DETERMINATION OF SAFE BUFFER WIDTH OF ROADWAY TO PROTECT

HUMAN HEALTH FORM HARMFUL $NO_X$ EXPOSURE

by

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## ABSTRACT

## DETERMINATION OF SAFE BUFFER WIDTH OF ROADWAY TO PROTECT HUMAN HEALTH FORM HAZARDOUS $NO_X$ EXPOSURE

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According to the 2004 EPA Trends Report, US on-road transportation sources emit 36% of nitrogen oxides (NOx), 63% of carbon monoxide (CO), and 29% of volatile organic compounds (VOCs). This research determines a safe roadway buffer width to protect human health from air pollutant (NOx) exposure.

The method was used to determine a buffer width for $NO_x$ along Great Southwest Parkway in Grand Prairie, Texas. $NO_x$ health effects include eye, nose, throat, and lung irritation; cough; shortness of breath; tiredness and nausea. In the

Dallas Fort Worth region, where Grand Prairie is located, on-road vehicles contribute over 50 % of $NO_x$ emissions.

Vehicle $NO_x$ emission rates along Great Southwest Parkway were measured using a Horiba 1300 OBS on-board emission measurement system, to determine a maximum 2.02 g/mile emission factor for the corridor. Hourly DFW meteorological data for a 5-year period was processed using Cal3qhcr to determine the 10 worst-case meteorological combinations for a 1-hour averaging time, and the 5 worst for an 8-hour averaging time. The maximum emission factor and worst-case meteorological conditions were input into the line source dispersion model CALINE4 to determine worst-case concentrations at 5-m intervals away from the roadway. CALINE4 output was post-processed in Arc View GIS to plot concentrations at receptor locations. Worst-case concentrations were compared to 1-hour $NO_x$ standards implemented in Hong Kong. For the current Great Southwest traffic volume, it was found that 1-hour $NO_x$ standards would not be exceeded. Additional CALINE4 runs were conducted to determine how much the traffic volume could increase, and still avoid exceedances outside a 20-foot buffer width, which is a common setback distance in residential areas. It was determined that the traffic volume could increase by a factor of 15 and still protect human health from $NO_x$ impacts, using a 20-foot buffer.

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Chapter 1

# INTRODUCTION

## 1.1 Introduction

"**According to the World Health Organization (WHO), 4–8% of deaths occurring annually in the world are related to air pollution**." (*Kathuria, 2002*)

Dallas/Fort Worth, Texas (DFW) is one of the most polluted regions across the nation due to significant vehicular growth in the past 2–3 decades. To restore the air quality and refurbish its image, numerous command and control policy instruments have been implemented in DFW by the state and the local governments. The Texas State Implementation Plan (SIP) contains legally enforceable provisions bringing the region into attainment with the federal national ambient air quality standard (NAAQS) for ozone. Ozone is formed in the atmosphere from the interaction between volatile organic compounds (VOCs) and nitrogen oxides ($NO_X$) from various sources like industrial stacks, natural sources, area sources and on-road and off-road vehicles. In the DFW region, 50 % of $NO_X$ is contributed by on-road vehicles (see Fig. 1). This research attempts to determine a safe roadway buffer width to protect human health from exposure to $NO_X$ vehicular pollution. Not only is $NO_X$ a precursor to ozone formulation, but it is also a pollutant in and of itself. Its health effect includes irritation to eyes, nose, throat, and lungs. It can also cause cough and shortness of breath, tiredness and nausea. The health effects of $NO_X$ are discussed in detail in Chapter 2.

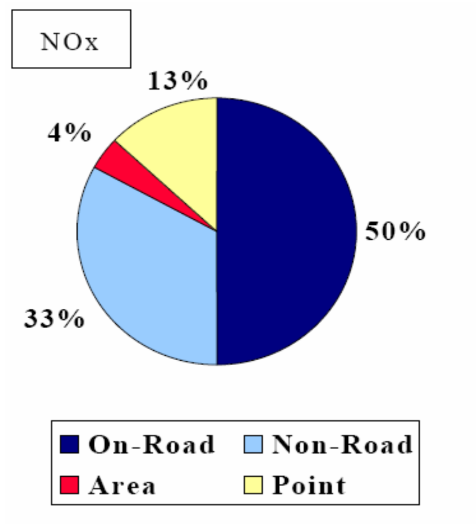



Fig.1.1 $NO_X$ Emissions by Source
http://www.tnrcc.state.tx.us/oprd/sips/sip101.pdf

## 1.2 Dispersion Modeling

Dispersion modeling is a method for estimating pollutant concentrations at a given distance from a source, over a time average. A Gaussian dispersion equation has been developed from statistical rationale, as well as derived from the mass balance principle, to estimate pollutant concentrations. Modeling of various sources and receptors can then be readily conducted by incorporation of the dispersion equation into computer programs. Dispersion modeling offers numerous advantages over ambient concentration measurement, like the ability to asses the impact of new sources, the ability to test the "what if scenarios", and reduced cost.

## 1.3 Line Source Dispersion Modeling and its Role in Transportation Planning

Line source models are used to simulate the dispersion of pollutants near the roadways, where vehicles continuously emit pollutants of varying characteristics. Various highway dispersion models have been developed using different methodologies/techniques and encompassing roadway geometry, traffic characteristics and atmospheric conditions. These models have been continuously upgraded and modified based on field experiments and numerical and physical modeling results. These models, despite several assumptions and limitations, are used throughout the world. Air quality models enable regulatory agencies to carry out air pollution prediction analysises due to vehicular traffic near the roadways as a part of the environmental impact assessment (EIA) procedure, and thus play a key role in development of air quality management strategies. (Sharma, 2000)

## 1.4 Purpose of the Research and Organizational Structure

A disadvantage of line source dispersion modeling computer programs is that the output is not always oriented toward the needs of transportation planners. In particular, appropriate graphical output can facilitate decision making and engineering judgment. Geographical information systems (GIS) can be a great aid to mitigate the above mentioned shortcoming of the line source dispersion modeling computer programs.

The purpose of this research is to determine, for a given traffic volume, a roadway buffer width needed to protect human health from exposure to $NO_X$. In particular, measured vehicle emission data will be input into the line source dispersion model CALINE4 and post processed in ArcGIS to determine the roadway buffer width.

Chapter 2 includes a literature review and background theories underlying the research. The methodology, results, and conclusions & recommendations are covered in Chapters 3, 4 and 5, respectively.

CHAPTER 2

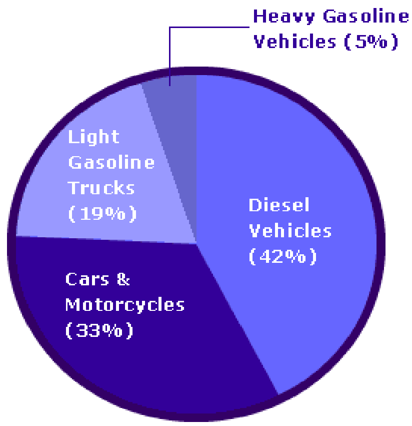
# LITERATURE REVIEW

## 2.1 Background

### *2.1.1 Transportation Sources and Impacts*

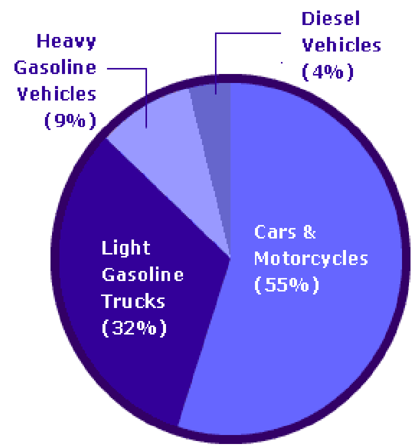
Transportation facilities are considered to be the backbone of a country and essential for its socioeconomic advance and national defense. They reflect the economical and technological development of the country. On a personal level, vehicles enable an individual to enjoy their freedom of ‘self-being’ to its fullest. Vehicles increase the quality of life. However, the downside of vehicles is impossible to overlook. Accidents, congestion, sprawl, and air pollution are issues which demand serious thoughts and strict actions. The undesirable effects of the transportation facilities on environmental degradation create serious worries. They consume high levels of non-renewable sources like energy and fossil fuel. Vehicle induced air pollution has serious negative effects on human health and environment from local to regional scales. Figure 2.1 shows emission of major pollutants form transportation sources in year 1999.

*1999 National Emissions by Source:*
*Nitrogen Oxides*
*On-Road Mobile Sources*



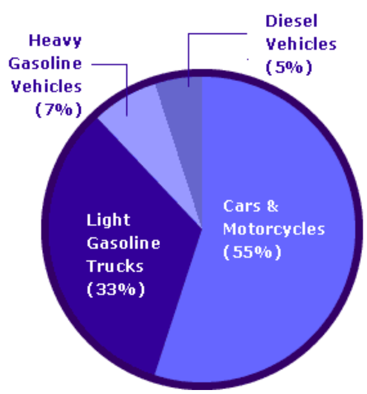

Some percentage totals do not equal 100 due to rounding.

*1999 National Emissions by Source:*
*Carbon Monoxide*
*On-Road Mobile Sources*




Some percentage totals do not equal 100 due to rounding.

*1999 National Emissions by Source:*
*Hydrocarbons*
*On-Road Mobile Sources*




Some percentage totals do not equal 100 due to rounding.

http://www.epa.gov/otaq/invntory/overview/pollutants/nox.htm#

Fig. 2.1 Percent Emission of VOC, $NO_X$ and CO from Transportation Sources

## 2.2 Air Quality Standards

### *2.2.1 National Ambient Air Quality Standards (NAAQS)*

The Clean Air Act, which was last amended in 1990, requires the Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for pollutants which are harmful to public health and the environment. The Clean Air Act established two types of national air quality standards. ***Primary standards*** set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. ***Secondary standards*** set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings.

The EPA has set NAAQS for six principal pollutants, which are called "criteria pollutants". They are listed in Table 2.1 below. Units of measure for the standards are parts per million (ppm) by volume, milligrams per cubic meter of air ($mg/m^3$), and micrograms per cubic meter of air ($\mu g/m^3$).

Table 2.1 National Ambient Air Quality Standards (TCEQ, 2005)

| Pollutant | Averaging Period | Standard | Primary NAAQS | Secondary NAAQS |
|---|---|---|---|---|
| Ozone | 8-hr | The average of the annual fourth highest daily eight-hour maximum over a three-year period is not to be at or above this level. | 85 ppb | 85 ppb |
| Carbon Monoxide | 1-hr | Not to be at or above this level more than once per calendar year. | 35.5 ppm | 35.5 ppm |
| | 8-hr | Not to be at or above this level more than once per calendar year. | 9.5 ppm | 9.5 ppm |
| Sulfur Dioxide | 3-hr | Not to be at or above this level more than once per calendar year. | – | 550 ppb |
| | 24-hr | Not to be at or above this level more than once per calendar year. | 145 ppb | – |
| | Annual | Not to be at or above this level. | 35 ppb | – |
| Nitrogen Dioxide | Annual | Not to be at or above this level. | 54 ppb | 54 ppb |
| Respirable Particulate Matter (10 microns or less) (PM10) | 24-hr | Not to be at or above this level on more than three days over three years with daily sampling. | 155 $\mu g/m^3$ | 155 $\mu g/m^3$ |
| | Annual | The three-year average of annual arithmetic mean concentrations at each monitor within an area is not to be at or above this level. | 51 $\mu g/m^3$ | 51 $\mu g/m^3$ |
| Respirable Particulate Matter (2.5 microns or less) (PM2.5) | 24-hr | The three-year average of the annual 98th percentile for each population-oriented monitor within an area is not to be at or above this level. | 66 $\mu g/m^3$ | 66 $\mu g/m^3$ |
| | Annual | The three-year average of annual arithmetic mean concentrations from single or multiple community-oriented monitors is not to be at or above this level. | 15.1 $\mu g/m^3$ | 15.1 $\mu g/m^3$ |
| Lead | Quarter | Not to be at or above this level. | 1.55 $\mu g/m^3$ | 1.55 $\mu g/m^3$ |

The U.S. $NO_X$ standard is based on an annual averaging time. This research used Caline4 as a dispersion modeling tool, which is able to predict $NO_X$ concentration with time average of 1-hour and 8 hours but unable to produce result a with a time average of

1 year. To resolve this challenge, Hong Kong air quality standards with 1-hour averaging time were used as a basis for comparison in this study. Section 2.2.2 discusses this standard briefly. The Hong Kong standards are the only standard to my knowledge which considers a 1-hour time average concentration of $NO_X$.

*2.2.2 Hong Kong Air Quality Standards*

Air quality in Hong Kong is badly affected by the high density of vehicles on the roads, coupled with the hilly geography and cavernous streets. Regional air pollution has increasingly affected visibility. Also, air pollution topped the list of complaints to the Environmental Protection Department (EPD) with 14,554 in year 2003, almost double that of 1998.

2.2.2.1 Air Quality Objectives

Air Quality Objectives (AQOs) for seven widespread air pollutants were established in 1987 under the Air Pollution Control Ordinance (APCO). In 1989, the entire territory was declared as air control zone, with a set of Air Quality Objectives (AQOs) for seven pollutants: sulfur dioxide, total suspended particulates (TSP), respirable suspended particulates (RSP), nitrogen dioxide, carbon monoxide, photochemical oxidants (ozone) and lead. The AQOs derive from scientific analyses of the relationship between pollutant concentrations in the air and the associated adverse effects of the polluted air on the health of the public. The established AQOs, as shown in Table 2.2, apply to the whole territory.

Table 2.2 Hong Kong Air Quality Objectives for Seven Pollutants and Potential Health Effects of Pollutants

| Pollutant | Concentration in Micrograms per Cubic Meter | | | | | Health effects of pollutant at elevated ambient levels |
|---|---|---|---|---|---|---|
| | Averaging Time | | | | | |
| | 1hr | 8hr | 24hr | 3mths | 1yr | |
| Sulphur Dioxide | 800 | --- | 350 | --- | 80 | Respiratory illness; reduced lung function; morbidity and mortality rates increase at higher levels. |
| Total Suspended Particulates | --- | --- | 260 | --- | 80 | Respirable fraction has effects on health. |
| Respirable Suspended Particulates (v) | --- | --- | 180 | --- | 55 | Respiratory illness; reduced lung function; cancer risk for certain particles; morbidity and mortality rates increase at higher levels. |
| Nitrogen Dioxide | 350 | --- | 150 | --- | 80 | Respiratory irritation; increased susceptibility to respiratory infection; lung development impairment. |
| Carbon Monoxide | 30,000 | 10,000 | --- | --- | --- | Impairment of co-ordination; deleterious to pregnant women and those with heart and circulatory conditions. |
| Photochemical Oxidants (as ozone) | 240 | --- | --- | --- | --- | Eye irritation; cough; reduced athletic performance; possible chromosome damage. |
| Lead | --- | --- | --- | 1.5 | --- | Affects cell and body processes; likely neuro-psychological effects, particularly in children; likely effects on rates of incidence of heart attacks, strokes and hypertension. |

(Reference:- http://resources.emb.gov.hk/envir-ed/text/lifewide/e_m3_3_3_n0.htm)

2.3 Dispersion Modeling & Roadway/Line Source Modeling - The Caline4 Model

Most dispersion models are based on the Gaussian plume dispersion model. The Gaussian plume model gives concentration of a pollutant at position (x,y,z) as follows:

$$C(x, y, z) = \frac{Q}{2\pi u\, \sigma_y \sigma_z} \cdot \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \cdot \left\{\exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right]\right\} \qquad (2.1)$$

Where

$C(x, y, z)$ = contaminant concentration at the specified coordinate [$ML^{-3}$],

$\sigma_y$ = lateral dispersion coefficient function [L],

$\sigma_z$ = vertical dispersion coefficient function [L],

u = wind speed [L/T],

H = effective stack height [L],

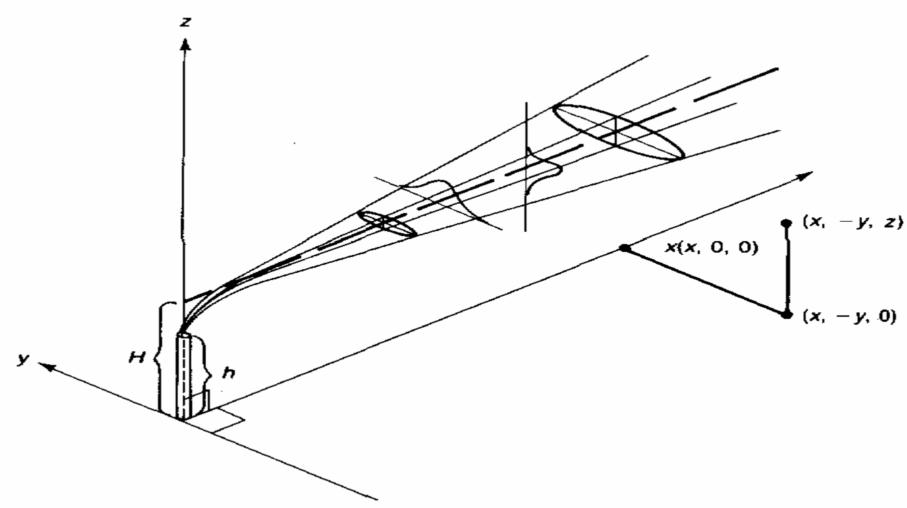
x = downwind distance [L],

y = crosswind distance [L],

z = vertical distance [L].

The standard Gaussian coordinate system is shown in Fig. 2.2

**Figure 19.4** Coordinate system showing Gaussian distributions in the horizontal and vertical.




Adapted from Turner, 1970.

Fig. 2.2 Standard Gaussian Coordinate System

*2.3.1 Model Description*

The **Ca**lifornia **line** source Dispersion model (Caline) is one of those models based on the Gaussian plume dispersion model. Caline was developed first by DOT California (Caltran) to estimate CO concentration.

**CALINE4** is latest version of the series. **CALINE4** divides individual highway links into a series of elements from which incremental concentrations are computed and summed, as shown in Fig. 2.3.

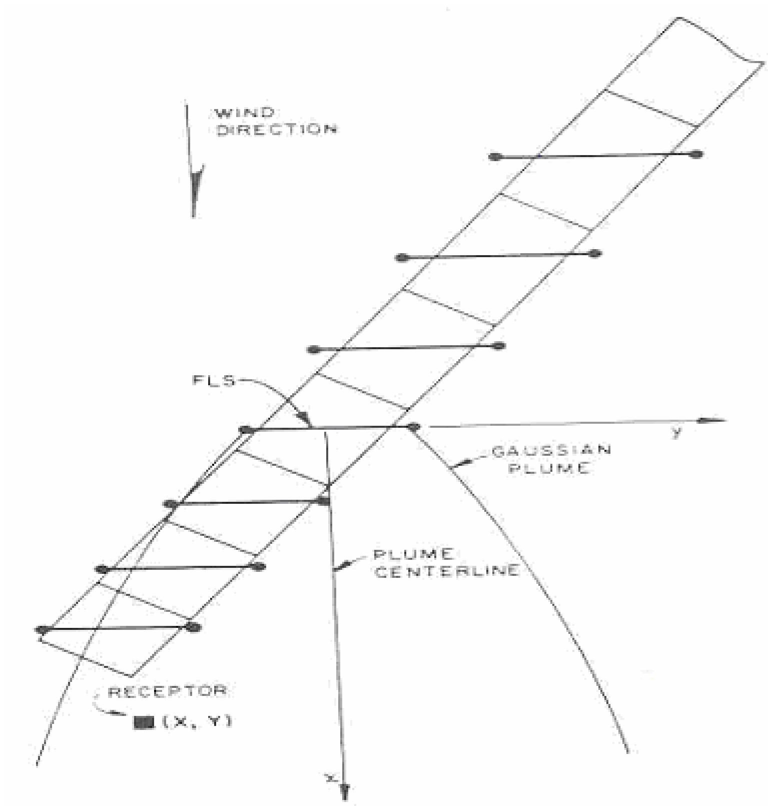



Fig. 2.3 Finite Line Source (FLS) of Caline Series Models (adopted from Benson, 1991)

Each element is modeled as an "equivalent" finite line source (FLS) positioned normal to the wind direction and centered at the element midpoint. Element size increases with distance from the receptor to improve computational efficiency.

The emissions from an element are released uniformly along the **FLS** and dispersed in a Gaussian manner by the model. Incremental downwind concentration is computed by using the crosswind Gaussian formulation for a line source of finite length (Equation 2) (Benson, 1991). Each finite length element is considered to be a series of point sources; concentrations from each differential "point source" are integrated over the length of the segment, as shown in Eq. 2.

$$C(x, y) = \frac{q}{\pi \sigma_z u} \int_{y_1 - y}^{y_2 - y} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) dy \qquad (2.2)$$

where q is the lineal source strength, u is the wind speed, and $y_1$ & $y_2$ are the **FLS** endpoint y coordinates.

The EPA version of the model permits the specification of up to 20 links and 20 receptors. This short-coming has been nullified by CalRoadView and enables the user to use the number of links and length of his/her desire. Each link defines a relatively straight segment of roadway with a constant width, height, traffic volume and vehicle emission factor.

**CALINE4** treats the region directly above the highway as a zone of uniform mixing with uniform emissions and turbulence. This "mixing zone" is defined as the region over the traveled way plus 3 m (almost two vehicle widths) on each side, as shown in Fig. 2.4.

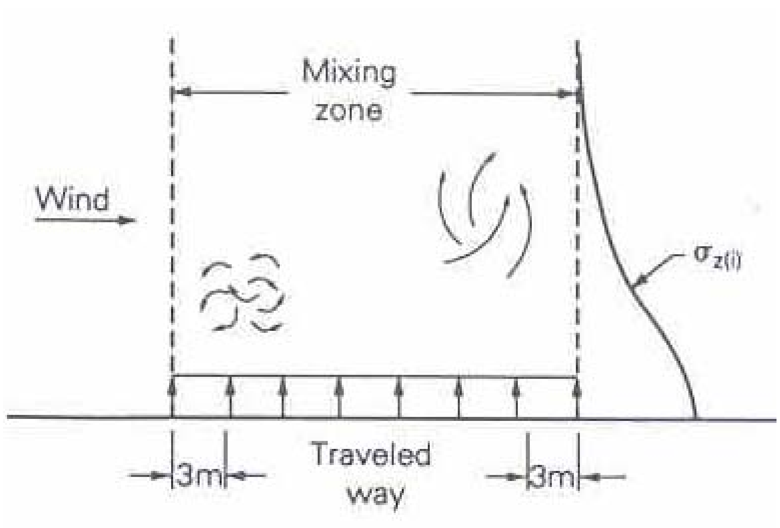



Fig. 2.4 Mixing Zone (adopted from Benson, 1991)

The additional width accounts for the initial horizontal dispersion imparted to pollutants by the vehicle wake. Within the mixing zone, the mechanical turbulence created by moving vehicles and the thermal turbulence created by hot vehicle exhaust are treated as significant dispersive mechanisms.

CALINE4 assumes that initial vertical dispersion at the edge of the mixing zone, $\sigma_{z,}$ is determined by the length of time air resides in the mixing zone, $t_{r.}$ Equation 3, which is empirically derived, is used to calculate $\sigma_z$

$$\sigma_z = 1.5 + (t_r/10) \tag{2.3}$$

where $\sigma_z$ in meters and $t_r$ in seconds.

Horizontal dispersion is estimated directly from the wind direction standard deviation, to account for site specific conditions and unique meteorological regimes.

*2.3.2 Intersection Link Option*

At controlled intersections, the operational modes of deceleration, idle, acceleration and cruise have a significant effect on the rate of vehicle emissions. Traffic parameters such as queue length and average vehicle delay define the location and duration of these emissions. The net result is a concentration of emissions near the intersection which cannot be modeled adequately using a single, composite emission factor. For this reason, a specialized intersection link option has been added to **CALINE4**. (Benson, 1991)

*2.3.3 $NO_2$ Option*

A number of methods have been developed to expand the use of the Gaussian plume formulation for reactive species such as $NO_2$. These include the exponential decay, ozone limiting and photo stationary state methods. An unfortunate weakness of these methods is their assumption that reactants mix instantaneously as they disperse and that the resulting time averaged concentrations determine the reactions rates. Because the component reactants, NO and ambient $O_3$, are not mixed instantaneously by the relatively large scale dispersive processes of the atmosphere, the assumption leads to overestimates of $NO_2$ production. Discrete parcel $NO_2$ concentrations are computed by CALINE4 for each element-receptor combination because of the variable travel time involved. These concentrations are not, of course, the same as time-averaged $NO_2$ concentrations. To arrive at time averaged values, the link source strength is adjusted by element to yield an initial $NO_2$ mixing zone concentration equal to the discrete parcel concentration at the receptor. The model then proceeds to compute the time average concentration exactly as the concentration for a non-reactive species such as CO would be computed.

