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ASSESSMENT OF NEAR-ROADWAY NO2 CONCENTRATIONS

Final Report

November 2012

COORDINATING RESEARCH COUNCIL, INC.
3650 MANSELL ROAD·SUITE 140·ALPHARETTA, GA 30022

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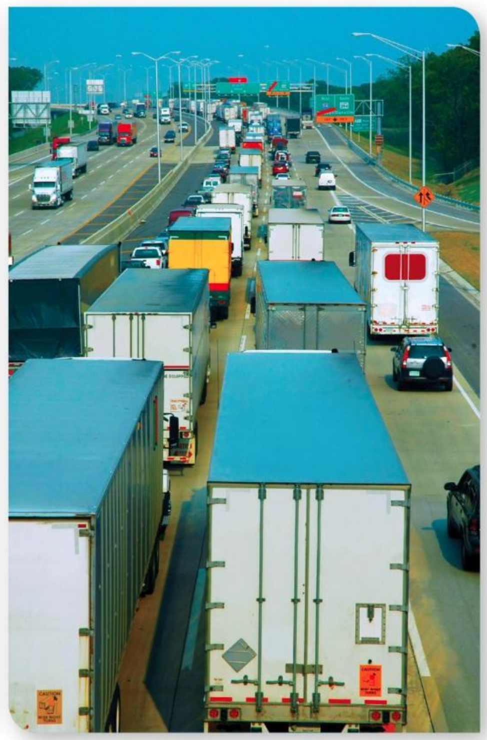
Sonoma Technology, Inc.
Air Quality Research and Innovative Solutions

Assessment of Near-Roadway NO_2 Concentrations



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Prepared by
Andrew P. Rutter, Ph.D.
Hilary R. Hafner

Sonoma Technology, Inc.
1455 N. McDowell Blvd., Suite D
Petaluma, CA 94954-6503
Ph 707.665.9900 | F 707.665.9800
sonomatech.com

Prepared for
Coordinating Research Council, Inc. (CRC)
3650 Mansell Road, Suite 140
Alpharetta, GA 30022

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Cover graphic illustrates peak hour traffic and a highway with a high proportion of heavy-duty diesel vehicles.

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Glossary

Term	**Definition**
AADT	Annual average daily traffic
Caltrans	California Department of Transportation
CASAC	Clean Air Science Advisory Committee
CH_3CO_3	peroxy acyl radical
EPA	U.S. Environmental Protection Agency
FE-AADT	fleet-equivalent annual average daily traffic
FE-HT	federal equivalent hourly traffic counts
FES	Ruth Fyfe Elementary School
HDDV	heavy-duty diesel vehicles
HNO_3	nitric acid
HNO_4	peroxynitric acid
IQR	interquartile range
LA	Los Angeles
LDV	light-duty vehicles
LQL	lower quantifiable limits
LV	Las Vegas, Nevada
NAAQS	National Ambient Air Quality Standards
NDOT	Nevada Department of Transportation
NO	nitric oxide
NO_2	nitrogen dioxide
N_2O_5	dinitrogen pentoxide
NO_3	nitrate radical
NO_x	oxides of nitrogen, defined as the sum of NO and NO_2
O	atomic oxygen
O_2	molecular oxygen
O_3	ozone
OH	hydroxyl radical
PAN	peroxyacetylnitrate
PeMS	Caltrans Performance Measurement System
photo stationary state	an equilibrium condition between formation and destruction reactions of a chemical species, such as ozone or nitrogen dioxide. At least one of the reactions involves light photons.
QA/QC	quality assurance/quality control
WIM	Weigh-in-Motion

Executive Summary

A new 1-hr nitrogen dioxide (NO_2) National Ambient Air Quality Standard (NAAQS) was promulgated by the U.S. Environmental Protection Agency (EPA) in June 2010, and requires near-road measurements to be made beginning January 1, 2013. It is unknown how many segments of roadway will be above or below the standard, and the factors controlling near-road NO_2 concentrations are currently not well understood. The goal of this work was to establish preliminary relationships between near-road NO_2 concentrations and the various factors determining those concentrations. These relationships were established using data collected during two near-road NO_2 measurement studies conducted in Las Vegas, NV, and in Long Beach, CA (in the greater Los Angeles area; henceforth referred to as Los Angeles). Measurements of NO_2, nitric oxide (NO), oxides of nitrogen (NO_x), wind direction, wind speed, ozone, and traffic counts revealed that the following factors controlled downwind NO_2 concentrations: wind direction, wind speed, proximity of the monitor to the roadway, traffic patterns, total vehicle counts, fraction of heavy-duty diesel vehicles, urban background ozone concentrations, and urban background NO_2 concentrations. Although neither study was designed specifically to investigate in depth the factors controlling NO_2 concentrations in the near-road environment, enough data were present in each study to give a strong preliminary understanding of the key factors and their typical influence on NO_2 concentrations.

Near-road NO_2 concentrations were measured in Las Vegas, NV, over one year between September 2007 and September 2008 at an elementary school located next to the US 95 freeway. The measurement site was 37 m from the edge of the road with a sound wall between the site and the road. The sample inlet was at the height of the top of the sound wall. US 95 is primarily a commuter artery to suburbs of Las Vegas and had Annual Average Daily Traffic counts (AADT) of 192,000 and 204,000 in 2007 and 2008, respectively, with 1–2% heavy-duty diesel vehicles. The measurements next to interstate freeway I-710 near Los Angeles were made between February 2009 and March 2012, with winter and summer intensive measurement studies taking place in 2009. The majority of the analysis presented in this report focused on the intensive study periods. I-710 is a major trucking route to and from the Port of Long Beach, with AADTs ranging between 187,000 and 191,000 during 2009–2011 and with approximately 17–18% of the traffic comprising heavy-duty diesel vehicles.

Both sites were found to have concentrations below the new 1-hr NO_2 NAAQS (100 ppb; three year average of the 98^{th} percentile 1-hr daily maximum concentration). Based on this data set, the I-710 location would be above the NAAQS if the standard were to be lowered to 80 ppb, the bottom end of the range originally proposed by the EPA during the rule-making process. The Las Vegas site would not have been above the standard even if the standard were reduced to 65 ppb, the lowest limit suggested for public comment in the EPA rule proposal.

Median urban background 1-hr NO_2 concentrations measured at short distances from the measurement sites were 13 and 14 ppb in Las Vegas and Los Angeles, respectively. Median 1-hr NO_2 concentrations downwind of the roadways were 22 ppb (Las Vegas, during one year) and 33 ppb (Los Angeles, 2009 winter and summer intensives). Winter 1-hr NO_2 concentrations at Los Angeles were the highest, with a median of 46 ppb due to lower boundary

layer heights increasing background NO_2 concentrations. At Las Vegas, meteorology was more consistent throughout the year, so little seasonal variation was observed.

The reaction between ozone and NO is the predominant source of NO_2 near current roadways. Because the monitors were placed within 50 m of the roadway in this study, the ozone-NO-NO_2 reaction system may not have been at, or close to, the photo stationary state when the air was sampled under some of the scenarios observed, according to our calculations. This is expected to have introduced variability in the measured NO_2 concentrations. Wind speed also played a key role in determining downwind concentrations, and measurements made in Las Vegas suggest that sufficient ozone was not always present to fully convert the available NO to NO_2.

Differences in the day-of-week and diurnal profiles of NO_2 in Las Vegas and Los Angeles were thought to be partially caused by differences in traffic patterns between the locations. Because all the relevant detectors were broken, traffic data were unavailable at the Los Angeles location during the intensive study periods. Therefore, we could not make direct comparisons to traffic measurements made in Las Vegas, so the exact influence of traffic in Los Angeles on NO_2 time series cannot be known for the measurements presented. The Las Vegas NO_2 and traffic data both showed typical day-of-week behavior, with the weekends having lower concentrations than weekdays. In Los Angeles, however, NO_2 concentrations decreased slowly throughout the week, with the lowest concentrations observed over the weekends. Las Vegas showed strong increases in NO_2 during both morning and evening rush hours, with some impact from the 1–2% of heavy-duty diesel vehicle traffic being observed during the regular work day. In Los Angeles, only the morning rush hour peak was apparent in the NO_2 concentrations; this effect was probably due to the meteorology of the location. Although both sites had similar AADTs, the data suggest that the much higher fraction of heavy-duty diesel vehicles in Los Angeles and the meteorology led to higher NO_2 contributions from the roadway.

This study demonstrated that while both sites were below the 1-hr NO_2 NAAQS, a reduction of the NAAQS to 80 ppb would likely cause the Los Angeles location to be above the standard. The data suggest that wind direction, wind speed, proximity of the monitor to the roadway, traffic patterns, total vehicle counts, fraction of heavy-duty diesel vehicles, urban background ozone concentrations, and urban background NO_2 concentrations were the key factors influencing near-road NO_2 concentrations.

1. Introduction

1.1 Context

Nitrogen dioxide (NO_2) has been associated with respiratory morbidity, a relationship which is considered likely to be causal, and recent research suggests the risk of respiratory complaints is increased in people living near major roadways (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010; U.S. Environmental Protection Agency, 2010a). Despite the apparent causal relationship, it is still not completely clear whether NO_2 is an active species in these health end points, or is a proxy for other active co-pollutants emitted by traffic (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010; U.S. Environmental Protection Agency, 2010a). Furthermore, research continues regarding possible associations with all-cause and cardiopulmonary mortality, as well as birth outcomes such as preterm delivery (U.S. Environmental Protection Agency, 2010a, b).

In response to the most recent NO_2 Risk and Exposure Assessment, the U.S. Environmental Protection Agency (EPA) revised the primary National Ambient Air Quality Standard (NAAQS) for NO_2 in 2010, implementing a 1-hr NO_2 rule that takes a 98^{th} percentile form averaged over three years with a maximum allowable concentration of 100 ppb. Compliance with the NAAQS is determined by calculating the 98^{th} percentile of all of the daily maximum 1-hr concentrations in a year, and then averaging three consecutive years of these 98^{th} percentile values (U.S. Environmental Protection Agency, 2010a). During the proposal process for the revision of the NAAQS, EPA suggested a range of 80–100 ppb, and solicited comments on limits as low as 65 ppb and as high as 150 ppb. EPA also required that a subset of new monitors be placed within 50 m of roadway segments that are expected to have high concentrations of NO_2; this requirement complements the protection offered by the existing NO_2 monitoring network. The annual standard of 53 ppb, calculated as the annual arithmetic mean, was not revised.

1.2 Chemistry of NO_2

Most of the NO_2 measured downwind of a roadway is due to the secondary formation from nitric oxide (NO) directly emitted by vehicles and ozone (O_3) in the urban background, as shown in reaction 1 **(R1)**.

