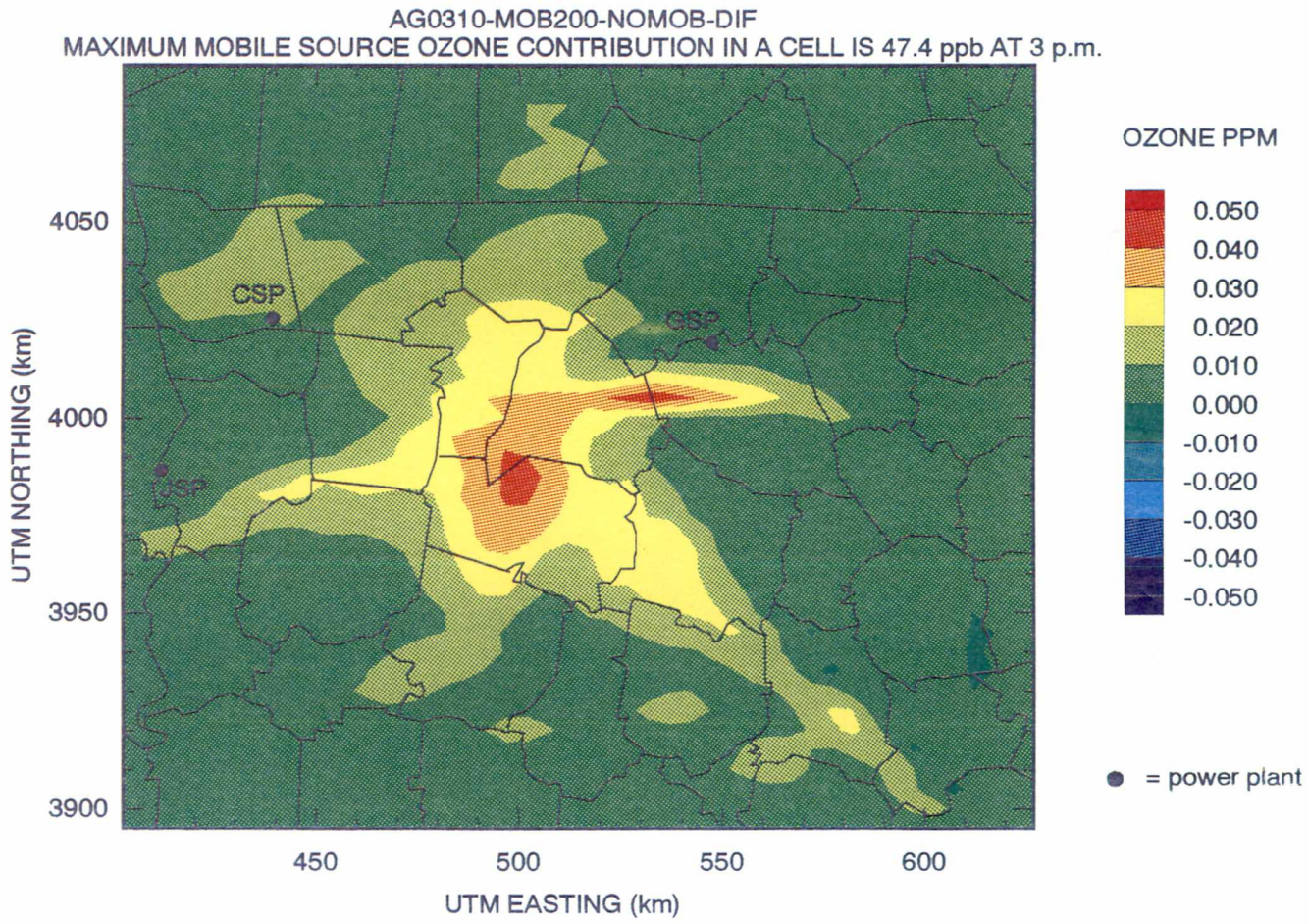


Figure 53. August 3, 2010 200 % Mobile Source Difference Plot

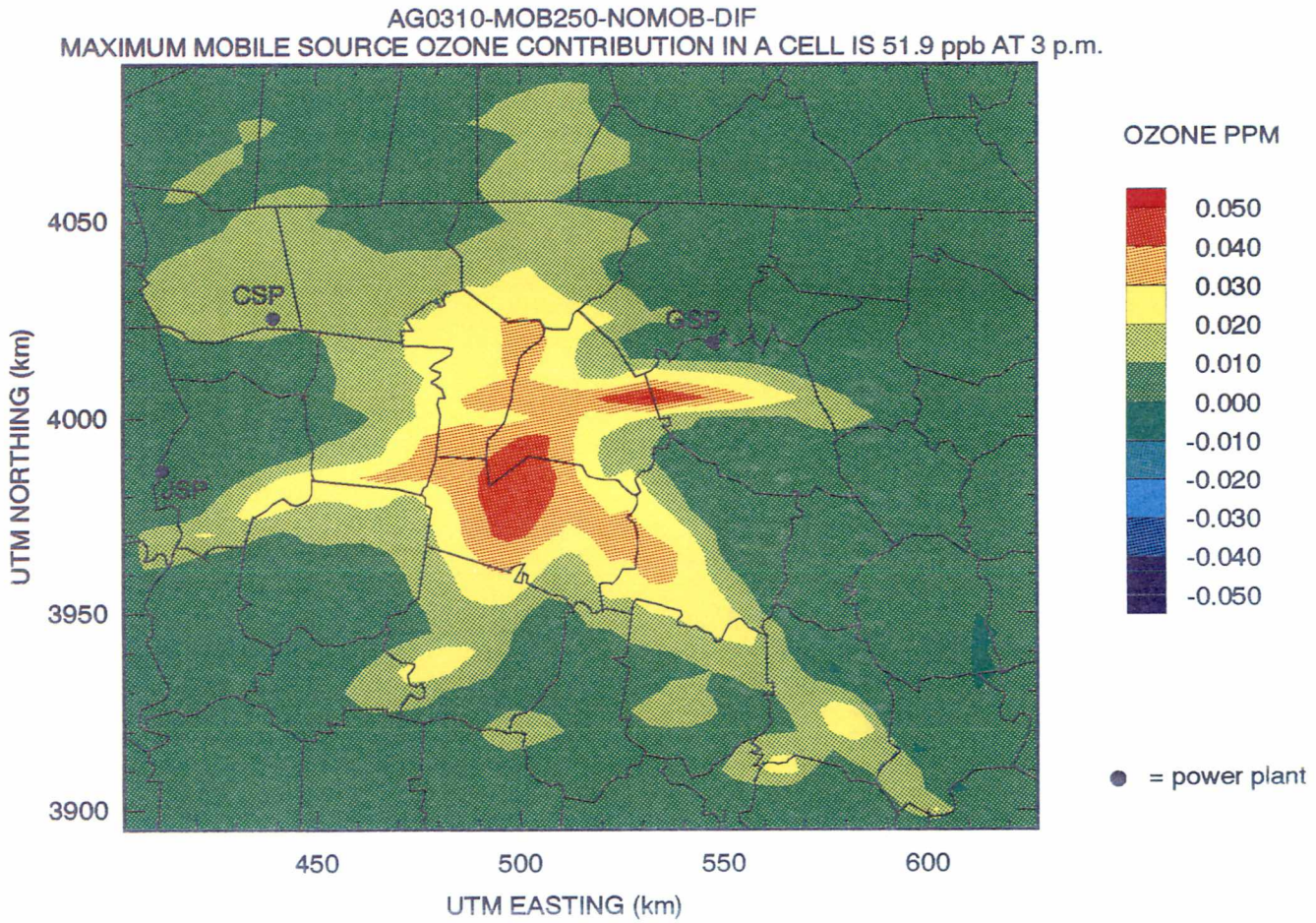


Figure 54. August 3, 2010 250 % Mobile Source Difference Plot

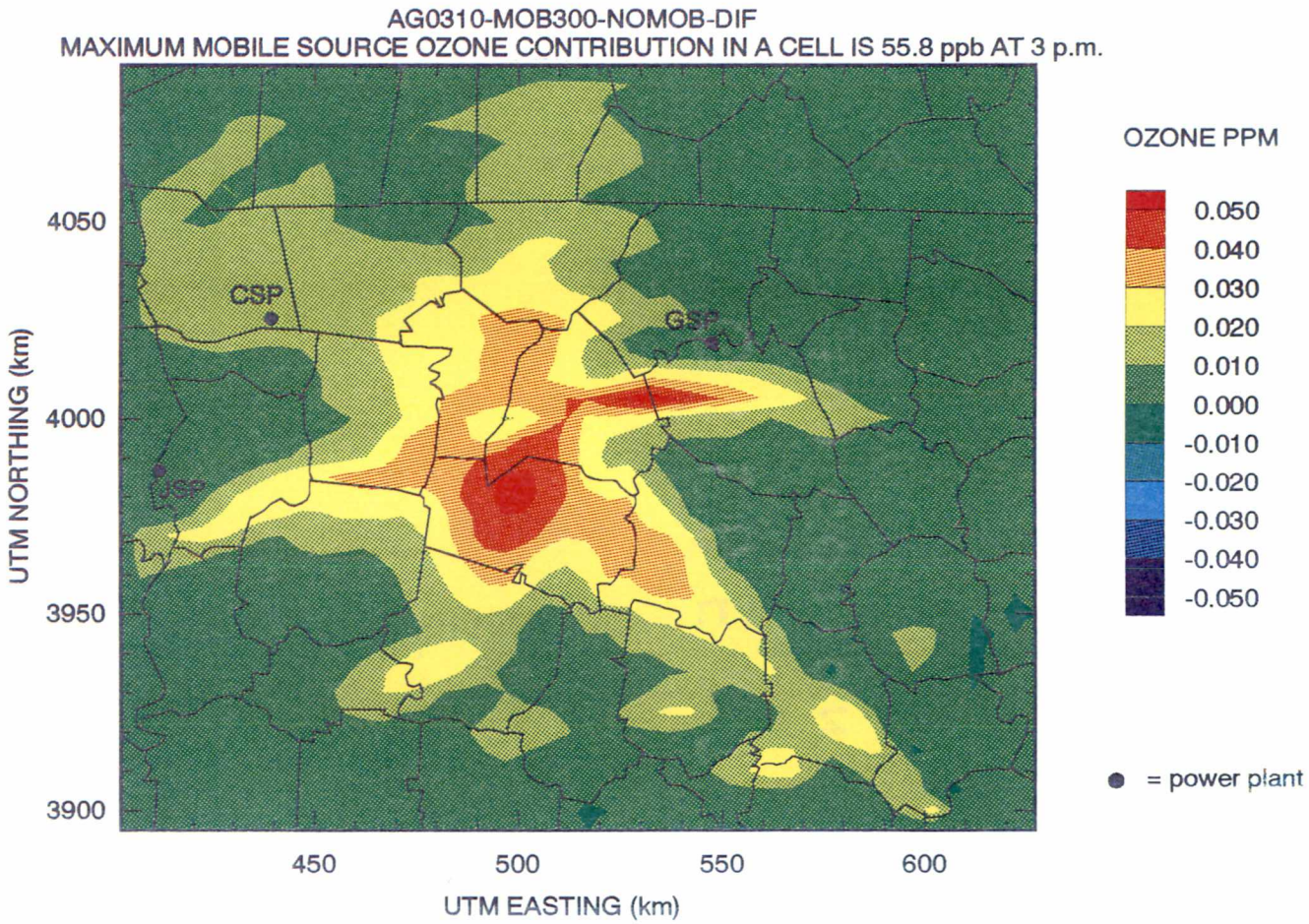


Figure 55. August 3, 2010 300 % Mobile Source Difference Plot

Chapter 7: Conclusions

7.1 UAM Simulations

All 2010 EV implementation scenarios modeled in this study predicted a decrease in the daily maximum ozone concentrations, referenced from a base case scenario with no EV usage. A decrease in maximum predicted ozone concentrations was noted regardless of which coal-fired TVA Steam plant increased power production for EV use.