## 2.4 Emission Data Collection

*2.4.1 Background*

Various methods for measuring or modeling vehicular emissions in order to develop emission factors for input into Caline4 are discussed below.

*2.4.2 Dynamometer*

In dynamometer testing, the federal test procedure is used to determine compliance of light-duty vehicles and light-duty trucks with federal emission standards. The vehicle is "driven" on a dynamometer over a simulated urban driving trip, intended to represent typical driving patterns in urban areas. Exhaust (tailpipe) emissions are measured during the trip. A vehicle is driven on a simulated cycle involving stops, starts, acceleration, deceleration, constant speed and idling. All these driving modes are characterized based on overall time-weighted average speed. (Munshi, 2005)

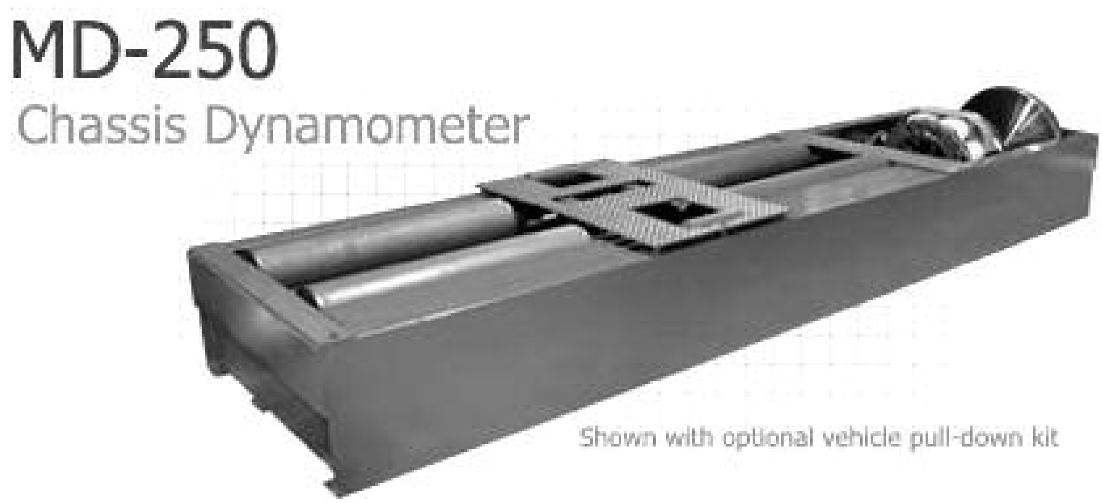



Figure 2.5 Chassis Dynamometer (adopted from Munshi, 2005)

*2.4.3 Remote Sensing*

Remote sensing is a method to measure pollutant levels in a vehicle's exhaust while the vehicle is traveling down the road. These devices are not attached to the vehicle. Remote sensing helps in collection of trend data for entire vehicle populations, identifies gross polluters between inspection cycles, and does not interfere with the commuter.

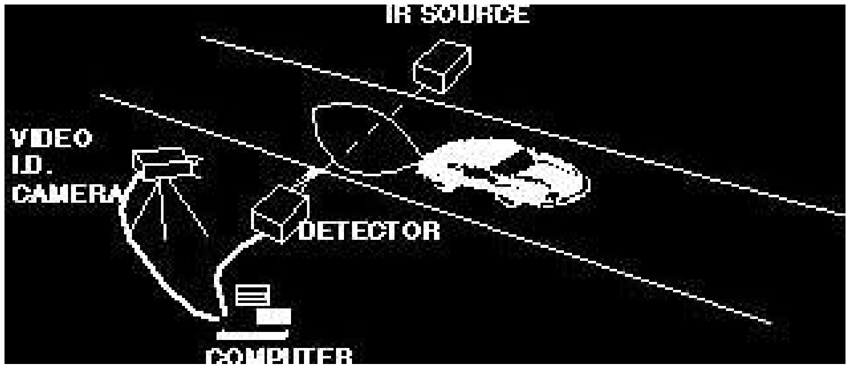



Fig 2.6 Typical Remote Sensing Setup (adopted from Munshi, 2005)

Figure 2.6 shows the typical setup of Remote Sensing Devices (RSD). The RSD system uses an infrared (IR) or ultraviolet (UV) absorption concept to measure emissions. To measure CO, $CO_2$, or HC, the system projects a beam of IR radiation across a roadway continuously. Two scenarios may be observed:

• When the RSD's detectors are receiving infrared light signals through the air with no vehicle emissions in the path, the signals maintain their strength.

• If there is some amount of CO, $CO_2$, or HC, present in the path, signals will get absorbed, which weakens the signals.

"In the case of NOx, the RSD uses an ultraviolet (UV) light source in addition to the infrared beam. This is due to the fact that NOx absorption characteristics are stronger and more selective in the ultraviolet light spectrum." (Munshi, 2005).

*2.4.4 Macroscopic Emission Models*

Macroscopic modeling uses a model that has been developed for freeway and arterial road networks for an entire region. There are various macroscopic models but

MOBILE6 is the most widely used because it is more efficient and detailed compared to other models. It is used by North Central Texas Council of Governments (NCTCOG) for estimating DFW mobile source emission reductions associated with the SIP and in determining transportation conformity. MOBILE6 estimates on-road vehicle emissions under various conditions. In MOBILE6, emission rates can be combined with activity from a travel demand model to develop highway emission inventories expressed in tons per time period. Further, it calculates region wide emission factors (EF) in grams/mile for arterials, freeways, ramps and other major road connectors. (Munshi, 2005)

*2.4.5 Microscopic Emission Models*

Numerous microscopic models also exist that simulate traffic on different roadway facility types such as freeway segments, freeway on-ramps, arterial intersections, and rural highways. For example, CORSIM was developed for the Federal Highway Administration. This model is made up of two principal modules, a preprocessor and simulator. Emission data is provided from dynamometer testing. An urban street is represented as a set of nodes and directed links. Total emissions on each link are determined by applying default emission rates (based on speed and acceleration from look-up tables) to each driving vehicle second by second traveling on the link. CORSIM can accommodate a variety of traffic control conditions. Each vehicle which enters the simulation network is stochastically assigned a set of performance characteristics, which include a vehicle type as well as driver behavior characteristics. Microscopic models are more accurate than region-wide macroscopic models but may still be inaccurate if not calibrated for local conditions. Also, vehicle operating history can impact emissions, but speed-acceleration tables sometimes used in microsimulation models cannot account for this. Microscopic models, however, represent the best strategy for estimating benefits of emission reduction pre-implementation. (Munshi, 2005)

*2.4.6 On-Board Emission Measurement*

On-board emission measurement is a "micro-scale" technique for quantifying vehicular emissions since the data is collected under real-world conditions at any point of time and location where the vehicle is driven. Real-world emissions are measured during various driving situations (accelerations and decelerations), which is an advantage over dynamometer testing. Also, on-board measurement proves advantageous over RSDs since remote sensing gives an instantaneous snap-shot in time and space; in addition, RSDs cannot be used across multiple lanes of heavy traffic. Improvements at individual intersections, which are too small to observe in a macroscopic model but are significant when aggregated, can be measured using on-board systems. Also, on-board systems measure real-world emissions for actual driving conditions rather than model simulated conditions, which proves advantageous over micro scale modeling. (Munsh, 2005)

This study used data from on-board measurement to develop emissions for use in Caline4.

## 2.5 Literature Review

Table 2.3 summarizes articles reviewed related to air quality and GIS.

Table 2.3 Literature Review

| No. | Research Title | Year | Author | Objective | Major Findings | Remarks |
|---|---|---|---|---|---|---|
| 1 | The use of GIS in climatology and meteorology | 2003 | Lee Chapman & John E. Thornes | To review GIS ability in capturing, modeling, analyzing and displaying special data. | This is article reviews uses of GIS in fields of Climatology and Meteorology. | A distinction is made between the derivation of spatial datasets from their subsequent modified applications. |
| 2 | A qualitative tool combining an interaction matrix and a GIS to map vulnerability to traffic induced air pollution | 2004 | Maria Mavroulidou, Susan J. Hughes, and Emma E. Hellawell | To define 'interaction matrix' using key parameters such as traffic, meteorology, and buildings, and locate hot spots where detailed air quality monitoring is required. | Interaction matrix works well at local scale. | |
| 3 | Rapid urban growth, land use changes and air pollution in Santiago Chile | 1999 | H. Romero, M. Ihl, A. Rivera, P. Zalzar, P. Azocar | To observe air quality impact of urban growth using satellite images and digital terrain model. | Urban heat island, Normal Difference Vegetation Index (NDVI), and thermal inversion layers were mapped using GIS. Heavy traffic and wind direction has | |

Table 2.3 - continued

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | caused maximum CO concentration in southern part of city. Ozone exceedances were observed throughout the year, with maximum frequency in summer and spring. | |
| 4 | An integrated simulation system for traffic induced air pollution | 1998 | Matthias Schmidt, Ralf Peter Schalfer | To model vehicle induced pollution for local agencies to conduct air quality planning. | High accuracy in case of macroscale modeling (150km * 150km). | SIMTRAP project is currently funded by the European community. It simulates realistic traffic data using DYNEMO model and air pollution data using DYMOS model. Interpretation and visualization of results are readily conducted in GIS but it demands High Performance Computing Network (HPCN). |

Table 2.3 - continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | Comparative study of 3D numerical and puff models for dense air pollution | 1999 | Ni Bin Chang, C. Y. J. Kao, Y. L. Wei , C. C. Tseng | To conduct risk assessment and establish an emergency response system for hazardous chemical release using 3D mathematical model integrated with GIS. | This research has considered seven industrial zones in the Kaohsiung metropolitan area. Release and dispersion of various hazardous chemicals were predicted using developed 3D numerical model and then results were compared with output of puff model. Developed 3D model predictions were found to be conservative compared to puff model output. | Can be applicable for Title V permitting (future recommendation) |
| 6 | GIS based mathematical modeling of urban air pollution | 1999 | E.A. Zakarin, B.M. Mrkarimova | To develop GIS based mathematical model of urban air pollution. | Researchers claim that their derived mathematical model gives more control over variables and can be used as an air pollution predicting system for areas other than considered in this study. | |

Table 2.3 - continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 7 | Integration of the global positioning system (GPS) and GIS for traffic congestion studies | 2000 | Michael A. P. Taylor, Jeremy E. Woolley, Rocco Zito | To develop an integrated system of GIS and GPS which can be installed in a probe vehicle to collect traffic data, engine data and pollution data. | Research proves effectiveness and efficiency of GIS in facilitating multi-faceted data collection and analysis for traffic planning. | |
| 8 | Estimating urban air pollution levels from road traffic in TRAEMS | 1999 | Dr. Joseph Kwame Affum, Prof. Lex Brown | To provide an overview of design and development of Transport Add-on Environmental Modeling System (TRAEMS). | $NO_X$ emissions up to 2011 are predicted for line sources in the City of Brisbane, Australia. | It is not clear that the authors have considered atmospheric reactions of NOx in modeling. |
| 9 | Estimation of car fuel consumption in urban traffic | 1986 | D. C. Biggs, R. Akcelik | To derive a mathematical model for fuel consumption. | Various functions and graphs are presented to predict fuel consumption based on various parameters. | Applicable to macro and meso scale traffic. |
| 10 | Travel time study with GPS and GIS: An integrated methodology | 1998 | Cesar A. Quiroga, Darcy Bullock | To assimilate various transportation data related to travel time studies, using developed GIS -GPS system. | Median speed, harmonic mean speed and other parameters were found based on functional class. | Research shows GPS' ability for extensive data collection (second by second logging), and GIS' ability for data handling and filtration. |

Table 2.3 - continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | On-road measurement of vehicle tailpipe emission using a portable instrument. | 2003 | Christopher Frey, Nagui Rouphail | To measure CO, NO and HC from a fleet of 11 vehicles. | Emission comparison based on driver behavior.<br>The article found that the phases of the driving cycle, in order from greatest pollutant generation to least, are acceleration, cruising, deceleration, and idling. | This kind of work can be useful to check the accuracy of Sate Implementation Plan (SIP) Transportation Control Measures (TCM). |
| 12 | A review of the development and application of the CaLine3 and 4 models | 1991 | Paul E. Benson | To provide scholarly review of CaLine3 and 4 models, their advancement and application. | Article discusses background theories in development of model and integration of these theories in model. | |
| 13 | Development and verification of the California Line source dispersion models | 1988 | Paul E. Benson | To verify CaLine4 model results by conducting independent studies. | Error is reported as a function of wind direction for CaLine3. 75% of Caline predictions fall within a factor 2 of measured values. This error has been reduced by 66% in CaLine4. | |
| 14 | CALINE4 - A dispersion model for | 1984<br>1989 | State of California | Comprehensive technical report | | |

Table 2.3 - continued

| | | | | | | |
|---|---|---|---|---|---|---|
| | predicting air pollutant concentrations near roadways | (revised) | Department of Transportation Division of New Technology and Research | focusing on each and every parameter of model, including a CO, NO and HC sensitivity analysis of model and field tracer study. | | |
| 15 | User's guide for CL4: A user-friendly interface for the Caline4 model for transportation project impact assessments | 1998 | Dana L. Coe, Douglas S. Eisinger, Jeffrey D. Prouty, Tom Kear | Shows use of all components within the Caline4. | | |
| 16 | User's Guide for CALRoads View | 2001 | Jeese L. The, Cristiane L. The, Michael A. Johnson | Provides detailed descriptions of various CAL-series and other associated software, with their GUI applications and screen shots of interfaces. | | |
| 17 | Impact of Signal Synchronization on Vehicular Emission – An On-Board Measurement Case Study. | 2005 | Rupangi Prakash Munshi | To determine the impacts of signal synchronization on real-world, on-road emissions of $NO_X$. | Signal re-timing, opposite to popular belief, has not reduced $NO_X$ emissions for the particular corridor studied. In all cases except one, there was | |

Table 2.3 - continued

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | no statistical difference in emissions before and after retiming. In the one case, emissions increased due to increased average speed. | |
| 18 | Determination of the Meteorological Conditions Responsible for the Worst-case Odor Impacts from Area Sources Using Two Dispersion Models – ISC3 and AEROMOD | 2005 | Sapna Devanathan | To determine meteorology responsible for worst-case odor concentrations from a wastewater treatment plant. | High temperatures in summer cause the worst-case situations. | |
| 19 | Vehicular pollution control in Delhi | 2002 | Vinish Kathuria | Research investigates the effectiveness of the policy enhancements made in order to control vehicular pollution in New Delhi, the capital city of India. | Research concluded that against uncontrolled vehicular growth (360-400 vehicles per day), all the enhancements are falling short of controlling vehicle induced air pollution. | |
| 20 | GIS applications in air pollution modeling | 2000 | Niraj Sharma | This research mainly explores the potential | Integration of GIS and air quality dispersion | |

Table 2.3 - continued

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | of GIS applications in field of air quality to meet transportation planning needs. | models can facilitate and improve decision making. | |

Articles 2 to 6 focus on GIS applications in the field of air quality. They focus on behavior of various air quality parameters/concepts in time and space. They model these parameters/concepts in a GIS environment using various techniques. Articles 7 and 10 discuss use of GPS system in real time data collection, which has provided a bigger picture for use of GPS in the data collection of current study.

In his research Mr. Niraj Sharma (Article 20) has adopted a macro-scale dispersion modeling approach. The real time concentrations for various pollutants like carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides ($NO_X$), sulfur dioxide ($SO_2$), and Suspended Particulate Matter (SPM) were measured at six different locations on a highway segment of almost 200 km, using air quality sampling devices. Meteorological data like wind speed, wind direction, temperature, and humidity were collected from the local meteorological department. Traffic characteristic data were also measured at the same locations where pollutant concentrations were measured. All these real time data were used as an input to the Caline4 model. The researcher assumed that CO can be used as indicator of vehicular pollution. The Caline4 model was run for CO with multi run worst-case condition (i.e. time average of 8 hours and worst-case wind angle). Using output of Caline4 model, pollution dispersion maps were developed using ArcGIS. This study has highest resemblance in methodology with this research. Sharma's study does not consider health impacts of the pollutant, nor does it compare concentrations with any standard threshold value. In a broad sense, one can say that this study goes beyond the point where Sharma concludes his research.

Devnathan (2005) (article 18) has exported ISC3 and AERMOD output into an ArcGIS environment. Exceedance contours of odors from a wastewater treatment plant were prepared using various GIS tools.

From the above literature review and to best of my knowledge, only this research takes $NO_X$ in exclusive consideration in terms of health effect and subsequent requirement of buffer width of roadway required to protect human health from harmful exposure of $NO_X$.

# CHAPTER 3

# METHODOLOGY

## 3.1 Overview

The research was carried out in two parts; one was real-time data collection and the second was computer modeling.  This chapter describes briefly how an emission factor was measured for use in Caline4, and in greater detail the methodology for computer modeling of ambient concentrations.

## 3.2 Measurement of Emission Factor

The emission factor is one of the most critical parameters of dispersion modeling. For line source modeling, it is expressed in units of ‘mass of pollutant/vehicle miles traveled’.  There are various ways to derive an emission factor, depending upon the kind of pollution source being considered: area source, point source or line source.  In the case of line sources, computer models, dynamometer testing or on-road testing can be used to generate the emission factors.  To ensure the highest degree of accuracy in this research, the emission factor was derived from real-time data.

Student Ms. Rupangi P. Munshi (Graduate student of Department of Civil and Environmental Engineering UTA) carried out her research “Impact of Signal Synchronization on Vehicular Emission - An On-Board Measurement Case Study.” The emission factors used in this research result from this previous research.  The author was a member of the on-board data collection and analysis team.  The emission data was collected using the department 2000 Chevrolet Astro van out fitted with a tailpipe emission analyzer, On-Board System OBS-1300, provided by the Horiba Instruments, Inc. Fig. 3.1 shows the experimental setup and Table 3.1 describes all accessories that were used in measurement of emission factor.

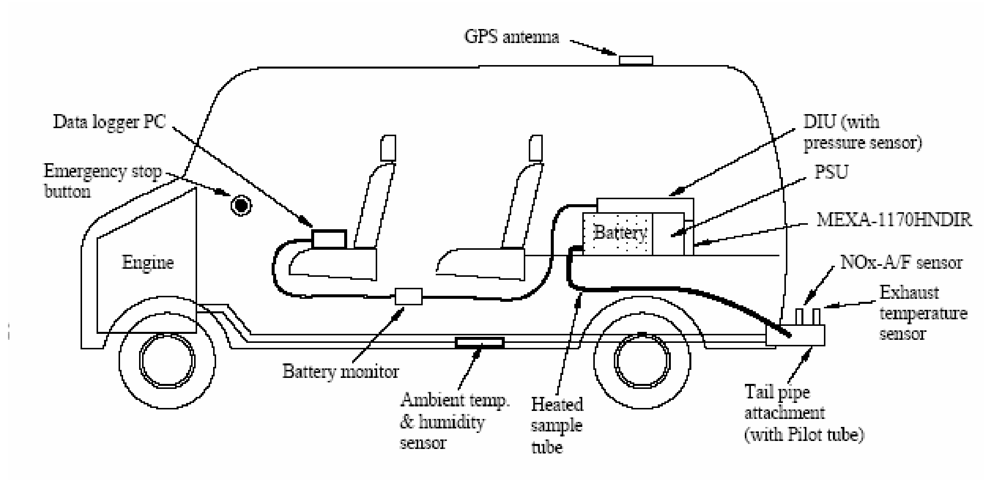



Fig. 3.1 Schematic Diagram of Chevy Astro Van Outfitted with OBS-1300 and Accessories (Munshi, 2005)

Table 3.1 OBS-1300 and Accessories and their Use

| Unit | Use |
|---|---|
| Chevy Astro Van | This vehicle is used to collect emission data. |
| The OBS 1300 | An on-board emission measurement system which performs simple analysis of exhaust gases. |
| The Data Interpretation Unit (DIU) | An interface between sensor, data analyzer and data logging PC |
| Mexa720 $NO_x$ Analyzer | This instrument attaches $NO_x$ probe and provides $NO_x$ concentration readings in ppm. |
| Data logging PC | A DELL laptop is provided with data logging software. The software that is used in conjunction with OBS logs the pollutant emissions, A/F ratio, exhaust pipe temperature and ambient temperature and ambient humidity data. |
| GPS system | A GPS system is used to determine velocity, altitude and position of vehicle on the roadway. |
| Battery | Two 12V – 24V batteries are provided for power supply. |
| Tail pipe attachment | An attachment is provided for the exhaust pipe to hold the tubing and wiring that connects to MEXA-1170 HNDIR and DIU. |

## 3.3 Data Collection Procedure

### *3.3.1 Great Southwest Parkway*

"Great Southwest (GSW) Parkway is a road in the city of Grand Prairie, Texas. The stretch of Great Southwest Parkway under study is from the signalized intersections of GSW and Abram Street to GSW and Fairmont Street. This stretch of road has multiple facets such as a school zone, two railroad crossings, commercial zone and residential neighborhood. It also runs perpendicular to an approach road of I-20 at one signalized intersection. These facets impact the flow of traffic and thereby the traffic volume is unique at each signalized intersection. For example, at the intersection connecting to I-20, the traffic volume is higher compared with the GSW intersections connecting to residential neighborhoods. Also, the school zone lowers the speed limit for a small stretch of GSW from the normal speed limit of 45 mph to 20 mph. A detailed map of the Great Southwest Parkway between the signalized intersections under study is shown in Figure 3.2". (Munishi, 2005)

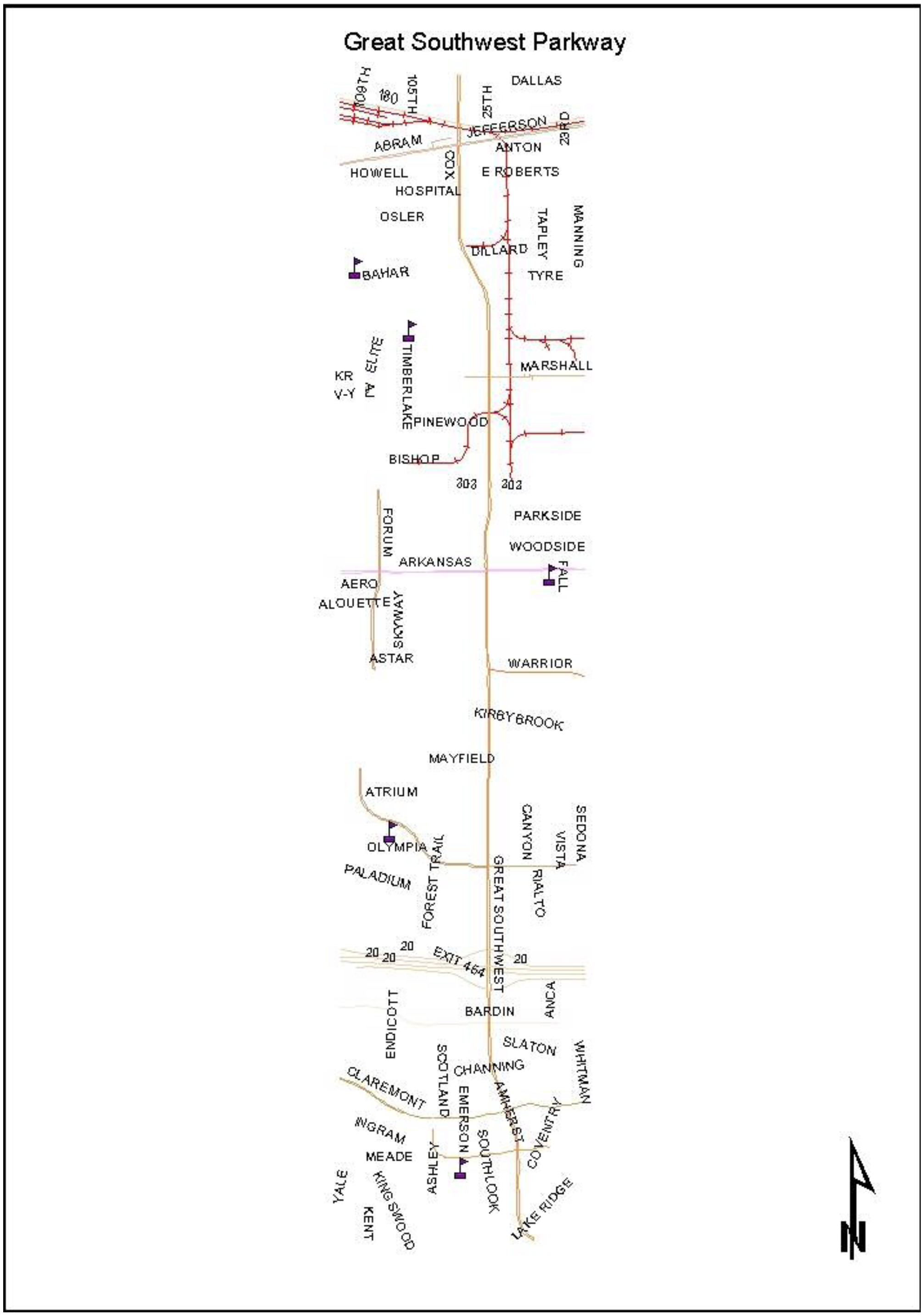



Figure 3.2 Layout of Great Southwest Parkway between Study Signals (Munshi, 2005)

*3.3.2 Data Collection Procedure*

The OBS-1300 and its accessories were installed in the Chevy Astro van. Runs were made to ensure that the system worked properly and a data check was also conducted. After the pilot runs, detailed data collection began. Runs were made for three different traffic conditions:

1. AM Peak – 7:00 to 8:30 AM

2. Off-Peak – 8:30 to 11:00 AM and 4:00 to 4:30 PM

3. PM Peak – 4:30 to 6:30 PM

"The peak hours were determined by Kimley-Horn and Associates Inc. from the traffic count data. These runs were made before and after signal retiming. The signal retiming was implemented by Kimley-Horn Associates Inc., a consulting firm hired by the North Central Texas Council of Governments. The before signal retiming runs were made in December and January, which are considered to be winter months, and the after signal retiming runs were made in April and May, which are spring months." (Munshi, 2005)

In her research Ms. Munshi assumed that signal synchronization and retiming reduce vehicular emissions, so in the present research we have considered emission factors for before signal synchronization to model a worst-case scenario. The emission factor data used from Ms. Munshi's research is shown in table 3.2.