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (\mathbf{R1})$$

where k_1= 2.02 e-14 cm^3 molecules-1 s-1 (T = 300 K) (Carter, 2010).

NO_2 is subsequently photolyzed back to NO (and O_3) fairly rapidly in the daylight.

$$NO_2 + hv \rightarrow NO + O \qquad (\mathbf{R2})$$

$$O + O_2 + M \rightarrow O_3 + M \qquad (\mathbf{R3})$$

where j_{NO2} = 0.01s^{-1} (Jorba et al., 2012), and k_3 = 5.6 e-34 (T/300)$^{-2.6}$ cm^6 molecules^{-2} s^{-1} (Atkinson et al., 2004)

NO_2 also reacts with free radicals, such as the hydroxyl radical (OH) to form nitric acid (HNO_3), the hydroperoxyl radical (HO_2) to form peroxynitric acid (HNO_4), the peroxyl acyl radical (CH_3CO_3) to form peroxyacetylnitrate (PAN), atomic oxygen (O) to form the nitrate radical (NO_3), and NO_3 to form dinitrogen pentoxide (N_2O_5); however, these reactions are not fast enough to significantly affect concentrations in the formation of NO_2 within 50 m of the roadway.

Reactions 1, 2, and 3 are typically viewed from the perspective of ozone formation and destruction, so we will take this perspective for a moment. Competition between the ozone destruction (R1) and formation pathways (R2 and R3) results in what is called a photo stationary state (an equilibrium between the formation and destruction reactions) where O_3 is destroyed and formed at similar rates. This causes ozone concentrations to maintain a particular concentration until one of the factors affecting R1, R2, or R3 is changed, at which point the system responds by changing to a new photo stationary state (observed as a new ozone concentration). NO_2 and NO concentrations will also exhibit the same behavior, and it would be useful for us to understand how close to the roadway this photo stationary state is established, because it determines whether the maximum NO_2 concentrations possible have been achieved. In some respects, it is analogous to how close a one-way reaction is to completion. The photo stationary state is described using equations **E1** through **E3**.

$$\frac{d[NO_2]}{dt} = k_1[NO][O_3] - j_{NO_2}[NO_2] \qquad \text{(}\mathbf{E1}\text{)}$$

At the photo stationary state, the change in NO_2 is zero.

$$0 = k_1[NO][O_3] - j_{NO_2}[NO_2] \qquad \text{(}\mathbf{E2}\text{)}$$

$$k_1[NO][O_3] = j_{NO_2}[NO_2] \qquad \text{(}\mathbf{E3}\text{)}$$

Numerical estimates calculated using R1-R3 (not presented) suggest that unless wind speeds are low and NO concentrations are several tens to a few hundred ppb, the photo stationary state will not have been achieved by the time the air has advected to monitors within 50 m of the roadway. This will be a secondary source of variability in near-road NO_2 concentration measurements after the key factors identified in this report.

The results of several near-road NO_2 studies have been published in peer-reviewed literature, providing insight into the diurnal profiles of NO_2, the inter-conversion between NO and NO_2 caused by reaction with ozone, and the decrease in concentrations as the air mass is advected away from the road (Baldauf et al., 2008; Beckerman et al., 2008; Clements et al., 2009; McAdam et al., 2011; Gidhagen et al., 2004; Gilbert et al., 2007; Thoma et al., 2008). However, all these studies were conducted over short periods of time, limiting their representation of the three-year regulatory period for the 1-hr standard, and the one-year regulatory period for the annual standard. The literature is currently lacking long term data sets which allow a deeper understanding of temporal trends, associations with chronic health problems, and the key controlling factors. Furthermore, long-term data sets are required by the regulatory process, and are therefore necessary to give an understanding of whether a particular location will be above or below the NAAQS.

1.3 Overview of the Study

In this study, two long-term hourly data sets of NO, NO_2, and ozone concentrations in Las Vegas, NV, and near Los Angeles, CA, were used to investigate the concentration distributions near roadways. Near-road concentrations of NO_2 were measured next to two major highways (US 95 in Las Vegas, NV, and I-710 in Long Beach, CA, in the greater Los Angeles area), and at one urban background site in each city. Both highways had similar annual average daily traffic (AADT) volumes, but I-710 had a higher percentage of truck traffic (17–18% versus 1–2%), leading to much higher NO_x emissions.

Neither study discussed here was designed specifically to investigate the factors controlling NO_2 concentrations in the near-road environment. This study is a meta-analysis of the available monitoring data from these two studies; both studies provide enough data to give a strong preliminary understanding of the key factors and their typical influence on NO_2 concentrations. The study conducted at Fyfe Elementary School in Las Vegas was designed by STI to measure mobile source air toxics before and after a road-widening project; nitrogen dioxide measurements were made as an opportunistic, unfunded measurement. The study conducted next to I-710 in Long Beach, CA, was designed and conducted by South Coast Air Quality Management District (SCAQMD) to measure only the ambient concentrations of criteria pollutants and air toxics in the near-road environment.

Because neither study was designed to understand near-road NO_2 on a chemical process level, no ozone measurements were made in the near-road environment. If a chemical process focus were required, measurements of ozone, NO, and NO_2 would be needed on both the upwind and downwind sides of the road, allowing an understanding of how close to the photo stationary state the reaction system was.

The primary objectives of the study were to

1. characterize the NO_2 contributions made by vehicle traffic on roadways in the context of urban background concentrations,
2. assess whether the sites would be in compliance with the 1-hr and annual NO_2 NAAQS, and
3. provide insight into the key factors controlling the downwind NO_2 concentrations.

2. Methods

2.1 Measurement Locations and Date Ranges

The measurements made at Las Vegas were collected at Ruth Fyfe Elementary School (FES) located next to US 95, and at Air Quality Station (AIRS site code 32-003-2002) located at J.D. Smith Middle School (**Figure 2-1**).

The FES sample site was located in the school yard, which was separated from US 95 by a sound wall (**Figure 2-2**). The sample collection inlet was located 20 m from the sound wall, 37 m from the outside (slow) lane of US 95, and 2.5 m above the ground (approximately level with the top of the sound wall). The measurements made at FES were collected between September 2007 and September 2008 (**Table 2-1**). The highway underwent a width expansion during the fall of 2007 from three lanes to six lanes in each direction; this expansion was completed on November 20, 2007.

Table 2-1. Time ranges of measurements made in Las Vegas, NV.

Parameter	Las Vegas, NV	
	Fyfe Elementary School	Background (AQS 32-003-2002 at J.D. Smith Middle School)
NO_2	Sep 07–Sep 08	Nov 07–Sep 08
Meteorology	Sep 07–Sep 08	Not Applicable
Traffic	Jan 08–Sep 08	Not Applicable
Ozone	Not Available	Sep 07–Sep 08

The air quality station at J.D. Smith Middle School was used as an urban background site. This was one of only two sites in Las Vegas which had active NO, NO_2, and ozone measurements. NO_2 data were only available between November 2007 and September 2008 at this site. It should also be noted that the background site was displaced from FES to the east by several kilometers (Figure 2-1). No ozone measurements were made in the near-road environment because the original study was designed to measure MSAT concentrations before and after a road-widening project, as discussed in the Introduction.

For the Los Angeles data, an urban background sample station was established at the Del Amo monitoring site approximately 4.5 km southwest of the I-710 near-road sites (**Figure 2-3**). The measurements made at Los Angeles were collected at two near-road locations next to I-710 approximately 200 m south of the N. Long Beach Boulevard overpass (**Figure 2-4**). The two sampling locations were 15 m and 80 m from the outside lane and are referred to as the West and East sites, respectively. The Del Amo site was favored over the permanent air quality station at N. Long Beach Boulevard because it was located on the opposite side of the highway, usually upwind, and not near any other major highway. In contrast, the N. Long Beach monitor was within 1 mile of the interchange between I-710 and

I-405 in a downwind location, meaning that it was not considered representative of the urban background ozone, NO, and NO_2 concentrations.

Measurements of NO_2 were made during each of the winter and summer intensive campaigns: the winter intensive campaign was conducted between February 1, 2009, and March 11, 2009; the summer intensive was between June 24, 2009 and August 19, 2009 (**Table 2-2**). A long-term data set of NO_2 measurements made at the 15 m site was also analyzed and was collected between February 1, 2009, and March 23, 2012, with no data between the winter and summer intensive campaigns in 2009.

A preliminary quality assurance/quality control (QA/QC) analysis was performed to remove all calibration data and instrument malfunctions. Approximately two-thirds of the span measurements were within 15% of the expected value. Due to time constraints, no adjustments were made to the remaining one-third, which were biased high. Despite this bias, the data were still useful for assessing whether the studied portion of I-710 will have 1-hr NO_2 concentrations above 100 ppb frequently enough to exceed the NO_2 standard. Therefore, the NO_2 concentrations from the I-710 site collected outside of the intensive studies are currently considered preliminary, conservative estimates. It should be noted that NO_2 concentration data collected during the intensive campaigns at the I-710 site were not subject to this bias.

No ozone measurements were made in the near-road environment because the original study was designed to measure criteria pollutant and MSAT concentrations, as discussed in the Introduction.

Table 2-2. Time ranges of intensive measurements made in Los Angeles, CA.

Parameter	Los Angeles, CA		
	15 m site	80 m site	Background Site (Del Amo)
NO_2	Feb 09–Mar 09; July 09–Aug-09[a]	Feb 09–Mar 09; July 09–Aug-09	Feb 09–Mar 09; July 09–Aug-09
Meteorology	July 09–Aug 09	Not Available	Feb 09–Mar 09; July 09–Aug-09
Traffic	Not Available	Not Available	Not Applicable
Ozone	Not Available	Not Available	Feb 09–Mar 09

[a] Long-term data set for NO_2 at the I-710 site runs between February 1, 2009, and March 23, 2012, with no data between the winter and summer intensive campaigns in 2009. The long-term data set only exists for the 15 m site.