Predicted domain wide ozone maximums for the August 3, 2010 simulations decreased from a high of 3.6 ppb, for the 25 percent EV with no utility load increase scenario, to a low of 2.3 ppb from the 25 percent EV with 100 percent of the EV load placed at the Gallatin Steam plant during the night-time hours of 6 p.m. through 6 a.m. All other simulations predicted domain wide ozone maximum reductions bracketed by these two scenarios.

The Gallatin Steam plant had the greatest potential to increase domain maximum ozone concentrations, of the three TVA steam plants in the MTMD, due to increased power plant load from EVs, in the August 3, 2010 simulations. This was simply due to the fact that this facility was upwind of the Nashville Urban area under the August 3 meteorological conditions.

Predicted domain wide ozone maximums for the June 24, 2010 simulations decreased from a high of 1.8 ppb, for the 25 percent EV with no utility load increase scenario, to a low of 0.2 ppb for the 25 percent EV with 100 percent of the EV load

placed at the Cumberland Steam plant during the night-time hours of 6 p.m. through 6 a.m. The 25 percent EV with 100 percent of the EV load at the Gallatin plant and the 25 percent EV with 100 percent of the EV load at the Johnsonville plant scenarios both predicted the same domain wide ozone maximum as the 25 percent EV, no EV utility load scenario. All other simulations predicted domain wide ozone maximum reductions bracketed by the 25 percent EV, no EV utility load scenario, and the 25 percent EV, 100 percent EV load at Cumberland 6 a.m. through 6 p.m. scenario.

The Cumberland Steam plant had the greatest potential to increase domain maximum ozone concentrations, of the three TVA steam plants in the MTMD, due to increased power plant load from EVs, in the June 24, 2010 simulations. Although all three steam plants can impact the MTMD under the June 24 meteorological conditions, the Cumberland steam plant emissions crossed the Nashville Urban area and then were transported down the I-24 corridor due to the meteorological conditions used for this simulation.

The use of two different meteorological conditions and the results of those simulations illustrate how important the meteorological conditions are to ozone formation. Depending upon windspeed and direction, any one of these utilities can be "upwind" of the Nashville Urban area, and therefore increased utility loads at each plant could effect ozone concentrations in the Nashville Urban area. As a result, there is no clear best or worst facility to which increased loads should be allocated. A scenario was modeled for both simulation dates where the needed EV load was split between the

Gallatin and Cumberland facilities. In both cases, the area of ozone increase, and the magnitude of the increase, from each plant, was reduced when compared to increasing the load at either plant alone.

If ozone concentrations exist in 2010, such as the 130 ppb concentrations simulated in the August 3, 2010 scenario, in the Nashville, Tennessee urban area, it can be concluded from this study that the introduction of EVs into the MTMD at a 25 percent penetration is not predicted to reduce ozone concentrations to levels that are below the current NAAQS of 120 ppb. The on-road mobile source simulations conducted in this study suggest that EV penetrations in excess of 50 percent, without any additional utility load increase at coal-fired power plants, would be required to meet the 120 ppb standard. This is based on the assumption that all other source types increase at rates based on the BEA data.

Further analysis over the highest 8 hour period of ozone concentrations, for both the August 3, 2010 and June 24, 2010 simulations, revealed that although the changes in domain wide maximum concentrations were very small, that approximately 85 percent of the grid-cells experienced predicted ozone decreases due to the 25 percent penetration of EVs in the MTMD. These predicted decreases, however, were also very small, with approximately 80 percent of the grid-cells which had predicted decreases of less than 1 ppb in ozone concentration reduction over the 8 hour period of concern.

The addition of increased utility loads, due to EV usage, resulted in both a slightly larger number of cells experiencing ozone increases, and caused some cells to

show a greater magnitude of ozone decrease. The larger ozone decrease in cells near the power plants, and in some plume centers was the result of ozone scavenging due to increased NO_X emissions.

The reduction of ozone, due to NO_X scavenging should not be considered a beneficial effect. Air pollution is a regional problem and although the increased NO_X emissions may reduce ozone concentrations in a localized area, these same emissions have the potential to form ozone concentrations in a more distant location.

Advocates of EVs have stated that even if power sources which cause air pollution, such as coal-fired boilers, are used to provide power for EVs, that the allocation of emissions away from urban population centers to rural settings (i.e. where the power plants are assumed to be) reduces exposure and is a positive situation. While the removal of emissions from urban areas will certainly reduce population exposure to these pollutants, it is not necessarily true that their re-allocation to utilities removed from urban centers means that urban areas are not exposed to these emissions. In the case of the secondary pollutant, ozone, the re-allocation of NO_X emissions away from the urban centers can potentially increase urban population ozone exposure. Ozone requires time to form in the atmosphere. If NO_X emissions are increased at upwind locations, i.e. rural located power plants, such as the Cumberland Steam Plant, the NO_X can cause a greater ozone concentration when it is mixed with biogenic and anthropogenic hydrocarbons as it is transported downwind into urban areas. Again the point should be made that air pollution is a regional problem. The idea of locating an emissions source where the

effect on a specific urban area is reduced, is not likely to solve regional air pollution problems.

It should also be noted that the smallest reduction of the daily ozone maximum on both simulation dates was due to the increased utility load being placed in the 6 p.m. to 7.am. hours, applied as a level load, rather than distributed proportionally over 24 hours. In previous EV studies, reviewed in preparation for this study, several authors pointed out that the allocation of EV loads to power plants could be during the night-time hours. This is a logical assumption since most utilities have diurnal power production patterns and have lower loads at night. Several of the EV studies concluded (without modeling) that increased utility loads during the night-time hours would result in a negligible effect on ozone formation, since ozone requires sunlight to form. The results of this study show that this assumption is erroneous. Power plant plumes have been shown to travel several hundred kilometers and last for days (Early, 1994; McIlvaine, 1994). If the power plant is located upwind of an urban area, greater releases of NO_X at night can result in greater ozone concentrations in the urban area the next day, if the NO_X emissions have sufficient VOCs to react with when the sun's energy is available to fuel the photochemical reactions.

7.2 Electric Vehicles

This study was based on the assumption that EVs consumed 0.5 kilowatt hours per mile of electricity metered at the battery charger. Although some authors predict

lower future consumption values than this, most EV researchers use values close to 0.5 kilowatt hours per mile, or more, as was shown in Table 2 of this document. The Conceptor G-Van, a current production vehicle uses more that twice this amount of energy (OEDC, 1993). This study did not directly address the economic feasibility of EVs directly. It was simply assumed that EVs were available, and economically feasible to reach the projected sale figures needed to reach a 25 percent penetration in 2010. The calculated changes in VOC, NO_X and CO emissions for the MTMD for a 25 percent EV penetration with no utility load increases, and with load increases at the Cumberland power plant are summarized in Table 21.

Table 21. Projected 2010 MTMD Emission Changes due to EV Use

Projected 2010 MTMD Emission Changes due to 25 percent EV Penetration			
Scenario	VOC	NO_X	CO
2010 Base case (No EV) Emissions (Tons / Day)	2584.29	818.70	2613.08
percent Change due to 25 percent EV penetration and no Utility load Increase	- 1.71 percent	- 4.50 percent	- 8.12 percent
percent Change due to 25 percent EV penetration and 100 percent EV Utility load Increase at Cumberland	- 1.71 percent	+ 0.74 percent	- 8.07 percent

The values shown in Table 21 indicate that the reduction in VOC emissions due to the use of EVs in the MTMD is negligible, due to the high biogenic VOC emissions already

present in the MTMD, and other southeastern areas. Total domain NO_X emissions were calculated to decrease by 4.50 percent with 25 percent EV penetration in the LDGV and LDGT1 vehicle classes if no additional loads were placed on the TVA coal-fired utilities within the domain. If the Cumberland Steam plant were assumed to produce the power required by the EVs , a domain total NO_X increase of 0.74 percent, over and above the EV NO_X reductions in the mobile source category was calculated. Emissions of CO were calculated to decrease from 8.12 percent, without increased utility loads, to 8.07 percent considering EV utility load increase.

Overall emissions decreases from a 25 percent EV penetration in the LDGV and LDGT1 vehicle classes are small. However most researchers assume a 10 percent - 15 percent EV penetration in their studies of EV impact, as shown in section 2 of this document. In order to gain substantial emission decreases, EV penetrations would need to be greater than 50 percent of the total fleet. Reaching a penetration this large would require several years. Also a clean power source, such as nuclear power, would need to be used to generate the power required by EVs.

Using a fleet average emission factor generated by the MOBILE5A model for 2010, and using projected power plant NO_X emissions in 2010 emission factors on a grams per mile basis for gasoline autos (fleet average) are shown to range from 1.26 to 1.69 grams NO_X per mile, see Table 4, and emissions at coal-fired power plants, due to EVs, are calculated to be 1.03 to 1.73 grams NO_X per mile. Using the assumptions defined by this study, and the 2010 fleet emission factors, EVs re-allocate NO_X emissions to power plant plumes at

approximately a 1:1 ratio, for 2010 fleet average emissions. If the EV utility NO_X emissions on a per mile basis are compared to new vehicle emission factors, or the Tier II Clean Fuel emission limits EVs could increase NO_X emissions. Compared to a LDGV with a 0.4 gram / mile NO_X limit emissions from a plant such as Gallatin would result in a reallocation of mobile NO_X to a power plant at a 1:2.58 ratio. If the Tier II standard of 0.25 grams NO_X / mile is considered and emissions produced from a plant such as Cumberland the mobile NO_X reallocation would be at a ratio of 1:6.29 when comparing a single new car and EV. In order to make real progress in reducing regional air pollution, emissions must be removed from the system, rather than reallocated within it. Ozone pollution is a regional scale problem.

For areas which adopt the optional Phase II Clean Fuel Vehicle Standards, set forth in the CAAA, the potential positive impact of EVs could be reduced below the levels predicted in this study because the new gasoline vehicles replaced by EVs, would be cleaner than those assumed to be replaced by EVs in this study.

The first EV to meet the U.S. federal motor vehicle safety standard, the Conceptor G-Van, which was predicted to have a range of 60 miles, only had a 40 mile range when put to actual roadway use (DOE, 1992). The EV technology is clearly in a very early stage of it's potential development. EVs will have to undergo an accelerated improvement if consumers are expected to begin purchasing EVs for real world on-road use by the 1998 model year.

7.3 Suggested Further Study

A suggested topic of further research indicated by the results of this study, is a comparison of the relative benefits from the adoption of the Phase II Clean Fuel Vehicle Standards and LPG fuel vehicles verses the use of electric vehicles. The use of cleaner new vehicle standards would result in a true reduction of emissions. The potential benefit of mandating that the same percentage of new vehicles meet these standards, in the same time frame, to which EV sales have been currently mandated in three U.S. states could be compared, with the projected benefits of the EV mandate. As the introduction of substantially cleaner vehicles into the fleet is accelerated, the potential benefits of EV usage should be reduced.

REFERENCES

REFERENCES

Alcohol Week, "EPA Seeks Public Comment Before Finalizing Controversial EV Report", New Fuels Report, March 28, 1994.

Altshuller, A. P., "The Role of Nitrogen Dioxides in Nonurban Ozone Formation in the Planetary Boundary Layer over North America, Western Europe, and Adjacent Areas of Ocean", Atmospheric Environment, Vol. 20 No. 2, pp 245 - 268., 1986.

Bandyopadhyay, N., Evaluation of the Effect of Various Emission Sources on Ozone Formation in Memphis, TN., Thesis: University of Tennessee, Knoxville, 1993.

Bentley, J.M., P. Teagan, D. Walls, E. Balles and T. Parish, The Impact of Electric Vehicles on CO_2 Emissions, Arthur D. Little, 1992.

Blanchard, C. L., P. Roth and H. Jeffries, "Spatial Mapping of Preferred Strategies for Reducing Ambient Ozone Concentrations Nationwide", Paper presented at 1993 Air and Waste Management Association National Conference, 1993.

