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Case Report Open Access

Determination of Safe Roadway Buffer Width to Protect Human Health from NO_2 Exposure: A Case Study for Grand Prairie, TX

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Abstract

According to the U.S. Environmental Protection Agency (EPA), in 2010 mobile sources in the U.S. contributed 58% of carbon monoxide (CO), 56% of nitrogen oxide (NO_x), and 33% of Volatile Organic Compounds (VOCs). On-road sources also emit a variety of air toxics, including benzene, toluene, and xylenes. The case study presented here determines a safe roadway buffer width to protect human health from nitrogen dioxide (NO_2) exposure along an arterial in Grand Prairie, Texas. NO_2 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 about half of NOx emissions.

Vehicle NOx emission rates along Great Southwest Parkway were measured using a Horiba 1300 OBS on-board emission measurement system, to determine a maximum 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 hourly meteorological combinations. The maximum emission factor and worst-case meteorological conditions were input into the line source dispersion model CALRoads View to determine worst-case NO_2 concentrations at 5- m intervals away from the roadway. CALRoads View output was post-processed in Arc View GIS to plot concentrations at receptor locations.

Worst-case concentrations were compared to the 1-hour NO_2 National Ambient Air Quality Standard (100 ppb). For the current Great Southwest traffic volume, it was found that the standard would not be exceeded. Additional CALRoads View 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 10 and still protect human health from NO_2 impacts, using a 20-foot buffer.

Keywords: Air pollution; Nitrogen dioxide; Dispersion modeling; Caline; Roadways; Vehicle emissions

Introduction

Despite stringent exhaust emissions standards, increases in the number of vehicles in use and a corresponding increase in Vehicle Miles Traveled (VMT) mean that vehicles still account for a large percentage of U.S. air pollutant emissions. Between 1980 and 2011, total vehicle miles traveled in the U.S. increased by 94% [1]. According to the U.S. Environmental Protection Agency (EPA), in 2010 mobile sources in the U.S. contributed 58% of Carbon Monoxide (CO), 56% of Nitrogen Oxide (NO_x), and 33% of Volatile Organic Compounds (VOCs). [1]

Such contributions to emissions have prompted substantial interest over the past 5 years, and particularly over the past 2 years, in measurement and modeling of near-road air quality [2-32]. Specifically, interest has emerged determining in roadway buffer widths needed to protect human health [33-36].

In many regions across the US, on-road vehicles such as cars, motorcycles and light duty gasoline trucks contribute 50% of nitrogen oxide ($NO + NO_2 = NO_x$) emissions [2]. Not only is NO_x a precursor to formation of ozone, acid rain, and fine particulates, but nitrogen dioxide (NO_2) in particular is also a pollutant in and of itself. Its health effects include irritation to eyes, nose, throat, and lungs; it can also cause cough and shortness of breath, tiredness and nausea. Because of this, NO_2 is one of six criteria pollutants for which the U.S. Environmental Protection Agency has issued National Ambient Air Quality Standards (NAAQS). The current NAAQS for NO_2 are 100 parts per billion (ppb) and 53 ppb for 1-hour and annual averaging times, respectively [37].

The purpose of this case study was to determine a safe roadway buffer width to protect human health from nitrogen dioxide exposure along an arterial located in Grand Prairie, Texas. Measured vehicle emission data was input into the line source dispersion model CALRoads View to determine an appropriate buffer width for Great Southwest Parkway in Grand Prairie, Texas.

Materials and Methods

Measurement of vehicle emission factor

The emission data was collected using the UTA Civil Engineering Department 2000 Chevrolet Astro van, with specifications shown in Table 1. The van was outfitted with a tailpipe emissions analyzer, Horiba Instruments On-Board Measurement System OBS-1300. The OBS is composed of two on-board gas analyzers, a laptop computer equipped with data logger software, a power supply unit, a tailpipe attachment and other accessories. The OBS-1300 collects second-by-

Parameter	Value
Engine	4.3 L V6
Power	142 kW, 190 HP @4400 rpm
Fuel Tank capacity	25 gallons
Injection system	Multi-point

Table 1: Specifications of 2000 Chevrolet Astro Van.