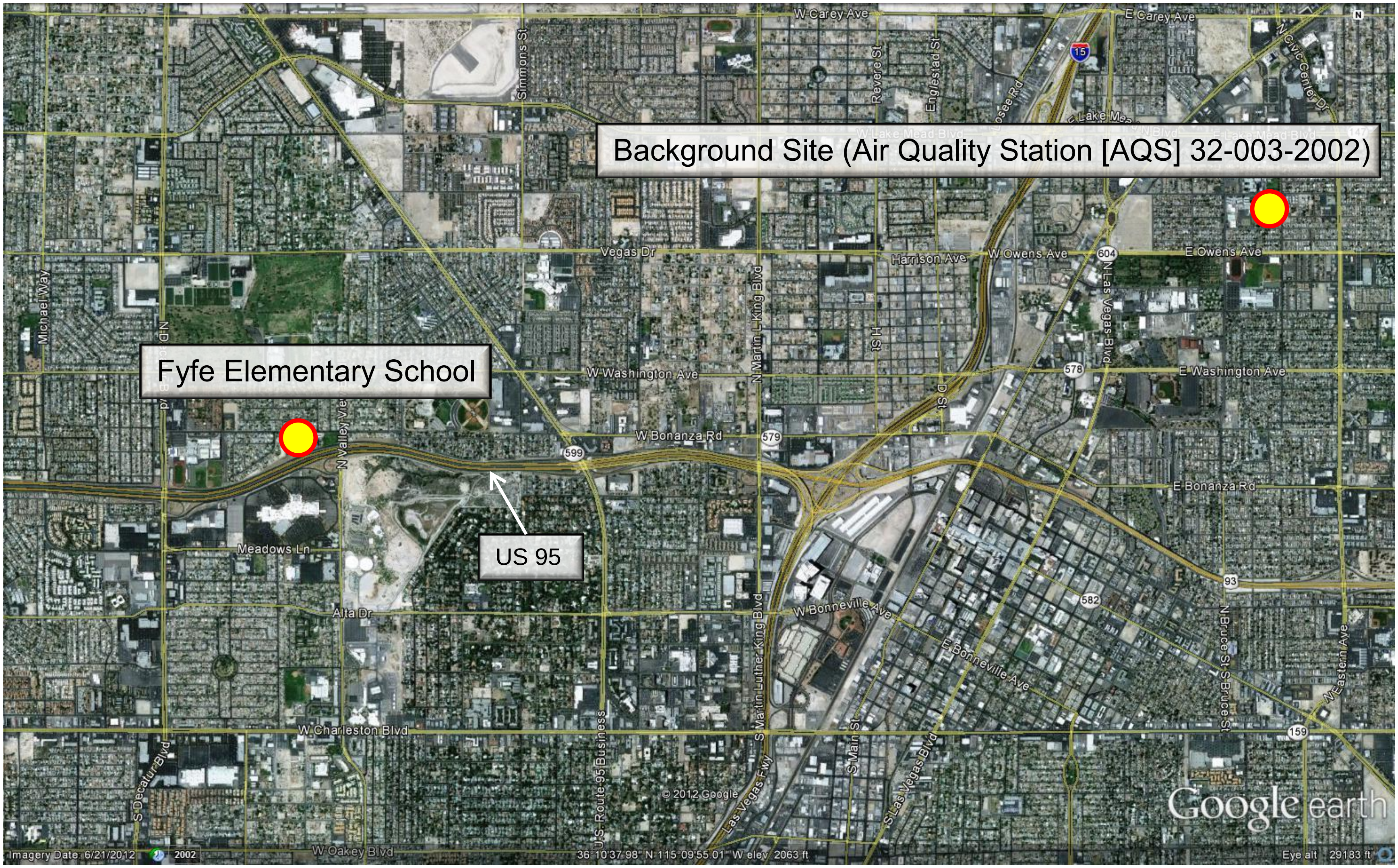


Figure 2-1. Map showing the location of Fyfe Elementary School, where the near-road NO_2 site was located, and the Air Quality Station (32-003-2002), which was used for urban background NO_2 and ozone concentrations.

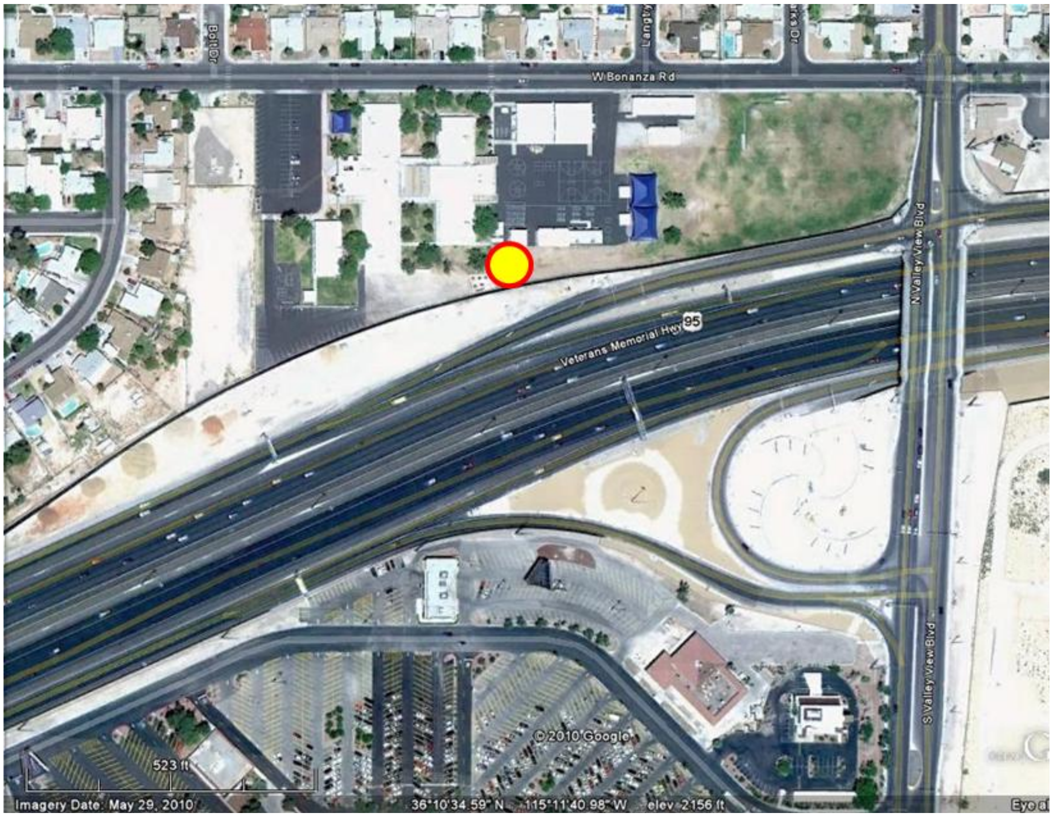
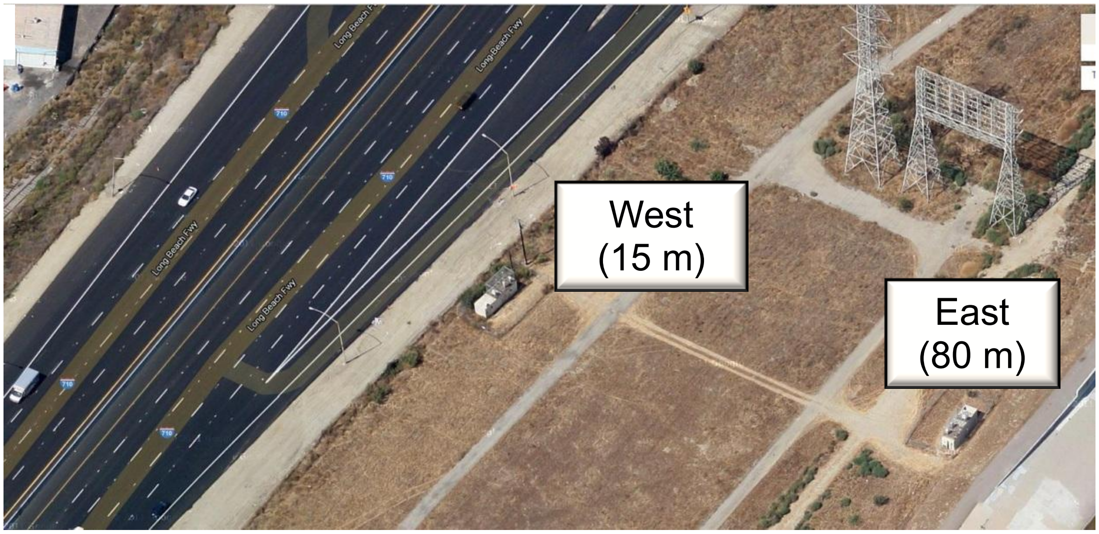


Figure 2-2. Map showing the relative position of the measurement site at Fyfe Elementary School to Highway US 95. A sound wall sits between the school and the roadway. The measurement site was 20 m from the sound wall; 37 m from the road edge.

Figure 2-3. Map showing the location of the I-710 near-road NO_2 sites, and the Del Amo monitoring site, which was used for measuring urban background NO_2 and ozone concentrations.

(a)



(b)

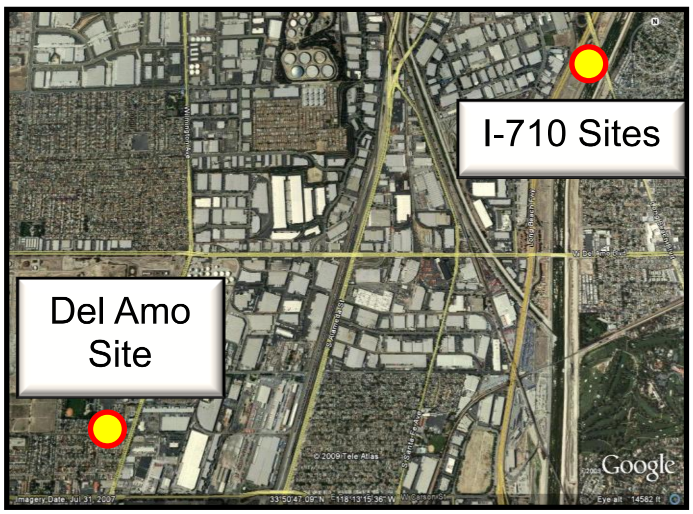


Figure 2-4. Map showing (a) the relative position of the measurement sites next to I-710, and (b) the upwind urban background site at Del Amo (all images from Google).

2.2 Nitrogen Dioxide

At FES and all of the Los Angeles sites, measurements of NO_2 were made with a Thermo Scientific 42i; at the Las Vegas urban background site, measurements were made with an API model 200A (Table 2-3). The 1-min averages provided by the instruments were aggregated into 1-hr averages. All of these instruments operate using the chemiluminescence technique. The method directly measures NO and NO_x, and then uses the difference between these two species to calculate NO_2. The operating principle of the instrument is to react NO with ozone. The products of this reaction fluoresce as the chemical species are dissipating the energy released during the reaction, allowing a quantitative measurement of the NO concentration. During the NO measurement phase, the sample is filtered and mixed with ozone and the NO concentration is measured directly, with no additional sample preparation steps needed. However, during the NO_x measurement mode, the NO_2 and the higher oxides of nitrogen also present in the sample must first be reduced to NO using a heated molybdenum converter, and then reacted with ozone. The NO_x mode therefore measures the NO originally in the sample, the NO_2 and higher oxides of nitrogen (including PAN, for example) which were converted to NO during the sample preparation phase. At urban sites such as these, near strong NO sources, the higher oxides of nitrogen are typically dominated by NO_2.