Table 3.2 Emission Factor (EF) Summary

| | Overall | AM Peak | Off Peak | PM Peak |
|---|---|---|---|---|
| **Max. EF (g/vmt)** | 2.02 | 1.22 | 2.02 | 1.74 |
| **Min. EF (g/vmt)** | 0.36 | 0.58 | 0.58 | 0.77 |
| **Avg. EF (g/vmt)** | 1.08 | 0.81 | 0.78 | 1.30 |

## 3.4 Computer Estimation of NOx Concentrations

The computer modeling process is preformed in two parts:

1. Creation of pollutant concentration data base using Caline4 software.
2. Post processing of output from Caline4→ Creation of pollution concentration distribution maps using ESRI ArcGIS 9.0.

To perform Task 1, the software used was CalroadView designed by Lakes Environmental Inc. The reason for using CalroadView over the free version of Caline4 is the GUI provided by Calroadview and $NO_2$ modeling ability. In this section whenever and where ever Caline4 is mentioned, CalroadView software is meant.

In order to determine worst-case ambient concentrations, the following assumption was made:

**Max. Ambient Concentration = Function (Max. Emission Factor, Worst-Case Meteorology)** (3.1)

The flow chart shown in Fig. 3.3 explains how, the above assumption was incorporated in order to obtain pollution concentration using Caline4.

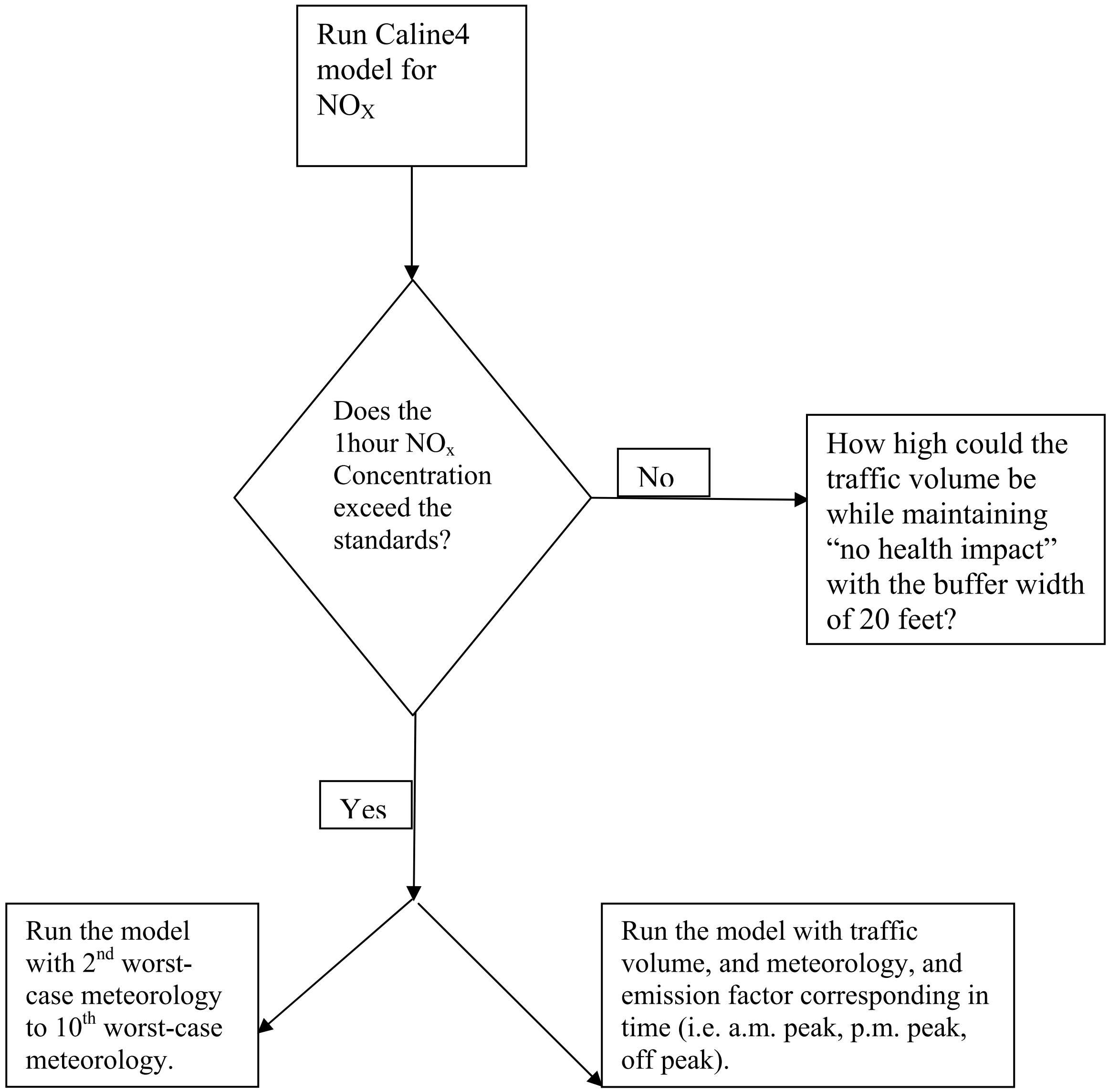



Figure 3.3 Flow Chart for Caline4 Runs

Caline4 is broadly divided into five parts.

1. Job options
2. Meteorological options
3. Output options
4. Links
5. Receptors

Each of these parts is discussed in greater detail below.

### *3.4.1 Job Options*

Figure 3.4 below shows the job option screen.

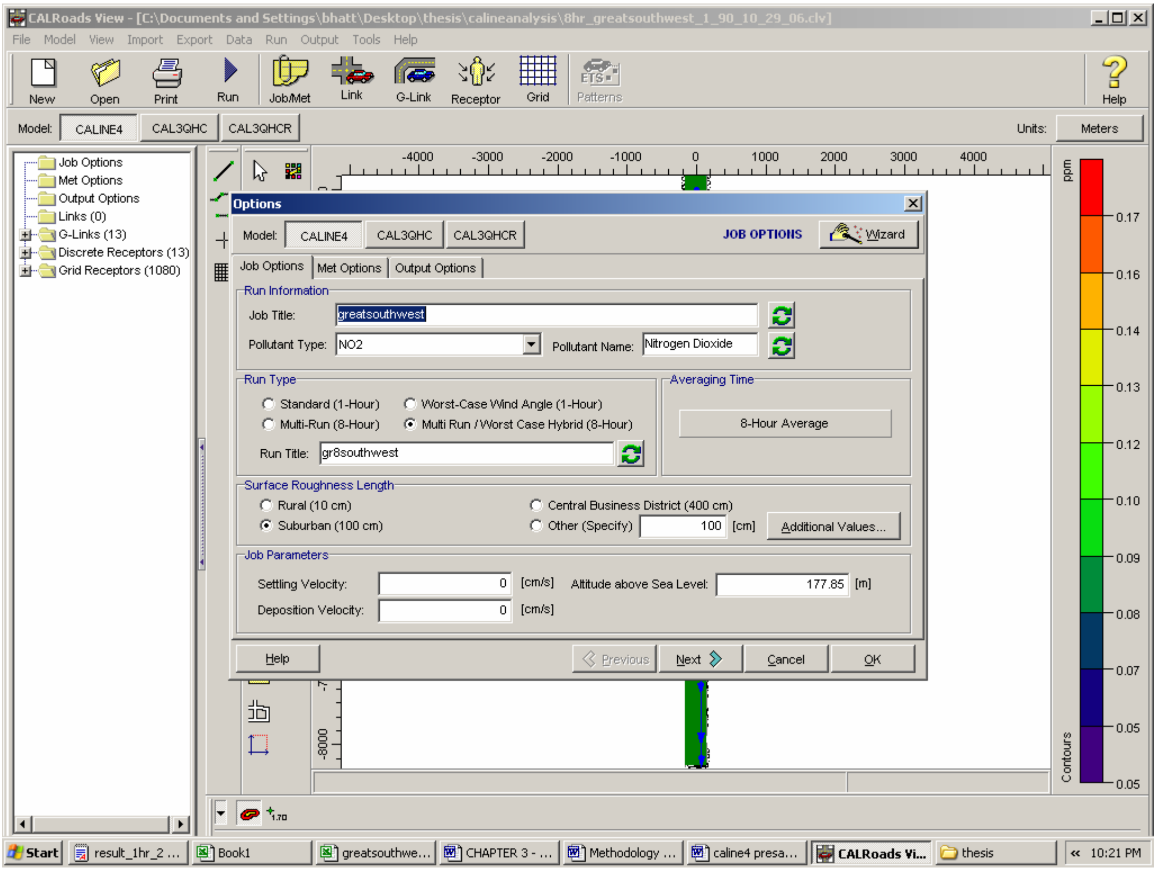



Fig. 3.4 The Job Options Screen

The following items are defined as job options:

1. Run Information

   - Job title (optional)

   - Pollutant Type

     Select one from CO, PM, $NO_2$, Inert Gases (such as $SF_6$)

2. Run Type
    - Standard – Calculates 1-hour average $NO_2$ concentrations at the receptors. The user must input a wind direction on the Run Conditions Screen.
    - Multi-Run – Calculates 8-hour average $NO_2$ concentrations at the receptors. The user must input wind angles for each hour.
    - Worst-case wind angle – Calculates 1-hour average $NO_2$ concentrations at the receptors. The model selects the wind angles that produce the highest $NO_2$ concentrations at each of the receptors. **This is the most appropriate choice for most users**.
    - Multi-Run/Worst-Case hybrid – Calculates 8-hour average $NO_2$ concentrations at the receptors. The model selects the wind angles that produce the highest $NO_2$ concentrations at each of the receptors.

3. Surface Roughness Length - This is a measure of the amount of local air turbulence that affects the spread of the plune. There are four radio buttons for quick selections :
    - Rural: Roughness Coefficient = 10 cm
    - Suburban: Roughness Coefficient = 100 cm
    - Central Business District: Roughness Coefficient = 400 cm
    - Other (see Table 3.3 below)

Table 3.3 Surface Roughness Length

| Roughness Coefficient (cm) | Landscape Type |
|---|---|
| .002 | Sea, paved areas, snow-covered flat plain, tide flat, smooth desert |
| .5 | Beaches, pack ice, morass, snow-covered fields |
| 3 | Grass prairie or farm fields, tundra, airports, heather |
| 10 | Cultivated areas with low crops and occasional obstacles (such as bushes) |
| 25 | High crops, crops with varied height, scattered obstacles (such as trees or hedgerows), vineyards |
| 50 | Mixed far fields and forest clumps, orchards, scattered buildings |
| 100 | Regular coverage with large obstacles, open spaces roughly equal to obstacle heights, suburban houses, villages, mature forests |
| ≥ 200 | Centers of large towns or cities, irregular forests with scattered clearings. |

4. Job Parameters

- Settling Velocity – This is the rate at which a particle falls with respect to its immediate surroundings. It is the actual physical velocity of the particle in the downward direction.
- Deposition Velocity- This is a measure of the rate at which a pollutant can be absorbed/adsorbed by a surface.
- Altitude above Sea Level - This gives the site altitude for the run. This data was taken from OBS 1300 data collection. The mean of all values for all runs is taken as input.

The following is the summary of job option inputs for this research.

Table 3.4 Summary of Input for Job Options

| Field Name | Value | Comments |
|---|---|---|
| Job Title | Great Southwest | |
| Pollutant Type | $NO_2$ | |
| Run Type | • Worst-case Wind Angle<br>• Worst-case Wind Angle Multi Run | 1-hour time average<br>8 hr time average |
| Surface Roughness | 100 cm | Suburban |
| Settling Velocity | 0 cm/s | $NO_2$ is a gas which does not have settling velocity |
| Deposition Velocity | 0 cm/s | Conservative Assumption |
| Altitude above sea level | 177.85 m | From OBS -1300 data |

*3.4.2 Meteorological Options*

Figure 3.5 below shows the Meteorological Options screen.

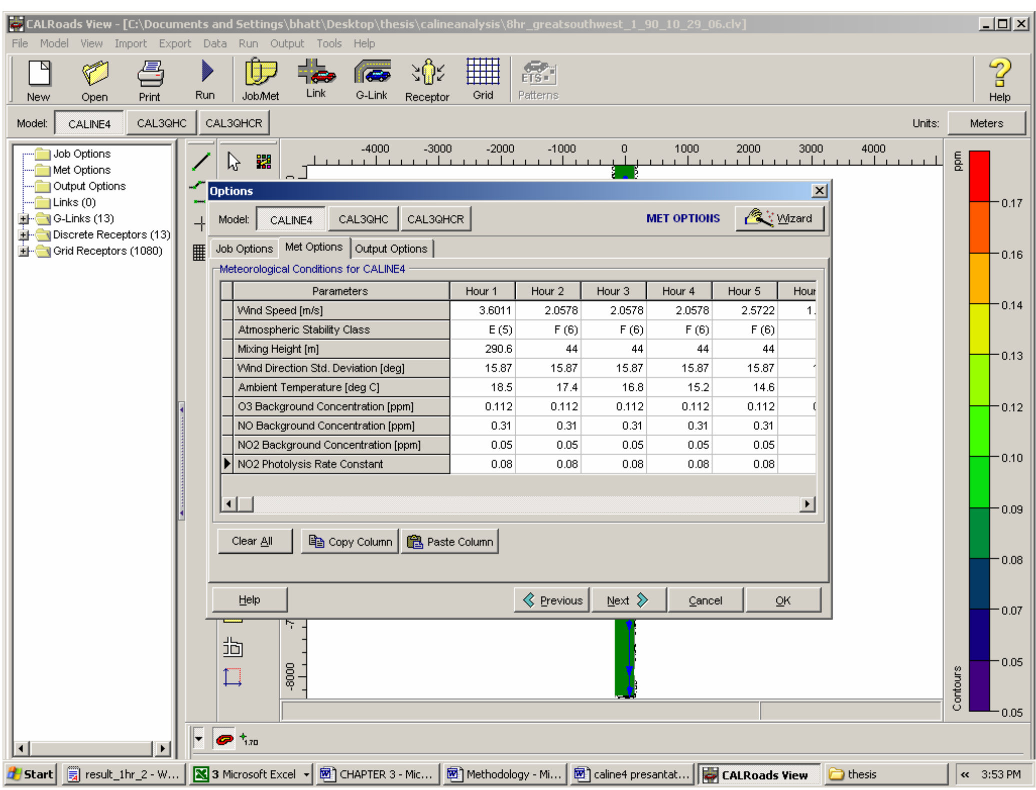



Fig. 3.5 Meteorological Option Screen

As shown in equation 3.1, meteorology is a key parameter in determining ambient pollutant concentrations. Thus it is very essential to consider 3 to 5 years meteorological data on an hourly basis. Caline4, however, does not have ability to process hourly meteorological data. In order to derive worst-case meteorology, 'Cal3hcqr' (intersection dispersion modeling software in CALROADS family, which has the ability to handle hourly meteorological data) was run with a unit emission factor for carbon monoxide (CO). The five meteorological conditions giving the highest CO concentrations were selected for years 1984, 1987, 1988, 1989, and 1990. The meteorological data was taken from the www.weblakes.com; the upper air data was not available for 1986 and CAL3HCQR was unable to process 1985 data, so these years were skipped. From these five years of data analyzed, the 10 worst-cases for time average 1-hour and 5 worst-cases for time average 8-hour were selected for modeling in Caline4. In order to do so, the following assumptions were made:

- Meteorological conditions creating the worst-case concentration for an intersection give the same effects for a segment.
- Meteorological conditions creating the worst-case concentration for CO create the same effects for $NO_2$.

These should be reasonable assumptions.

The meteorological files obtained from www.weblakes.com were not in a format which could be input into the model. PCRAMMET is a meteorological preprocessor used in the Cal3qhcr model. Rammet View, the Lakes Environmental interface for PCRAMMET, was used to preprocess the data for Cal3qhcr. The operations performed by Rammet View are:

- Calculation of hourly values for atmospheric stability from meteorological surface observations, and
- Interpolating the twice daily mixing heights to hourly values.

The inputs to Rammet View include an hourly surface data file and a mixing height data file. The hourly file and mixing height data file were obtained from the Lakes website in the SCRAM (MET 144) file format.

The meteorological stations chosen were Stephenville (upper air) and Dallas Fort Worth International Airport (surface, station number 03927). The default ASCII format was chosen for the files, to obtain a sequential hourly file. The anemometer height was 22 ft for upper air and the option to use the default values for the wind speed categories was chosen. An example of the Rammet output file with the various meteorological parameters is illustrated in Table 3.5. Table 3.6 and Table 3.7 summarize the worst-case meteorology for 1 -hour and 8-hour time averages, respectively.

Table 3.5 Rammet Output File

| **Year** | **Month** | **Day** | **Hour** | **Random Flow Vector** | **Wind Speed (m/s)** | **Ambient Temperature (K)** | **Stability Category** | **Rural Mixing Height (m)** | **Urban Mixing Height (m)** |
|---|---|---|---|---|---|---|---|---|---|
| 88 | 1 | 1 | 1 | 171 | 5.14 | 272 | 5 | 50 | 89 |

Table 3.6 Worst-Case Meteorology for 1-Hour Time Average

| Year | Month | Day | Hour | Wind Speed (m/s) | Amb. Temp (K) | Stability Class | Rural Mixing Height (m) | Urban Mixing Ht . (m) |
|---|---|---|---|---|---|---|---|---|
| 84 | 1 | 8 | 7 | 1.54 | 275.9 | 7 | 834.5 | 43 |
| 84 | 2 | 3 | 24 | 1.54 | 282 | 7 | 1432.9 | 61 |
| 84 | 3 | 3 | 19 | 5.66 | 294.3 | 4 | 998 | 998 |
| 84 | 3 | 28 | 4 | 12.35 | 282 | 4 | 1972.8 | 1972.8 |
| 87 | 4 | 17 | 2 | 1.54 | 289.8 | 7 | 1959.6 | 49 |
| 87 | 12 | 10 | 2 | 1.54 | 279.8 | 7 | 1115 | 45 |
| 87 | 12 | 29 | 21 | 1.03 | 272 | 7 | 660 | 437 |
| 88 | 6 | 12 | 5 | 2.57 | 289.3 | 6 | 1510.2 | 112 |
| 88 | 7 | 23 | 5 | 3.09 | 294.3 | 6 | 2253.1 | 82 |
| 88 | 9 | 11 | 24 | 7.20 | 301.5 | 4 | 1910.9 | 1910.9 |
| 88 | 11 | 14 | 5 | 6.69 | 291.5 | 4 | 1102.4 | 1102.4 |
| 89 | 3 | 13 | 4 | 5.14 | 287.6 | 5 | 953.5 | 103 |
| 89 | 4 | 17 | 2 | 6.17 | 290.9 | 4 | 828.3 | 828.3 |
| 89 | 12 | 10 | 2 | 6.17 | 281.5 | 4 | 1030.5 | 1030.5 |
| 89 | 12 | 29 | 23 | 6.17 | 279.8 | 4 | 377.6 | 377.6 |
| 90 | 1 | 10 | 2 | 2.06 | 279.3 | 6 | 835.4 | 38 |
| 90 | 2 | 1 | 1 | 1.03 | 285.9 | 4 | 503.2 | 503.2 |
| 90 | 2 | 2 | 1 | 2.57 | 283.2 | 6 | 778.1 | 54 |
| 90 | 12 | 14 | 7 | 1.54 | 281.5 | 4 | 421.8 | 421.8 |

Table 3.7 Worst-Case Meteorology for 8-Hour Time Average

| Year | Month | Day | Hour | Wind Speed (m/s) | Amb. Temp (K) | Stability Class | Rural Mixing Height (m) | Urban mixing Ht. (m) |
|---|---|---|---|---|---|---|---|---|
| 84 | 2 | 17 | 7 | 1.03 | 272 | 7 | 660 | 437 |
| 84 | 9 | 21 | 4 | 3.09 | 293.7 | 5 | 1048.8 | 674 |
| 84 | 10 | 11 | 10 | 5.14 | 296.5 | 3 | 198 | 536.4 |
| 84 | 11 | 13 | 7 | 2.06 | 279.3 | 6 | 1211.1 | 142 |
| 84 | 11 | 13 | 8 | 1.5 | 280.9 | 5 | 169 | 291.1 |
| 87 | 1 | 28 | 4 | 2.57 | 280.9 | 6 | 924.4 | 36 |
| 87 | 4 | 4 | 4 | 3.09 | 277.6 | 6 | 1823.5 | 114 |
| 87 | 9 | 2 | 23 | 2.57 | 296.5 | 6 | 1815.3 | 378.3 |
| 87 | 11 | 3 | 8 | 0 | 287.6 | 5 | 219.5 | 267.4 |
| 87 | 12 | 4 | 21 | 2.57 | 285.9 | 6 | 926.8 | 769.7 |
| 88 | 3 | 5 | 24 | 3.09 | 279.8 | 6 | 925.1 | 50 |
| 88 | 5 | 27 | 7 | 1.54 | 290.4 | 4 | 347.2 | 418.4 |
| 88 | 6 | 2 | 23 | 4.1155 | 293.2 | 4 | 426.7 | 426.7 |
| 88 | 9 | 12 | 1 | 7.72 | 300.4 | 4 | 1872.9 | 1872.9 |

Table 3.7 - continued

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 88 | 10 | 11 | 6 | 4.63 | 286.5 | 5 | 1186.3 | 93 |
| 89 | 1 | 28 | 4 | 5.14 | 284.3 | 4 | 215.3 | 215.3 |
| 89 | 6 | 21 | 11 | 5.69 | 304.8 | 3 | 1224.3 | 1299.7 |
| 89 | 9 | 2 | 23 | 3.61 | 303.7 | 5 | 2249 | 577.9 |
| 89 | 11 | 3 | 8 | 2.57 | 275.9 | 5 | 192.4 | 215 |
| 89 | 11 | 21 | 11 | 4.12 | 296.5 | 3 | 738.6 | 778.4 |
| 90 | 2 | 24 | 23 | 3.09 | 284.3 | 6 | 1830.9 | 342.8 |
| 90 | 2 | 25 | 2 | 3.61 | 283.2 | 5 | 1865.6 | 40 |
| 90 | 10 | 29 | 6 | 2.57 | 285.4 | 6 | 1624.9 | 44 |

The following parameters are defined as meteorological inputs:

1. Wind Speed (m/s)
2. Atmospheric Stability class – This is a measure of the turbulence of the atmosphere and defined by numbers 1-7 (1 most unstable and 7 most stable)
3. Mixing Height – It is defined as the altitude to which thermal turbulence occurs due to solar radiation. Mixing height is a cap to vertical mixing.
4. Pollutant Background Concentration

Maritime tropical wind blows most frequently from the south in Texas (Arya, 1999) so Arlington Municipal Airport (C61) http://www.tnrcc.state.tx.us serves as the best station for background concentrations for Great Southwest Parkway. Table 3.8 summarizes data obtained from this station. This station provides data as an hourly average and average, maximum, minimum, and standard deviation of 24 hours of a day. Since Caline4 can handle only one value, average, maximum, minimum, and standard deviation of 24 hours from Jan-04 to May-05 were considered and their average, maximum and minimum values are shown in Table 3.8. From this station pollutant background concentrations for Great Southwest, wind speed, and wind direction standard deviation were taken. After various trials, it was concluded that the maximum background concentration and minimum standard deviation of wind angle produce the maximum concentration at receptors.