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second measurements of Nitrogen Oxides (NO_x), Hydrocarbons (HC), Carbon Monoxide (CO), Carbon Dioxide (CO_2), exhaust temperature, exhaust pressure, and vehicle position (via a Global Position System, or GPS). HC, CO, and CO_2 are measured using Heated Non-Dispersive Infrared (HNDIR), and NO_x is measured using a non-sampling type zirconium sensor. Routine instrument calibrations and warm up were carried out each day before the start of each session of data collection. The sensor was also calibrated weekly as required by the protocol. Maintenance and diagnostic procedures were conducted as required.

NO_x emissions data was collected along Great Southwest Parkway in Grand Prairie, Texas, from Abram Street to Fairmont Street as part of a study, described elsewhere, to measure changes in vehicle emissions before and after traffic signal retiming [38]. Figure 1 shows the stretch of Great Southwest Parkway used for measurement, which was more than 5 miles. This stretch of roadway includes a school zone, two railroad crossings, commercial zone, and residential neighborhoods. On-road emission measurements were able to capture variations in emissions due to accelerations, decelerations, and variations in speeds, which would have been caused by the presence of the school zone and railroad crossings in the roadway segment tested. This is an advantage of using a measured emission factor rather than a modeled (e.g. MOVES) emission factor. However, the fact that emission measurements were made for only one vehicle, which may not be representative of the vehicle fleet, is a limitation.

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

Data was collected on Tuesdays, Wednesdays and Thursdays because the traffic volume remains more stable on these weekdays. No runs were made on days with rain. The study vehicle was driven on average speed maintained by the cars on the corridor. The vehicle was warmed up when data collection was started, so cold starts did not impact the data.

Dispersion modeling of NOx concentrations

CALRoads View software (commercial version of Caline4 designed by Lakes Environmental, Inc.) was used for dispersion modeling. Caline4 is a Gaussian dispersion model specifically tailored to modeling concentrations of pollutants adjacent to roadways. Model inputs are discussed below.

Link geometry and activity: The roadway segment of the Great Southwest Parkway under consideration was divided into 13 sub-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 CALRoads View compatible. All links were considered "at grade."

The maximum traffic volume per hour, obtained from the North Central Texas Council of Governments, was 1428 on Great Southwest at the Bardin Street intersection. This maximum value was used as a conservative assumption to model the worst-case scenario.

The emission factor used was 2.02 gram per vehicle mile traveled, which was the overall maximum from the on-road data collection, as discussed below. The emission factor was actually for total NO_x (NO + NO_2), since that is what the OBS measured; the National Ambient Air Quality Standard, however, is for NO_2 alone. Although automobiles and other combustion sources typically emit NOx as 90-95% NO, and only 5-10% NO_2, volatile organic compounds can oxidize NO in the atmosphere to NO_2. Thus, using the NO_x emission factor to represent NO_2 emissions was conservative, assuming that VOCs in the atmosphere oxidized all NO emitted to NO_2.

Worst-Case meteorology: The CALRoads View version of Caline4 does not have ability to process hourly meteorological data. In order to determine worst-case meteorology, 'CAL3HCQR' (intersection dispersion modeling software in CALRoads View family, which has