Table 2-3. Summary of manufacturer-specified lower quantifiable limits (LQL) and precision for continuous monitors and meteorological sensors. Data were acquired from manufacturer literature.

Site	Parameter	Manufacturer	Model	LQL	Precision
Fyfe Elementary School, I-710, LA Urban Background	NO, NO_x, NO_2	Thermo Scientific	42i	0.4 ppb	0.4 ppb
Las Vegas urban background	NO, NO_x, NO_2	Teledyne API	200A	0.4 ppb	0.5 %
LA urban background	Ozone	Thermo Scientific	49i	0.05 ppb	7 ppb
Las Vegas urban background	Ozone	Teledyne API	400	<0.06 ppb	0.5 %
Fyfe Elementary School	Wind speed Wind direction	RM Young	AQ 5305-L	0.4 m/s Not Applicable	±0.2 m/s ±3°
LA urban background	Wind speed Wind direction	RM Young	AQ	0.4 m/s Not Applicable	±0.2 m/s ±3°

2.3 Ozone

Hourly ozone concentrations assessed in this study were determined using measurements made at urban background sites. Measurements at the Las Vegas urban background site were made using a Teledyne Model 400 ozone analyzer, which is based on the UV absorbance technique (**Table 2-3**). The ozone measurements made at the Los Angeles urban background site were made using the same UV absorbance technique, but using a Thermo Scientific 49i (Table 2-3). Las Vegas ozone measurements at the urban background site were available between September 2007 and September 2008. Los Angeles ozone measurements at the urban background site were only available during the winter intensive campaign.

2.4 Traffic Measurements

AADT counts for Las Vegas (**Table 2-4**) were obtained from the Nevada Department of Transportation (NDOT) annual traffic reports available on the Internet (Nevada Department of Transportation, 2012a).

Table 2-4. AADT for the sections of US 95 (Las Vegas, NV) and I-710 (Los Angeles, CA) that were studied.

City	Highway	Station	2007	2008	2009	2010	2011
Las Vegas	US 95	323	192,000	204,000	197,000	209,000	200,000[a]
Los Angeles	I-710	59 and 60	199,000	194,000	189,000	191,000	187,000

[a] NDOT 2011 Annual Traffic Report flagged this data as "adjusted or estimated."

AADT counts for Los Angeles (Table 2-4) were downloaded from the California Department of Transportation (Caltrans) website (California Department of Transportation, 2012a). However, the traffic counters along the section of I-710 studied in this report were broken and inoperative during the study period. Therefore, the AADT numbers presented here are likely imputations (calculations done to fill in missing measurements) based on the techniques described at the California Freeway Performance Measurement (PeMS) website (California Department of Transportation, 2012b).

AADT counts for trucks of two or more axles were also available at the Caltrans website (12.6%, 14.1%, and 14.9% of total AADT for 2007, 2008, and 2009); however, the preface in the spreadsheet and data flags communicated that these were estimates based on measurements made somewhere along the I-710 highway. Data from the PeMS website for 2011 and 2012 gave daily average truck counts of between 9% and 11%. Published heavy-duty diesel vehicle (HDDV) fractions determined by visual inspection of video tape revealed higher HDDV fractions: 17-18% during February through March 2006 (Biswas et al., 2007), and 15% during February through April 2006 (Ntziachristos et al., 2007). Although the traffic measurements were made in

2006 at a location slightly further north on I-710, they are still likely to be representative of the sample locations discussed in this study. Trucks emit considerably more NO_x than light-duty vehicles (LDV), so the relationships between near-road NO_2 concentrations and traffic for each highway can only be compared if the AADTs are normalized to a common basis. The normalization is performed by calculating the fleet-equivalent-annual average daily traffic (FE-AADT), a metric which normalizes all vehicle traffic emissions to emulate those of LDV. The FE-AADT calculations require an understanding of the fraction of truck traffic (U.S. Environmental Protection Agency, 2012):

$$\text{FE-AADT} = (\text{AADT} - HD_c) + (HD_m * HD_c) \qquad \textbf{(E5)}$$

where AADT is the total traffic volume count for a particular road segment, HD_c is the total number of heavy-duty vehicles for a particular road segment, and HD_m is a multiplier that represents the heavy-duty to light-duty NO_x emission ratio for a particular road segment.

For consistency with the published literature, we have chosen to use the fractions published by Biswas, et al. (2007) in our calculations of FE-AADT (**Table 2-5**), because differences in vehicle classifications can occur between visual and other methods, such as the use of weigh-in-motion data from truck scales.

No measurements appropriate for determining an on-road HD_m were made during the study. However, HD_m can be estimated from national or regional emission inventories; to make this document applicable to the entire United States, we used the EPA MOVES-derived national average factor of 10 in all of the calculations presented in this study. EMFAC2011, a California-specific traffic model, gives a factor of 20 because California emission regulations are different from Federal regulations.

Traffic measurements were made at Las Vegas, NV, using a downward-facing radar that separated reflections into vehicle length categories: small (0–21 ft), medium (22–40 ft), and large (>40 ft). For the purposes of this study, the radar data were aggregated into hourly totals. All the vehicles in the large class were assumed to be HDDV, and the small class was assumed to be gasoline-fueled LDV. The total percentage of vehicles measured in the medium class that were HDDV was constrained at two percent by visually inspecting images collected from traffic cameras mounted at the Rancho overpass (east of FES) and Decatur overpass (west of FES). Two images were collected per day (one between 8 a.m. and 10 a.m., and one between 2 p.m. and 4 p.m.) on most working days between June and November 2007. HDDV were defined as a bus or any large truck which was likely to have a diesel engine. The 2008 NDOT annual traffic report reported an HDDV fraction of one percent. We have selected two percent as a conservative estimate.

2.5 Meteorology

Wind speed and direction measurements were made at FES using a rotary vane anemometer (RM Young model AQ; Table 2-3). Because wind speed and direction measurements were not available at the I-710 near-road sites during the winter intensive, measurements were made at the Del Amo urban background site also with an RM Young AQ anemometer, and were considered to be representative of the I-710 sites.

Table 2-5. FE-AADT calculation results for the sections of US 95 (Las Vegas, NV) and I-710 (Los Angeles, CA) that were studied. FE-AADT accounts for the relatively higher NO_x emissions from trucks by converting each truck into an equivalent number of cars. If no emission ratio is available for a section of highway being studied, one heavy-duty diesel vehicle (HDDV) is assumed to emit the same NO_x as about 10 cars. Therefore, the calculations used to generate this table assumed a default emission ratio of 10:1

City	Site	Year	AADT	% of Trucks	Truck AADT	FE-AADT[a]
Las Vegas	US 95 at Fyfe Elementary School	2008	204,000	1–2[a]	4080	240,720
Los Angeles	I-710 at Long Beach Blvd	2009	189,000	17–18[b]	34,020	495,180

[a] One percent value obtained from 2008 NDOT annual traffic report (Nevada Department of Transportation, 2012b). Two percent value derived from direct measurements made by NDOT and traffic imagery. Two percent value was used as a conservative estimate. Exploratory calculations revealed that a total HDDV volume fraction of 2% was achieved with the Las Vegas data set by asserting that 10% of all medium-length vehicles (between 22 and 40 ft) were HDDV, and that all vehicles longer than 40 ft were HDDV.

[b] Biswas, et al. (2007).

3. Results and Discussion

3.1 Characteristics of Near-Roadway and Background NO_2 Concentrations

The new 1-hr NO_2 standard is determined by taking the 98^{th} percentile of all of the daily maximum 1-hr concentrations in a year, and then averaging three years of these 98^{th} percentile values (U.S. Environmental Protection Agency, 2010a). For a monitoring site to comply with the NAAQS, the three-year average of the annual 98^{th} percentiles must not exceed 100 ppb. In addition, the annual NO_2 standard is calculated as the mean of 1-hr NO_2 concentrations during a year, which must not exceed 53 ppb.

The three highest 1-hr concentrations measured at FES in Las Vegas were 66 ppb, 63 ppb, and 62 ppb, and the 98th percentile of measurements made between September 2007 and September 2008 was 48.8 ppb (**Table 3-1**). None of these values was higher than the 1-hr standard of 100 ppb, although it is noted that three full calendar years of data are used by the EPA to determine whether a site is complying with the NAAQS. The three highest 1-hr concentrations at the I-710 site were 111 ppb (August 2009), 110 ppb (September 2010), and 101 ppb (September 2010), all of which were higher than the standard, but since no other concentrations were higher than 100 ppb throughout the entire data set available, the site would be unlikely to exceed the standard (98^{th} percentile over a full three calendar years cycle). The 98^{th} percentile concentration of the data analyzed was 82 ppb.

We note here that the Las Vegas study was conducted to assess the change in mobile source air toxic (MSAT) concentrations at FES before and after US 95 was widened to cope with the increased traffic from the recently expanded northwest suburbs. The road widening was completed in November 2007, and the average NO_2 concentrations between December 2007 and the end of the study was 22 ppb, no different from the annual average calculated for the entire data set. The 98^{th} percentile over this same period was 47.7 ppb, which is a small difference from the 48.8 ppb value presented in Table 3-1. This difference we believe to be minimal, does not impact the conclusions drawn from the study, and shows that the road-widening does not significantly impact the representativeness of the data. The minimal impact of the road widening was tolerated in this analysis to benefit from an entire year of data, making the analysis as parallel to regulatory calculations as possible.

During the proposal phases of the new 1-hr NO_2 NAAQS, EPA proposed a regulatory concentration range of 80 ppb to 100 ppb and asked for comments on maximum allowable concentrations as low as 65 ppb and as high as 150 ppb (U.S. Environmental Protection Agency, 2010a). It is of interest then to investigate whether either of these sites would still be above the NAAQS if the maximum allowable concentration were lowered, and if so, at what concentration could an exceedance of the NAAQS occur. The 98^{th} percentile concentrations for each of the data sets are presented in Table 3-1. The Las Vegas site demonstrated a 98^{th} percentile of 49 ppb for the year of data available, and therefore is likely to be below the standard even if it were to be lowered to 65 ppb.

The 98th percentile concentrations measured at the Los Angeles sites next to I-710 were 81 and 83 ppb for 2010 and 2011, which is inside the range of concentrations initially proposed by the EPA. A caveat is that the data sets used to calculate these values require more QA/QC analysis; because the measurements are biased high, this assessment is preliminary but conservative. Approximately one-third of the span measurements were outside the recommended ±15% tolerance around the expected standard concentration. However, our QA/QC assessment of the data reveals that a complete QA/QC analysis will not change the conclusions drawn from the comparisons to the 100 ppb standard, which we consider robust.