Table 3.8 Summary of Meteorological Data (Hourly Averages)

| Wind Direction (Degrees) | | | | | Ozone (ppm) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Observed from Jan-04 to May-05 | | | | | Observed from Jan-04 to May-05 | | | | |
| | **Max.** | **Avg.** | **Min.** | **Stdev.** | | **Max.** | **Avg.** | **Min.** | **Stdev.** |
| **Max.** | 22.0 | 18.5 | 15.9 | 1.9 | **Max.** | 112 | 67.6 | 46.0 | 17.0 |
| **Avg.** | 10.4 | 7.90 | 5.67 | 1.43 | **Avg.** | 35.1 | 24.3 | 14.3 | 7.01 |
| **Min.** | 2.78 | 1.30 | 0.77 | 0.62 | **Min.** | 1.00 | 0.41 | 0.00 | 0.51 |
| NO (ppm) | | | | | $NO_2$ (ppm) | | | | |
| Observed from Jan-04 to May-05 | | | | | Observed from Jan-04 to May-05 | | | | |
| | **Max.** | **Avg.** | **Min.** | **Stdev.** | | **Max.** | **Avg.** | **Min.** | **Stdev.** |
| **Max.** | 309.5 | 138.2 | 37.2 | 71.8 | **Max.** | 49.6 | 36.9 | 18.3 | 8.54 |
| **Avg.** | 25.1 | 17.3 | 7.14 | 6.18 | **Avg.** | 15.1 | 10.9 | 5.77 | 3.03 |
| **Min.** | 2.50 | 1.20 | 0.00 | 0.76 | **Min.** | 2.60 | 1.17 | 0.00 | 0.66 |

*3.4.3 Output Options*

This option enables user to define link and receptor nomenclature. By default the system assigns capital alphabet letters to the links and numbers to the receptors. This pattern was maintained in this research. Fig. 3.6 below shows the screen of output options.

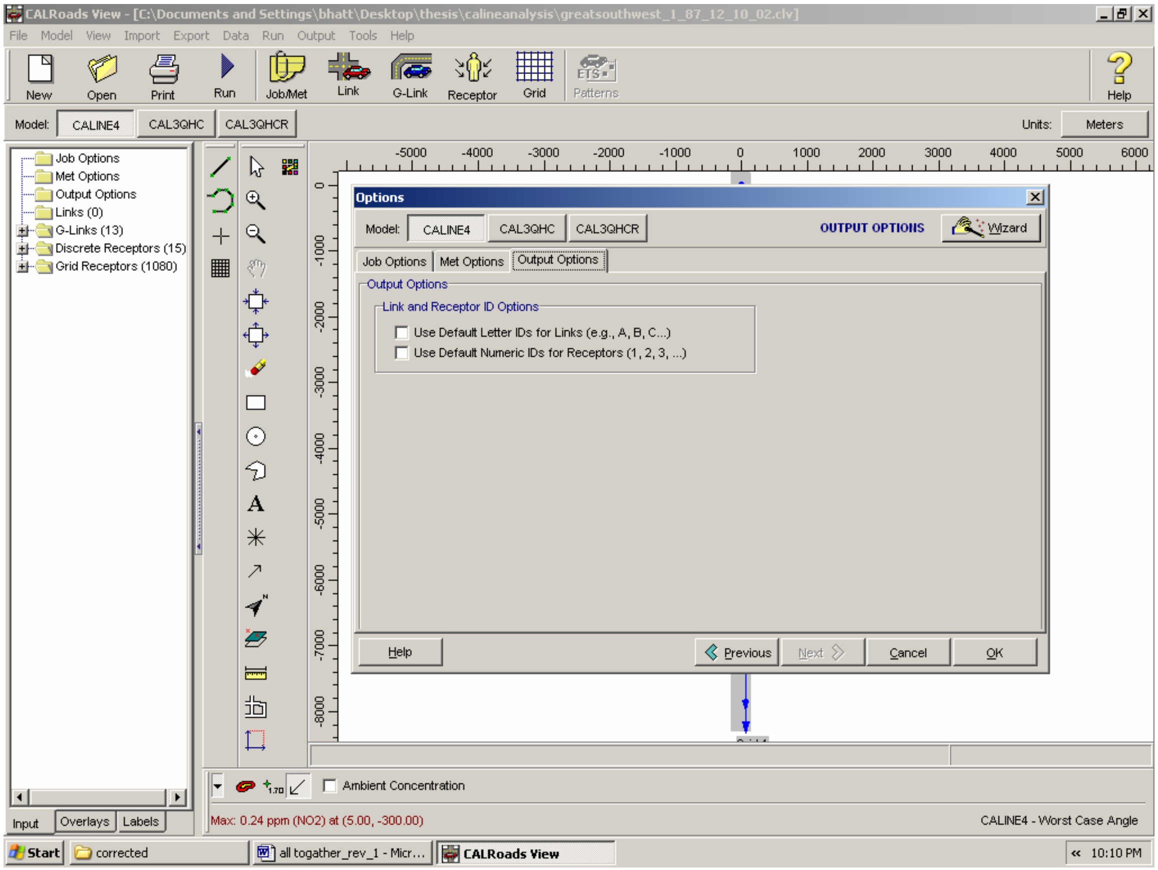



Fig. 3.6 The Output Options Screen

### *3.4.4 Link Options*

1. Link Geometry

The roadway segment of the Great Southwest Parkway under consideration was divided into 13 segments based upon the signalized intersections. The longitude and latitude data of every signalized intersection was taken from the Transportation Department of the North Central Texas Council of Governments (NCTCOG); this data was converted into an X-Y coordinate system, which is Caline4 compatible. This information is illustrated in Table 3.9. Caline4 has the ability to identify various kinds of link types, as discussed in Chapter 2. In the present research, all links were considered 'at grade'.

2. Link Activity

Traffic Volume: The hourly traffic volume anticipated to travel on each link, in units of vehicles per hour. If a multi-run scenario is selected, traffic volume must be defined for 8 hours. This data was obtained from NCTCOG. The maximum traffic volume per hour was 1428 on Great Southwest at the Bardin Street intersection. The maximum was used as a conservative assumption to model the worst-case scenario.

Emission Factor: The weighted average emission rate of the local vehicle fleet, expressed in terms of grams per mile per vehicle. The value used was 2.02 gram per vehicle mile traveled, which was the overall maximum from the on-road data collection, as discussed in Section 3.3.

Table 3.9 Link Geometry

| | | | | | After Setting First links at (0,0) | |
|---|---|---|---|---|---|---|
| **Longitude (Degrees)** | **Latitude (Degrees)** | **Radian Conversion of Latitude** | **X coordinate (Meters)** | **Y coordinate (Meters)** | **X coordinate (Meters)** | **Y coordinate (Meters)** |
| 97.0 | 32.7 | 0.571 | 93368 | 3633909 | 0.00 | 0 |
| 97.0 | 32.7 | 0.571 | 93371 | 3633596 | 3.00 | -313 |
| 97.0 | 32.7 | 0.571 | 93379 | 3632791 | 10.6 | -1118 |
| 97.0 | 32.7 | 0.571 | 93386 | 3631983 | 18.2 | -1926 |
| 97.0 | 32.7 | 0.571 | 93395 | 3631004 | 27.4 | -2905 |
| 97.0 | 32.7 | 0.571 | 93401 | 3630374 | 33.4 | -3535 |
| 97.0 | 32.7 | 0.571 | 93417 | 3628743 | 48.7 | -5166 |
| 97.0 | 32.7 | 0.570 | 93424 | 3627928 | 56.4 | -5981 |
| 97.0 | 32.7 | 0.570 | 93430 | 3627374 | 61.6 | -6535 |
| 97.0 | 32.7 | 0.570 | 93431 | 3627237 | 62.9 | -6672 |
| 97.0 | 32.7 | 0.570 | 93434 | 3626909 | 66.0 | -7000 |
| 97.0 | 32.7 | 0.570 | 93437 | 3626632 | 68.6 | -7277 |
| 97.0 | 32.7 | 0.570 | 93443 | 3625908 | 75.4 | -8001 |
| 97.0 | 32.7 | 0.570 | 93447 | 3625577 | 78.6 | -8332 |

### *3.4.5 Receptor Options*

Grid receptors were used to define receptor locations 1080 receptors were defined with longitudinal spacing of 500 m and lateral spacing of 5 m. The origin of the grid was set at the southwest corner with coordinates (-150,-8300).

## 3.5 Post-Processing of Output in GIS

With all above input, Caline4 runs were conducted and no exceedances were observed; therefore vehicle volume was increased to see at what traffic volume an exceedance occurs at a buffer width of 20 feet. With this data contours were generated in ArcGIS as follows:

1. Output from Caline4 was saved in .rtf format.
2. Data from the .rtf file was then imported in to a spreadsheet.

3. The spreadsheet was saved in .csv format, since .xls format is not compatible with M.S. Access.
4. The .csv was then converted into M.S. Access data base.
5. Using the entire data base a shape file was created using ArcCatalog. The set of the data base and shape file were jointly known as ‘personal geodata base’.
6. Using ArcMap and ArcSeen, various maps were created (see Chapter 4).

CHAPTER 4

RESULTS AND DISCUSSION

## 4.1 Overview

### *4.1.1 Introduction*

As discussed in Chapter 3, $NO_x$ emissions data was collected on Great Southwest Parkway. The emissions data were used as an input to Caline4. This chapter presents dispersion modeling results.

### *4.1.2 Data Interpretation and Emission Factor Calculation*

Using various variables mentioned in Table 4.1, Munshi et al. developed a database and calculated the emission factor for $NO_X$ for the Great Southwest Parkway corridor for every run. Table 4.2 shows the typical summary sheet developed by the research team and Table 4.3 shows the summary of emission factors.

Table 4.1 OBS-1300 Parameters

| | |
|---|---|
| 1. Date and time | 2. $NO_x$ concentration (ppm) |
| 3. Air to Fuel Ratio (AFR) | 4. Exhaust flow rate (L/min) |
| 5. Exhaust Temperature (°C) | 6. Exhaust Pressure (kPa) |
| 7. Ambient Temperature (°C) | 8. Ambient Pressure (kPa) |
| 9. Humidity (%) | 10. Velocity (km/hour) |
| 11. Latitude (degree) | 12. Longitude (degree) |
| 13. Altitude (m) | 14. GPS Velocity (km/hour) |
| 15. North/South | 16. East/West |
| 17. No of Satellites | |

(Munshi, 2005)

Table 4.2 Typical Summary Data Sheet for Each Day

| | | |
|---|---|---|
| Date: | 11/16/2004 | |
| | AM | PM |
| Driver: | Vyethavya | --- |

| | AM Peak | Off-Peak |
|---|---|---|
| No of Runs in North | 2 | 3 |
| No of Runs in South | 2 | 3 |
| Trip Duration | 3054.00 | 4185.00 |

| AM Peak Run | N | S | N | S |
|---|---|---|---|---|
| Parameters | Run1 | Run2 | Run3 | Run4 |
| Trip Duration (seconds) | 686.00 | 768.00 | 776.00 | 824.00 |
| Total Speed (miles/hour) | 28.24 | 25.24 | 24.96 | 23.42 |
| Control Delay (seconds) | 133.00 | 140.00 | 197.00 | 198.00 |
| Total No. of Stops per Run | 5.00 | 6.00 | 6.00 | 7.00 |
| Concentration of NOx (g/mile) | 0.88 | 0.62 | 0.88 | 0.66 |

| Off-Peak Run | N | S | N | S | N | S |
|---|---|---|---|---|---|---|
| Parameters | Run1 | Run2 | Run3 | Run4 | Run5 | Run6 |
| Trip Duration (seconds) | 686.00 | 686.00 | 755.00 | 686.00 | 686.00 | 686.00 |
| Total Speed (miles/hour) | 30.20 | 35.31 | 25.53 | 31.48 | 32.26 | 30.98 |
| Control Delay (seconds) | 110.00 | 53.00 | 177.00 | 111.00 | 77.00 | 66.00 |
| Total No. of Stops per Run | 3.00 | 2.00 | 6.00 | 1.00 | 4.00 | 6.00 |
| Concentration of NOx (g/mile) | 0.95 | 0.62 | 0.69 | 0.62 | 0.75 | 0.68 |

(Munshi, 2005)

Table 4.3 Summary of Emission Factors

| **Emission Factor (EF), gram/mile** | **Overall** | **A.M. peak** | **Off-peak** | **P.M. peak** |
|---|---|---|---|---|
| **Max. EF** | 2.02 | 1.22 | 2.02 | 1.74 |
| **Min. EF** | 0.36 | 0.58 | 0.58 | 0.77 |
| **Average EF** | 1.08 | 0.81 | 0.78 | 1.30 |

This research aims to model the worst-case concentration; hence the maximum emission factor from all runs was used. This emission factor is associated with the Northbound Off-Peak run taken on November 14th, 2004.

## 4.2 Determination of the Worst-Case Meteorology

In order to determine worst-case meteorology, CAL3QHCR was run using five years meteorological data (see Chapter 3). Worst-case meteorology was determined based on concentration of CO. To identify the 10 worst-cases of meteorology for 1-hour time average, all results of CAL3QHCR were observed. The top 5 worst-cases were extracted from each year (first 3 if CO concentration was considerably low with respect to CO concentration of other years). This exercise is summarized in Table 4.4. The top 10 worst-cases of meteorology derived from Table 4.4 are summarized in Table 4.5. A similar procedure was repeated for 8-hour time average, and results are summarized in Tables 4.6 and 4.7. Table 4.8 and Figure 4.3 break out worst-case meteorology occurrences according to season.

Table 4.4 Meteorological Conditions Giving Highest Concentrations for 1 Hour Time Average

| Serial Number | Year | Month | Day | Hour | Wind Speed (m/sec) | Ambient Temp (K) | Stability Class | Rural Mixing Ht. (m) | Urban Mixing Ht. (m) | Concentrations (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 84 | 1 | 8 | 7 | 1.54 | 275.9 | 7 | 835 | 43 | 30.6 |
| 2 | 84 | 2 | 3 | 24 | 1.54 | 282 | 7 | 1433 | 61 | 27.4 |
| 3 | 84 | 3 | 3 | 19 | 5.66 | 294.3 | 4 | 998 | 998 | 23.8 |
| 4 | 84 | 3 | 28 | 4 | 12.3 | 282 | 4 | 1973 | 1972.8 | 26.1 |
| 5 | 87 | 4 | 17 | 2 | 1.54 | 289.8 | 7 | 1960 | 49 | 29 |
| 6 | 87 | 12 | 10 | 2 | 1.54 | 279.8 | 7 | 1115 | 45 | 31.6 |
| 7 | 87 | 12 | 29 | 21 | 1.03 | 272 | 7 | 660 | 437 | 27.2 |
| 8 | 88 | 6 | 12 | 5 | 2.57 | 289.3 | 6 | 1510 | 112 | 22.6 |
| 9 | 88 | 7 | 23 | 5 | 3.09 | 294.3 | 6 | 2253 | 82 | 26.5 |
| 10 | 88 | 9 | 11 | 24 | 7.20 | 301.5 | 4 | 1911 | 1910.9 | 27.7 |
| 11 | 88 | 11 | 14 | 5 | 6.69 | 291.5 | 4 | 1102 | 1102.4 | 26.7 |
| 12 | 89 | 3 | 13 | 4 | 5.14 | 287.6 | 5 | 954 | 103 | 29 |
| 13 | 89 | 4 | 17 | 2 | 6.17 | 290.9 | 4 | 828 | 828.3 | 26.4 |
| 14 | 89 | 12 | 10 | 2 | 6.17 | 281.5 | 4 | 1031 | 1030.5 | 31.6 |
| 15 | 89 | 12 | 29 | 23 | 6.17 | 279.8 | 4 | 378 | 377.6 | 27.2 |
| 16 | 90 | 1 | 10 | 2 | 2.06 | 279.3 | 6 | 835 | 38 | 27.6 |
| 17 | 90 | 2 | 1 | 1 | 1.03 | 285.9 | 4 | 503 | 503.2 | 27 |
| 18 | 90 | 2 | 2 | 1 | 2.57 | 283.2 | 6 | 778 | 54 | 25.9 |
| 19 | 90 | 10 | 28 | 24 | 2.06 | 290.4 | 6 | 1620 | 44 | 25.5 |
| 20 | 90 | 12 | 14 | 7 | 1.54 | 281.5 | 4 | 422 | 421.8 | 20.6 |

Table 4.5 Top Ten Worst-Case Meteorological Conditions for 1 Hour Time Average

| Order Number | Year | Month | Day | Hour | Wind Speed (m/sec) | Ambient Temp (K) | Stability Class | Rural Mixing Ht (m) | Urban Mixing Ht (m) | Concentrations (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 87 | 12 | 10 | 2 | 1.54 | 279.8 | 7 | 1115 | 45 | 31.6 |
| 2 | 89 | 12 | 10 | 2 | 6.17 | 281.5 | 4 | 1031 | 1031 | 31.6 |
| 3 | 84 | 1 | 8 | 7 | 1.54 | 275.9 | 7 | 834.5 | 43 | 30.6 |
| 4 | 89 | 3 | 13 | 4 | 5.14 | 287.6 | 5 | 953.5 | 103 | 29 |
| 5 | 87 | 4 | 17 | 2 | 1.54 | 289.8 | 7 | 1960 | 49 | 29 |
| 6 | 88 | 9 | 11 | 24 | 7.20 | 301.5 | 4 | 1911 | 1911 | 27.7 |
| 7 | 90 | 1 | 10 | 2 | 2.06 | 279.3 | 6 | 835.4 | 38 | 27.6 |
| 8 | 84 | 2 | 3 | 24 | 1.54 | 282 | 7 | 1433 | 61 | 27.4 |
| 9 | 87 | 12 | 29 | 21 | 1.03 | 272 | 7 | 660 | 437 | 27.2 |
| 10 | 89 | 12 | 29 | 23 | 6.17 | 279.8 | 4 | 378 | 378 | 27.2 |

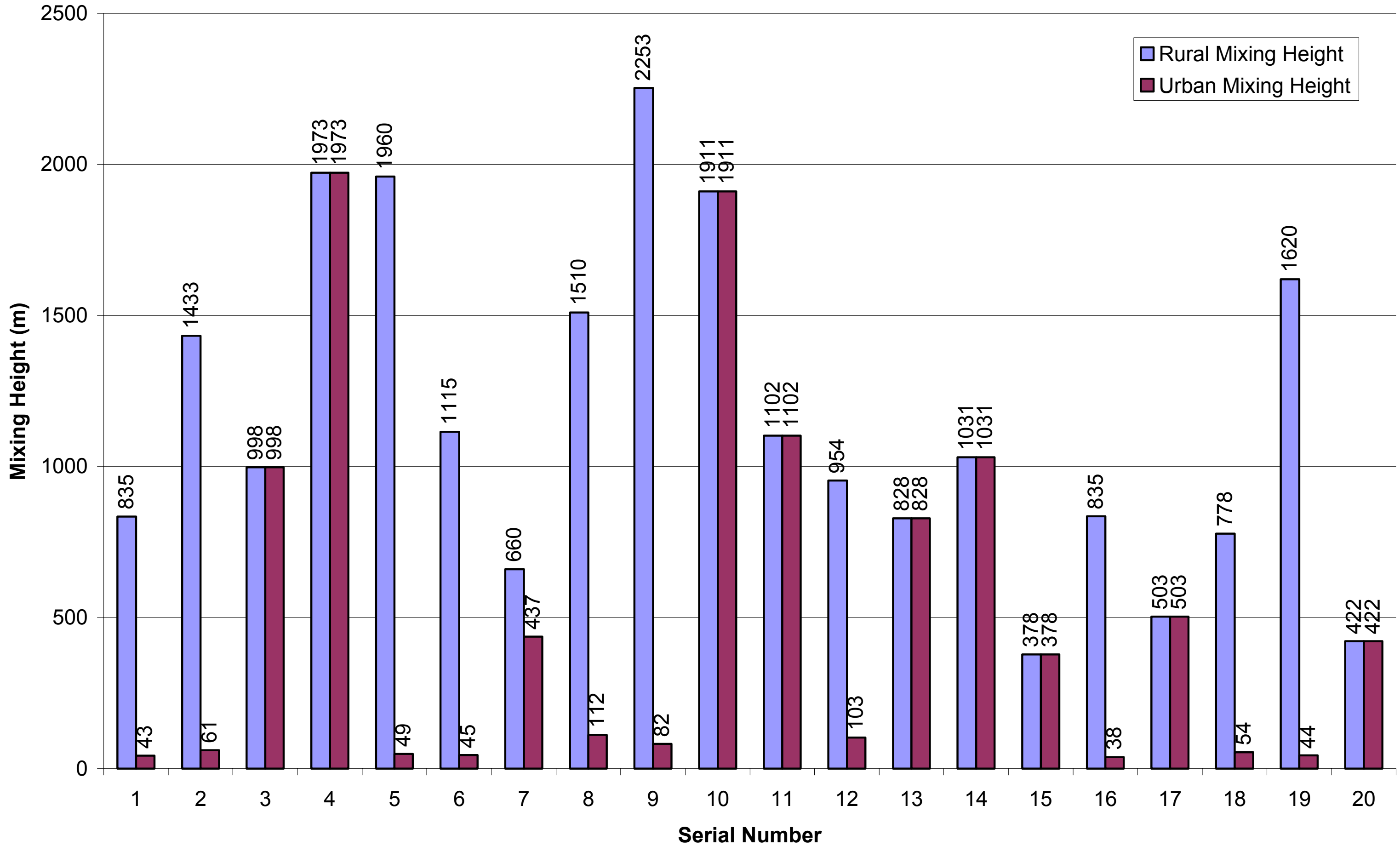



Fig. 4.1. Comparison of Rural and Urban Mixing Heights for 1-Hour Time Average

Table 4.6 Meteorological Conditions Giving Highest Concentrations for 8 Hour Time Average.