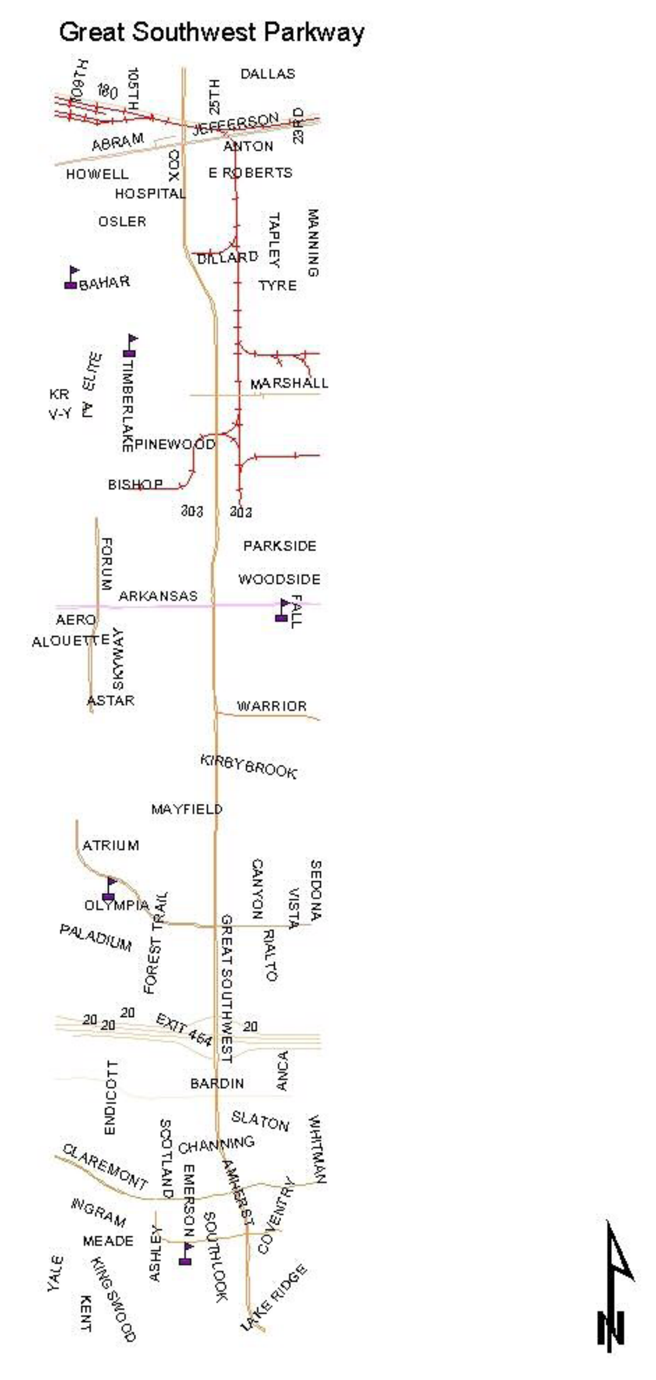

Figure 1: Great Southwest Parkway, Grand Prairie, TX.

the ability to handle hourly meteorological data) was run with a unit emission factor for Carbon Monoxide (CO) (Cal3hcqr does not model NO_2).

Hourly surface meteorological data from Dallas-Fort Worth International Airport (station number 03927) was obtained from the Lakes Environmental web site (www.weblakes.com) for 1984, 1987, 1988, 1989, and 1990. The upper air data was not available for 1986 and CAL3HCQR was unable to process 1985 data, so these years were skipped. The 1984-1990 data is part of the quality-controlled data currently used for air quality permit application modeling in Texas. Meteorological data collected at the Dallas-Fort Worth International Airport is routinely used for modeling conducted for locations across the DFW Metroplex for permit applications. Hourly upper air meteorological data was obtained for the Stephenville weather station, the closest station to DFW with upper air data. PCRAMMET was used to preprocess the met data.

The five meteorological conditions giving the highest CO concentrations were selected for years 1984, 1987, 1988, 1989, and 1990. From these five years of data analyzed, the 10 hourly worst-cases were selected for modeling in CALRoads View. It was assumed that the meteorological conditions creating the worst-case concentrations for an intersection in CAL3HCQR will give the worst-case concentrations for roadway segments in CALRoads View. It was also assumed that meteorological conditions creating the worst-case concentration for CO create the same effects for NO_2.

Table 2 summarizes the top 10 1-hour worst-cases of meteorology identified by CAL3HCQR over the 5 years. Most incidents of worst-case meteorology occurred between mid-night to early morning 7 a.m., with low wind speeds (1-3 m/sec) and low temperatures (<13°C). Warmer temperatures are often associated with solar heating of the ground surface, which generates thermal turbulence that disperses pollutants.

In addition to the worst-cases of meteorology in terms of wind speed, temperature, stability, and mixing height, a standard deviation of wind angle and background concentrations of ozone, NO, and NO_2 were needed as model inputs. Maritime tropical wind blows most frequently from the south in Texas [39], so Arlington Municipal Airport serves as the best station for background concentrations for Great Southwest Parkway. After various trials, it was concluded that the maximum background concentrations (112 ppb, 310 ppb, and 50 ppb for ozone, NO, and NO_2, respectively) and a minimum standard deviation of wind angle (15.87°) produce the maximum concentration at receptors. An NO_2 photolysis rate constant of 0.08 was used.