Table 3-1. Maximum concentrations of NO_2 at the near-road measurement sites used in this study. The NAAQS for 1-hr NO_2 is 100 ppb, which is determined by first calculating the 98^{th} percentile concentration for each of three consecutive years, and then taking the average of these three 98^{th} percentile concentrations.

City	Highway	Site	Distance to Road (m)	Date Ranges	Max Near-Road NO_2 (ppb)	98th Percentile	98th Percentile
Las Vegas	US 95	Fyfe Elementary School	37	9/07–9/08	66; 63; 62	48.8[a]	N/A
Los Angeles	I-710	West	15	1/09–3/12[b]	111; 101; 110[c]	83.3 (2010)[d]	81.3 (2011)[d]

a Computed over available date range, not calendar years.

b Preliminary analysis only on data outside of intensives; ~ 1/3 to 1/2 of instrument spans were modestly outside of the acceptable limit, therefore the non-intensive data are currently considered preliminary.

c 111.1 ppb occurred in August 2009; other concentrations occurred three days apart in September 2010.

d No measurements were made between 3/11/09 and 6/24/09, so 98th percentiles were not calculated for 2009.

Measurements made at each location were compared to the annual standard. The annual means were calculated using all of the complete sampling years at Las Vegas (which are different from the calendar years January through December used for the standard), and 2010 and 2011 calendar years at Los Angeles (**Table 3-2**). The annual averages were less than 53 ppb at both locations. At Las Vegas, the annual mean concentration was 23 ppb, while at Los Angeles, the annual means were slightly higher at 28 ppb and 29 ppb. Note the annual mean next to the I-710 freeway is similar to that at other routine air monitoring sites in the Los Angeles Basin (e.g., Upland, where annual NO_2 was 26 ppb in 2010).

Median background concentrations at Las Vegas and Los Angeles are not statistically different at the 95% confidence level: 14 and 13 ppb, respectively (**Figure 3-1**). The box shows the 25^{th}, 50^{th} (median), and 75^{th} percentiles[1]. The greater Los Angeles area is much bigger and known to have much worse air quality problems than Las Vegas, and so the urban background of NO_2 might be expected to be higher. However, the Los Angeles site at Long Beach is close to the coast, meaning that the urban background of pollutants is lower than further inland because the air travels over relatively short stretches of city when moving in from the sea. The Las Vegas data demonstrated a larger interquartile spread of concentrations ranging from 4 ppb to 32 ppb, whereas measurements in the interquartile range at Los Angeles were between 7 ppb and 26 ppb. The background concentrations at Las Vegas were more variable than at Los Angeles.

The downwind median NO_2 concentrations at both sites were usually larger than the upwind sites at both Las Vegas and Los Angeles, although the difference between the upwind and downwind directions at Las Vegas was much smaller than at Los Angeles (**Figures 3-2 and 3-3**). This finding may be partly because the sound wall at FES was found to cause wind flow patterns at low wind speeds that allowed roadway emissions to approach the sample inlet from upwind directions. This is explored further later in this report. The first quartiles follow this same pattern, but the third quartile at Las Vegas is very similar from both directions, as opposed to Los Angeles, where all the downwind interquartile markers indicate higher concentrations than those from the upwind direction.

Seasonal differences in NO_2 concentrations were observed at Los Angeles, with much higher concentrations in the winter (**Figure 3-4**). The higher concentrations are likely due to the lack of ventilation in the Los Angeles Air Basin during that season. In contrast, there was no statistical difference in the median concentrations at Las Vegas between winter and summer, although a larger interquartile spread in winter indicated higher concentration variability overall. Summer at Las Vegas brought less variability in concentrations (narrower interquartile range), but higher extreme concentrations, as shown by the presence of asterisk data markers.

[1] The whisker always ends on a data point, so when the plots show no data beyond the end of a whisker, the whisker shows the highest or lowest data point. The whiskers have a maximum length equal to 1.5 times the length of the box (the interquartile range, IQR). If there are data outside this range, the points are shown on the plot and the whisker ends on the highest or lowest data point within the range of the whisker. The outliers are also further identified with asterisks, which represent the points that fall within three times the IQR from the end of the box, and circles, which represent points beyond this. The waist of the notch is the median, while the top and bottom of the notches are the 95% confidence limits.

Table 3-2. The annual mean of NO_2 concentrations at the near-road measurement sites used in this study. The NO_2 annual NAAQS is 53 ppb, calculated using the annual mean.

City	Highway	Site	Distance to Road (m)	Date Ranges	Annual Mean (ppb)
Las Vegas	US 95	Fyfe Elementary School	37	9/07–9/08	22.6
Los Angeles	I-710	West	15	1/09–3/12	29.1 (2010)[a]; 27.6 (2011)[a]

[a] No measurements were made between 3/11/09 and 6/24/09, so 98th percentiles were not calculated for 2009.

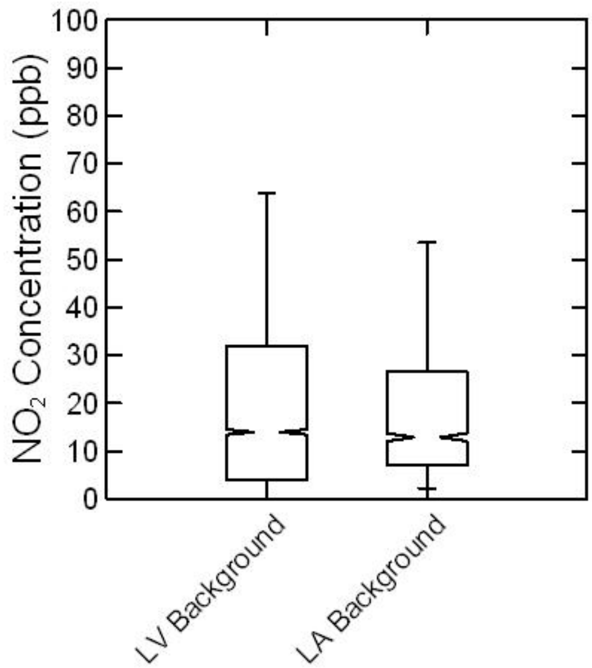


Figure 3-1. Background NO_2 concentrations for Las Vegas, NV (LV) and Los Angeles, CA (LA). Las Vegas measurements were made at Air Quality Station 32-003-2002 between November 2007 and September 2008. Los Angeles measurements were made at the Del Amo measurement station during January, February, July, and August 2009.

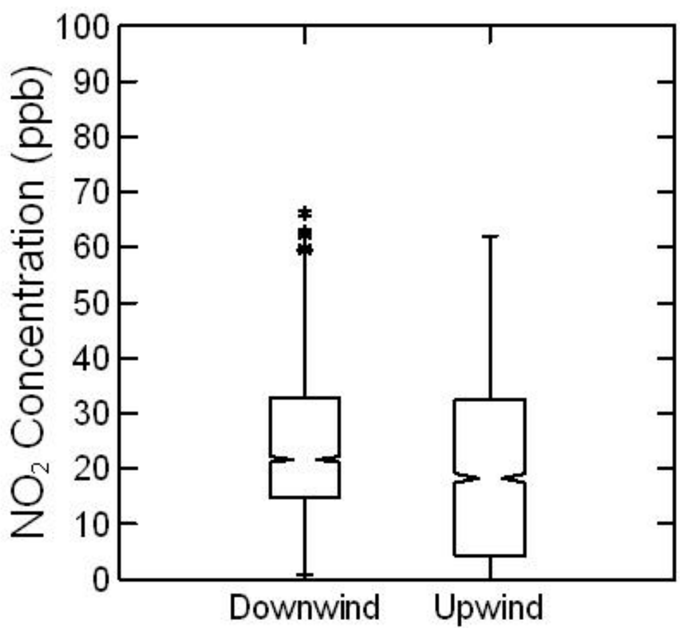


Figure 3-2. NO_2 concentrations at Fyfe Elementary School when the site was located downwind and upwind of US 95. The measurements used here were made between September 2007 and September 2008.

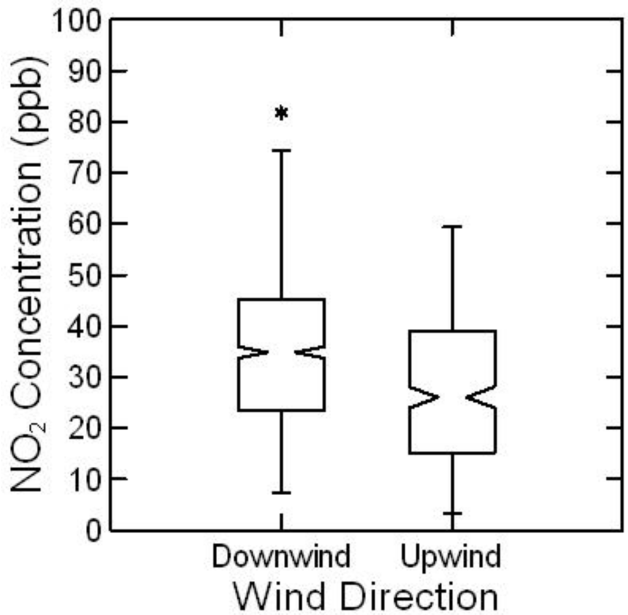


Figure 3-3. NO_2 concentrations at the West (15 m) site when the site was located downwind and upwind of I-710. The measurements used here were made during January, February, July, and August 2009.

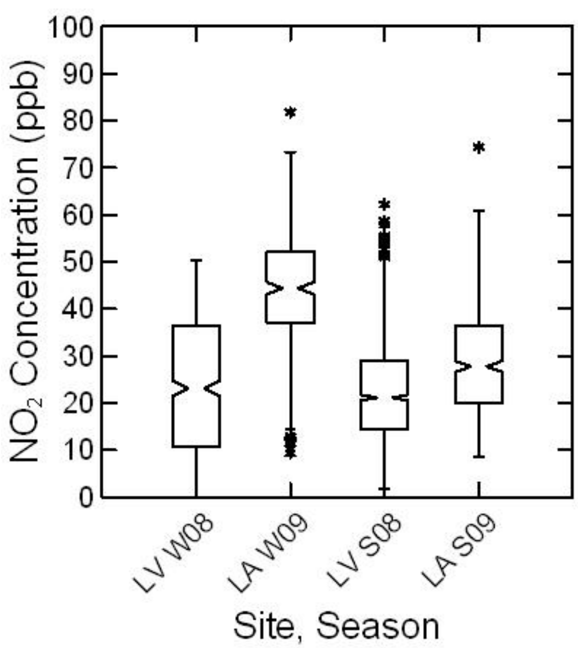


Figure 3-4. NO_2 concentrations for Las Vegas, NV (LV) and Los Angeles, CA (LA). The data for each site is presented as corresponding months during the winter and summer during the study years. Winter (W) is represented by February, and Summer (S) is represented by July–August.