| **Serial Number** | **Year** | **Month** | **Day** | **Hour** | **Wind Speed (m/sec)** | **Ambient Temp (K)** | **Stability Class** | **Rural Mixing Ht. (m)** | **Urban Mixing Ht. (m)** | **Concentrations (ppm)** |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 84 | 2 | 17 | 7 | 1.03 | 272 | 7 | 660 | 437 | 13.1 |
| 2 | 84 | 9 | 21 | 4 | 3.09 | 293.7 | 5 | 1049 | 674 | 12.6 |
| 3 | 84 | 10 | 11 | 10 | 5.14 | 296.5 | 3 | 198 | 536.4 | 15.2 |
| 4 | 84 | 11 | 13 | 7 | 2.06 | 279.3 | 6 | 1211 | 142 | 15.0 |
| 5 | 84 | 11 | 13 | 8 | 1.54 | 280.9 | 5 | 169 | 291.1 | 13.6 |
| 6 | 87 | 1 | 28 | 4 | 2.57 | 280.9 | 6 | 924 | 36 | 12.3 |
| 7 | 87 | 4 | 4 | 4 | 3.09 | 277.6 | 6 | 1824 | 114 | 9.3 |
| 8 | 87 | 9 | 2 | 23 | 2.57 | 296.5 | 6 | 1815 | 378.3 | 11.2 |
| 9 | 87 | 11 | 3 | 8 | 0.00 | 287.6 | 5 | 220 | 267.4 | 13.1 |
| 10 | 87 | 12 | 4 | 21 | 2.57 | 285.9 | 6 | 927 | 769.7 | 9.4 |
| 11 | 88 | 3 | 5 | 24 | 3.09 | 279.8 | 6 | 925 | 50 | 13.3 |
| 12 | 88 | 5 | 27 | 7 | 1.54 | 290.4 | 4 | 347 | 418.4 | 11.1 |
| 13 | 88 | 6 | 2 | 23 | 4.12 | 293.2 | 4 | 427 | 426.7 | 12.2 |
| 14 | 88 | 9 | 12 | 1 | 7.72 | 300.4 | 4 | 1873 | 1872.9 | 13.3 |
| 15 | 88 | 10 | 11 | 6 | 4.63 | 286.5 | 5 | 1186 | 93 | 12.8 |
| 16 | 89 | 1 | 28 | 4 | 5.14 | 284.3 | 4 | 215 | 215.3 | 12.3 |
| 17 | 89 | 6 | 21 | 11 | 5.66 | 304.8 | 3 | 1224 | 1299.7 | 10.6 |
| 18 | 89 | 9 | 2 | 23 | 3.60 | 303.7 | 5 | 2249 | 577.9 | 11.3 |
| 19 | 89 | 11 | 3 | 8 | 2.57 | 275.9 | 5 | 192 | 215 | 9.2 |
| 20 | 89 | 11 | 21 | 11 | 4.12 | 296.5 | 3 | 739 | 778.4 | 9.7 |
| 21 | 90 | 2 | 24 | 23 | 3.09 | 284.3 | 6 | 1831 | 342.8 | 10.7 |
| 22 | 90 | 2 | 25 | 2 | 3.60 | 283.2 | 5 | 1866 | 40 | 12.5 |
| 23 | 90 | 10 | 29 | 6 | 2.57 | 285.4 | 6 | 1625 | 44 | 17.0 |

Table 4.7 Top Five Worst-case Meteorological Concentrations for 8 Hour Time Average

| **Order Number** | **Year** | **Month** | **Day** | **Hour** | **Wind Speed (m/sec)** | **Ambient Temp (K)** | **Stability Class** | **Rural Mixing Ht (m)** | **Urban Mixing Ht (m)** | **Concentrations (ppm)** |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 90 | 10 | 29 | 6 | 2.57 | 285.4 | 6 | 1625 | 44 | 17.0 |
| 2 | 84 | 10 | 11 | 10 | 5.14 | 296.5 | 3 | 198 | 536.4 | 15.2 |
| 3 | 84 | 10 | 11 | 10 | 5.14 | 296.5 | 3 | 198 | 536.4 | 15.2 |
| 4 | 84 | 11 | 13 | 8 | 1.54 | 280.9 | 5 | 169 | 291.1 | 13.6 |
| 5 | 84 | 11 | 13 | 7 | 2.06 | 279.3 | 6 | 1211 | 142 | 15.0 |

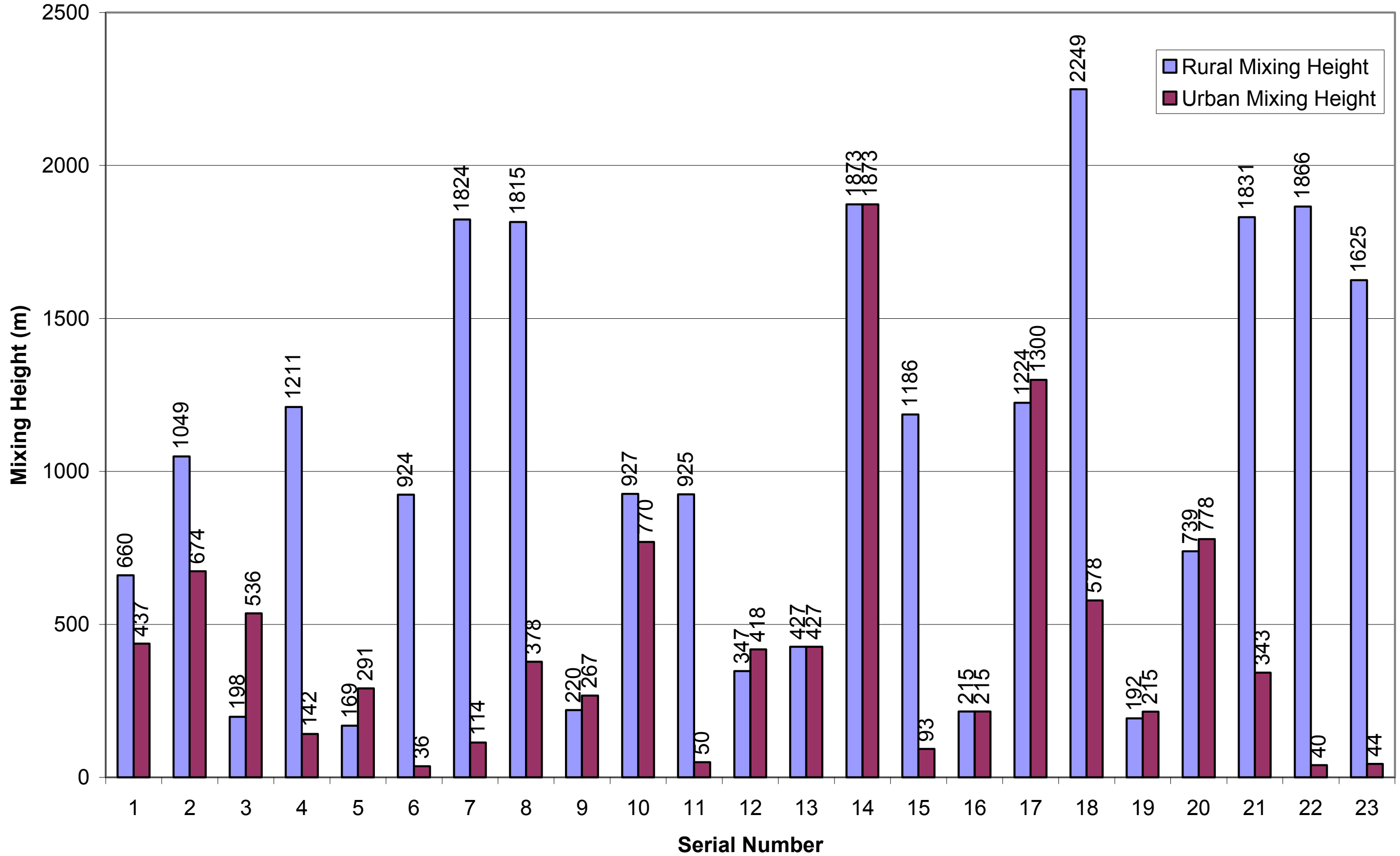



Fig. 4.2. Comparison of Rural and Urban Mixing Heights for 8-Hour Time Average.

Table 4.8 Worst-Case Meteorological Occurrences by Season

| | | | 1984 | 1987 | 1988 | 1989 | 1990 | Frequency of Occurrence | Total |
|---|---|---|---|---|---|---|---|---|---|
| Spring | Mar. 21- June 21 | March | 28 | | | | | 1 | |
| | | April | | | | 17 | | 1 | |
| | | May | | | 27 | | | 1 | |
| | | June | | | 2,12 | 21 | | 3 | 6 |
| Summer | June 22 – Sept. 21 | June | | | | | | 0 | |
| | | July | | | 23 | | | 1 | |
| | | August | | | | | | 0 | |
| | | September | 21 | 2 | 11,1 2 | 2 | | 5 | 6 |
| Fall | Sept. 22 – Dec. 21 | September | | | | | | 0 | |
| | | October | 11 | | 11 | | 12,2 8,29 | 5 | |
| | | November | 13 | 3 | 14 | 3,21 | | 5 | |
| | | December | | 4,10 | | 8,10 | 14 | 5 | 15 |
| Winter | Dec. 22- Mar. 20 | December | | | | 29 | | 1 | |
| | | January | 8 | | | 28 | 10 | 3 | |
| | | February | 3,17 | | | | 1,2,2 4,25 | 6 | |
| | | March | 3 | 4,17 | 5 | 13 | | 5 | 15 |

(Note:- Numbers in columns headed 1984-1990 show dates of occurrence)

### *4.2.1 Observations/Discussion of Table 4.3 – Table 4.6 and Figures 4.1 & 4.2*

- From Table 4.3, 16 out of 20 cases of worst-case meteorology occurred between mid-night to early morning 7 a.m. (hours 24 to 7). Only 3 cases of worst-case meteorology occurred during rush hours (hours 7 to 17). During the night, traffic volumes are generally lower than during the day, and lower than volumes used as Caline4 inputs. Thus, pairing worst-case meteorology (which occurs from hours

24 to 7) with worst-case emissions (which occurs from hours 7 to 17) was a conservative assumption since the two are not likely to occur at the same time.

- Worst-case concentration for 8 hour time average in Cal3qhr indicates concentration at the end of the $8^{th}$ hour. From Table 4.6, 13 out of 23 worst-case meteorological occurrences range from mid night to early morning (7 a.m.).
- The higher the turbulence in the atmosphere, the lower is the pollutant concentration in atmosphere due to higher mixing/dispersion. Temperature gradient causes thermal turbulence and horizontal component of wind velocity causes mechanical turbulence in atmosphere. Out of the 43 cases of worst-case meteorology (20 from Table 4.3 and 23 from Table 4.5), only 4 cases have a wind velocity greater than or equal to 7 m/s; most wind speeds vary between 1 - 3 m/s, both inclusive. Out of the 43 cases, only 2 cases have temperatures greater than $25^{o}$ C ($77^{o}$ F), and the majority of cases have temperature between -2 – $13^{o}$C ($35.6^{o}$ F – $55.4^{o}$F). Warmer temperatures are often associated with solar heating of the ground surface, which generates temperature gradients that cause instability and thermal turbulence. Hence we can say that conditions with lower wind speed and low temperatures favor low mechanical and thermal turbulence.
- Stability class is a measure of atmospheric turbulence. As discussed earlier, conditions are favoring low mechanical and thermal turbulence, so stability class varies form 4 (Neutral) to 7 (extremely stable). The most prevailing stability class is 7 (5 cases out of 10). However, one outlier observation is the $2^{nd}$ from Table 4.6, which has wind speed of nearly 5 m/s, temperature more than $20^{o}$C and

urban mixing height higher than rural mixing height (mixing height is discussed later in this section). This may explained by the argument that the worst-case wind angle is causing the higher concentration rather than simply meteorology.

- Mixing height is defined as the altitude to which thermal mixing occurs due to solar heating of the ground. In other words, it defines the vertical limit of mixing. The lower the mixing height, the higher is the possibility of a pollutant being trapped, causing a higher concentration of the pollutant. An interesting observation is made that in majority for cases, urban mixing height is much lower than rural mixing height (6 out of 10 cases in Table 4.4 and 3 out of 5 in Table 4.7). Comparisons are made between urban and rural mixing heights in Figures 4.1 and 4.2. Land is much more open and uncovered in rural areas, while asphalt and concrete roads cover the majority of lands in urban areas. Concrete and asphalt have lower heat absorbing capacities than open land/soil, which means they liberate infrared radiation more quickly at night. This means the Earth's surface could be cooler than the overlying air, which would lead to a radiation inversion, which could explain the lower mixing height.

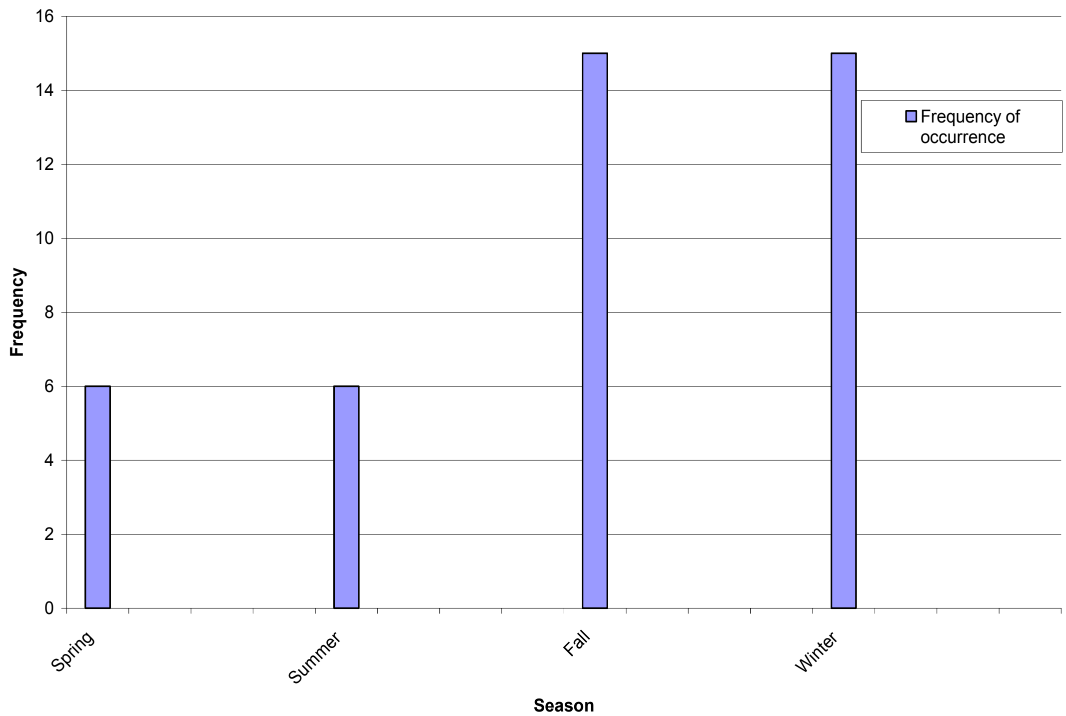



Fig 4.3 Frequency of Worst-Case Meteorological Occurrence by Season

### *4.2.2 Observation/Discussion of Table 4.8 and Figure 4.3*

In summer, strong solar radiation heats the ground surface, which causes thermal turbulence in the atmosphere. In summer thermal turbulence typically prevails and the atmosphere remains well mixed. These are favorable conditions for high dispersion and low pollution concentrations. This is the reason why Figure 4.3 shows minimum frequency of worst-case meteorology in summer. Fall and winter have exactly the opposite situation to summer, with stable conditions occurring more frequently; hence, maximum frequencies of worst-cases happened during October to January (i.e. fall to winter). On-road testing showed that in fall vehicular pollution was higher (the maximum emission factor was observed on November 14, 2004). All the rush hour worst-case meteorology for 1-hour time average were observed in fall and winter ( November, December and January) except, one in September, which was during fall.

## 4.3 Caline4 Analysis

Worst-case meteorological data given in Table 4.5 for 1-hour time average and Table 4.7 for 8-hour time average were used as meteorological inputs (see Chapter 3 for more information on input to Caline4). Table 4.9 shows the Caline4 output of $NO_2$ concentrations at 90 receptors. Appendix A shows $NO_2$ concentrations in ppm at all 1080 receptors in the receptor grid. Table 4.10 summarizes the maximum concentration and its receptor location for all 10 runs for 1-hour time average and 5 runs for 8-hour time average.

Table 4.9 Caline4 Output – $NO_2$ Concentrations

| REC | REPTOR | BRG (DEG) | PRED CONC (ppm) | REC | REPTOR | BRG (DEG) | PRED CONC (ppm) |
|---|---|---|---|---|---|---|---|
| 1 | G1_1 | 11 | 0.07 | 46 | G1_46 | 167 | 0.07 |
| 2 | G1_2 | 11 | 0.07 | 47 | G1_47 | 168 | 0.07 |
| 3 | G1_3 | 11 | 0.07 | 48 | G1_48 | 168 | 0.07 |
| 4 | G1_4 | 11 | 0.07 | 49 | G1_49 | 169 | 0.07 |
| 5 | G1_5 | 11 | 0.07 | 50 | G1_50 | 169 | 0.07 |
| 6 | G1_6 | 11 | 0.07 | 51 | G1_51 | 170 | 0.07 |
| 7 | G1_7 | 12 | 0.07 | 52 | G1_52 | 170 | 0.07 |
| 8 | G1_8 | 12 | 0.07 | 53 | G1_53 | 170 | 0.07 |
| 9 | G1_9 | 12 | 0.07 | 54 | G1_54 | 170 | 0.07 |

Table 4.9 - continued

| | | | |
|---|---|---|---|
| 10 | G1_10 | 167 | 0.07 |
| 11 | G1_11 | 168 | 0.07 |
| 12 | G1_12 | 168 | 0.07 |
| 13 | G1_13 | 168 | 0.07 |
| 14 | G1_14 | 169 | 0.07 |
| 15 | G1_15 | 169 | 0.07 |
| 16 | G1_16 | 169 | 0.07 |
| 17 | G1_17 | 170 | 0.07 |
| 18 | G1_18 | 170 | 0.07 |
| 19 | G1_19 | 11 | 0.07 |
| 20 | G1_20 | 11 | 0.07 |
| 21 | G1_21 | 11 | 0.07 |
| 22 | G1_22 | 11 | 0.07 |
| 23 | G1_23 | 11 | 0.07 |
| 24 | G1_24 | 11 | 0.07 |
| 25 | G1_25 | 12 | 0.07 |
| 26 | G1_26 | 12 | 0.07 |
| 27 | G1_27 | 12 | 0.07 |
| 28 | G1_28 | 167 | 0.07 |
| 29 | G1_29 | 168 | 0.07 |
| 30 | G1_30 | 168 | 0.07 |
| 31 | G1_31 | 169 | 0.07 |
| 32 | G1_32 | 169 | 0.07 |
| 33 | G1_33 | 169 | 0.07 |
| 34 | G1_34 | 170 | 0.07 |
| 35 | G1_35 | 170 | 0.07 |
| 36 | G1_36 | 170 | 0.07 |
| 37 | G1_37 | 10 | 0.07 |
| 38 | G1_38 | 10 | 0.07 |
| 39 | G1_39 | 11 | 0.07 |
| 40 | G1_40 | 11 | 0.07 |
| 41 | G1_41 | 11 | 0.07 |
| 42 | G1_42 | 11 | 0.07 |
| 43 | G1_43 | 11 | 0.07 |
| 44 | G1_44 | 12 | 0.07 |
| 45 | G1_45 | 12 | 0.07 |

| | | | |
|---|---|---|---|
| 55 | G1_55 | 10 | 0.07 |
| 56 | G1_56 | 10 | 0.07 |
| 57 | G1_57 | 11 | 0.07 |
| 58 | G1_58 | 11 | 0.07 |
| 59 | G1_59 | 11 | 0.07 |
| 60 | G1_60 | 11 | 0.07 |
| 61 | G1_61 | 11 | 0.07 |
| 62 | G1_62 | 11 | 0.07 |
| 63 | G1_63 | 12 | 0.07 |
| 64 | G1_64 | 168 | 0.07 |
| 65 | G1_65 | 168 | 0.07 |
| 66 | G1_66 | 169 | 0.07 |
| 67 | G1_67 | 169 | 0.07 |
| 68 | G1_68 | 169 | 0.07 |
| 69 | G1_69 | 170 | 0.07 |
| 70 | G1_70 | 170 | 0.07 |
| 71 | G1_71 | 170 | 0.07 |
| 72 | G1_72 | 170 | 0.07 |
| 73 | G1_73 | 10 | 0.07 |
| 74 | G1_74 | 10 | 0.07 |
| 75 | G1_75 | 11 | 0.07 |
| 76 | G1_76 | 11 | 0.07 |
| 77 | G1_77 | 11 | 0.07 |
| 78 | G1_78 | 11 | 0.07 |
| 79 | G1_79 | 11 | 0.07 |
| 80 | G1_80 | 11 | 0.07 |
| 81 | G1_81 | 12 | 0.07 |
| 82 | G1_82 | 168 | 0.07 |
| 83 | G1_83 | 168 | 0.07 |
| 84 | G1_84 | 169 | 0.07 |
| 85 | G1_85 | 169 | 0.07 |
| 86 | G1_86 | 169 | 0.07 |
| 87 | G1_87 | 170 | 0.07 |
| 88 | G1_88 | 170 | 0.07 |
| 89 | G1_89 | 170 | 0.07 |
| 90 | G1_90 | 171 | 0.07 |

Where

REC = Record

BRG (DEG) = Worst-case wind angle in degree

PRED CONC (ppm) = Predicted concentration in ppm

Table 4.10 Caline4 Output – $NO_2$ Concentration with Position of Occurrence and Threshold Value

| Run No. | Run Type | Max Conc. (ppm) | Position X (m) | Position Y (m) | Exceedance Threshold (ppm) |
|---|---|---|---|---|---|
| 1 | 1 Hour | 0.16 | 0 | -300 | 0.19 |
| 2 | 1 Hour | 0.12 | 0 | -800 | 0.19 |
| 3 | 1 Hour | 0.15 | 0 | -300 | 0.19 |
| 4 | 1 Hour | 0.18 | 5 | -300 | 0.19 |
| 5 | 1 Hour | 0.13 | 5 | -1000 | 0.19 |
| 6 | 1 Hour | 0.14 | 0 | -300 | 0.19 |
| 7 | 1 Hour | 0.16 | 10 | -1000 | 0.19 |
| 8 | 1 Hour | 0.16 | 0 | -300 | 0.19 |
| 9 | 1 Hour | 0.12 | 0 | -300 | 0.19 |
| 10 | 1 Hour | 0.15 | 0 | -300 | 0.19 |
| 11 | 8 Hour | 0.17 | 0 | -300 | |
| 12 | 8 Hour | 0.17 | 0 | -300 | |
| 13 | 8 Hour | 0.15 | 0 | -300 | |
| 14 | 8 Hour | 0.15 | 0 | -300 | |
| 15 | 8 Hour | 0.15 | 0 | -300 | |

### 4.3.1 Observations/Discussions of Table 4.10

- As discussed in Chapter 3, the entire roadway was centered at X=0; as expected, most maximum concentrations occurred at X=0 (i.e. centerline). Some variation in position of the maximum concentration was because of the curvilinear profile of Great Southwest Parkway corridor. Due to worst-case wind angle selection, almost all maximum concentrations occurred at X=0 and Y=-300; this also includes contribution from all individual links.

- The method used for finding worst-case meteorology using Cal3qhcr is valid. The 8-hour concentration of $NO_X$ follows the degree of worseness of meteorology. However, 1-hour time average $NO_X$ concentration does not quite following this pattern, but 1-hour time average is a relatively small averaging period, so we can consider the discrepancy as an exception.
- Calculation of Threshold Value

  Hong Kong air quality standards (see Chapter 2) give an air quality health impact threshold 350 $\mu g/m^3$ for NOx. The following procedure was adopted to convert this value into ppm.

$$C_{mass} = \frac{1000 * MW * C_{ppm} * P}{RT}$$

MW = NOx molecular weight which is 31.6 g/gmole (assuming 90% NO and 10% $NO_2$)

Cppm = Concentration in units of ppm

P = Ambient Pressure (atm)

T = Ambient Temperature (Kelvin)

R = 0.08206 atm-l/gmol-K

Using the above formula, the 1-hour NOx standard of 350 $\mu g/m^3$ was found to equal to 0.19 ppm. No NOx standard was found with an 8-hour averaging time; thus, no 8-hour value is given in Table 4.10. In Table 4.10, the highest 1-hour concentration is 0.18 ppm; thus, the 0.19 ppm standard is not exceeded.