Receptor grid and other model options: 1080 grid receptors with longitudinal spacing of 500 m and lateral spacing of 5 m were used. Settling and deposition velocities were set to zero, to be conservative. The surface roughness length was set at 100 cm, typical of suburban areas. The worst-case wind angle option was chosen. Output concentration contours were generated in ArcGIS, to obtain more control over output format.

Results

Table 3 summarizes emission factors from the on-road data collection. The current fleet-average NO_x standard for new vehicles is 0.07 g/mile, which is less than the measured emission factor. Vehicles older than the van tested, as well as diesel vehicles, would likely have higher NO_x emission rates. A limitation of this research is that the emission factor for the van tested may not be representative of the entire vehicle fleet in Dallas-Fort Worth, Texas.

The maximum concentration and its receptor location are shown for all 10 runs (10 worst-case hours of meteorology). Most maximum concentrations occurred at the roadway centerline (X = 0 m), as expected; in a couple of cases, the maximum occurred 5 or 10 m away from the centerline. The 1-hour NO_2 standard is 100 ppb. According to Table 4, the standard was exceeded at or near the roadway centerline for all 10 worst cases of meteorology. Figure 2 shows concentration isopleths at the intersection of Great Southwest Parkway and Abrams Street.

Additional analysis was conducted to determine whether twenty feet is a sufficient buffer width to protect human health. Twenty feet is a setback distance required by some cities in residential and/or commercial areas, sometimes for storm water conveyance. 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). With the current traffic volume, the 1-hour standard is not exceeded 20 feet from the roadway. In fact, the traffic volume would have to increase by more than a factor of 10 (from 1428 to 16,300) for the 1-hour standard to be exceeded.

Hence, a 20 foot (nearly 6 m) buffer width is adequate to protect human health from NO_2 exposure along Great Southwest Parkway, given the assumptions made in this study. Worst-case meteorology was used, which was conservative. The emission factor used was the highest observed in van, which was conservative; however, the van is a gasoline vehicle, which means it would likely have lower emissions than diesel vehicles. Using the NO_x emission factor to represent NO_2 emissions was conservative, assuming that VOCs in the atmosphere oxidized all NO emitted to NO_2. Moreover, the input 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.

Conclusions and Recommendations

A roadway buffer width of 20 feet (nearly 6m) is adequate to protect

Order No.	Year	Month	Day	Hour	Wind Speed (m/s)	Amb. Temp (K)	Stability Class	Rural Mixing Height (m)	Urban Mixing Ht. (m)	Conc.
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	29.0
5	87	4	17	2	1.54	289.8	7	1960	49	29.0
6	88	9	11	24	7.2	301.5	4	1911	1911	27.7
7	90	1	10	2	2.06	279.3	6	835	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

Table 2: Top Ten Worst-Case Hourly Meteorological Conditions for Dallas-Fort Worth.

NO_x Emission Factor, g/mi	a.m. Peak	Off-peak	p.m. Peak	Overall
Max.	1.22	2.02	1.74	2.02
Min.	0.58	0.58	0.77	0.36
Avg.	0.81	0.78	1.30	1.08

Table 3: Chevy Astro Measured NO_x Emission Factor (EF) Summary.

Run No.	Max. Concentration (ppm)	Location of Maximum Concentration (X,Y) (m,m)
1	0.16	(0,-300)
2	0.12	(0,-800)
3	0.15	(0,-300)
4	0.18	(0,-300)
5	0.13	(0,-1000)
6	0.14	(0,-300)
7	0.16	(0,-1000)
8	0.16	(0,-300)
9	0.12	(0,-300)
10	0.15	(0,-300)

Table 4: Maximum Modeled NO_2 Concentrations for Ten Worst Cases of DFW Meteorology.

Figure 2: NO_2 Concentration Contours.

human health from NO_2 along Great Southwest Pathway, assuming that the van is representative of vehicles on the roadway. Traffic volumes on the roadway could increase by a factor of 10, and the 20 foot buffer width would still be sufficient to protect human health from NO_2 exposure. The 20 foot buffer width may not, however, be sufficient to protect against health impacts of other potential pollutants like carbon monoxide and particulates. Further research should consider other pollutants and their combined effect in order to determine a safe buffer width.

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