3.2 Factors Affecting NO_2 Concentrations Next to Roadways

There are several factors which are believed to affect NO_2 concentrations measured by the edge of a road. They can be divided into the following categories:

- Chemistry
- Traffic
- Meteorology
- Urban background NO_2 and O_3 concentrations
- Physical location of the monitor and obstructions between the roadway and the monitoring site

The amount of NO which is released in a particular segment of highway is dependent upon the number of vehicles, their speeds, and the fleet mix. Passenger vehicles and older diesel trucks emit less than 10% of NO_x as NO_2 directly (Dallmann et al., 2012).

Wind direction was used to determine whether a measurement site is upwind or downwind of a roadway. In this analysis, only winds coming from between bearings of the roadway direction were flagged as roadway-influenced data (Las Vegas: to the South between 73^o and 247^o; Los Angeles: to the West between 195^o and 28^o). All other wind directions were considered non-roadway. All of the data were hourly averages.

Higher wind speeds lead to increased vertical and horizontal mixing of the pollutant as it is advected away from the road. Decreased boundary layer heights and nighttime inversions cause increases in background concentrations. At the locations studied in this project, the end of the morning rush hour coincided with the break-up of nighttime inversion layers, which allowed much enhanced vertical mixing of pollution. However, the break-up of the nighttime inversion has a much larger impact on urban background concentrations than at locations within 50 m of the roadway because the roadway is a strong source of NO, and the vertical and horizontal length-scales of eddies for convective turbulent mixing in the boundary layer are typically much longer than 50 m (because the eddies are several hundred meters in diameter). This effect is observed at both Las Vegas and Los Angeles when the nighttime inversion breaks after the morning rush hour, as NO_2 concentrations in the roadway contribution (the difference between the near-road and background concentrations) remain consistent throughout the day, and do not decrease during the afternoon due to the enhanced convective mixing.

Urban background concentrations of ozone determine how much NO_2 can be produced by reaction with NO (R1) that is emitted from highway traffic as the air mass is advected away from a roadway. Background NO_2 concentrations provide a foundational concentration to which roadway contributions of NO_2 concentrations will be added. In addition to the existing network of area-wide monitoring sites, EPA is establishing requirements for a subset of NO_2 monitoring sites to be within 50 m of roadways. However, primarily because of wind speed and the associated advection times and dispersion, the proximity of the monitor can affect the concentrations observed. Obstructions between the road edge and monitoring site, such as sound walls and rows of trees, are expected to disrupt wind flow patterns and cause increased mixing.

3.3 Temporal Trends

Day-of-week traffic trends in both total vehicles and HDDV at Las Vegas show decreases on Saturday and Sunday compared with weekdays (**Figure 3-5** and **Figure 3-6**). This trend is reflected in both the Las Vegas and Los Angeles day-of-week NO_2 time series (**Figure 3-7** and **Figure 3-8**), although it is interesting that NO_2 concentrations progressively decrease from Wednesday through to the weekend at Los Angeles. No traffic data were available at Los Angeles to provide insight into this trend. Day-of-week NO_2 data at Las Vegas are more typical and reflective of the observed traffic patterns.

The total number of vehicles at Las Vegas peaked during the morning and evening rush hour periods (12,000 and 14,000 vehicles per hour, respectively), with the traffic volumes in the period between rush hours being approximately 85–90% of the peak values (10,000–11,000 vehicles per hour; **Figure 3-9**a). Heavy Duty truck traffic was approximately 1–2% of total vehicle traffic (Figure 3-9b). Federal-equivalent hourly traffic counts (FE-HT) were calculated following the form for FE-AADT:

$$\text{FE-HT} = (V_h - HD_c) + HD_m * HD_c \qquad \textbf{(E6)}$$

where V_h is total vehicle counts per hour, HD_c is the count of heavy-duty diesel vehicles, and HD_m is the HDDV-to-LDV NO_x emission ratio, set to 10 as discussed earlier.

FE-HT trends follow total vehicle trends well, but medians are increased by a factor of approximately 25% due to the influence of HDDV, which appears to have introduced some extreme values of FE-HT (Figure 3-9c). A caveat to this analysis is that we have applied a nationally averaged ratio of HDDV-to-LDV NO_x emissions ratios derived from a model, rather than an empirically derived ratio from the measurements at the sites studied. Therefore, this analysis should be considered an estimate.

Models of NO_x emissions from vehicles reach a minimum at approximately 40 mph and increase as vehicle speed either decreases or increases, forming a U shape (Eisinger et al., 2012). During the study period, the speeds at Las Vegas were never less than 45 mph (Figure 3-9d). The Las Vegas NO_2 time series reflected the rush hour periods both at FES and the urban background site, although concentrations were higher at FES (**Figure 3-10**a, b). Subtracting the urban background from the FES measurements revealed a roadway contribution that increased during daylight hours but did not show statistically significant increases during the rush hour periods compared with the time periods immediately before and after (Figure 3-10c).

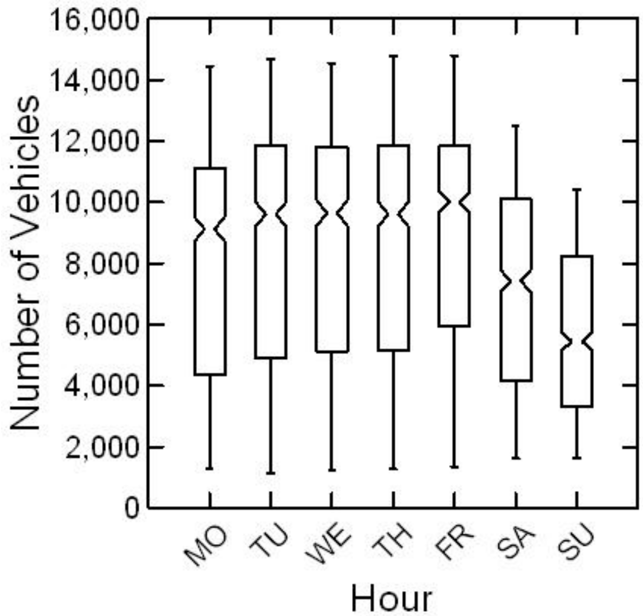


Figure 3-5. Day-of-week trends in total number of vehicles on US 95 near Fyfe Elementary School, Las Vegas, NV.

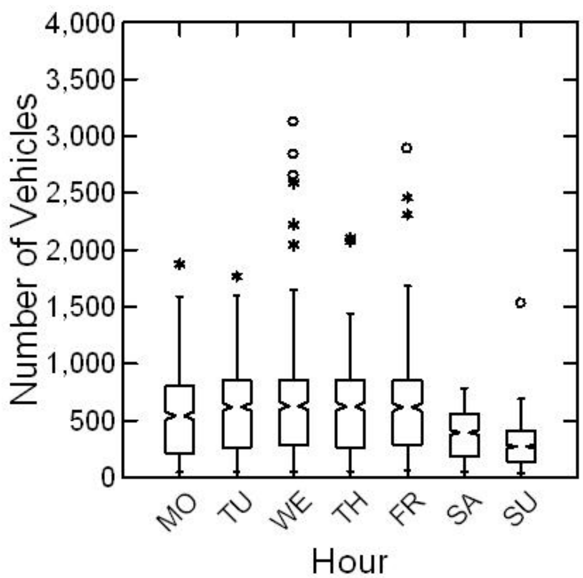


Figure 3-6. Day-of-week trends for HDDV on US 95 near Fyfe Elementary School, Las Vegas, NV. Calculation procedure for HDDV counts is discussed in Table 2-5.

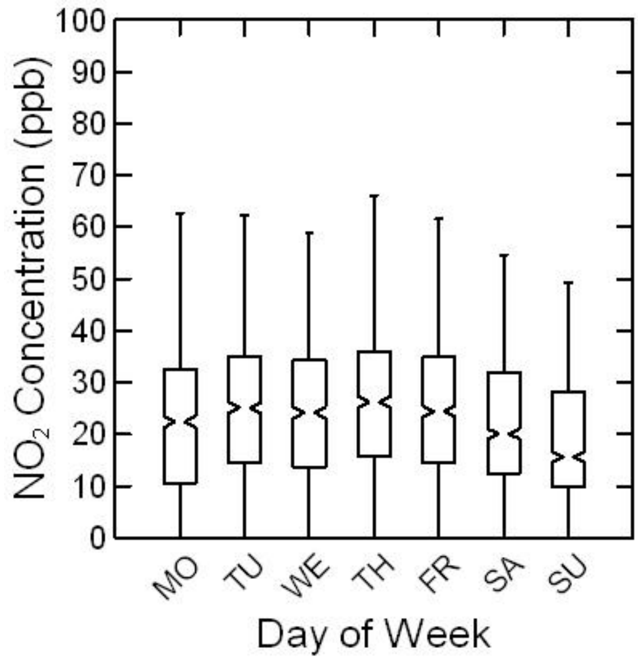


Figure 3-7. Day-of-week trends in NO_2 concentrations at Fyfe Elementary School, Las Vegas, NV.

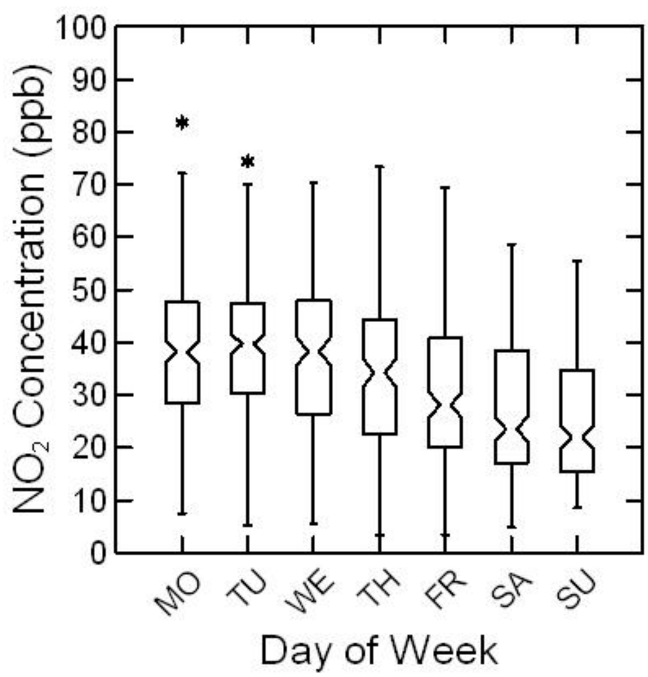


Figure 3-8. Day-of-week trends in NO_2 concentrations at I-710, Los Angeles, CA.