*4.3.2 Finding the Traffic Volume which Exceeds the Threshold limit of 0.19 ppm, Considering 20 Foot Buffer Width*

Since there was not any exceedance of the 0.19 ppm 1-hour standard with the current traffic volume, the traffic volume was increased to determine the theoretical level of traffic which would produce an exceedance of the standard 20' from the roadway edge. Twenty feet is a buffer width or setback distance required by some cities in residential and/or commercial areas. A filter strip made up of close-growing grasses or other vegetation used to convey sheet runoff from impervious surfaces. To achieve effective pollution removal from storm water runoff a 20 feet of filter strip is recommended; i.e. 20 foot buffer width (Storm Water Fact Sheets NCTCOG, 1998). Structures must be built a minimum 20 foot from the edge of the pavement.

Three discrete receptors were located at the centerline and on the both sides of the roadway at 20 foot from roadway edge (13.41 m from centerline). The following results were obtained by increasing the traffic volume, with first worst-case meteorological conditions.

Table 4.11 Concentration in ppm as a Function of Traffic Volume

| Receptor | Location (x,y) m ↓ / Traffic volume→ | Concentration in ppm | | | |
|---|---|---|---|---|---|
| | | 5000 | 10000 | 21000 | 20000 |
| 1 | (0,-300) | 0.21 | 0.27 | 0.33 | 0.38 |
| 2 | (-13.41,-300) | 0.13 | 0.16 | 0.18 | 0.20 |
| 3 | (13.41,-300) | 0.13 | 0.16 | 0.18 | 0.20 |

4.3.2.1 Observations/Discussion of Table 4.11

Health effect exceedance first takes place at centerline with traffic volume of 5000 vehicles/hr. Health effect exceedance is observed beyond the buffer width, when the traffic volume reaches 31,000 vehicles/hr, which is not realistic for Great Southwest Parkway. Hence, 20 feet (nearly 6 m) buffer width is adequate to protect human health from $NO_X$ exposure on Great Southwest Parkway. The methodology used was conservative. Emission factor was highest observed in van; however, van is a fairly new vehicle with relatively low emission factor.

## 4.4 GIS Analysis

CalroadView can plot concentration isopleths; however, to obtain more control over output format, ArcGIS had been chosen to plot dispersion maps. The following maps were developed using ArcGIS 9.0. Figure 4.4 shows the contour map of maximum concentrations of NOx with 1-hour time average. Figure 4.5 shows 3-D NOx distribution for 1-hour time average.

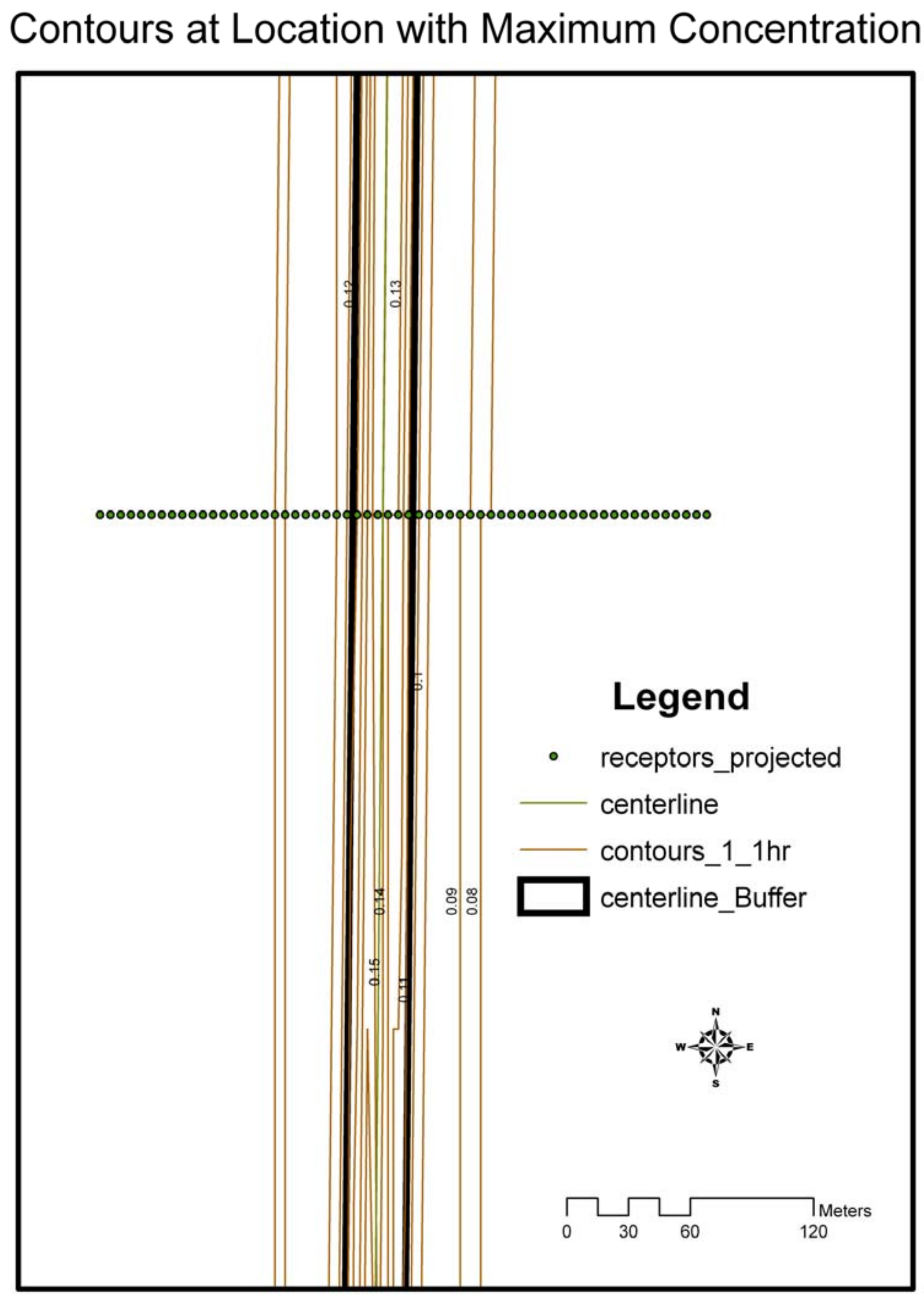



Fig. 4.4 Contour Map of Maximum 1-hour $NO_X$

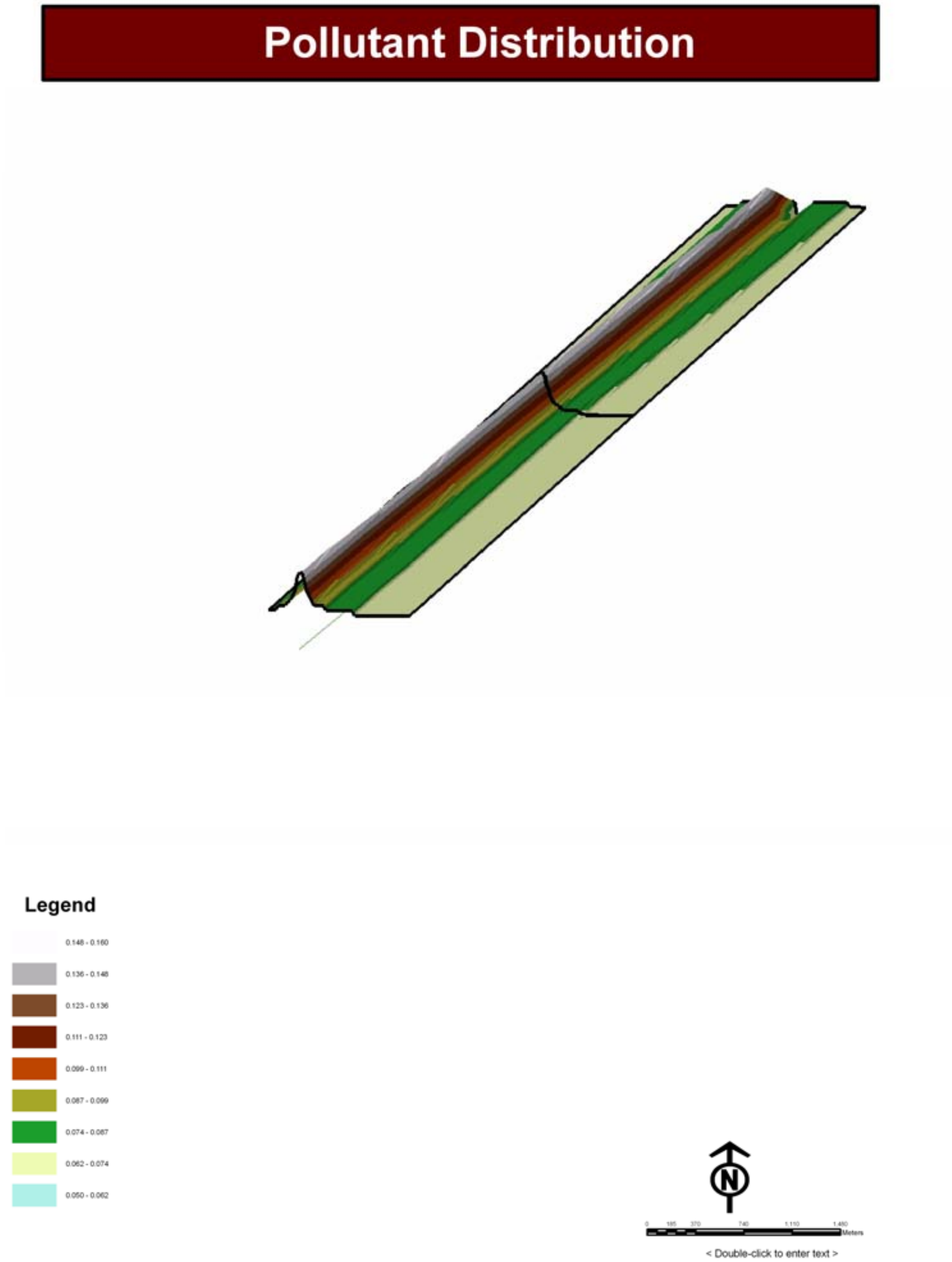



Fig. 4.5 3-Dimensional NOx Distribution, 1-Hour Time Average

Fig 4.5 was developed using ArcSCENE to generate the 3-D effect. To make the figure aesthetically pleasant, the figure is divided in two zones viz. North zone and South zone. To develop a 3-D effect, a Triangulated Irregular Network was created using surface analysis functionality of ArcGIS in the geostatistical analyst extension. Since contour values are small, it was not possible to make the 3-D effect visible plotting x, y and z to scale; thus z values were increased by a factor of 1000. Figures 4.6 and 4.7 show NOx dispersion in North zone and South zone, respectively. The pollutant concentration is highest at the center and decreases away from the center, following the bell-shaped curve typical of Gaussian dispersion behavior.

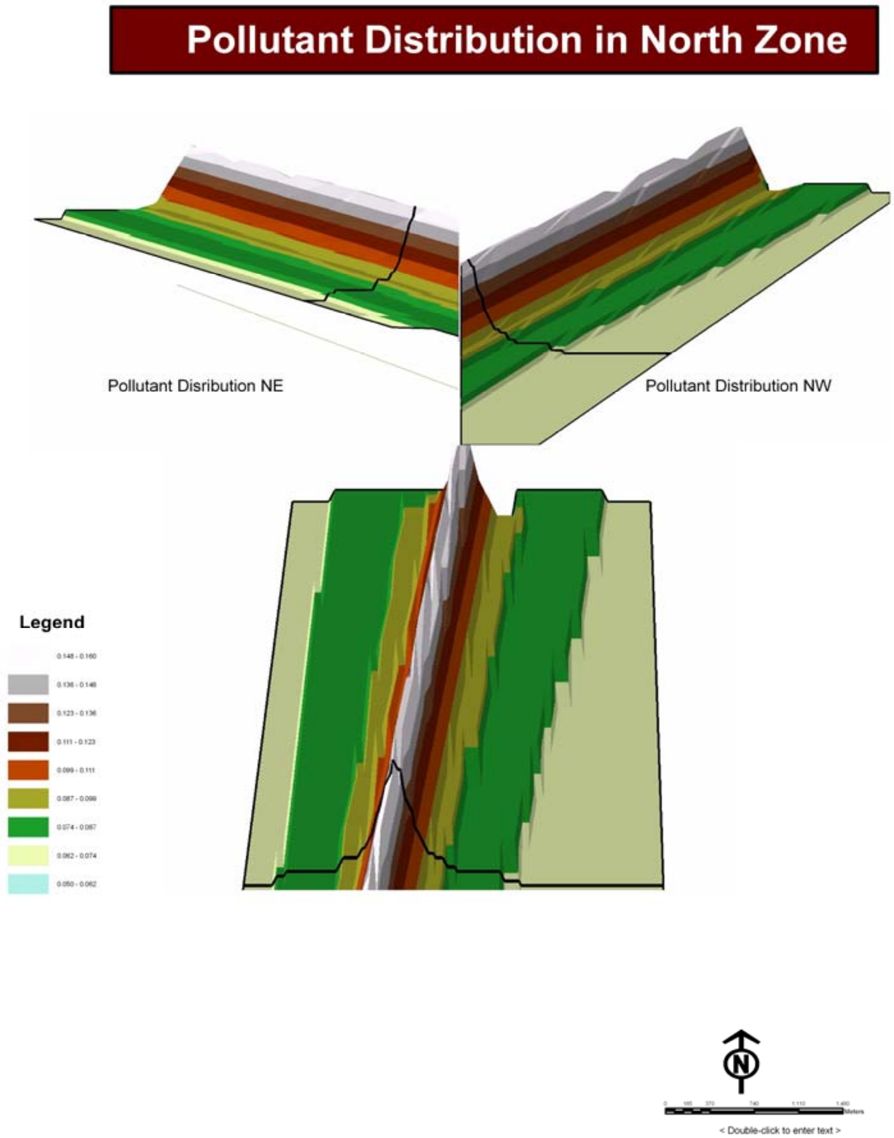



Fig. 4.6 NOx Concentration Distribution in North Zone, 1-Hour time Average

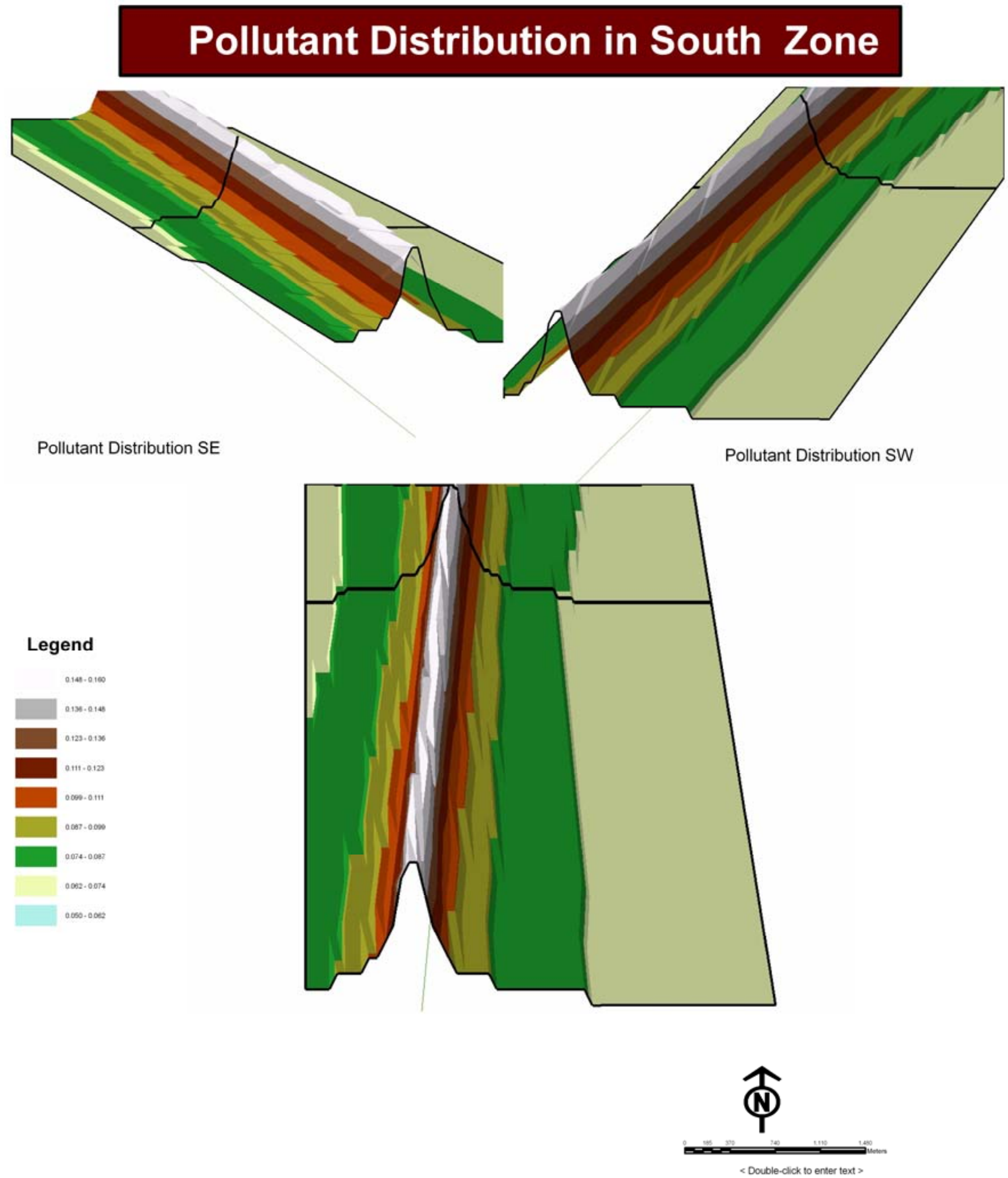



Fig. 4.7 NOx Concentration Distribution in South Zone, 1-Hour time Average

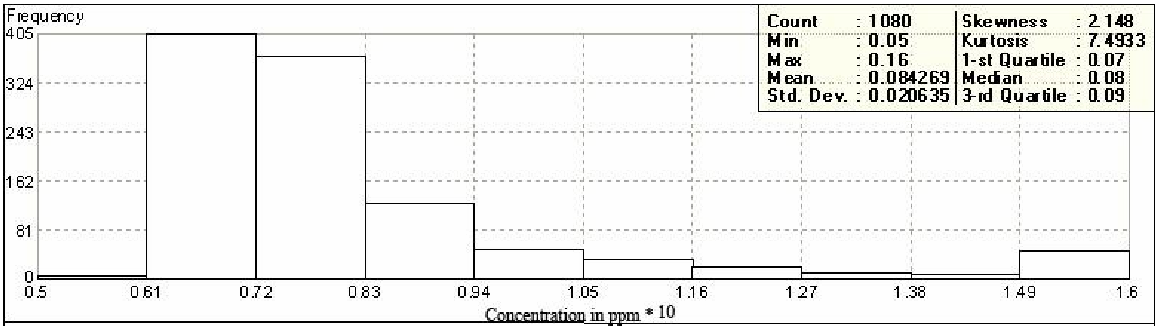



Fig. 4.8 $NO_X$ Concentration Frequency Distribution

Figure 4.8 shows a frequency distribution of the maximum 1-hour NOx concentration observed at each of the 1080 receptor. Geostatistical analyst of ArcGIS was used to obtain the distribution. The most frequently observed 1-hour maximum concentrations fall between 0.061 ppm and 0.083 ppm; in fact, over 700 of the 1080 values fall within this range. Figure 4.9 shows the contour map at the intersection of Great Southwest Parkway and Abrams street, superimposed on aerial photograph.

Contours at Intersection of Abrams street and Great Southwest Parkway


Fig. 4.9 Contour Map Superimposed with Aerial Photograph

CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

This research aimed to model NOx concentrations and determine a safe buffer width of roadway to protect human health from harmful exposure of $NO_X$. A number to Caline4 runs were made in order to model $NO_X$ concentration. After making careful observations in Chapter 4, the following conclusions can be drawn.

- A roadway buffer width of 20 feet (nearly 6 m) is adequate to protect human health from $NO_X$ along Great Southwest Pathway, assuming that the van is representative of vehicles on the roadway. This is non-conservative assumption since the van is relatively new and thus a relatively clean vehicle. Every individual with normal health is safe during this exposure. Traffic volumes on the roadway could increase by a factor of 15, and the 20 foot buffer width would still be sufficient to protect human health. The data used for the model were conservative, in that worst-case emission and meteorology were modeled simultaneously; this buffer width would thus likely be valid for any corridor with a similar traffic volume and number of signals.
- Worst-case meteorology for 1-hour time average is most likely to occur during night hours (Table 4.4); these are the hours when traffic tends to be at minimum.

Hence, it is highly unlikely that worst-case meteorology and maximum traffic volume could couple together and create maximum pollution concentrations.

- A distinct pattern was observed for worst-case meteorology when divided according to season. Fall and winter showed maximum frequency of worst-case meteorology; spring and summer showing the least. On-road testing showed that in fall vehicular pollution was higher (the maximum emission factor was observed on November 14, 2004). All the rush hour worst-case meteorology for 1-hour time average were observed in months of November, December and January, except one in September.
- The method used for finding worst-case meteorology using Cal3qhcr is valid. The 8-hour concentration of $NO_X$ follows the degree of worseness of meteorology. However, 1-hour time average $NO_X$ concentration does not quite following this pattern, but 1-hour time average is relatively small averaging period, so we can consider the discrepancy as an exception.

## 5.2 Recommendations for Future Research

- A relationship between vehicular activity and emission factor should be developed. The emission factor will change with increased traffic volume due to increased dispersion parameters due to increased mechanical and thermal turbulence. In the present research to determine safe buffer width, only the traffic volume was increased but the EF was kept constant. This approach contains some error, which may or may not be significant.
- Photolysis rate defines rate of $NO_2$ generation in atmosphere; this rate depends on solar radiation, which is not constant across the globe. Yet, to our knowledge no research work has been done to find out this constant for Dallas-Fort Worth area. This could be a great aid to all permitting and regulatory agencies to model $NO_2$ generation in the area of concern.
- A buffer width of 20 feet was sufficient to protect human health from the $NO_X$ exposure given the roadway and vehicle modeled in this research; however, a 20 feet buffer width may not be sufficient to protect against health impacts of other potential pollutants like CO, HC, and $SO_2$ further research should consider all the pollutants and quantify their combined effect in order to determine safe buffer width.
- A comprehensive modeling effort should take into account all kinds of sources like area, point and line and considering all possible exposure path-ways.