Burns, R.T., W.T. Davis, T.L. Miller and M.A. Kaminski, "Interactive Visualization of Urban Airshed Modeling Simulations", 1994 AWMA Computing Specialty Conference, Durham, NC, 1994.

Butala, R., Temporal Resolution of Ozone Precursor Emissions for the Middle Tennessee Modeling Domain, Thesis: The University of Tennessee, Knoxville, 1994.

Cawlfield, J.E, Spatial Resolution of Ozone Precursor Emissions for a Selected Area in Middle Tennessee, 1990, Thesis: The University of Tennessee, Knoxville, TN, 1994.

Consumer Reports, "Is Detroit Trying to Unplug Electric Cars ?", Consumer Reports April, 1994.

Cooper, D. C. and F.C. Alley, Air Pollution Control: A Design Approach, Waveland Press, Prospect Heights, Illinois, 1986.

Davis, W.T., T.L. Miller and R.T. Burns, Executive Summary of the 1988/1996 Urban Airshed Modeling Demonstration for the Middle Tennessee Ozone Nonattainment Area, The University of Tennessee, Knoxville, 1995.

Davis, W.T., and T.L. Miller, Emission Inventory Preparation Plan for the 1994/1995 SOS Intensive Study in Nashville, Tennessee., The University of Tennessee, Knoxville, 1994.

Davis, W.T., T.L. Miller, and A. Chatterjee, SIP BASE YEAR 1990 EMISSIONS INVENTORY FOR PRECURSORS OF OZONE FOR THE NASHVILLE NONATTAINMENT AREA AND MIDDLE TENNESSEE MODELING DOMAIN, Vol. 1-6, submitted to U.S. EPA Region IV, July 23, 1993.

Davis, W.T., and T.L. Miller, Protocol for Photochemical Air Quality Modeling of the Middle Tennessee (Nashville) Area, report submitted to U.S. EPA Office of Air Quality Planning and Standards and U.S. EPA Region IV, June 1992.

DeLuchi, M., Q. Wang and D. Sperling, Electric Vehicles: Performance, Life Cycle Costs, Emissions, and Recharging Requirements, 1989. Transportation Research Group, University of California, Davis. Davis, California

DOE, Utility Emissions Associated with Electric and Hybrid Vehicle (EHV) Charging, Interim Draft Prepared by EPRI., U.S. Department of Energy, 1993.

DOE, Electric and Hybrid Vehicles Program, U.S. Department of Energy, 1993.

DOE, Atmospheric Science and Power Production, Edited by Darryl Randerson, U.S. Department of Energy, 1984.

Dowlatabadi, H., A. Krupnick and A. Russell, Electric Vehicles and the Environment: Consequences for Emissions and Air Quality in Los Angeles, 1990. Resources for the Future, Washington, D,C.

Early, A.E., The Significance of Nox Emissions from Coal - Fired Power Plants in the Middle Tennessee Area on Tropospheric Ozone , Thesis: University of Tennessee, Knoxville, 1994.

Electric Power Research Institute (EPRI), The Impact of Electric Passenger Automobiles on Utility System Loads, 1985 - 2000, 1978. Prepared by Mathtech Inc., Princeton Junction, New Jersey.

Gery, M., G. Whitten and J. Killus, "Development of the Carbon Bond-IV Mechanism", paper in the Ozone Control Strategy Proceedings, Air and Waste Management Association, 1989.

Healey, James R., "Debate Could Short-Circuit Debut of Electric Car", USA TODAY, May 2, 1994.

Hegg, D., "Reactions of Ozone and Nitrogen Oxides in Power Plant Plumes", Atmospheric Environment, Vol. 11, pp 521 - 526., 1977.

Jackson, M.W. and P.E. Korsog, Estimated Impact of the 1990 Clean Air Act Amendments on Vehicle Emissions, Presented at the 87th Annual AWMA Meeting, Cincinnati, OH, 1994.

Kaminski, M.A., Urban Airshed Modeling of the Middle Tennessee Modeling Domain: Model Performance Evaluation, Thesis: University of Tennessee, Knoxville, 1994.

Kelly, N. A.,G. Wolff, and M. Ferman, "Sources and Sinks of Ozone in Rural Areas", Atmospheric Environment, Vol. 18, pp. 1251 - 1266., 1984.

Lefon, Allen S., Surface Level Ozone Exposures and Their Effects on Vegetation, Lewis Publishers, Inc., 1992.

Lents, J.M. and W. J. Kelly, "Clearing the Air in Los Angeles", Scientific American, October, 1993.

Levy, A. and C.W. Spicer, The Atmospheric Chemistry of NO_X, The American Institute of Chemical Engineers, 1978.

MacKenzie, J.J., The Keys to the Car: Electric and Hydrogen Vehicles in the 21st Century, World Resources Institute, 1994.

McIlvaine, C. M., Development of the MAP-O_3 Model for Predicting Seasonal Average Ozone Concentrations Due to Large Point Source NO_x Emissions, Dissertation: The University of Tennessee, Knoxville, 1994.

National Research Council, (NRC), Rethinking The Ozone Problem in Urban and Regional Air Pollution, National Academy Press, Washington, D.C., 1991.

National Research Council, (NRC), Ozone and Other Photochemical Oxidants, National Academy Press, Washington, D.C., 1977.

Organization for Economic Co-operation and Development (OEDC), Electric Vehicles: Technology, Performance and Potential, OEDC, 1993.

Russel, A., A. Krupnick and H. Dawlatabadi, "Electric Vehicles and The Air Pollution in Los Angeles", Energy and The Environment, Vol. 3, No. 2, 1992.

Seigneur, C. T., The Effect of Power Plant Plume Emissions of NOX on Ozone Levels in Three Different Environments, System Applications International, San Rafael, California, SYSAPP-84/218, 1984.

Smith, K.L., Strategies for Reducing Ozone Pollution in Atlanta GA: Analysis of Biogenics and Implications of NOX Control, Presented and published at the 85th Annual Meeting and Exhibition of the Air and Waste Management Association, 1992.

Sperling, D.and M. DeLuchi, Transportation Energy Futures, 1989. University of California, Davis. Davis, California.

Spicer, C.W., "Photochemical Atmospheric Pollutants Derived from Nitrogen Oxides", Atmospheric Environment, Vol. 11, pp 1089 - 1095, 1977.

Suris, O., "Electric Cars Also Pollute Air, EPA Study Says", The Wall Street Journal, April 5, 1994-A.

Suris, O., "Regulators Back Electric Vehicles for Northeast", The Wall Street Journal, February 2, 1994-B.

Tennessee Valley Authority, Letter describing expected future power outputs from the Cumberland, New Johnsonville, and Gallatin Fossil Fuel Plants for 2010. 1994 - A.

Tennessee Valley Authority, Letter describing expected future power outputs and emission factors from the Cumberland, New Johnsonville, and Gallatin Fossil Fuel Plants for 1988 and 1996. 1994 - B.

The Wall Street Journal, "Electric Car Shorts", September 9, 1994.

U.S. House of Represenatives, The Clean Air Act Amendments of 1990, U.S. House of Representatives Report 101-952, published by the U.S. Government Printing Office, Washington, D.C., 1990.

Wang, Q., and D. Santini, "Magnitude and Value of Electric Vehicle Emissions Reductions for Six Driving Cycles in Four U.S. Cities with Varying Air Quality Problems", Transportation Research Record No. 1416, Energy and Environment. Environmental Analysis, Air Quality, Noise, Energy, and Alternative Fuels. Transportation Research Board, 1993.

Wang, Q., M. DeLuchi, and D Sperling, "Emission Impacts of Electric Vehicles", Journal of Air and Waste Management Asocciation, Vol. 40, No. 9, 1990.

Wang, Q., M. DeLuchi, and D Sperling, Air Pollutant Emissions and Electric Vehicles, 1989. Transportation Research Group, University of California, Davis. Davis, California.

Wark, K. and C. Warner, Air Pollution: It's Origin and Control, Second Edition, Harper and Row Publishers, 1981.

BIBLIOGRAPHY

Bibliography

Causley, M.C., J.L. Fieber, M. Jimenez and L. Gardner, User's Guide for the Urban Airshed Model, Volume IV: User's Manual for the Emissions Preprocessor Systems, EPA-450/4-90-007D, U.S. Environmental Protection Agency, Research Triangle Park, NC (NTIS No.: PB91-131250), 1990.

Christian, J.M., World Guide to Battery-Powered Road Transportation: Comparative Technical and Performance Specifications, McGraw Hill Publications, New York, NY., 1980.

Davis, W.T., T.L. Miller, and A. Chatterjee, SIP Base Year 1990 Emissions Inventories for Precursors of Ozone and for Carbon Monoxide for the Memphis Nonattainment Area, Report submitted to U.S. Office of Air Quality Planning and Standards and U.S. EPA Region IV, October, 1992.

Davis, W.T., T.L. Miller, and A. Chatterjee, SIP Base Year 1990 Emissions Inventory for Precursors of Ozone for the Knoxville Nonattainment Area, Report submitted to U.S. EPA Office of Air Quality Planning and Standards and U.S. EPA Region IV, October 1992.

Davis, W.T., and T.L. Miller, Protocol for Photochemical Air Quality Modeling of the Middle Tennessee (Nashville) Area, report submitted to U.S. EPA Office of Air Quality Planning and Standards and U.S. EPA Region IV, June 1992.

Davis, W.T., T.L. Miller, and A. Chatterjee, SIP Base Year 1990 Emissions Inventory for Carbon Monoxide and Precursors of Ozone for the State of Tennessee, Report submitted to U.S. EPA Office of Air Quality Planning and Standards and U.S. EPA Region IV, July 1992.

Douglas, S.G., R.C. Kessler and E.L. Carr, 1990. User's Guide for the Urban Airshed Model, Volume III: User's Manual for the Diagnostic Wind Model, EPA-450/4-90-007C, U.S. Environmental Protection Agency, Research Triangle Park, NC (NTIS No.: PB91-131243).

Morris, R.E., T.C. Myers and J.L. Haney, User's Guide for the Urban Airshed Model, Volume I: User's Manual for UAM (CB-IV), EPA-450/4-90-007A, U.S. Environmental Protection Agency, Research Triangle Park, NC (NTIS No.: PB91-131227), 1990.

Morris, R.E., T.C. Myers, E.L. Carr, M.C. Causley, S.G. Douglas and J. L. Haney, 1990. User's Guide for the Urban Airshed Model, Volume II: User's Manual for the UAM (CB-IV) Modeling System, EPA-450/4-90-007B, U.S. Environmental Protection Agency, Research Triangle Park, NC (NTIS No.: PB91-131235).

SAMAB, Forum on Air Quality Management for Class I Areas in the Southern Appalachians, Gatlinburg TN, March 3-5, 1992.

Schneider, T. and L. Grant, Air Pollution by Nitrogen Oxides, Elsevier Scientific Publishing Company, Amsterdam, 1982.

Tang, R.T., S.C. Gerry, J.S. Newsom, A.R. Van Meter, R.A. Wayland, J.M. Godwitch and K.L. Schere, User's Guide for the Urban Airshed Model, Volume V: Description and Operation of the ROM-UAM Interface Program System, EPA-450/4-90-007E, U.S. Environmental Protection Agency, Research Triangle Park, NC (NTIS No.: PB91-131268), 1990,

Tennessee Department of Health and Environment (TDHE) , Comprehensive Emission Inventory for Precursors of Ozone in the Nashville and Memphis Tennessee Areas, Tennessee Department of Health and Environment, December 1990.

U.S. EPA, Summary of Public Comments and EPA Responses on the Draft Report, The Role of Ozone Precursors in Tropospheric Ozone Formation and Control, EPA-454/R-93-025, July, 1993.

U.S. EPA, Procedures for the Preparation of Emission Inventories for Carbon Monoxide and Precursors of Ozone, EPA-450/4-91-016, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1991.

U.S. EPA, Procedures for Emission Inventory Preparation Volume IV: Mobile Sources, EPA-450/4-81-026d (Revised), U.S. Environmental Protection Agency, Research Triangle Park, NC, July 1989.