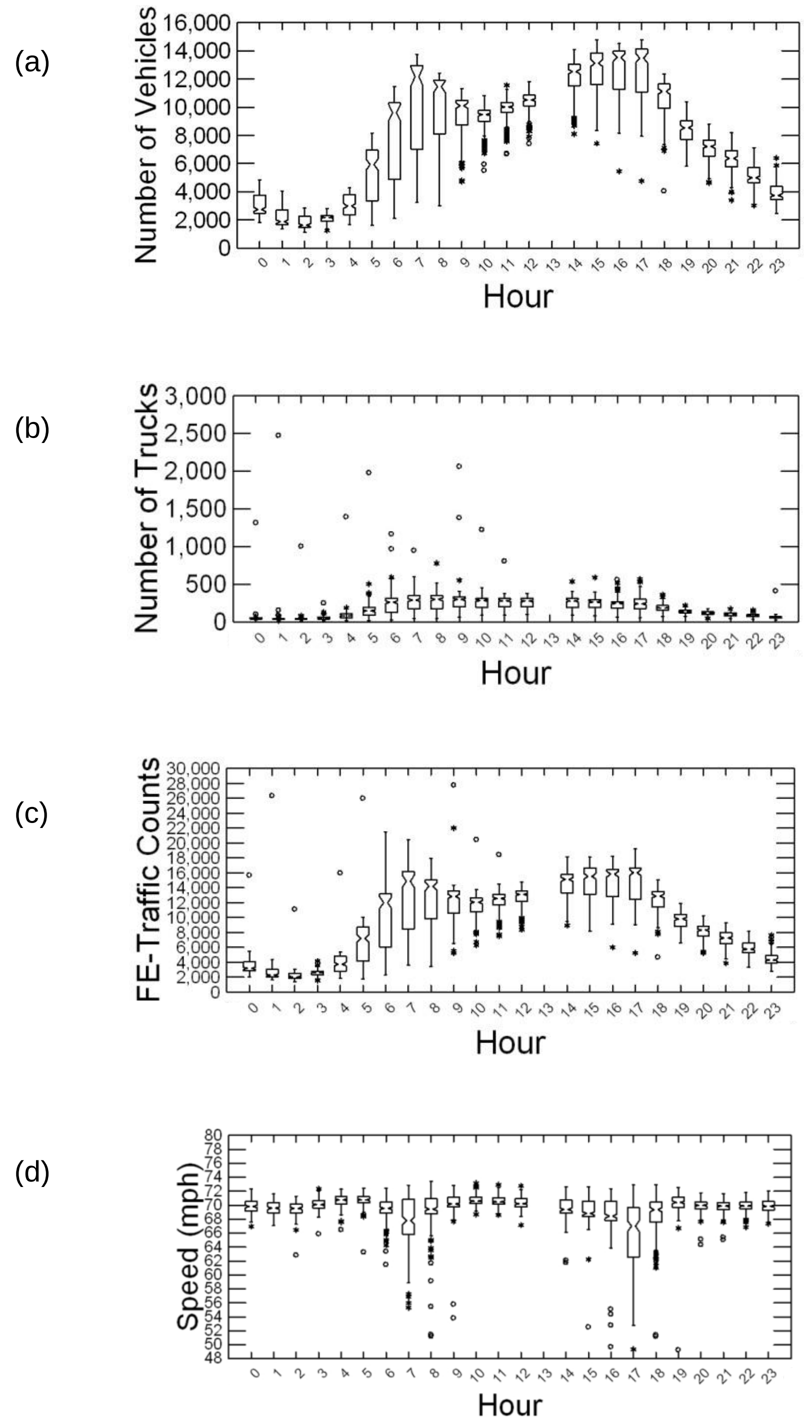


Figure 3-9. Hourly totals of (a) overall vehicle count, (b) HDDV count, (c) fleet-equivalent traffic counts, and (d) vehicle speed measured between January and September 2008 near Fyfe Elementary School on US 95, Las Vegas, NV.

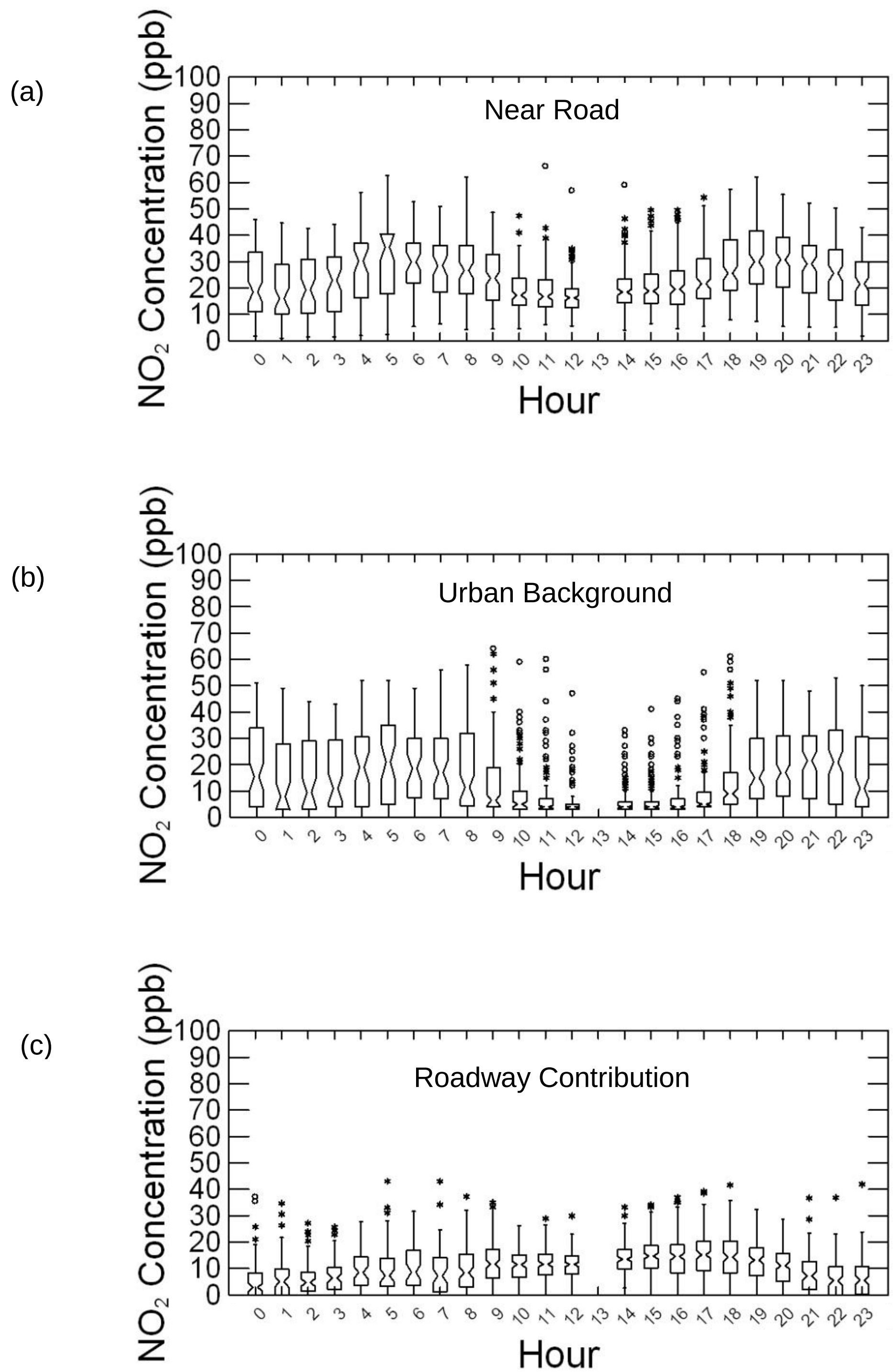


Figure 3-10. Diurnal NO_2 concentrations for the measurement site at (a) Fyfe Elementary School, (b) the Air Quality Station at J.D. Smith Middle School (32-003-2002), and (c) the contribution made by US 95 [pairwise differences between data points summarized in (a) and (b)] to the Fyfe Elementary School measurement site when the wind was coming from the direction of the roadway.

Differences in traffic patterns and meteorology between Long Beach and Las Vegas may account for differences in near-road NO_2 concentrations (Figure 3-9; **Figure 3-11**). The peak values of NO_2 were typically observed later in the morning at Los Angeles than in Las Vegas, and the evening rush hour peak was not as obvious. The roadway contribution showed higher NO_2 concentrations during the workday hours than at night. However, no statistically significant increase was seen in NO_2 concentrations during rush hour periods compared with the time periods immediately before and after. No hourly measurements of traffic data were available along the stretch of I-710 in Los Angeles, because all the relevant detectors were broken during the study. Annual weigh-in-motion (WIM) data collected in 2000 for the I-710 sites (Coe et al., 2001) show HDDV traffic peaks at midday on weekdays, while LDV traffic peaks were observed in the morning and evening on weekdays.

The pollution roses presented in **Figure 3-12** through **Figure 3-17** provide summaries of pollutant concentrations and wind patterns for both the Las Vegas and Los Angeles sampling sites. The size of the triangle emanating from the center of the rose indicates the percentage of time that winds are from a specific direction (position on axes); the NO_2 concentration time percentages are indicated with color bins along the length of the triangle. Pollution rose analyses of the Las Vegas data clearly identified US 95 as the predominant source of NO_2 during summer months, although there are some instances of high concentrations of NO_2 from non-road directions (**Figure 3-12**). Clearly wind direction is a primary factor controlling near-road NO_2 concentrations.

During winter months, high concentrations of NO_2 are frequently observed both from the road and non-road directions (**Figure 3-13**). These high concentrations were thought to be due to the sound wall causing air from the roadway to approach the sample inlet from non-road directions at slow wind speeds, although upwind meandering due to traffic turbulence may also occur under stagnant conditions (U.S. Environmental Protection Agency, 2012). To test this hypothesis, we excluded measurements made during the winter while wind speeds were less than 1 ms^{-1} from **Figure 3-14** leaving only measurements made while wind speeds were greater than 1 ms^{-1}. A similar analysis was performed to produce **Figure 3-15**, except that all measurements less than 2 ms^{-1} were excluded from the pollution rose. Both of these analyses revealed that with progressively higher wind thresholds, the frequency of high NO_2 concentrations from the non-road direction decreased. A similar conclusion was reached with black carbon particle measurements made at the same location, which are discussed elsewhere (Roberts et al., 2010). This information confirmed the lack of a consistently operating source of NO_2 from the non-road direction, which was expected to be the case given our knowledge of the surrounding area, and lent credibility to the idea of the sound wall causing turbulent recirculation of air from the roadway at low wind speeds.