# APPENDIX A

# SAMPLE CALINE4 OUTPUT

| REC | REPTOR | BRG (DEG) | PRED CONC (PPM) |
|---|---|---|---|
| 1 | G1_1 | 11 | 0.07 |
| 2 | G1_2 | 11 | 0.07 |
| 3 | G1_3 | 11 | 0.07 |
| 4 | G1_4 | 11 | 0.07 |
| 5 | G1_5 | 11 | 0.07 |
| 6 | G1_6 | 11 | 0.07 |
| 7 | G1_7 | 12 | 0.07 |
| 8 | G1_8 | 12 | 0.07 |
| 9 | G1_9 | 12 | 0.07 |
| 10 | G1_10 | 167 | 0.07 |
| 11 | G1_11 | 168 | 0.07 |
| 12 | G1_12 | 168 | 0.07 |
| 13 | G1_13 | 168 | 0.07 |
| 14 | G1_14 | 169 | 0.07 |
| 15 | G1_15 | 169 | 0.07 |
| 16 | G1_16 | 169 | 0.07 |
| 17 | G1_17 | 170 | 0.07 |
| 18 | G1_18 | 170 | 0.07 |
| 19 | G1_19 | 11 | 0.07 |
| 20 | G1_20 | 11 | 0.07 |
| 21 | G1_21 | 11 | 0.07 |
| 22 | G1_22 | 11 | 0.07 |
| 23 | G1_23 | 11 | 0.07 |
| 24 | G1_24 | 11 | 0.07 |
| 25 | G1_25 | 12 | 0.07 |
| 26 | G1_26 | 12 | 0.07 |
| 27 | G1_27 | 12 | 0.07 |
| 28 | G1_28 | 167 | 0.07 |
| 29 | G1_29 | 168 | 0.07 |
| 30 | G1_30 | 168 | 0.07 |
| 31 | G1_31 | 169 | 0.07 |
| 32 | G1_32 | 169 | 0.07 |
| 33 | G1_33 | 169 | 0.07 |
| 34 | G1_34 | 170 | 0.07 |
| 35 | G1_35 | 170 | 0.07 |
| 36 | G1_36 | 170 | 0.07 |
| 37 | G1_37 | 10 | 0.07 |
| 38 | G1_38 | 10 | 0.07 |
| 39 | G1_39 | 11 | 0.07 |
| 40 | G1_40 | 11 | 0.07 |
| 41 | G1_41 | 11 | 0.07 |
| 42 | G1_42 | 11 | 0.07 |
| 43 | G1_43 | 11 | 0.07 |
| 44 | G1_44 | 12 | 0.07 |
| 45 | G1_45 | 12 | 0.07 |
| 46 | G1_46 | 167 | 0.07 |
| 47 | G1_47 | 168 | 0.07 |
| 48 | G1_48 | 168 | 0.07 |
| 49 | G1_49 | 169 | 0.07 |
| 50 | G1_50 | 169 | 0.07 |
| 51 | G1_51 | 170 | 0.07 |
| 52 | G1_52 | 170 | 0.07 |
| 53 | G1_53 | 170 | 0.07 |
| 54 | G1_54 | 170 | 0.07 |
| 55 | G1_55 | 10 | 0.07 |
| 56 | G1_56 | 10 | 0.07 |
| 57 | G1_57 | 11 | 0.07 |
| 58 | G1_58 | 11 | 0.07 |
| 59 | G1_59 | 11 | 0.07 |
| 60 | G1_60 | 11 | 0.07 |
| 61 | G1_61 | 11 | 0.07 |
| 62 | G1_62 | 11 | 0.07 |
| 63 | G1_63 | 12 | 0.07 |
| 64 | G1_64 | 168 | 0.07 |
| 65 | G1_65 | 168 | 0.07 |
| 66 | G1_66 | 169 | 0.07 |
| 67 | G1_67 | 169 | 0.07 |
| 68 | G1_68 | 169 | 0.07 |
| 69 | G1_69 | 170 | 0.07 |
| 70 | G1_70 | 170 | 0.07 |
| 71 | G1_71 | 170 | 0.07 |
| 72 | G1_72 | 170 | 0.07 |
| 73 | G1_73 | 10 | 0.07 |
| 74 | G1_74 | 10 | 0.07 |
| 75 | G1_75 | 11 | 0.07 |
| 76 | G1_76 | 11 | 0.07 |
| 77 | G1_77 | 11 | 0.07 |
| 78 | G1_78 | 11 | 0.07 |
| 79 | G1_79 | 11 | 0.07 |
| 80 | G1_80 | 11 | 0.07 |
| 81 | G1_81 | 12 | 0.07 |
| 82 | G1_82 | 168 | 0.07 |
| 83 | G1_83 | 168 | 0.07 |
| 84 | G1_84 | 169 | 0.07 |
| 85 | G1_85 | 169 | 0.07 |
| 86 | G1_86 | 169 | 0.07 |
| 87 | G1_87 | 170 | 0.07 |
| 88 | G1_88 | 170 | 0.07 |
| 89 | G1_89 | 170 | 0.07 |
| 90 | G1_90 | 171 | 0.07 |
| 91 | G1_91 | 10 | 0.07 |
| 92 | G1_92 | 10 | 0.07 |

| | | | |
|---|---|---|---|
| 93 | G1_93 | 10 | 0.07 |
| 94 | G1_94 | 10 | 0.07 |
| 95 | G1_95 | 11 | 0.07 |
| 96 | G1_96 | 11 | 0.07 |
| 97 | G1_97 | 11 | 0.07 |
| 98 | G1_98 | 11 | 0.07 |
| 99 | G1_99 | 11 | 0.07 |
| 100 | G1_100 | 168 | 0.07 |
| 101 | G1_101 | 168 | 0.07 |
| 102 | G1_102 | 169 | 0.07 |
| 103 | G1_103 | 169 | 0.07 |
| 104 | G1_104 | 170 | 0.07 |
| 105 | G1_105 | 170 | 0.07 |
| 106 | G1_106 | 170 | 0.07 |
| 107 | G1_107 | 170 | 0.07 |
| 108 | G1_108 | 171 | 0.07 |
| 109 | G1_109 | 10 | 0.07 |
| 110 | G1_110 | 10 | 0.07 |
| 111 | G1_111 | 10 | 0.07 |
| 112 | G1_112 | 10 | 0.07 |
| 113 | G1_113 | 11 | 0.07 |
| 114 | G1_114 | 11 | 0.07 |
| 115 | G1_115 | 11 | 0.07 |
| 116 | G1_116 | 11 | 0.07 |
| 117 | G1_117 | 11 | 0.07 |
| 118 | G1_118 | 168 | 0.07 |
| 119 | G1_119 | 169 | 0.07 |
| 120 | G1_120 | 169 | 0.07 |
| 121 | G1_121 | 169 | 0.07 |
| 122 | G1_122 | 170 | 0.07 |
| 123 | G1_123 | 170 | 0.07 |
| 124 | G1_124 | 170 | 0.07 |
| 125 | G1_125 | 170 | 0.07 |
| 126 | G1_126 | 172 | 0.07 |
| 127 | G1_127 | 10 | 0.07 |
| 128 | G1_128 | 10 | 0.07 |
| 129 | G1_129 | 10 | 0.07 |
| 130 | G1_130 | 10 | 0.07 |
| 131 | G1_131 | 10 | 0.07 |
| 132 | G1_132 | 10 | 0.07 |
| 133 | G1_133 | 11 | 0.07 |
| 134 | G1_134 | 11 | 0.07 |
| 135 | G1_135 | 11 | 0.07 |
| 136 | G1_136 | 168 | 0.07 |
| 137 | G1_137 | 169 | 0.07 |
| 138 | G1_138 | 169 | 0.07 |
| 139 | G1_139 | 170 | 0.07 |
| 140 | G1_140 | 170 | 0.07 |

| | | | |
|---|---|---|---|
| 141 | G1_141 | 170 | 0.07 |
| 142 | G1_142 | 170 | 0.07 |
| 143 | G1_143 | 171 | 0.07 |
| 144 | G1_144 | 172 | 0.07 |
| 145 | G1_145 | 10 | 0.07 |
| 146 | G1_146 | 10 | 0.07 |
| 147 | G1_147 | 10 | 0.07 |
| 148 | G1_148 | 10 | 0.07 |
| 149 | G1_149 | 10 | 0.07 |
| 150 | G1_150 | 10 | 0.07 |
| 151 | G1_151 | 10 | 0.07 |
| 152 | G1_152 | 11 | 0.07 |
| 153 | G1_153 | 11 | 0.07 |
| 154 | G1_154 | 168 | 0.07 |
| 155 | G1_155 | 169 | 0.07 |
| 156 | G1_156 | 169 | 0.07 |
| 157 | G1_157 | 170 | 0.07 |
| 158 | G1_158 | 170 | 0.07 |
| 159 | G1_159 | 170 | 0.07 |
| 160 | G1_160 | 171 | 0.07 |
| 161 | G1_161 | 172 | 0.07 |
| 162 | G1_162 | 172 | 0.08 |
| 163 | G1_163 | 10 | 0.07 |
| 164 | G1_164 | 10 | 0.07 |
| 165 | G1_165 | 10 | 0.07 |
| 166 | G1_166 | 10 | 0.07 |
| 167 | G1_167 | 10 | 0.07 |
| 168 | G1_168 | 10 | 0.07 |
| 169 | G1_169 | 10 | 0.07 |
| 170 | G1_170 | 10 | 0.07 |
| 171 | G1_171 | 11 | 0.07 |
| 172 | G1_172 | 169 | 0.07 |
| 173 | G1_173 | 169 | 0.07 |
| 174 | G1_174 | 169 | 0.07 |
| 175 | G1_175 | 170 | 0.07 |
| 176 | G1_176 | 170 | 0.07 |
| 177 | G1_177 | 170 | 0.07 |
| 178 | G1_178 | 171 | 0.07 |
| 179 | G1_179 | 172 | 0.08 |
| 180 | G1_180 | 172 | 0.08 |
| 181 | G1_181 | 10 | 0.07 |
| 182 | G1_182 | 10 | 0.07 |
| 183 | G1_183 | 10 | 0.07 |
| 184 | G1_184 | 10 | 0.07 |
| 185 | G1_185 | 10 | 0.07 |
| 186 | G1_186 | 10 | 0.07 |
| 187 | G1_187 | 10 | 0.07 |
| 188 | G1_188 | 10 | 0.07 |

| | | | |
|---|---|---|---|
| 189 | G1_189 | 10 | 0.07 |
| 190 | G1_190 | 169 | 0.07 |
| 191 | G1_191 | 169 | 0.07 |
| 192 | G1_192 | 170 | 0.07 |
| 193 | G1_193 | 170 | 0.07 |
| 194 | G1_194 | 170 | 0.07 |
| 195 | G1_195 | 171 | 0.07 |
| 196 | G1_196 | 172 | 0.07 |
| 197 | G1_197 | 172 | 0.08 |
| 198 | G1_198 | 173 | 0.08 |
| 199 | G1_199 | 10 | 0.07 |
| 200 | G1_200 | 10 | 0.07 |
| 201 | G1_201 | 10 | 0.07 |
| 202 | G1_202 | 10 | 0.07 |
| 203 | G1_203 | 10 | 0.07 |
| 204 | G1_204 | 10 | 0.07 |
| 205 | G1_205 | 10 | 0.07 |
| 206 | G1_206 | 10 | 0.07 |
| 207 | G1_207 | 10 | 0.07 |
| 208 | G1_208 | 169 | 0.07 |
| 209 | G1_209 | 169 | 0.07 |
| 210 | G1_210 | 170 | 0.07 |
| 211 | G1_211 | 170 | 0.07 |
| 212 | G1_212 | 170 | 0.07 |
| 213 | G1_213 | 172 | 0.07 |
| 214 | G1_214 | 172 | 0.08 |
| 215 | G1_215 | 172 | 0.08 |
| 216 | G1_216 | 173 | 0.08 |
| 217 | G1_217 | 9 | 0.07 |
| 218 | G1_218 | 9 | 0.07 |
| 219 | G1_219 | 10 | 0.07 |
| 220 | G1_220 | 10 | 0.07 |
| 221 | G1_221 | 10 | 0.07 |
| 222 | G1_222 | 10 | 0.07 |
| 223 | G1_223 | 10 | 0.07 |
| 224 | G1_224 | 10 | 0.07 |
| 225 | G1_225 | 10 | 0.07 |
| 226 | G1_226 | 169 | 0.07 |
| 227 | G1_227 | 170 | 0.07 |
| 228 | G1_228 | 170 | 0.07 |
| 229 | G1_229 | 170 | 0.07 |
| 230 | G1_230 | 170 | 0.07 |
| 231 | G1_231 | 172 | 0.08 |
| 232 | G1_232 | 172 | 0.08 |
| 233 | G1_233 | 172 | 0.08 |
| 234 | G1_234 | 173 | 0.08 |
| 235 | G1_235 | 9 | 0.07 |
| 236 | G1_236 | 9 | 0.07 |

| | | | |
|---|---|---|---|
| 237 | G1_237 | 9 | 0.07 |
| 238 | G1_238 | 9 | 0.07 |
| 239 | G1_239 | 9 | 0.07 |
| 240 | G1_240 | 10 | 0.07 |
| 241 | G1_241 | 10 | 0.07 |
| 242 | G1_242 | 10 | 0.07 |
| 243 | G1_243 | 10 | 0.07 |
| 244 | G1_244 | 169 | 0.07 |
| 245 | G1_245 | 170 | 0.07 |
| 246 | G1_246 | 170 | 0.07 |
| 247 | G1_247 | 170 | 0.07 |
| 248 | G1_248 | 172 | 0.07 |
| 249 | G1_249 | 172 | 0.08 |
| 250 | G1_250 | 172 | 0.08 |
| 251 | G1_251 | 173 | 0.08 |
| 252 | G1_252 | 173 | 0.08 |
| 253 | G1_253 | 9 | 0.07 |
| 254 | G1_254 | 9 | 0.07 |
| 255 | G1_255 | 9 | 0.07 |
| 256 | G1_256 | 9 | 0.07 |
| 257 | G1_257 | 9 | 0.07 |
| 258 | G1_258 | 9 | 0.07 |
| 259 | G1_259 | 10 | 0.07 |
| 260 | G1_260 | 10 | 0.07 |
| 261 | G1_261 | 10 | 0.07 |
| 262 | G1_262 | 169 | 0.07 |
| 263 | G1_263 | 170 | 0.07 |
| 264 | G1_264 | 170 | 0.07 |
| 265 | G1_265 | 171 | 0.07 |
| 266 | G1_266 | 172 | 0.08 |
| 267 | G1_267 | 172 | 0.08 |
| 268 | G1_268 | 172 | 0.08 |
| 269 | G1_269 | 173 | 0.08 |
| 270 | G1_270 | 174 | 0.08 |
| 271 | G1_271 | 9 | 0.07 |
| 272 | G1_272 | 9 | 0.07 |
| 273 | G1_273 | 9 | 0.07 |
| 274 | G1_274 | 9 | 0.07 |
| 275 | G1_275 | 9 | 0.07 |
| 276 | G1_276 | 9 | 0.07 |
| 277 | G1_277 | 9 | 0.07 |
| 278 | G1_278 | 9 | 0.07 |
| 279 | G1_279 | 10 | 0.07 |
| 280 | G1_280 | 170 | 0.07 |
| 281 | G1_281 | 170 | 0.07 |
| 282 | G1_282 | 170 | 0.07 |
| 283 | G1_283 | 172 | 0.07 |
| 284 | G1_284 | 172 | 0.08 |

| | | | |
|---|---|---|---|
| 285 | G1_285 | 172 | 0.08 |
| 286 | G1_286 | 173 | 0.08 |
| 287 | G1_287 | 173 | 0.08 |
| 288 | G1_288 | 174 | 0.08 |
| 289 | G1_289 | 9 | 0.07 |
| 290 | G1_290 | 9 | 0.07 |
| 291 | G1_291 | 9 | 0.07 |
| 292 | G1_292 | 9 | 0.07 |
| 293 | G1_293 | 9 | 0.07 |
| 294 | G1_294 | 9 | 0.07 |
| 295 | G1_295 | 9 | 0.07 |
| 296 | G1_296 | 9 | 0.07 |
| 297 | G1_297 | 9 | 0.07 |
| 298 | G1_298 | 170 | 0.07 |
| 299 | G1_299 | 170 | 0.07 |
| 300 | G1_300 | 170 | 0.07 |
| 301 | G1_301 | 172 | 0.08 |
| 302 | G1_302 | 172 | 0.08 |
| 303 | G1_303 | 173 | 0.08 |
| 304 | G1_304 | 173 | 0.08 |
| 305 | G1_305 | 173 | 0.08 |
| 306 | G1_306 | 174 | 0.08 |
| 307 | G1_307 | 9 | 0.07 |
| 308 | G1_308 | 9 | 0.07 |
| 309 | G1_309 | 9 | 0.07 |
| 310 | G1_310 | 9 | 0.07 |
| 311 | G1_311 | 9 | 0.07 |
| 312 | G1_312 | 9 | 0.07 |
| 313 | G1_313 | 9 | 0.07 |
| 314 | G1_314 | 9 | 0.07 |
| 315 | G1_315 | 9 | 0.07 |
| 316 | G1_316 | 170 | 0.07 |
| 317 | G1_317 | 170 | 0.07 |
| 318 | G1_318 | 172 | 0.07 |
| 319 | G1_319 | 172 | 0.08 |
| 320 | G1_320 | 172 | 0.08 |
| 321 | G1_321 | 173 | 0.08 |
| 322 | G1_322 | 173 | 0.08 |
| 323 | G1_323 | 173 | 0.08 |
| 324 | G1_324 | 174 | 0.08 |
| 325 | G1_325 | 9 | 0.07 |
| 326 | G1_326 | 9 | 0.07 |
| 327 | G1_327 | 9 | 0.07 |
| 328 | G1_328 | 9 | 0.07 |
| 329 | G1_329 | 9 | 0.07 |
| 330 | G1_330 | 9 | 0.07 |
| 331 | G1_331 | 9 | 0.07 |
| 332 | G1_332 | 9 | 0.07 |

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|---|---|---|---|
| 333 | G1_333 | 9 | 0.07 |
| 334 | G1_334 | 170 | 0.07 |
| 335 | G1_335 | 172 | 0.07 |
| 336 | G1_336 | 172 | 0.08 |
| 337 | G1_337 | 172 | 0.08 |
| 338 | G1_338 | 173 | 0.08 |
| 339 | G1_339 | 173 | 0.08 |
| 340 | G1_340 | 173 | 0.08 |
| 341 | G1_341 | 173 | 0.08 |
| 342 | G1_342 | 175 | 0.08 |
| 343 | G1_343 | 9 | 0.07 |
| 344 | G1_344 | 9 | 0.07 |
| 345 | G1_345 | 9 | 0.07 |
| 346 | G1_346 | 9 | 0.07 |
| 347 | G1_347 | 9 | 0.07 |
| 348 | G1_348 | 9 | 0.07 |
| 349 | G1_349 | 9 | 0.07 |
| 350 | G1_350 | 9 | 0.07 |
| 351 | G1_351 | 9 | 0.07 |
| 352 | G1_352 | 170 | 0.07 |
| 353 | G1_353 | 172 | 0.08 |
| 354 | G1_354 | 172 | 0.08 |
| 355 | G1_355 | 173 | 0.08 |
| 356 | G1_356 | 173 | 0.08 |
| 357 | G1_357 | 173 | 0.08 |
| 358 | G1_358 | 173 | 0.08 |
| 359 | G1_359 | 173 | 0.08 |
| 360 | G1_360 | 175 | 0.08 |
| 361 | G1_361 | 9 | 0.07 |
| 362 | G1_362 | 9 | 0.07 |
| 363 | G1_363 | 9 | 0.07 |
| 364 | G1_364 | 8 | 0.07 |
| 365 | G1_365 | 9 | 0.07 |
| 366 | G1_366 | 9 | 0.07 |
| 367 | G1_367 | 9 | 0.07 |
| 368 | G1_368 | 9 | 0.07 |
| 369 | G1_369 | 9 | 0.07 |
| 370 | G1_370 | 171 | 0.07 |
| 371 | G1_371 | 172 | 0.08 |
| 372 | G1_372 | 172 | 0.08 |
| 373 | G1_373 | 173 | 0.08 |
| 374 | G1_374 | 173 | 0.08 |
| 375 | G1_375 | 173 | 0.08 |
| 376 | G1_376 | 173 | 0.08 |
| 377 | G1_377 | 174 | 0.08 |
| 378 | G1_378 | 175 | 0.08 |
| 379 | G1_379 | 8 | 0.07 |
| 380 | G1_380 | 8 | 0.07 |

| | | | |
|---|---|---|---|
| 381 | G1_381 | 8 | 0.07 |
| 382 | G1_382 | 8 | 0.07 |
| 383 | G1_383 | 8 | 0.07 |
| 384 | G1_384 | 8 | 0.07 |
| 385 | G1_385 | 9 | 0.07 |
| 386 | G1_386 | 8 | 0.07 |
| 387 | G1_387 | 9 | 0.07 |
| 388 | G1_388 | 172 | 0.08 |
| 389 | G1_389 | 172 | 0.08 |
| 390 | G1_390 | 173 | 0.08 |
| 391 | G1_391 | 173 | 0.08 |
| 392 | G1_392 | 173 | 0.08 |
| 393 | G1_393 | 173 | 0.08 |
| 394 | G1_394 | 174 | 0.08 |
| 395 | G1_395 | 174 | 0.09 |
| 396 | G1_396 | 176 | 0.08 |
| 397 | G1_397 | 8 | 0.07 |
| 398 | G1_398 | 8 | 0.07 |
| 399 | G1_399 | 7 | 0.07 |
| 400 | G1_400 | 7 | 0.07 |
| 401 | G1_401 | 7 | 0.07 |
| 402 | G1_402 | 7 | 0.07 |
| 403 | G1_403 | 7 | 0.07 |
| 404 | G1_404 | 7 | 0.07 |
| 405 | G1_405 | 7 | 0.07 |
| 406 | G1_406 | 172 | 0.08 |
| 407 | G1_407 | 173 | 0.08 |
| 408 | G1_408 | 173 | 0.08 |
| 409 | G1_409 | 173 | 0.08 |
| 410 | G1_410 | 173 | 0.08 |
| 411 | G1_411 | 173 | 0.08 |
| 412 | G1_412 | 174 | 0.08 |
| 413 | G1_413 | 174 | 0.09 |
| 414 | G1_414 | 176 | 0.08 |
| 415 | G1_415 | 7 | 0.07 |
| 416 | G1_416 | 7 | 0.07 |
| 417 | G1_417 | 7 | 0.08 |
| 418 | G1_418 | 7 | 0.08 |
| 419 | G1_419 | 7 | 0.08 |
| 420 | G1_420 | 7 | 0.08 |
| 421 | G1_421 | 7 | 0.08 |
| 422 | G1_422 | 7 | 0.08 |
| 423 | G1_423 | 7 | 0.08 |
| 424 | G1_424 | 172 | 0.08 |
| 425 | G1_425 | 173 | 0.08 |
| 426 | G1_426 | 173 | 0.08 |
| 427 | G1_427 | 173 | 0.08 |
| 428 | G1_428 | 173 | 0.08 |
| 429 | G1_429 | 174 | 0.08 |
| 430 | G1_430 | 174 | 0.09 |
| 431 | G1_431 | 174 | 0.09 |
| 432 | G1_432 | 359 | 0.05 |
| 433 | G1_433 | 7 | 0.08 |
| 434 | G1_434 | 7 | 0.08 |
| 435 | G1_435 | 7 | 0.08 |
| 436 | G1_436 | 7 | 0.08 |
| 437 | G1_437 | 7 | 0.08 |
| 438 | G1_438 | 7 | 0.08 |
| 439 | G1_439 | 7 | 0.08 |
| 440 | G1_440 | 7 | 0.08 |
| 441 | G1_441 | 7 | 0.08 |
| 442 | G1_442 | 172 | 0.08 |
| 443 | G1_443 | 173 | 0.08 |
| 444 | G1_444 | 173 | 0.08 |
| 445 | G1_445 | 173 | 0.08 |
| 446 | G1_446 | 173 | 0.08 |
| 447 | G1_447 | 174 | 0.09 |
| 448 | G1_448 | 174 | 0.09 |
| 449 | G1_449 | 174 | 0.09 |
| 450 | G1_450 | 359 | 0.05 |
| 451 | G1_451 | 7 | 0.08 |
| 452 | G1_452 | 7 | 0.08 |
| 453 | G1_453 | 7 | 0.08 |
| 454 | G1_454 | 7 | 0.08 |
| 455 | G1_455 | 7 | 0.08 |
| 456 | G1_456 | 7 | 0.08 |
| 457 | G1_457 | 6 | 0.08 |
| 458 | G1_458 | 6 | 0.08 |
| 459 | G1_459 | 6 | 0.08 |
| 460 | G1_460 | 173 | 0.08 |
| 461 | G1_461 | 173 | 0.08 |
| 462 | G1_462 | 173 | 0.08 |
| 463 | G1_463 | 173 | 0.08 |
| 464 | G1_464 | 174 | 0.09 |
| 465 | G1_465 | 174 | 0.09 |
| 466 | G1_466 | 174 | 0.09 |
| 467 | G1_467 | 174 | 0.09 |
| 468 | G1_468 | 359 | 0.05 |
| 469 | G1_469 | 7 | 0.08 |
| 470 | G1_470 | 7 | 0.08 |
| 471 | G1_471 | 7 | 0.08 |
| 472 | G1_472 | 6 | 0.08 |
| 473 | G1_473 | 7 | 0.08 |
| 474 | G1_474 | 6 | 0.08 |
| 475 | G1_475 | 6 | 0.08 |
| 476 | G1_476 | 6 | 0.08 |