U.S. EPA, Compilation of Air Pollutant Emission Factors, Fourth Edition and Supplements, AP-42, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1985.

U.S. EPA, Compilation of Air Pollutant Emission Factors, Volume II, Fourth Edition, AP-42, U.S. Environmental Protection Agency, Office of Mobile Source Air Pollution Control, Ann Arbor, MI, September 1985.

U.S. EPA, Guideline for Regulatory Application of the Urban Airshed Model, OAQPS, EPA-450/4-91-013, July 1991.

U.S. EPA, User's Guide for the Urban Airshed Model, Volume IV: User's Manual for the Emissions Preprocessor System 2.0, Part A: Core FORTRAN System, OAQPS, EPA-450/4-90-007(R), June, 1992.

Wakefield, Earnest H., The Consumer's Electric Car, Ann Arbor Science, Ann Arbor, MI, 1977.

APPENDIX

TENNESSEE AFFECTED AREA MOBILE5A INPUT FILE

```
1       PROMPT - vertical flag input, no prompting
MOBILE5 RUN FOR AFFECTED TN COUNTIES : Daily Run Ozone Season 2010
1       TAMFLG - default tampering rates
1       SPDFLG - input one speed per scenario for all vehicle types
1       VMFLAG - default vmt mix
1       MYMRFG - default registration and mileage accrual rates
1       NEWFLG - default exhaust emission rates
1       IMFLAG - no I/M  program
1       ALHFLG - no additional correction factor inputs
1       ATPFLG - no anti-tampering program
1       RLFLAG - uncontrolled rates for refueling emission factors
1       LOCFLG - read in local area parameters as 2nd req sc rec
2       TEMFLG - use input value of ambient temperature
3       OUTFMT - 112 column descriptive output format
4       PRTFLG - print exhaust HC, CO and NOx emission factor results
1       IDLFLG - do print idle emissions results
3       NMHFLG - print VOC
3       HCFLAG - print HC components and detailed evaporative breakdown
1 10 60.9 79.0 20.6 27.3 20.6  7              1st req sc rec
60 MPH  U/INT  C  73.101.  9.0  7.8 20     LAP rec
1 10 66.0 79.0 20.6 27.3 20.6  7              2nd req sc rec
65 MPH  R/INT  C  73.101.  9.0  7.8 20     LAP rec
1 10 27.9 79.0 20.6 27.3 20.6  7              3rd req sc rec
26 MPH U MA/ART  C  73.101.  9.0  7.8 20     LAP rec
1 10 46.2 79.0 20.6 27.3 20.6  7              4th req sc rec
43 MPH R MA/ART  C  73.101.  9.0  7.8 20     LAP rec
1 10 27.7 79.0 20.6 27.3 20.6  7              5th req sc rec
26 MPH U MI/ART  C  73.101.  9.0  7.8 20     LAP rec
1 10 50.1 79.0 20.6 27.3 20.6  7              6th req sc rec
47 MPH R MI/ART  C  73.101.  9.0  7.8 20     LAP rec
1 10 26.0 79.0 20.6 27.3 20.6  7              7th req sc rec
25 MPH  U COLL.  C  73.101.  9.0  7.8 20     LAP rec
1 10 41.5 79.0 20.6 27.3 20.6  7              8th req sc rec
40 MPH  R COLL.  C  73.101.  9.0  7.8 20     LAP rec
1 10 15.6 79.0 20.6 27.3 20.6  7              9th req sc rec
15 MPH  U LOCAL  C  73.101.  9.0  7.8 20     LAP rec
1 10 26.0 79.0 20.6 27.3 20.6  7             10th req sc rec
25 MPH  R LOCAL  C  73.101.  9.0  7.8 20     LAP rec
```

KENTUCKY AFFECTED AREA MOBILE5A INPUT FILE

```
1       PROMPT - vertical flag input, no prompting
MOBILE5 RUN FOR AFFECTED KY COUNTIES : Daily Run Ozone Season 2010
1       TAMFLG - default tampering rates
1       SPDFLG - input one speed per scenario for all vehicle types
1       VMFLAG - default vmt mix
1       MYMRFG - default registration and mileage accrual rates
1       NEWFLG - default exhaust emission rates
1       IMFLAG - no I/M  program
1       ALHFLG - no additional correction factor inputs
1       ATPFLG - no anti-tampering program
1       RLFLAG - uncontrolled rates for refueling emission factors
1       LOCFLG - read in local area parameters as 2nd req sc rec
2       TEMFLG - use user input value of ambient temperature
3       OUTFMT - 112 column descriptive output format
4       PRTFLG - print exhaust HC, CO and NOx emission factor results
2       IDLFLG - do print idle emissions results
3       NMHFLG - print VOC
3       HCFLAG - print HC components and detailed evaporative breakdown
1 10 47.2 79.0 20.6 27.3 20.6  7              1st req sc rec
46.5mph  U/INT   C  73. 101.  8.7  8.7  20    LAP rec
1 10 51.4 79.0 20.6 27.3 20.6  7              2nd req sc rec
50.6mph  R/INT   C  73. 101.  8.7  8.7  20    LAP rec
1 10 21.4 79.0 20.6 27.3 20.6  7              3rd req sc rec
19.9mph U MA/ART C  73. 101.  8.7  8.7  20    LAP rec
1 10 49.0 79.0 20.6 27.3 20.6  7              4th req sc rec
45.6mph R MA/ART C  73. 101.  8.7  8.7  20    LAP rec
1 10 22.4 79.0 20.6 27.3 20.6  7              5th req sc rec
21.0mph U MI/ART C  73. 101.  8.7  8.7  20    LAP rec
1 10 38.4 79.0 20.6 27.3 20.6  7              6th req sc rec
36.0mph R MI/ART C  73. 101.  8.7  8.7  20    LAP rec
1 10 20.8 79.0 20.6 27.3 20.6  7              7th req sc rec
20.0mph U COLL.  C  73. 101.  8.7  8.7  20    LAP rec
1 10 34.9 79.0 20.6 27.3 20.6  7              8th req sc rec
33.6mph R COLL.  C  73. 101.  8.7  8.7  20    LAP rec
1 10 20.8 79.0 20.6 27.3 20.6  7              9th req sc rec
20.0mph U LOCAL  C  73. 101.  8.7  8.7  20    LAP rec
1 10 33.1 79.0 20.6 27.3 20.6  7              10th req sc rec
31.8mph R LOCAL  C  73. 101.  8.7  8.7  20    LAP rec
```

DAVIDSON COUNTY MOBILE5A INPUT FILE

```
1       PROMPT - vertical flag input, no prompting
MOBILE5 RUN FOR NASHVILLE-DAVIDSON COUNTY : DAILY RUN (2010)
1       TAMFLG - default tampering rates
1       SPDFLG - input one speed per scenario for all vehicle types
2       VMFLAG - input one vmt mix for each scenario
1       MYMRFG - default registration and mileage accrual rates
1       NEWFLG - default exhaust emission rates
2       IMFLAG - I/M  program
1       ALHFLG - no additional correction factor inputs
2       ATPFLG - anti-tampering program
5       RLFLAG - no refueling losses
1       LOCFLG - read in local area parameters as 2nd req sc rec
1       TEMFLG - calculate exhaust temperatures
3       OUTFMT - 112 column descriptive output format
4       PRTFLG - print exhaust HC, CO and NOx emission factor results
2       IDLFLG - do print idle emissions results
3       NMHFLG - print VOC
3       HCFLAG - print HC components and detailed evaporative breakdown
85 30 75 20 00 00 098 1 1 2221 1 11     I/M PROGRAM
94 75 20 2221 11 098. 12211112          anti-tampering
1 10 51.8 83.0 20.6 27.3 20.6  7                1st req sc rec
51.8 MPH U INT   C  76.100.  9.5  7.8  92     LAP rec
.671.224.019.003.010.004.067.002
1 10 50.1 83.0 20.6 27.3 20.6  7                2nd req sc rec
50.1 MPH U EXP   C  76.100.  9.5  7.8  92     LAP rec
.668.239.021.002.010.004.054.002
1 10 39.5 83.0 20.6 27.3 20.6  7                3rd req sc rec
39.5 MPH U MAJ   C  76.100.  9.5  7.8  92     LAP rec
.735.212.018.001.011.004.017.002
1 10 34.7 83.0 20.6 27.3 20.6  7                4th req sc rec
34.7 MPH U COL   C  76.100.  9.5  7.8  92     LAP rec
.730.195.017.002.011.003.040.002
1 10 20.0 83.0 20.6 27.3 20.6  7                5th req sc rec
20.0 MPH U LOC   C  76.100.  9.5  7.8  92     LAP rec
.856.044.043.002.013.034.002.006
```

```
RUTHERFORD COUNTY MOBILE5A INPUT FILE

1       PROMPT
RUTHERFORD COUNTY MOBILE5A INPUT FILE (2010)
1       TAMFLG
1       SPDFLG
2       VMFLAG
1       MYMRFG
1       NEWFLG
2       IMFLAG
1       ALHFLG
2       ATPFLG
2       RLFLAG
1       LOCFLG - read in local area parameters as 2nd req sc rec
2       TEMFLG - calculate exhaust temperatures
3       OUTFMT
4       PRTFLG
1       IDLFLG
3       NMHFLG
3       HCFLAG - print HC components
95 30 75 20 00 00 098 1 1 2221 1 11
95 75 20 2221 11 098. 12211112
94 2 83. 83.
1 10 66.0 79.0 20.6 27.3 20.6 7
RUTHFR RUR INTST  73.0 101.  7.8  7.8 20
.552.119.028.064.008.002.215.012
1 10 63.0 79.0 20.6 27.3 20.6 7
RUTHFR URB INTST  73.0 101.  7.8  7.8 20
.564.121.029.063.008.002.212.001
1 10 46.2 79.0 20.6 27.3 20.6 7
RUTHFR RUR MJ AR  73.0 101.  7.8  7.8 20
.699.150.036.023.008.002.078.004
1 10 33.3 79.0 20.6 27.3 20.6 7
RUTHFR URB MJ AR  73.0 101.  7.8  7.8 20
.741.160.038.011.008.002.038.002
1 10 47.9 79.0 20.6 27.3 20.6 7
RUTHFR RUR MN AR  73.0 101.  7.8  7.8 20
.734.158.037.013.008.002.044.004
1 10 34.1 79.0 20.6 27.3 20.6 7
RUTHFR URB MN AR  73.0 101.  7.8  7.8 20
.728.157.037.015.008.002.051.002
1 10 41.5 79.0 20.6 27.3 20.6 7
RUTHFR RUR COLL   73.0 101.  9.5  7.8 90
```

RUTHERFORD COUNTY MOBILE5A INPUT FILE (CONTINUED)

.725.156.036.016.008.002.054.003
1 10 28.0 79.0 20.6 27.3 20.6 7
RUTHFR URB COLL 73.0 101. 7.8 7.8 20
.749.161.038.009.008.002.031.002
1 10 26.0 79.0 20.6 27.3 20.6 7
RUTHFR RUR LOC 73.0 101. 7.8 7.8 20
.755.162.038.008.008.002.025.002
1 10 15.6 79.0 20.6 27.3 20.6 7
RUTHFR URB LOC 73.0 101. 7.8 7.8 20
.769.166.039.003.008.002.011.002

SUMNER COUNTY MOBILE5A INPUT FILE

```
1       PROMPT
SUMNER COUNTY MOBILE5A INPUT FILE (2010)
1       TAMFLG
1       SPDFLG
2       VMFLAG
1       MYMRFG
1       NEWFLG
2       IMFLAG
1       ALHFLG
2       ATPFLG
2       RLFLAG
1       LOCFLG
2       TEMFLG
3       OUTFMT
4       PRTFLG
1       IDLFLG
3       NMHFLG
3       HCFLAG
95 30 75 20 00 00 098 1 1 2221 1 11
95 75 20 2221 11 098. 12211112
94 2 83. 83.
1 10 66.0 83.0 20.6 27.3 20.6 7
SUMNER RUR INTST   73.0 101.  7.8  7.8 20
.560.120.028.062.008.002.208.012
1 10 60.9 83.0 20.6 27.3 20.6 7
SUMNER URB INTST   73.0 101.  7.8  7.8 20
.568.122.029.062.008.002.208.001
1 10 53.7 83.0 20.6 27.3 20.6 7
SUMNER RUR MJ AR   73.0 101.  7.8  7.8 20
.678.146.034.029.008.002.099.004
1 10 35.5 83.0 20.6 27.3 20.6 7
SUMNER URB MJ AR   73.0 101.  7.8  7.8 20
.732.158.037.014.008.002.047.002
1 10 51.1 83.0 20.6 27.3 20.6 7
SUMNER RUR MNAR    73.0 101.  7.8  7.8 20
.705.152.036.021.008.002.072.004
1 10 27.7 83.0 20.6 27.3 20.6 7
SUMNER URB MN AR   73.0 101.  7.8  7.8 20
.722.155.037.017.008.002.057.002
1 10 41.5 83.0 20.6 27.3 20.6 7
```

SUMNER COUNTY MOBILE5A INPUT FILE (CONTINUED)

```
SUMNER RUR COLL   73.0 101.  7.8  7.8 20
.713.154.036.019.008.002.065.003
1 10 29.1 83.0 20.6 27.3 20.6 7
SUMNER URB COLL   73.0 101.  7.8  7.8 20
.718.155.036.018.008.002.061.002
1 10 26.0 83.0 20.6 27.3 20.6 7
SUMNER RUR LOC    73.0 101.  7.8  7.8 20
.755.162.038.008.008.002.025.002
1 10 15.6 83.0 20.6 27.3 20.6 7
SUMNER URB LOC    73.0 101.  7.8  7.8 20
.769.166.039.003.008.002.011.002
```

WILLIAMSON COUNTY MOBILE5A INPUT FILE

```
1       PROMPT
WILLIAMSON COUNTY MOBILE5A INPUT FILE (2010)
1       TAMFLG
1       SPDFLG
2       VMFLAG
1       MYMRFG
1       NEWFLG
2       IMFLAG
1       ALHFLG
2       ATPFLG
2       RLFLAG
1       LOCFLG
2       TEMFLG
3       OUTFMT
4       PRTFLG
1       IDLFLG
3       NMHFLG
3       HCFLAG
95 30 75 20 00 00 098 1 1 2221 1 11
95 75 20 2221 11 098. 12211112
94 2 83. 83.
1 10 66.0 79.0 20.6 27.3 20.6 7
WILLMN RUR INTST  73. 101.  7.8  7.8 20
.555.119.028.063.008.002.213.012
1 10 60.9 79.0 20.6 27.3 20.6 7
WILLMN URB INTST  73. 101.  7.8  7.8 20
.653.140.033.037.008.002.126.001
1 10 17.2 79.0 20.6 27.3 20.6 7
WILLMN URB MJ AR  73. 101.  7.8  7.8 20
.734.158.037.014.008.002.045.002
1 10 49.0 79.0 20.6 27.3 20.6 7
WILLMN RUR MN AR  73. 101.  7.8  7.8 20
.728.157.037.015.008.002.049.004
1 10 27.7 79.0 20.6 27.3 20.6 7
WILLMN URB MN AR  73. 101.  7.8  7.8 20
.741.160.038.011.008.002.038.002
1 10 54.0 79.0 20.6 27.3 20.6 7
WILLMN RUR COLL   73. 101.  7.8  7.8 20
.720.155.036.017.008.002.059.003
1 10 26.0 79.0 20.6 27.3 20.6 7
```

WILLIAMSON COUNTY MOBILE5A INPUT FILE (CONTINUED)

```
WILLMN URB COLL   73. 101.  7.8  7.8 20
.741.159.038.012.008.002.038.002
1 10 26.0 79.0 20.6 27.3 20.6 7
WILLMN RUR LOC    73. 101.  7.8  7.8 20
.754.163.038.008.008.002.025.002
1 10 15.6 79.0 20.6 27.3 20.6 7
WILLMN URB LOC    73. 101.  7.8  7.8 20
.769.166.039.003.008.002.011.002
```

WILSON COUNTY MOBILE5A INPUT FILE

```
1       PROMPT
WILSON COUNTY MOBILE5A INPUT FILE  (2010)
1       TAMFLG
1       SPDFLG
2       VMFLAG
1       MYMRFG
1       NEWFLG
2       IMFLAG
1       ALHFLG
2       ATPFLG
2       RLFLAG
1       LOCFLG
2       TEMFLG
3       OUTFMT
4       PRTFLG
1       IDLFLG
3       NMHFLG
3       HCFLAG
95 30 75 20 00 00 098 1 1 2221 1 11
95 75 20 2221 11 098. 12211112
94 2 83. 83.
1 10 66.0 79.0 20.6 27.3 20.6 7
WILSON RUR INTST  73. 101.  7.8  7.8 20
.588.127.030.054.008.002.179.012
1 10 46.2 79.0 20.6 27.3 20.6 7
WILSON RUR MJ AR  73. 101.  7.8  7.8 20
.698.150.035.024.008.002.079.004
1 10 26.9 79.0 20.6 27.3 20.6 7
WILSON URB MJ AR  73. 101.  7.8  7.8 20
.729.157.037.015.008.002.050.002
1 10 52.2 79.0 20.6 27.3 20.6 7
WILSON RUR MN AR  73. 101.  7.8  7.8 20
.721.155.037.017.008.002.056.004
1 10 26.6 79.0 20.6 27.3 20.6 7
WILSON URB MN AR  73. 101.  7.8  7.8 20
.737.159.037.013.008.002.042.002
1 10 41.5 79.0 20.6 27.3 20.6 7
WILSON RUR COLL   73. 101.  7.8  7.8 20
.737.159.037.012.008.002.042.003
1 10 26.0 79.0 20.6 27.3 20.6 7
```

WILSON COUNTY MOBILE5A INPUT FILE (CONTINUED)

```
WILSON URB COLL   73. 101.  7.8  7.8 20
.744.160.038.011.008.002.035.002
1 10 26.0 79.0 20.6 27.3 20.6 7
WILSON RUR LOC    73. 101.  7.8  7.8 20
.754.162.039.008.008.002.025.002
1 10 15.6 79.0 20.6 27.3 20.6 7
WILSON URB LOC    73. 101.  7.8  7.8 20
.769.166.039.003.008.002.011.002
```

Tennessee Attainment Area MOBILE5A Default Fleet Mix Output File

1 MOBILE5 RUN FOR AFFECTED COUNTIES : 2010 Default Fleet Mix
MOBILE5a (26-Mar-93)
0VOC HC emission factors include all evaporative HC emission factors, except for refueling emissions.
0

0Emission factors are as of July 1st of the indicated calendar year.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
060 MPH U/INT Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	60.9	60.9	60.9	60.9	60.9	60.9	60.9	60.9		
VMT Mix:	0.589	0.201	0.088	0.032	0.002	0.003	0.080	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	0.97	1.22	1.65	1.35	1.62	0.23	0.31	0.94	4.78	1.113
Exhaust HC:	0.71	0.91	1.31	1.03	0.53	0.23	0.31	0.94	1.51	0.815
Evaporat HC:	0.20	0.25	0.26	0.25	0.99			2.88	0.240	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.04	0.04	0.05	0.04	0.06				0.035	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.024	
Exhaust CO:	8.96	11.62	16.44	13.09	14.50	0.77	0.86	6.08	20.58	10.119
Exhaust NOX:	1.87	2.24	3.15	2.52	5.64	1.57	1.77	10.09	1.63	2.831

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.59	0.65	0.77	0.69	1.99		6.80
WtDiurnal	3.17	4.27	4.92	4.45	21.10		19.71
Multiple	7.81	9.33	9.96	9.51	33.67		
Crankcase	0.01	0.01	0.01	0.01	0.01		0.00
Refuel	3.61	3.61	3.61	3.61	3.61		
Resting	0.03	0.03	0.03	0.03	0.04		0.16

0
-M 96 Warning:
+ 66.0 speed reduced to 65 mph maximum
0Emission factors are as of July 1st of the indicated calendar year.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
065 MPH R/INT Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0		
VMT Mix:	0.589	0.201	0.088	0.032	0.002	0.003	0.080	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	1.05	1.31	1.77	1.45	1.63	0.23	0.31	0.94	5.09	1.192
Exhaust HC:	0.79	1.00	1.44	1.13	0.55	0.23	0.31	0.94	1.82	0.898
Evaporat HC:	0.20	0.25	0.26	0.25	0.99			2.88	0.240	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	

Tennessee Attainment Area MOBILE5A Default Fleet Mix Output File (Continued)

```
Runing L HC:   0.03   0.03   0.05   0.04   0.06                    0.031
Rsting L HC:   0.02   0.03   0.02   0.03   0.04                0.39  0.024
Exhaust CO:   11.15  14.31  20.29  16.13  17.12   0.86   0.96  6.78  28.98  12.472
Exhaust NOX:   2.03   2.47   3.47   2.78   5.79   1.86   2.10 11.96   1.79   3.157
0Evaporative Emissions by Component          Weathered RVP: 7.7      Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr)   Running Loss Temp: 79.0 (F)
                                                                     Resting Loss Temp: 79.0 (F)
Hot Soak      0.59   0.65   0.77   0.69   1.99                    6.80
WtDiurnal     3.17   4.27   4.92   4.45  21.10                   19.71
Multiple      7.81   9.33   9.96   9.51  33.67
Crankcase     0.01   0.01   0.01   0.01   0.01                    0.00
Refuel        3.61   3.61   3.61   3.61   3.61
Resting       0.03   0.03   0.03   0.03   0.04                    0.16

-------------------------------------------------------------------------------
0Emission factors are as of July 1st of the indicated calendar year.
0Cal. Year: 2010     I/M Program: No     Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
          Anti-tam. Program: No     Operating Mode: 20.6 / 27.3 / 20.6   Altitude:  500. Ft.
          Reformulated Gas: No
026 MPH U MA/ART                    Minimum Temp:  73. (F)     Maximum Temp: 101. (F)
          Period 1 RVP:  9.0     Period 2 RVP:  7.8     Period 2 Start Yr: 2000
0 Veh. Type:   LDGV   LDGT1   LDGT2   LDGT   HDGV   LDDV   LDDT   HDDV   MC   All
Veh
+
Veh. Speeds:  27.9   27.9   27.9   27.9   27.9   27.9   27.9   27.9
  VMT Mix:   0.589  0.201  0.088  0.032  0.002  0.003  0.080  0.005
0Composite Emission Factors (Gm/Mile)
VOC     HC:   1.30   1.57   2.13   1.74   2.36   0.38   0.52   1.58   4.76   1.496
Exhaust HC:   0.96   1.18   1.70   1.34   1.14   0.38   0.52   1.58   1.49   1.125
Evaporat HC:  0.20   0.25   0.26   0.25   0.99                 2.88   0.240
Refuel L HC:  0.16   0.21   0.22   0.21   0.34                        0.167
Runing L HC:  0.11   0.11   0.15   0.12   0.19                        0.107
Rsting L HC:  0.02   0.03   0.02   0.03   0.04                 0.39   0.024
Exhaust CO:  12.52  14.87  20.68  16.64  14.66   0.98   1.09   7.71  15.05  13.350
Exhaust NOX:  1.31   1.50   2.10   1.68   4.44   0.95   1.08   6.14   0.96   1.901
0Evaporative Emissions by Component          Weathered RVP: 7.7      Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr)   Running Loss Temp: 79.0 (F)
                                                                     Resting Loss Temp: 79.0 (F)
Hot Soak      0.59   0.65   0.77   0.69   1.99                    6.80
WtDiurnal     3.17   4.27   4.92   4.45  21.10                   19.71
Multiple      7.81   9.33   9.96   9.51  33.67
Crankcase     0.01   0.01   0.01   0.01   0.01                    0.00
Refuel        3.61   3.61   3.61   3.61   3.61
Resting       0.03   0.03   0.03   0.03   0.04                    0.16

-------------------------------------------------------------------------------
0Emission factors are as of July 1st of the indicated calendar year.
0Cal. Year: 2010     I/M Program: No     Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
          Anti-tam. Program: No     Operating Mode: 20.6 / 27.3 / 20.6   Altitude:  500. Ft.
          Reformulated Gas: No
043 MPH R MA/ART                    Minimum Temp:  73. (F)     Maximum Temp: 101. (F)
          Period 1 RVP:  9.0     Period 2 RVP:  7.8     Period 2 Start Yr: 2000
0 Veh. Type:   LDGV   LDGT1   LDGT2   LDGT   HDGV   LDDV   LDDT   HDDV   MC   All
Veh
```