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|---|---|---|---|
| 477 | G1_477 | 6 | 0.08 |
| 478 | G1_478 | 173 | 0.08 |
| 479 | G1_479 | 173 | 0.08 |
| 480 | G1_480 | 173 | 0.08 |
| 481 | G1_481 | 174 | 0.09 |
| 482 | G1_482 | 174 | 0.09 |
| 483 | G1_483 | 174 | 0.09 |
| 484 | G1_484 | 174 | 0.09 |
| 485 | G1_485 | 174 | 0.1 |
| 486 | G1_486 | 359 | 0.05 |
| 487 | G1_487 | 7 | 0.08 |
| 488 | G1_488 | 6 | 0.08 |
| 489 | G1_489 | 6 | 0.08 |
| 490 | G1_490 | 6 | 0.08 |
| 491 | G1_491 | 6 | 0.08 |
| 492 | G1_492 | 6 | 0.08 |
| 493 | G1_493 | 6 | 0.08 |
| 494 | G1_494 | 6 | 0.08 |
| 495 | G1_495 | 173 | 0.08 |
| 496 | G1_496 | 173 | 0.08 |
| 497 | G1_497 | 173 | 0.08 |
| 498 | G1_498 | 173 | 0.09 |
| 499 | G1_499 | 174 | 0.09 |
| 500 | G1_500 | 174 | 0.09 |
| 501 | G1_501 | 174 | 0.09 |
| 502 | G1_502 | 174 | 0.1 |
| 503 | G1_503 | 174 | 0.11 |
| 504 | G1_504 | 359 | 0.05 |
| 505 | G1_505 | 6 | 0.08 |
| 506 | G1_506 | 6 | 0.08 |
| 507 | G1_507 | 6 | 0.08 |
| 508 | G1_508 | 6 | 0.08 |
| 509 | G1_509 | 6 | 0.08 |
| 510 | G1_510 | 6 | 0.08 |
| 511 | G1_511 | 6 | 0.08 |
| 512 | G1_512 | 6 | 0.08 |
| 513 | G1_513 | 173 | 0.08 |
| 514 | G1_514 | 173 | 0.08 |
| 515 | G1_515 | 173 | 0.08 |
| 516 | G1_516 | 174 | 0.09 |
| 517 | G1_517 | 174 | 0.09 |
| 518 | G1_518 | 174 | 0.09 |
| 519 | G1_519 | 174 | 0.1 |
| 520 | G1_520 | 174 | 0.11 |
| 521 | G1_521 | 174 | 0.12 |
| 522 | G1_522 | 359 | 0.05 |
| 523 | G1_523 | 6 | 0.08 |
| 524 | G1_524 | 6 | 0.08 |
| 525 | G1_525 | 6 | 0.08 |
| 526 | G1_526 | 6 | 0.08 |
| 527 | G1_527 | 6 | 0.08 |
| 528 | G1_528 | 6 | 0.08 |
| 529 | G1_529 | 6 | 0.08 |
| 530 | G1_530 | 6 | 0.08 |
| 531 | G1_531 | 173 | 0.08 |
| 532 | G1_532 | 173 | 0.08 |
| 533 | G1_533 | 174 | 0.09 |
| 534 | G1_534 | 174 | 0.09 |
| 535 | G1_535 | 174 | 0.09 |
| 536 | G1_536 | 174 | 0.1 |
| 537 | G1_537 | 174 | 0.11 |
| 538 | G1_538 | 174 | 0.12 |
| 539 | G1_539 | 175 | 0.14 |
| 540 | G1_540 | 359 | 0.05 |
| 541 | G1_541 | 6 | 0.08 |
| 542 | G1_542 | 6 | 0.08 |
| 543 | G1_543 | 6 | 0.08 |
| 544 | G1_544 | 6 | 0.08 |
| 545 | G1_545 | 6 | 0.08 |
| 546 | G1_546 | 6 | 0.08 |
| 547 | G1_547 | 6 | 0.08 |
| 548 | G1_548 | 6 | 0.08 |
| 549 | G1_549 | 173 | 0.08 |
| 550 | G1_550 | 174 | 0.09 |
| 551 | G1_551 | 173 | 0.09 |
| 552 | G1_552 | 174 | 0.09 |
| 553 | G1_553 | 174 | 0.1 |
| 554 | G1_554 | 174 | 0.11 |
| 555 | G1_555 | 174 | 0.12 |
| 556 | G1_556 | 175 | 0.14 |
| 557 | G1_557 | 178 | 0.16 |
| 558 | G1_558 | 180 | 0.08 |
| 559 | G1_559 | 6 | 0.08 |
| 560 | G1_560 | 6 | 0.08 |
| 561 | G1_561 | 6 | 0.08 |
| 562 | G1_562 | 6 | 0.08 |
| 563 | G1_563 | 6 | 0.08 |
| 564 | G1_564 | 6 | 0.08 |
| 565 | G1_565 | 6 | 0.08 |
| 566 | G1_566 | 6 | 0.08 |
| 567 | G1_567 | 173 | 0.09 |
| 568 | G1_568 | 173 | 0.09 |
| 569 | G1_569 | 174 | 0.09 |
| 570 | G1_570 | 174 | 0.1 |
| 571 | G1_571 | 174 | 0.11 |
| 572 | G1_572 | 174 | 0.12 |

| | | | |
|---|---|---|---|
| 573 | G1_573 | 175 | 0.14 |
| 574 | G1_574 | 1 | 0.14 |
| 575 | G1_575 | 180 | 0.16 |
| 576 | G1_576 | 180 | 0.08 |
| 577 | G1_577 | 6 | 0.08 |
| 578 | G1_578 | 6 | 0.08 |
| 579 | G1_579 | 6 | 0.08 |
| 580 | G1_580 | 6 | 0.08 |
| 581 | G1_581 | 5 | 0.08 |
| 582 | G1_582 | 6 | 0.08 |
| 583 | G1_583 | 5 | 0.09 |
| 584 | G1_584 | 5 | 0.09 |
| 585 | G1_585 | 173 | 0.09 |
| 586 | G1_586 | 174 | 0.09 |
| 587 | G1_587 | 174 | 0.1 |
| 588 | G1_588 | 174 | 0.11 |
| 589 | G1_589 | 174 | 0.12 |
| 590 | G1_590 | 175 | 0.15 |
| 591 | G1_591 | 1 | 0.15 |
| 592 | G1_592 | 181 | 0.16 |
| 593 | G1_593 | 184 | 0.15 |
| 594 | G1_594 | 180 | 0.08 |
| 595 | G1_595 | 6 | 0.08 |
| 596 | G1_596 | 6 | 0.08 |
| 597 | G1_597 | 5 | 0.08 |
| 598 | G1_598 | 5 | 0.08 |
| 599 | G1_599 | 5 | 0.08 |
| 600 | G1_600 | 5 | 0.09 |
| 601 | G1_601 | 5 | 0.09 |
| 602 | G1_602 | 5 | 0.09 |
| 603 | G1_603 | 173 | 0.09 |
| 604 | G1_604 | 174 | 0.1 |
| 605 | G1_605 | 173 | 0.11 |
| 606 | G1_606 | 174 | 0.12 |
| 607 | G1_607 | 175 | 0.15 |
| 608 | G1_608 | 360 | 0.15 |
| 609 | G1_609 | 181 | 0.16 |
| 610 | G1_610 | 184 | 0.14 |
| 611 | G1_611 | 185 | 0.12 |
| 612 | G1_612 | 181 | 0.08 |
| 613 | G1_613 | 5 | 0.08 |
| 614 | G1_614 | 5 | 0.08 |
| 615 | G1_615 | 5 | 0.08 |
| 616 | G1_616 | 5 | 0.09 |
| 617 | G1_617 | 5 | 0.09 |
| 618 | G1_618 | 5 | 0.09 |
| 619 | G1_619 | 5 | 0.09 |
| 620 | G1_620 | 5 | 0.09 |
| 621 | G1_621 | 174 | 0.1 |
| 622 | G1_622 | 173 | 0.11 |
| 623 | G1_623 | 174 | 0.12 |
| 624 | G1_624 | 176 | 0.15 |
| 625 | G1_625 | 360 | 0.15 |
| 626 | G1_626 | 181 | 0.16 |
| 627 | G1_627 | 184 | 0.14 |
| 628 | G1_628 | 185 | 0.12 |
| 629 | G1_629 | 185 | 0.11 |
| 630 | G1_630 | 181 | 0.08 |
| 631 | G1_631 | 5 | 0.08 |
| 632 | G1_632 | 5 | 0.08 |
| 633 | G1_633 | 5 | 0.09 |
| 634 | G1_634 | 5 | 0.09 |
| 635 | G1_635 | 5 | 0.09 |
| 636 | G1_636 | 5 | 0.09 |
| 637 | G1_637 | 5 | 0.09 |
| 638 | G1_638 | 5 | 0.1 |
| 639 | G1_639 | 173 | 0.11 |
| 640 | G1_640 | 174 | 0.12 |
| 641 | G1_641 | 3 | 0.15 |
| 642 | G1_642 | 360 | 0.16 |
| 643 | G1_643 | 181 | 0.16 |
| 644 | G1_644 | 184 | 0.14 |
| 645 | G1_645 | 185 | 0.12 |
| 646 | G1_646 | 185 | 0.11 |
| 647 | G1_647 | 185 | 0.1 |
| 648 | G1_648 | 182 | 0.08 |
| 649 | G1_649 | 5 | 0.09 |
| 650 | G1_650 | 5 | 0.09 |
| 651 | G1_651 | 5 | 0.09 |
| 652 | G1_652 | 5 | 0.09 |
| 653 | G1_653 | 5 | 0.09 |
| 654 | G1_654 | 5 | 0.1 |
| 655 | G1_655 | 5 | 0.1 |
| 656 | G1_656 | 6 | 0.11 |
| 657 | G1_657 | 173 | 0.12 |
| 658 | G1_658 | 3 | 0.15 |
| 659 | G1_659 | 360 | 0.16 |
| 660 | G1_660 | 181 | 0.16 |
| 661 | G1_661 | 185 | 0.14 |
| 662 | G1_662 | 185 | 0.12 |
| 663 | G1_663 | 185 | 0.11 |
| 664 | G1_664 | 185 | 0.1 |
| 665 | G1_665 | 185 | 0.1 |
| 666 | G1_666 | 182 | 0.08 |
| 667 | G1_667 | 5 | 0.09 |
| 668 | G1_668 | 5 | 0.09 |

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| 669 | G1_669 | 5 | 0.09 |
| 670 | G1_670 | 5 | 0.09 |
| 671 | G1_671 | 5 | 0.1 |
| 672 | G1_672 | 5 | 0.1 |
| 673 | G1_673 | 6 | 0.11 |
| 674 | G1_674 | 5 | 0.12 |
| 675 | G1_675 | 3 | 0.15 |
| 676 | G1_676 | 360 | 0.16 |
| 677 | G1_677 | 181 | 0.16 |
| 678 | G1_678 | 185 | 0.13 |
| 679 | G1_679 | 185 | 0.11 |
| 680 | G1_680 | 185 | 0.1 |
| 681 | G1_681 | 185 | 0.1 |
| 682 | G1_682 | 185 | 0.09 |
| 683 | G1_683 | 185 | 0.09 |
| 684 | G1_684 | 183 | 0.08 |
| 685 | G1_685 | 5 | 0.09 |
| 686 | G1_686 | 5 | 0.09 |
| 687 | G1_687 | 5 | 0.09 |
| 688 | G1_688 | 5 | 0.1 |
| 689 | G1_689 | 5 | 0.1 |
| 690 | G1_690 | 5 | 0.11 |
| 691 | G1_691 | 5 | 0.13 |
| 692 | G1_692 | 3 | 0.15 |
| 693 | G1_693 | 360 | 0.16 |
| 694 | G1_694 | 182 | 0.16 |
| 695 | G1_695 | 185 | 0.13 |
| 696 | G1_696 | 186 | 0.11 |
| 697 | G1_697 | 184 | 0.1 |
| 698 | G1_698 | 185 | 0.1 |
| 699 | G1_699 | 185 | 0.09 |
| 700 | G1_700 | 185 | 0.09 |
| 701 | G1_701 | 185 | 0.09 |
| 702 | G1_702 | 183 | 0.08 |
| 703 | G1_703 | 5 | 0.09 |
| 704 | G1_704 | 5 | 0.09 |
| 705 | G1_705 | 5 | 0.1 |
| 706 | G1_706 | 5 | 0.1 |
| 707 | G1_707 | 5 | 0.11 |
| 708 | G1_708 | 5 | 0.13 |
| 709 | G1_709 | 2 | 0.15 |
| 710 | G1_710 | 360 | 0.16 |
| 711 | G1_711 | 182 | 0.15 |
| 712 | G1_712 | 185 | 0.13 |
| 713 | G1_713 | 186 | 0.11 |
| 714 | G1_714 | 185 | 0.1 |
| 715 | G1_715 | 185 | 0.1 |
| 716 | G1_716 | 185 | 0.09 |
| 717 | G1_717 | 185 | 0.09 |
| 718 | G1_718 | 185 | 0.09 |
| 719 | G1_719 | 185 | 0.09 |
| 720 | G1_720 | 183 | 0.08 |
| 721 | G1_721 | 5 | 0.09 |
| 722 | G1_722 | 5 | 0.1 |
| 723 | G1_723 | 5 | 0.1 |
| 724 | G1_724 | 5 | 0.11 |
| 725 | G1_725 | 5 | 0.13 |
| 726 | G1_726 | 2 | 0.16 |
| 727 | G1_727 | 359 | 0.16 |
| 728 | G1_728 | 182 | 0.15 |
| 729 | G1_729 | 353 | 0.13 |
| 730 | G1_730 | 186 | 0.11 |
| 731 | G1_731 | 185 | 0.1 |
| 732 | G1_732 | 185 | 0.1 |
| 733 | G1_733 | 185 | 0.09 |
| 734 | G1_734 | 185 | 0.09 |
| 735 | G1_735 | 185 | 0.09 |
| 736 | G1_736 | 185 | 0.09 |
| 737 | G1_737 | 185 | 0.09 |
| 738 | G1_738 | 184 | 0.08 |
| 739 | G1_739 | 5 | 0.1 |
| 740 | G1_740 | 4 | 0.1 |
| 741 | G1_741 | 5 | 0.11 |
| 742 | G1_742 | 5 | 0.13 |
| 743 | G1_743 | 2 | 0.16 |
| 744 | G1_744 | 180 | 0.16 |
| 745 | G1_745 | 182 | 0.15 |
| 746 | G1_746 | 354 | 0.13 |
| 747 | G1_747 | 353 | 0.11 |
| 748 | G1_748 | 185 | 0.1 |
| 749 | G1_749 | 185 | 0.1 |
| 750 | G1_750 | 185 | 0.09 |
| 751 | G1_751 | 185 | 0.09 |
| 752 | G1_752 | 185 | 0.09 |
| 753 | G1_753 | 185 | 0.09 |
| 754 | G1_754 | 185 | 0.09 |
| 755 | G1_755 | 185 | 0.08 |
| 756 | G1_756 | 184 | 0.08 |
| 757 | G1_757 | 4 | 0.11 |
| 758 | G1_758 | 5 | 0.12 |
| 759 | G1_759 | 5 | 0.13 |
| 760 | G1_760 | 2 | 0.16 |
| 761 | G1_761 | 180 | 0.15 |
| 762 | G1_762 | 183 | 0.15 |
| 763 | G1_763 | 354 | 0.13 |
| 764 | G1_764 | 353 | 0.11 |

| | | | |
|---|---|---|---|
| 765 | G1_765 | 354 | 0.1 |
| 766 | G1_766 | 185 | 0.09 |
| 767 | G1_767 | 185 | 0.09 |
| 768 | G1_768 | 185 | 0.09 |
| 769 | G1_769 | 185 | 0.09 |
| 770 | G1_770 | 185 | 0.09 |
| 771 | G1_771 | 185 | 0.08 |
| 772 | G1_772 | 185 | 0.08 |
| 773 | G1_773 | 185 | 0.08 |
| 774 | G1_774 | 184 | 0.08 |
| 775 | G1_775 | 5 | 0.12 |
| 776 | G1_776 | 5 | 0.14 |
| 777 | G1_777 | 2 | 0.16 |
| 778 | G1_778 | 180 | 0.15 |
| 779 | G1_779 | 356 | 0.15 |
| 780 | G1_780 | 354 | 0.13 |
| 781 | G1_781 | 353 | 0.11 |
| 782 | G1_782 | 354 | 0.1 |
| 783 | G1_783 | 353 | 0.09 |
| 784 | G1_784 | 185 | 0.09 |
| 785 | G1_785 | 185 | 0.09 |
| 786 | G1_786 | 185 | 0.09 |
| 787 | G1_787 | 185 | 0.09 |
| 788 | G1_788 | 185 | 0.08 |
| 789 | G1_789 | 185 | 0.08 |
| 790 | G1_790 | 186 | 0.08 |
| 791 | G1_791 | 186 | 0.08 |
| 792 | G1_792 | 185 | 0.08 |
| 793 | G1_793 | 5 | 0.14 |
| 794 | G1_794 | 1 | 0.16 |
| 795 | G1_795 | 180 | 0.15 |
| 796 | G1_796 | 356 | 0.15 |
| 797 | G1_797 | 354 | 0.12 |
| 798 | G1_798 | 353 | 0.11 |
| 799 | G1_799 | 354 | 0.1 |
| 800 | G1_800 | 354 | 0.09 |
| 801 | G1_801 | 353 | 0.09 |
| 802 | G1_802 | 185 | 0.09 |
| 803 | G1_803 | 185 | 0.09 |
| 804 | G1_804 | 186 | 0.08 |
| 805 | G1_805 | 186 | 0.08 |
| 806 | G1_806 | 186 | 0.08 |
| 807 | G1_807 | 186 | 0.08 |
| 808 | G1_808 | 186 | 0.08 |
| 809 | G1_809 | 186 | 0.08 |
| 810 | G1_810 | 185 | 0.08 |
| 811 | G1_811 | 1 | 0.16 |
| 812 | G1_812 | 358 | 0.16 |

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|---|---|---|---|
| 813 | G1_813 | 356 | 0.15 |
| 814 | G1_814 | 354 | 0.12 |
| 815 | G1_815 | 354 | 0.11 |
| 816 | G1_816 | 354 | 0.1 |
| 817 | G1_817 | 354 | 0.09 |
| 818 | G1_818 | 353 | 0.09 |
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| 822 | G1_822 | 186 | 0.08 |
| 823 | G1_823 | 186 | 0.08 |
| 824 | G1_824 | 186 | 0.08 |
| 825 | G1_825 | 186 | 0.08 |
| 826 | G1_826 | 186 | 0.08 |
| 827 | G1_827 | 186 | 0.08 |
| 828 | G1_828 | 185 | 0.08 |
| 829 | G1_829 | 358 | 0.16 |
| 830 | G1_830 | 356 | 0.15 |
| 831 | G1_831 | 354 | 0.12 |
| 832 | G1_832 | 354 | 0.11 |
| 833 | G1_833 | 354 | 0.1 |
| 834 | G1_834 | 354 | 0.1 |
| 835 | G1_835 | 354 | 0.09 |
| 836 | G1_836 | 354 | 0.09 |
| 837 | G1_837 | 353 | 0.08 |
| 838 | G1_838 | 186 | 0.08 |
| 839 | G1_839 | 186 | 0.08 |
| 840 | G1_840 | 186 | 0.08 |
| 841 | G1_841 | 186 | 0.08 |
| 842 | G1_842 | 186 | 0.08 |
| 843 | G1_843 | 186 | 0.08 |
| 844 | G1_844 | 186 | 0.08 |
| 845 | G1_845 | 186 | 0.08 |
| 846 | G1_846 | 186 | 0.08 |
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| 848 | G1_848 | 354 | 0.12 |
| 849 | G1_849 | 354 | 0.11 |
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| 851 | G1_851 | 354 | 0.1 |
| 852 | G1_852 | 354 | 0.09 |
| 853 | G1_853 | 354 | 0.09 |
| 854 | G1_854 | 353 | 0.09 |
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| 856 | G1_856 | 186 | 0.08 |
| 857 | G1_857 | 186 | 0.08 |
| 858 | G1_858 | 186 | 0.08 |
| 859 | G1_859 | 186 | 0.08 |
| 860 | G1_860 | 186 | 0.08 |

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|---|---|---|---|
| 861 | G1_861 | 186 | 0.08 |
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| 863 | G1_863 | 186 | 0.08 |
| 864 | G1_864 | 186 | 0.08 |
| 865 | G1_865 | 354 | 0.12 |
| 866 | G1_866 | 354 | 0.11 |
| 867 | G1_867 | 354 | 0.1 |
| 868 | G1_868 | 354 | 0.1 |
| 869 | G1_869 | 354 | 0.09 |
| 870 | G1_870 | 354 | 0.09 |
| 871 | G1_871 | 353 | 0.09 |
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| 893 | G1_893 | 186 | 0.08 |
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| 896 | G1_896 | 186 | 0.08 |
| 897 | G1_897 | 186 | 0.08 |
| 898 | G1_898 | 186 | 0.08 |
| 899 | G1_899 | 187 | 0.08 |
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| 902 | G1_902 | 354 | 0.1 |
| 903 | G1_903 | 354 | 0.09 |
| 904 | G1_904 | 354 | 0.09 |
| 905 | G1_905 | 354 | 0.09 |
| 906 | G1_906 | 353 | 0.08 |
| 907 | G1_907 | 353 | 0.08 |
| 908 | G1_908 | 353 | 0.08 |

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|---|---|---|---|
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| 919 | G1_919 | 354 | 0.1 |
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| 929 | G1_929 | 186 | 0.08 |
| 930 | G1_930 | 187 | 0.08 |
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| 933 | G1_933 | 187 | 0.08 |
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| 942 | G1_942 | 353 | 0.08 |
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| 946 | G1_946 | 187 | 0.08 |
| 947 | G1_947 | 187 | 0.08 |
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| 949 | G1_949 | 187 | 0.08 |
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| 953 | G1_953 | 187 | 0.08 |
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| 956 | G1_956 | 354 | 0.09 |

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| 959 | G1_959 | 353 | 0.08 |
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| 961 | G1_961 | 353 | 0.08 |
| 962 | G1_962 | 352 | 0.08 |
| 963 | G1_963 | 352 | 0.08 |
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| 965 | G1_965 | 187 | 0.08 |
| 966 | G1_966 | 187 | 0.08 |
| 967 | G1_967 | 187 | 0.08 |
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| 969 | G1_969 | 187 | 0.08 |
| 970 | G1_970 | 187 | 0.07 |
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| 972 | G1_972 | 187 | 0.07 |
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| 979 | G1_979 | 353 | 0.08 |
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| 987 | G1_987 | 187 | 0.07 |
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| 989 | G1_989 | 188 | 0.07 |
| 990 | G1_990 | 187 | 0.07 |
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| 1000 | G1_1000 | 189 | 0.07 |
| 1001 | G1_1001 | 189 | 0.07 |
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| 1003 | G1_1003 | 188 | 0.07 |
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| 1007 | G1_1007 | 188 | 0.07 |
| 1008 | G1_1008 | 188 | 0.07 |
| 1009 | G1_1009 | 354 | 0.08 |
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| 1011 | G1_1011 | 353 | 0.08 |
| 1012 | G1_1012 | 353 | 0.08 |
| 1013 | G1_1013 | 353 | 0.08 |
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| 1050 | G1_1050 | 352 | 0.08 |
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| 1052 | G1_1052 | 350 | 0.07 |

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|---|---|---|---|
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| 1078 | G1_1078 | 189 | 0.07 |
| 1079 | G1_1079 | 189 | 0.07 |
| 1080 | G1_1080 | 189 | 0.07 |

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Hetal Bhatt was born on September 05, 1980 in Vadodara, Gujarat, India, the son of Mr. H. K. Bhatt and Mrs. C. H. Bhatt. He completed his high school education at Vadodara, India in 1998. Subsequantly, he enrolled in the Maharaja Sayajirao University of Baroda, Vadodara, Guajarat, India, in 1999 and earned his B. E. (Bachelor of Engineering) in Civil Engineering in May 2003.

Hetal Bhatt had started his M.S. (Master of Science) degree in Environmental Engineering at The University of Texas at Arlington, Arlington, Texas in January 2004 and earned M.S. Degree in Civil Engineering in December 2005. During his tenure as a master's student, he was appointed as the Graduate Research Assistant. His thesis was based on $NO_X$ dispersion modeling and looked at the safe buffer width of roadway to protect human health from harmful $NO_X$ exposure. Also during his study, he did an internship in the Transportation Department of the North Central Texas Council of Governments (NCTCOG).