Tennessee Attainment Area MOBILE5A Default Fleet Mix Output File (Continued)

```
+
Veh. Speeds:   46.2   46.2   46.2        46.2   46.2   46.2   46.2   46.2
  VMT Mix:    0.589  0.201  0.088       0.032  0.002  0.003  0.080  0.005
0Composite Emission Factors (Gm/Mile)
VOC     HC:    0.89   1.14   1.52   1.25   1.73   0.25   0.35   1.05   4.34   1.049
Exhaust HC:    0.60   0.80   1.15   0.91   0.60   0.25   0.35   1.05   1.07   0.727
Evaporat HC:   0.20   0.25   0.26   0.25   0.99                 2.88   0.240
Refuel L HC:   0.16   0.21   0.22   0.21   0.34                        0.167
Runing L HC:   0.06   0.06   0.09   0.07   0.11                        0.059
Rsting L HC:   0.02   0.03   0.02   0.03   0.04                 0.39   0.024
Exhaust CO:    6.17   8.14  11.42   9.14  10.84   0.67   0.75   5.29   8.74   7.092
Exhaust NOX:   1.36   1.51   2.12   1.70   5.11   1.04   1.18   6.68   1.14   1.999
0Evaporative Emissions by Component          Weathered RVP:  7.7      Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr)   Running Loss Temp: 79.0 (F)
                                                                  Resting Loss Temp: 79.0 (F)
Hot Soak       0.59   0.65   0.77   0.69   1.99                        6.80
WtDiurnal      3.17   4.27   4.92   4.45  21.10                       19.71
Multiple       7.81   9.33   9.96   9.51  33.67
Crankcase      0.01   0.01   0.01   0.01   0.01                        0.00
Refuel         3.61   3.61   3.61   3.61   3.61
Resting        0.03   0.03   0.03   0.03   0.04                        0.16
```

```
0Emission factors are as of July 1st of the indicated calendar year.
0Cal. Year: 2010      I/M Program: No      Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
          Anti-tam. Program: No     Operating Mode: 20.6 / 27.3 / 20.6   Altitude:  500. Ft.
           Reformulated Gas: No
026 MPH U MI/ART                    Minimum Temp:  73. (F)      Maximum Temp: 101. (F)
              Period 1 RVP:  9.0    Period 2 RVP:  7.8     Period 2 Start Yr: 2000
0 Veh. Type:   LDGV   LDGT1   LDGT2    LDGT    HDGV    LDDV    LDDT    HDDV    MC    All
Veh
+
Veh. Speeds:   27.7   27.7   27.7        27.7   27.7   27.7   27.7   27.7
  VMT Mix:    0.589  0.201  0.088       0.032  0.002  0.003  0.080  0.005
0Composite Emission Factors (Gm/Mile)
VOC     HC:    1.30   1.58   2.14   1.75   2.38   0.38   0.52   1.59   4.77   1.504
Exhaust HC:    0.97   1.19   1.71   1.35   1.16   0.38   0.52   1.59   1.50   1.132
Evaporat HC:   0.20   0.25   0.26   0.25   0.99                 2.88   0.240
Refuel L HC:   0.16   0.21   0.22   0.21   0.34                        0.167
Runing L HC:   0.11   0.11   0.15   0.12   0.19                        0.108
Rsting L HC:   0.02   0.03   0.02   0.03   0.04                 0.39   0.024
Exhaust CO:   12.63  14.99  20.85  16.77  14.76   0.99   1.10   7.77  15.17  13.466
Exhaust NOX:   1.31   1.50   2.10   1.68   4.43   0.95   1.08   6.15   0.96   1.901
0Evaporative Emissions by Component          Weathered RVP:  7.7      Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr)   Running Loss Temp: 79.0 (F)
                                                                  Resting Loss Temp: 79.0 (F)
Hot Soak       0.59   0.65   0.77   0.69   1.99                        6.80
WtDiurnal      3.17   4.27   4.92   4.45  21.10                       19.71
Multiple       7.81   9.33   9.96   9.51  33.67
Crankcase      0.01   0.01   0.01   0.01   0.01                        0.00
Refuel         3.61   3.61   3.61   3.61   3.61
Resting        0.03   0.03   0.03   0.03   0.04                        0.16
```

Tennessee Attainment Area MOBILE5A Default Fleet Mix Output File (Continued)

0Emission factors are as of July 1st of the indicated calendar year.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
047 MPH R MI/ART Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1		
VMT Mix:	0.589	0.201	0.088	0.032	0.002	0.003	0.080	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	0.86	1.11	1.48	1.22	1.68	0.24	0.33	1.00	4.33	1.017
Exhaust HC:	0.58	0.78	1.12	0.88	0.56	0.24	0.33	1.00	1.06	0.702
Evaporat HC:	0.20	0.25	0.26	0.25	0.99			2.88	0.240	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.05	0.06	0.08	0.06	0.09				0.051	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.024	
Exhaust CO:	5.80	7.76	10.89	8.71	11.18	0.67	0.75	5.29	8.50	6.764
Exhaust NOX:	1.44	1.63	2.29	1.83	5.25	1.12	1.27	7.24	1.23	2.138

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.59	0.65	0.77	0.69	1.99	6.80	
WtDiurnal	3.17	4.27	4.92	4.45	21.10	19.71	
Multiple	7.81	9.33	9.96	9.51	33.67		
Crankcase	0.01	0.01	0.01	0.01	0.01	0.00	
Refuel	3.61	3.61	3.61	3.61	3.61		
Resting	0.03	0.03	0.03	0.03	0.04	0.16	

0Emission factors are as of July 1st of the indicated calendar year.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
025 MPH U COLL. Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0		
VMT Mix:	0.589	0.201	0.088	0.032	0.002	0.003	0.080	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	1.37	1.65	2.25	1.83	2.50	0.40	0.55	1.68	4.84	1.578
Exhaust HC:	1.03	1.25	1.80	1.42	1.26	0.40	0.55	1.68	1.57	1.199
Evaporat HC:	0.20	0.25	0.26	0.25	0.99			2.88	0.240	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.12	0.12	0.16	0.13	0.20				0.115	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.024	
Exhaust CO:	13.69	16.11	22.39	18.02	15.77	1.05	1.17	8.31	16.27	14.530
Exhaust NOX:	1.30	1.50	2.10	1.68	4.37	0.97	1.10	6.26	0.93	1.902

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Tennessee Attainment Area MOBILE5A Default Fleet Mix Output File (Continued)

Hot Soak	0.59	0.65	0.77	0.69	1.99	6.80	
WtDiurnal	3.17	4.27	4.92	4.45	21.10	19.71	
Multiple	7.81	9.33	9.96	9.51	33.67		
Crankcase	0.01	0.01	0.01	0.01	0.01	0.00	
Refuel	3.61	3.61	3.61	3.61	3.61		
Resting	0.03	0.03	0.03	0.03	0.04	0.16	

0Emission factors are as of July 1st of the indicated calendar year.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
040 MPH R COLL. Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5		
VMT Mix:	0.589	0.201	0.088	0.032	0.002	0.003	0.080	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	0.96	1.21	1.63	1.34	1.82	0.27	0.37	1.13	4.39	1.126
Exhaust HC:	0.66	0.86	1.25	0.98	0.67	0.27	0.37	1.13	1.12	0.794
Evaporat HC:	0.20	0.25	0.26	0.25	0.99			2.88	0.240	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.07	0.07	0.10	0.08	0.12				0.068	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.024	
Exhaust CO:	7.26	9.30	13.02	10.44	10.92	0.70	0.78	5.50	9.57	8.136
Exhaust NOX:	1.35	1.51	2.12	1.70	4.94	0.97	1.10	6.25	1.11	1.953

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.59	0.65	0.77	0.69	1.99	6.80	
WtDiurnal	3.17	4.27	4.92	4.45	21.10	19.71	
Multiple	7.81	9.33	9.96	9.51	33.67		
Crankcase	0.01	0.01	0.01	0.01	0.01	0.00	
Refuel	3.61	3.61	3.61	3.61	3.61		
Resting	0.03	0.03	0.03	0.03	0.04	0.16	

0Emission factors are as of July 1st of the indicated calendar year.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
015 MPH U LOCAL Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6		
VMT Mix:	0.589	0.201	0.088	0.032	0.002	0.003	0.080	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	1.96	2.32	3.20	2.59	3.80	0.59	0.81	2.46	5.52	2.252
Exhaust HC:	1.52	1.82	2.62	2.07	2.42	0.59	0.81	2.46	2.25	1.784
Evaporat HC:	0.20	0.25	0.26	0.25	0.99			2.88	0.240	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	

Tennessee Attainment Area MOBILE5A Default Fleet Mix Output File (Continued)

Runing L HC: 0.21 0.22 0.29 0.24 0.35 0.204
Rsting L HC: 0.02 0.03 0.02 0.03 0.04 0.39 0.024
Exhaust CO: 21.80 24.66 34.24 27.58 27.16 1.78 1.97 13.99 27.21 22.947
Exhaust NOX: 1.28 1.52 2.13 1.71 3.99 1.18 1.33 7.58 0.77 1.991
0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak 0.59 0.65 0.77 0.69 1.99 6.80
WtDiurnal 3.17 4.27 4.92 4.45 21.10 19.71
Multiple 7.81 9.33 9.96 9.51 33.67
Crankcase 0.01 0.01 0.01 0.01 0.01 0.00
Refuel 3.61 3.61 3.61 3.61 3.61
Resting 0.03 0.03 0.03 0.03 0.04 0.16

0Emission factors are as of July 1st of the indicated calendar year.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
025 MPH R LOCAL Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0		
VMT Mix:	0.589	0.201	0.088	0.032	0.002	0.003	0.080	0.005		

0Composite Emission Factors (Gm/Mile)

VOC HC: 1.37 1.65 2.25 1.83 2.50 0.40 0.55 1.68 4.84 1.578
Exhaust HC: 1.03 1.25 1.80 1.42 1.26 0.40 0.55 1.68 1.57 1.199
Evaporat HC: 0.20 0.25 0.26 0.25 0.99 2.88 0.240
Refuel L HC: 0.16 0.21 0.22 0.21 0.34 0.167
Runing L HC: 0.12 0.12 0.16 0.13 0.20 0.115
Rsting L HC: 0.02 0.03 0.02 0.03 0.04 0.39 0.024
Exhaust CO: 13.69 16.11 22.39 18.02 15.77 1.05 1.17 8.31 16.27 14.530
Exhaust NOX: 1.30 1.50 2.10 1.68 4.37 0.97 1.10 6.26 0.93 1.902
0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak 0.59 0.65 0.77 0.69 1.99 6.80
WtDiurnal 3.17 4.27 4.92 4.45 21.10 19.71
Multiple 7.81 9.33 9.96 9.51 33.67
Crankcase 0.01 0.01 0.01 0.01 0.01 0.00
Refuel 3.61 3.61 3.61 3.61 3.61
Resting 0.03 0.03 0.03 0.03 0.04 0.16

Tennessee Attainment Area MOBILE5A EV Adjusted Fleet Mix Output File

1 MOBILE5 RUN FOR AFFECTED COUNTIES : 2010 EV Adjusted Fleet Mix
MOBILE5a (26-Mar-93)
0
-M 49 Warning:
+ 0.998 MYR sum not = 1. (will normalize)
-M 49 Warning:
+ 1.00 MYR sum not = 1. (will normalize)
-M 49 Warning:
+ 1.00 MYR sum not = 1. (will normalize)
-M 49 Warning:
+ 0.998 MYR sum not = 1. (will normalize)
-M 49 Warning:
+ 1.00 MYR sum not = 1. (will normalize)
0VOC HC emission factors include all evaporative HC emission factors, except for refueling emissions.
0
0Emission factors are as of July 1st of the indicated calendar year.
0User supplied veh registration distributions.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
060 MPH U/INT Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	60.9	60.9	60.9	60.9	60.9	60.9	60.9	60.9		
VMT Mix:	0.586	0.197	0.091	0.033	0.002	0.003	0.083	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	1.10	1.41	1.65	1.49	1.62	0.23	0.32	0.94	4.78	1.230
Exhaust HC:	0.81	1.05	1.31	1.13	0.53	0.23	0.32	0.94	1.51	0.904
Evaporat HC:	0.23	0.29	0.26	0.28	0.99			2.88	0.263	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.04	0.04	0.05	0.05	0.06				0.038	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.026	
Exhaust CO:	10.11	13.35	16.44	14.33	14.50	0.79	0.87	6.08	20.58	11.151
Exhaust NOX:	2.09	2.54	3.15	2.74	5.64	1.60	1.81	10.09	1.63	3.054

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.64	0.72	0.77	0.74	1.99	6.80	
WtDiurnal	3.42	4.67	4.92	4.74	21.10	19.71	
Multiple	8.26	9.98	9.96	9.98	33.67		
Crankcase	0.01	0.01	0.01	0.01	0.01	0.00	
Refuel	3.61	3.61	3.61	3.61	3.61		
Resting	0.03	0.03	0.03	0.03	0.04	0.16	

-M 96 Warning:
+ 66.0 speed reduced to 65 mph maximum
0Emission factors are as of July 1st of the indicated calendar year.
0User supplied veh registration distributions.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
065 MPH R/INT Minimum Temp: 73. (F) Maximum Temp: 101. (F)

Tennessee Attainment Area MOBILE5A EV Adjusted Fleet Mix Output File (Cont.)

Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0		
VMT Mix:	0.586	0.197	0.091	0.033	0.002	0.003	0.083	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	1.19	1.51	1.77	1.60	1.63	0.24	0.32	0.94	5.09	1.319
Exhaust HC:	0.90	1.16	1.44	1.25	0.55	0.24	0.32	0.94	1.82	0.996
Evaporat HC:	0.23	0.29	0.26	0.28	0.99			2.88	0.263	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.03	0.04	0.05	0.04	0.06				0.034	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.026	
Exhaust CO:	12.58	16.44	20.29	17.66	17.12	0.88	0.97	6.78	28.98	13.752
Exhaust NOX:	2.27	2.81	3.47	3.02	5.79	1.89	2.14	11.96	1.79	3.403

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.64	0.72	0.77	0.74	1.99			6.80		
WtDiurnal	3.42	4.67	4.92	4.74	21.10			19.71		
Multiple	8.26	9.98	9.96	9.98	33.67					
Crankcase	0.01	0.01	0.01	0.01	0.01			0.00		
Refuel	3.61	3.61	3.61	3.61	3.61					
Resting	0.03	0.03	0.03	0.03	0.04			0.16		

0Emission factors are as of July 1st of the indicated calendar year.
0User supplied veh registration distributions.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
026 MPH U MA/ART Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9		
VMT Mix:	0.586	0.197	0.091	0.033	0.002	0.003	0.083	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	1.47	1.81	2.13	1.91	2.36	0.40	0.54	1.58	4.76	1.650
Exhaust HC:	1.09	1.37	1.70	1.47	1.14	0.40	0.54	1.58	1.49	1.245
Evaporat HC:	0.23	0.29	0.26	0.28	0.99			2.88	0.263	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.12	0.13	0.15	0.13	0.19				0.117	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.026	
Exhaust CO:	14.10	17.01	20.68	18.18	14.66	1.00	1.11	7.71	15.05	14.713
Exhaust NOX:	1.47	1.70	2.10	1.83	4.44	0.97	1.10	6.14	0.96	2.053

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.64	0.72	0.77	0.74	1.99			6.80		
WtDiurnal	3.42	4.67	4.92	4.74	21.10			19.71		
Multiple	8.26	9.98	9.96	9.98	33.67					
Crankcase	0.01	0.01	0.01	0.01	0.01			0.00		

Tennessee Attainment Area MOBILE5A EV Adjusted Fleet Mix Output File (Cont.)

Refuel	3.61	3.61	3.61	3.61	3.61
Resting	0.03	0.03	0.03	0.03	0.04

0.16

0Emission factors are as of July 1st of the indicated calendar year.
0User supplied veh registration distributions.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
043 MPH R MA/ART Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	46.2	46.2	46.2	46.2	46.2	46.2	46.2	46.2		
VMT Mix:	0.586	0.197	0.091	0.033	0.002	0.003	0.083	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	1.01	1.32	1.52	1.38	1.73	0.26	0.36	1.05	4.34	1.157
Exhaust HC:	0.69	0.93	1.15	1.00	0.60	0.26	0.36	1.05	1.07	0.804
Evaporat HC:	0.23	0.29	0.26	0.28	0.99			2.88	0.263	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.07	0.07	0.09	0.08	0.11				0.064	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.026	
Exhaust CO:	6.96	9.34	11.42	10.00	10.84	0.69	0.76	5.29	8.74	7.806
Exhaust NOX:	1.52	1.72	2.12	1.84	5.11	1.06	1.20	6.68	1.14	2.157

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.64	0.72	0.77	0.74	1.99	6.80	
WtDiurnal	3.42	4.67	4.92	4.74	21.10	19.71	
Multiple	8.26	9.98	9.96	9.98	33.67		
Crankcase	0.01	0.01	0.01	0.01	0.01	0.00	
Refuel	3.61	3.61	3.61	3.61	3.61		
Resting	0.03	0.03	0.03	0.03	0.04	0.16	

0Emission factors are as of July 1st of the indicated calendar year.
0User supplied veh registration distributions.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
026 MPH U MI/ART Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
+										
Veh. Speeds:	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7		
VMT Mix:	0.586	0.197	0.091	0.033	0.002	0.003	0.083	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	1.48	1.82	2.14	1.92	2.38	0.40	0.55	1.59	4.77	1.659
Exhaust HC:	1.10	1.38	1.71	1.48	1.16	0.40	0.55	1.59	1.50	1.253
Evaporat HC:	0.23	0.29	0.26	0.28	0.99			2.88	0.263	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.12	0.13	0.15	0.13	0.19				0.117	

Tennessee Attainment Area MOBILE5A EV Adjusted Fleet Mix Output File (Cont.)

```
Rsting L HC:    0.02    0.03    0.02    0.03    0.04                    0.39    0.026
Exhaust CO:    14.23   17.15   20.85   18.33   14.76    1.01    1.11    7.77   15.17   14.841
Exhaust NOX:    1.47    1.70    2.10    1.83    4.43    0.97    1.10    6.15    0.96    2.053
0Evaporative Emissions by Component          Weathered RVP: 7.7        Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr)   Running Loss Temp: 79.0 (F)
                                                    Resting Loss Temp: 79.0 (F)
Hot Soak        0.64    0.72    0.77    0.74    1.99                    6.80
WtDiurnal       3.42    4.67    4.92    4.74   21.10                   19.71
Multiple        8.26    9.98    9.96    9.98   33.67
Crankcase       0.01    0.01    0.01    0.01    0.01                    0.00
Refuel          3.61    3.61    3.61    3.61    3.61
Resting         0.03    0.03    0.03    0.03    0.04                    0.16
```

```
0Emission factors are as of July 1st of the indicated calendar year.
0User supplied veh registration distributions.
0Cal. Year: 2010      I/M Program: No      Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
          Anti-tam. Program: No      Operating Mode: 20.6 / 27.3 / 20.6   Altitude:  500. Ft.
          Reformulated Gas: No
047 MPH R MI/ART                    Minimum Temp:  73. (F)      Maximum Temp: 101. (F)
          Period 1 RVP:  9.0      Period 2 RVP:  7.8      Period 2 Start Yr: 2000
0 Veh. Type:   LDGV   LDGT1   LDGT2    LDGT    HDGV    LDDV    LDDT    HDDV     MC    All
Veh
+
Veh. Speeds:   50.1    50.1    50.1            50.1    50.1    50.1    50.1    50.1
  VMT Mix:    0.586   0.197   0.091           0.033   0.002   0.003   0.083   0.005
0Composite Emission Factors (Gm/Mile)
VOC     HC:    0.98    1.28    1.48    1.34    1.68    0.25    0.34    1.00    4.33   1.122
Exhaust HC:    0.66    0.90    1.12    0.97    0.56    0.25    0.34    1.00    1.06   0.777
Evaporat HC:   0.23    0.29    0.26    0.28    0.99                    2.88   0.263
Refuel L HC:   0.16    0.21    0.22    0.21    0.34                           0.167
Runing L HC:   0.06    0.06    0.08    0.07    0.09                           0.056
Rsting L HC:   0.02    0.03    0.02    0.03    0.04                    0.39   0.026
Exhaust CO:    6.55    8.90   10.89    9.53   11.18    0.68    0.76    5.29    8.50   7.441
Exhaust NOX:   1.62    1.85    2.29    1.99    5.25    1.14    1.29    7.24    1.23   2.307
0Evaporative Emissions by Component          Weathered RVP: 7.7        Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr)   Running Loss Temp: 79.0 (F)
                                                    Resting Loss Temp: 79.0 (F)
Hot Soak        0.64    0.72    0.77    0.74    1.99                    6.80
WtDiurnal       3.42    4.67    4.92    4.74   21.10                   19.71
Multiple        8.26    9.98    9.96    9.98   33.67
Crankcase       0.01    0.01    0.01    0.01    0.01                    0.00
Refuel          3.61    3.61    3.61    3.61    3.61
Resting         0.03    0.03    0.03    0.03    0.04                    0.16
```

```
0Emission factors are as of July 1st of the indicated calendar year.
0User supplied veh registration distributions.
0Cal. Year: 2010      I/M Program: No      Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
          Anti-tam. Program: No      Operating Mode: 20.6 / 27.3 / 20.6   Altitude:  500. Ft.
          Reformulated Gas: No
025 MPH U COLL.                     Minimum Temp:  73. (F)      Maximum Temp: 101. (F)
          Period 1 RVP:  9.0      Period 2 RVP:  7.8      Period 2 Start Yr: 2000
```

Tennessee Attainment Area MOBILE5A EV Adjusted Fleet Mix Output File (Cont.)

0 Veh. Type: LDGV LDGT1 LDGT2 LDGT HDGV LDDV LDDT HDDV MC All Veh

\+

Veh. Speeds:	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0		
VMT Mix:	0.586	0.197	0.091	0.033	0.002	0.003	0.083	0.005		

0Composite Emission Factors (Gm/Mile)

VOC HC:	1.55	1.90	2.25	2.01	2.50	0.42	0.58	1.68	4.84	1.740
Exhaust HC:	1.17	1.45	1.80	1.56	1.26	0.42	0.58	1.68	1.57	1.327
Evaporat HC:	0.23	0.29	0.26	0.28	0.99			2.88	0.263	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.13	0.14	0.16	0.14	0.20				0.125	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.026	
Exhaust CO:	15.42	18.43	22.39	19.69	15.77	1.08	1.19	8.31	16.27	16.013
Exhaust NOX:	1.46	1.70	2.10	1.83	4.37	0.99	1.12	6.26	0.93	2.053

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.64	0.72	0.77	0.74	1.99			6.80		
WtDiurnal	3.42	4.67	4.92	4.74	21.10			19.71		
Multiple	8.26	9.98	9.96	9.98	33.67					
Crankcase	0.01	0.01	0.01	0.01	0.01			0.00		
Refuel	3.61	3.61	3.61	3.61	3.61					
Resting	0.03	0.03	0.03	0.03	0.04			0.16		

0Emission factors are as of July 1st of the indicated calendar year.
0User supplied veh registration distributions.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
040 MPH R COLL. Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type: LDGV LDGT1 LDGT2 LDGT HDGV LDDV LDDT HDDV MC All Veh

\+

Veh. Speeds:	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5		
VMT Mix:	0.586	0.197	0.091	0.033	0.002	0.003	0.083	0.005		

0Composite Emission Factors (Gm/Mile)

VOC HC:	1.09	1.40	1.63	1.47	1.82	0.28	0.39	1.13	4.39	1.242
Exhaust HC:	0.76	1.00	1.25	1.08	0.67	0.28	0.39	1.13	1.12	0.879
Evaporat HC:	0.23	0.29	0.26	0.28	0.99			2.88	0.263	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.08	0.08	0.10	0.09	0.12				0.074	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.026	
Exhaust CO:	8.19	10.66	13.02	11.41	10.92	0.71	0.79	5.50	9.57	8.960
Exhaust NOX:	1.51	1.71	2.12	1.84	4.94	0.99	1.12	6.25	1.11	2.109

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.64	0.72	0.77	0.74	1.99			6.80		
WtDiurnal	3.42	4.67	4.92	4.74	21.10			19.71		
Multiple	8.26	9.98	9.96	9.98	33.67					
Crankcase	0.01	0.01	0.01	0.01	0.01			0.00		

Tennessee Attainment Area MOBILE5A EV Adjusted Fleet Mix Output File (Cont.)

Refuel	3.61	3.61	3.61	3.61	3.61						
Resting	0.03	0.03	0.03	0.03	0.04					0.16	

0Emission factors are as of July 1st of the indicated calendar year.
0User supplied veh registration distributions.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
015 MPH U LOCAL Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
Veh. Speeds:	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6		
VMT Mix:	0.586	0.197	0.091	0.033	0.002	0.003	0.083	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	2.22	2.68	3.20	2.85	3.80	0.62	0.85	2.46	5.52	2.483
Exhaust HC:	1.74	2.11	2.62	2.28	2.42	0.62	0.85	2.46	2.25	1.973
Evaporat HC:	0.23	0.29	0.26	0.28	0.99			2.88	0.263	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.23	0.25	0.29	0.26	0.35				0.221	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.026	
Exhaust CO:	24.55	28.22	34.24	30.13	27.16	1.81	2.01	13.99	27.21	25.280
Exhaust NOX:	1.43	1.73	2.13	1.86	3.99	1.20	1.36	7.58	0.77	2.145

0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.64	0.72	0.77	0.74	1.99			6.80		
WtDiurnal	3.42	4.67	4.92	4.74	21.10			19.71		
Multiple	8.26	9.98	9.96	9.98	33.67					
Crankcase	0.01	0.01	0.01	0.01	0.01			0.00		
Refuel	3.61	3.61	3.61	3.61	3.61					
Resting	0.03	0.03	0.03	0.03	0.04			0.16		

0Emission factors are as of July 1st of the indicated calendar year.
0User supplied veh registration distributions.
0Cal. Year: 2010 I/M Program: No Ambient Temp: 79.0 / 79.0 / 79.0 (F) Region: Low
Anti-tam. Program: No Operating Mode: 20.6 / 27.3 / 20.6 Altitude: 500. Ft.
Reformulated Gas: No
025 MPH R LOCAL Minimum Temp: 73. (F) Maximum Temp: 101. (F)
Period 1 RVP: 9.0 Period 2 RVP: 7.8 Period 2 Start Yr: 2000

0 Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
Veh. Speeds:	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0		
VMT Mix:	0.586	0.197	0.091	0.033	0.002	0.003	0.083	0.005		
0Composite Emission Factors (Gm/Mile)										
VOC HC:	1.55	1.90	2.25	2.01	2.50	0.42	0.58	1.68	4.84	1.740
Exhaust HC:	1.17	1.45	1.80	1.56	1.26	0.42	0.58	1.68	1.57	1.327
Evaporat HC:	0.23	0.29	0.26	0.28	0.99			2.88	0.263	
Refuel L HC:	0.16	0.21	0.22	0.21	0.34				0.167	
Runing L HC:	0.13	0.14	0.16	0.14	0.20				0.125	
Rsting L HC:	0.02	0.03	0.02	0.03	0.04			0.39	0.026	

Tennessee Attainment Area MOBILE5A EV Adjusted Fleet Mix Output File (Cont.)

Exhaust CO: 15.42 18.43 22.39 19.69 15.77 1.08 1.19 8.31 16.27 16.013
Exhaust NOX: 1.46 1.70 2.10 1.83 4.37 0.99 1.12 6.26 0.93 2.053
0Evaporative Emissions by Component Weathered RVP: 7.7 Hot Soak Temp: 79.0 (F)
(Hot Soak: g/trip, Diurnals: g, Crankcase: g/mi, Refuel: g/gal, Resting: g/hr) Running Loss Temp: 79.0 (F)
Resting Loss Temp: 79.0 (F)

Hot Soak	0.64	0.72	0.77	0.74	1.99	6.80	
WtDiurnal	3.42	4.67	4.92	4.74	21.10	19.71	
Multiple	8.26	9.98	9.96	9.98	33.67		
Crankcase	0.01	0.01	0.01	0.01	0.01	0.00	
Refuel	3.61	3.61	3.61	3.61	3.61		
Resting	0.03	0.03	0.03	0.03	0.04	0.16	

2010 VMT Growth Factors

County	Road Type	1990 VMT	2010 Growth	2010 VMT
47000	Urban	5,448,529	1.766	9,622,102
47000	Rural	2.49E+07	1.433	3.57E+07
TN Total	3.03E+07			4.53E+07
21000	Urban	2,767,416	1.814	5.02E+06
21000	Rural	6,932,609	1.771	1.23E+07
KY Total	9,700,025			1.73E+07
Davidson	Urban Interstate	5,743,742	1.74	9,994,111
Davidson	Urban Expressway	847,585	2.21	1,873,163
Davidson	Urban Major Arterial	4,767,360	1.225	5,840,016
Davidson	Urban Minor Arterial	906,706	1.225	1,110,715
Davidson	Urban Collector	846,428	3.629	3,071,687
Davidson	Urban Local	1,048,947	1.278	1,340,554
Davidson Total	1.42E+07			2.32E+07
Rutherford	Urban Interstate	216,535	2.504	542,204
Rutherford	Rural Interstate	957,613	1.615	1,546,545
Rutherford	Urban Major Arterial	626,253	2.466	1,544,340
Rutherford	Rural Major Arterial	165,338	1.535	253,794
Rutherford	Urban Minor Arterial	283,078	2.166	613,147
Rutherford	Rural Minor Arterial	329,268	1.912	629,560
Rutherford	Urban Collector	330,982	3.049	1,009,164
Rutherford	Rural Collector	435,401	2.466	1,073,699
Rutherford	Urban Local	263,871	1.356	357,809
Rutherford	Rural Local	363,284	1.283	466,093
Rutherford Total	3,971,623			8,036,355
Sumner	Urban Interstate	87,798	1.612	141,530
Sumner	Rural Interstate	141,992	1.67	237,127
Sumner	Urban Major Arterial	765,976	1.966	1,505,909
Sumner	Rural Major Arterial	32,997	1.703	56,194
Sumner	Urban Minor Arterial	62,213	1.023	63,644
Sumner	Rural Minor Arterial	448,633	1.807	810,680
Sumner	Urban Collector	216,933	1.978	429,093
Sumner	Rural Collector	509,185	1.806	919,588
Sumner	Urban Local	245,600	1.053	258,617
Sumner	Rural Local	376,594	1.083	407,851
Sumner Total	2,887,921			4,830,233
Williamson	Urban Interstate	398,213	2.63	1,047,300
Williamson	Rural Interstate	563,834	1.953	1,101,168
Williamson	Urban Major Arterial	303,965	2.399	729,212

2010 VMT Growth Factors (Continued)

Williamson		Urban Minor Arterial	103,015		3.519		362,510
Williamson		Rural Minor Arterial	610,475		1.786		1,090,308
Williamson		Urban Collector	149,455		2.189		327,157
Williamson		Rural Collector	326,912		1.453		475,003
Williamson		Urban Local	70,727		1.618		114,436
Williamson		Rural Local	427,180		1.209		516,461
Williamson Total		2,953,776				5,763,555	
Wilson		Rural Interstate	907,262		2.1		1,905,250
Wilson		Urban Major Arterial	258,362		1.488		384,443
Wilson		Rural Major Arterial	198,579		2.796		555,227
Wilson		Urban Minor Arterial	76,887		1.889		145,240
Wilson		Rural Minor Arterial	258,159		1.62		418,218
Wilson		Urban Collector	148,551		3.685		547,410
Wilson		Rural Collector	272,149		1.266		344,541
Wilson		Urban Local	42,674		1.045		44,594
Wilson		Rural Local	457,759		1.02		466,914
Wilson Total		2,620,382				4,811,836	
		6.66E+07		6.66E+07		1.09E+08	1.09E+08

Projected TVA Power Plant Loads

Tennessee Valley Authority, 1101 Market Street, Chattanooga, Tennessee 37402-2801

December 7, 1994

Robert T. Burns
c/o Dr. Wayne T. Davis, PhD
Environmental Engineering Department
University of Tennessee
73 Perkins Hall
Knoxville, Tennessee 37996

Dear Mr. Burns:

This is in response to your FAX of November 23, 1994. The forecasted generation for 2010 in gigawatt hours is as follows:

	Cumberland 2010	Gallatin 2010	Johnsonville 2010
June	1561	522	502
July	1662	551	551
August	1659	520	520
September	1557	409	321

The projected NO_x emission rates from 1995 on are 0.43 and 0.51 lb/MM-Btu for Gallatin and Johnsonville, respectively. The NO_x emission rate for Cumberland will not be determined for 2000 and beyond until 1997.

The 2010 monthly generation projections are based on long-term (25-30 year) hourly load forecasts which are updated once or twice a year. The medium load forecast is the basis of the above generation projects. The load forecast is used as input to our hourly loss of load expectation model which produces a long-term power unit schedule. The long-term unit schedule, system operating characteristics, and the load forecast are used as inputs to the production costing model to develop long-term generation projects, production costs, fuel use, and emission levels.

Please refer any questions regarding this data to Ed Howard at 615/751-2551.

Sincerely,

R. H. Riggs, Manager
Air Programs Implementation
LP 5D-C

VITA

Robert Thomas Burns was born in Dallas County, Texas on March 30, 1967. He attended grade school, junior high school and his first two years of high school in Franklin County, Tennessee. He graduated from Owasso High School in Tulsa County, Oklahoma in 1985. At that time he returned to Tennessee and enrolled in the Agricultural Engineering program at the University of Tennessee in Knoxville. In January 1990 he received his Engineer in Training (EIT) certification from the State of Tennessee. He received the degree of Bachelor of Science in Agricultural Engineering with a specialization in Soil and Water Conservation in May, 1990. At that time he enrolled in the Environmental Engineering Program at the University of Tennessee. In June, 1992 he formally received the degree of Master of Science in Environmental Engineering with a specialization in Air Quality Management / Pollution Control. After completing his masters he was employed as an Environmental Engineer with Sverdrup Technology at Arnold Engineering Development Center. After working briefly in industry, he returned to the University of Tennessee, Knoxville as a full time Research Associate and began work on his Doctorate in Civil Engineering, with a specialization in Environmental Engineering. In May, 1995 he completed all requirements for a Ph.D. in Civil Engineering and officially received the degree in August, 1995.

He is currently employed as an Assistant Professor in the Agricultural Engineering Department of the University of Tennessee, where he serves as the Water Quality Engineering Specialist for the Tennessee Agricultural Extension Service.