The I-710 sample site was consistently downwind of the roadway at the same grade (level) without obstruction. High concentrations of NO_2 were predominantly associated with the direction of the I-710 in both winter and summer (**Figure 3-16** and **Figure 3-17**). Wind speed strongly affected the concentrations observed downwind of the roadway (**Figure 3-18** and **Figure 3-19**). As wind speeds increase above an effectively constant emission source, the same amount of pollutant (in this case, the NO_2 precursor NO) is spread out through a longer volume of air because the air mass is traveling at a faster rate. This causes the pollutant to be observed as a lower concentration at the monitor. Some or all of the NO also reacts with ozone to form NO_2 during flight from the roadway to the sample inlet. Other effects also decrease observed concentrations of NO_2 at a near-road site. The higher wind speeds cause more vertical mixing because of mechanically induced turbulence at the earth's surface and around moving vehicles. The trend in the medians at both sites suggest a fairly linear decrease in concentration as wind speed increases; wind speed is clearly a primary factor in determining downwind concentrations.

Because current vehicle primary NO_2 emissions are small relative to NO emissions, NO_2 is largely a secondary pollutant near roadways. Therefore, background ozone concentrations are of primary importance in determining downwind NO_2 concentrations. If we ignore the slow hydrocarbon-related free radical reactions, and focus on the fast reaction forming NO_2 (R1), the O_3:NO_2 stoichiometry is 1:1, meaning one molecule of O_3 reacts with one molecule of NO to give one molecule of NO_2. Therefore, in an environment with excess ozone, we would expect to see a 1:1 relationship between NO_2 and total NO_x if all of the NO is converted upon arrival at the monitor. A strong correlation between NO_2 and NO_x was observed for much of the data set, revealing that background ozone concentrations are a primary factor controlling near-road NO_2 concentrations. A 1:1 relationship between NO_2 and NO_x was also observed at Las Vegas (**Figure 3-20** and **Figure 3-21**), although deviations from the expected form of the NO_2-NO_x relationships were observed (Figure 3-20) raising the following questions:

1. Why was there an asymptote?
2. Why were there some hours in which moderate ozone concentrations were measured but that the NO_2 yield was apparently not as high as expected (i.e., why do some data lie away from the 1:1 line in the graph)?
3. Why was there so much scatter in the data below the 1:1 line as concentrations increased, particularly before the asymptote?

The following points are thought to contribute to the observed deviations from the conceptual model. The numbering of the question list above corresponds to the numbering of the answers seen below:

1. The asymptote in NO_2 was caused by the lack of available ozone for NO to react with.
2. The low NO_2 yields when ozone concentrations were sufficient for more complete conversion may have been partly because the ozone measurements were made at a location several kilometers east of FES and therefore may not be perfectly representative of ozone at the near-road site. Future studies designed specifically to near-road NO_2 concentrations from a chemical process perspective should include ozone and NO_x measurements on either side of the roadway.
3. Numerical estimates calculated using R1-R3 suggested that near-road monitors are close enough to the roadways there may be insufficient time to achieve the photo stationary state (the same as equilibrium for this reaction system) under some conditions, and there may also be competition between the rate of mixing and chemical reactions that impede full conversion. Deviation from the photo stationary state would be expected to constitute a secondary source of variability in NO_2 concentrations,

superimposed on the primary influences of wind direction, wind speed, traffic characteristics, and background NO_2 and ozone concentrations.

Further research is needed to explore these hypotheses.

(a)

(b)

(c)

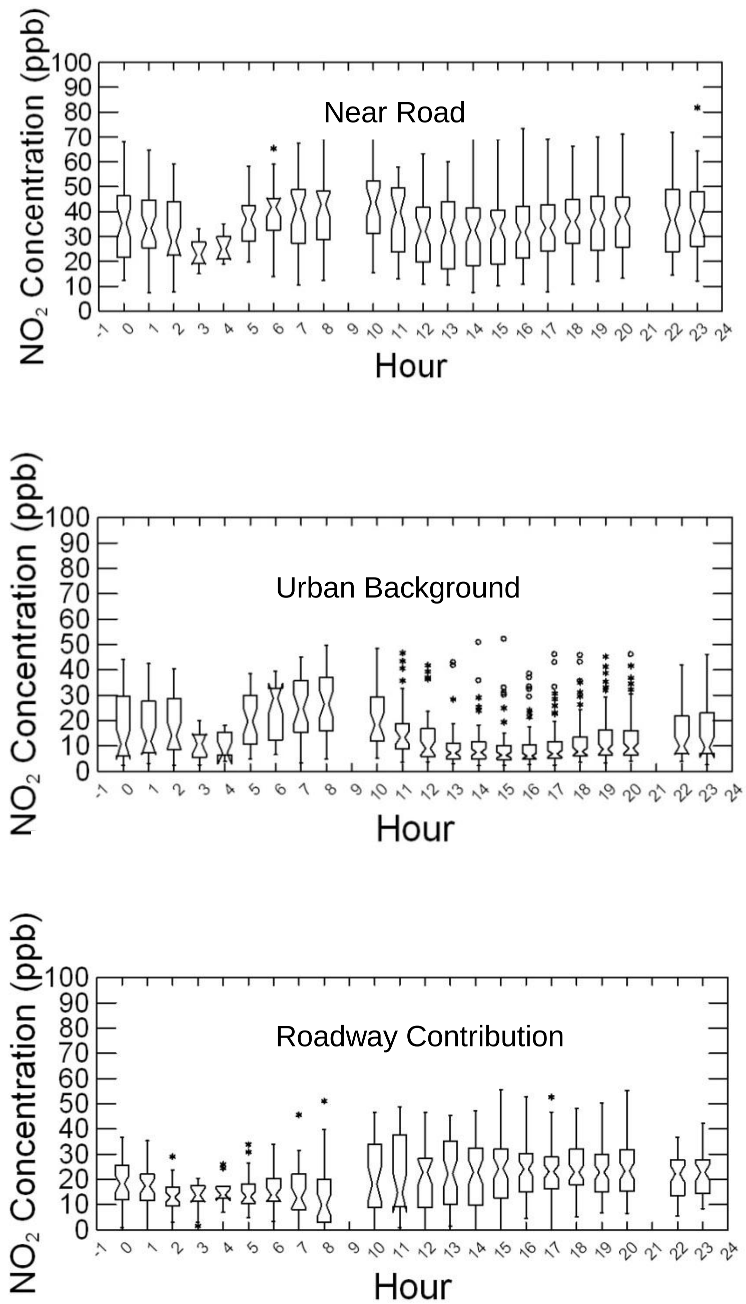


Figure 3-11. Diurnal NO_2 concentrations for (a) the West (15 m) measurement site next to I-710, (b) the measurement site at Del Amo, and (c) the contribution made by I-170 to the West (15 m) measurement site [pairwise differences between data points summarized in (a) and (b)] when the wind was coming from the direction of the roadway.

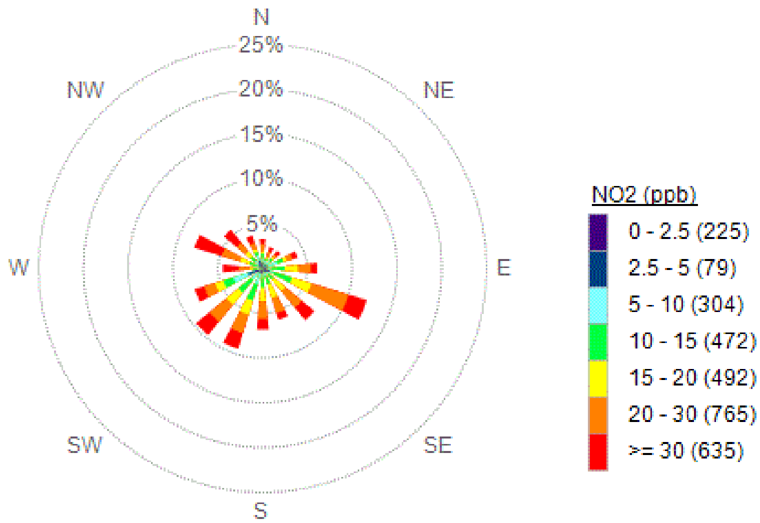


Figure 3-12. The frequency of NO_2 concentrations as a function of wind direction measured during the summer of the US 95 study (Las Vegas, NV). See text for instructions on interpreting a pollution rose.

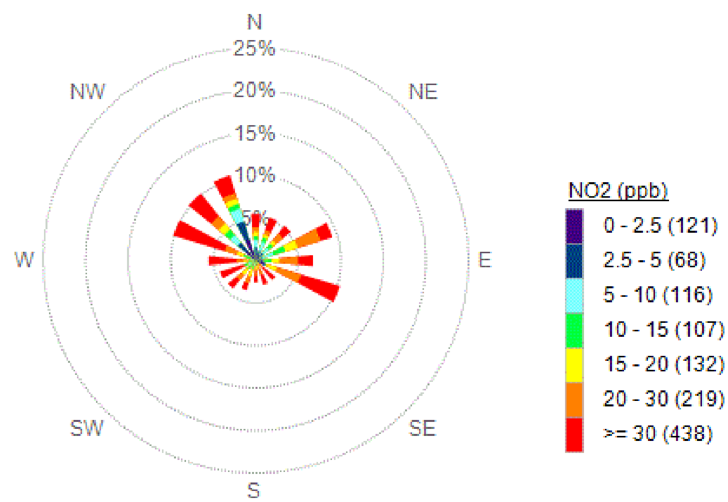


Figure 3-13. The frequency of NO_2 concentrations as a function of wind direction measured during the winter of the US 95 study (Las Vegas, NV). See text for instructions on interpreting a pollution rose.

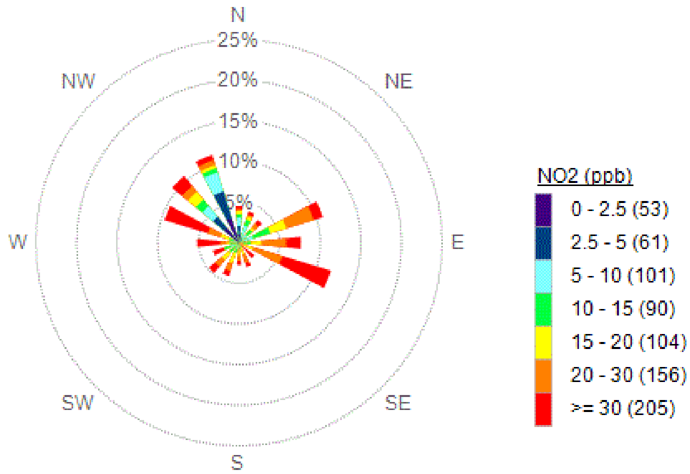


Figure 3-14. The frequency of NO_2 concentrations as a function of wind direction measured during the winter of the US 95 study (Las Vegas, NV). Only measurements collected at wind speeds equal to or greater than 1 ms^{-1} are included. See text for instructions on interpreting a pollution rose.

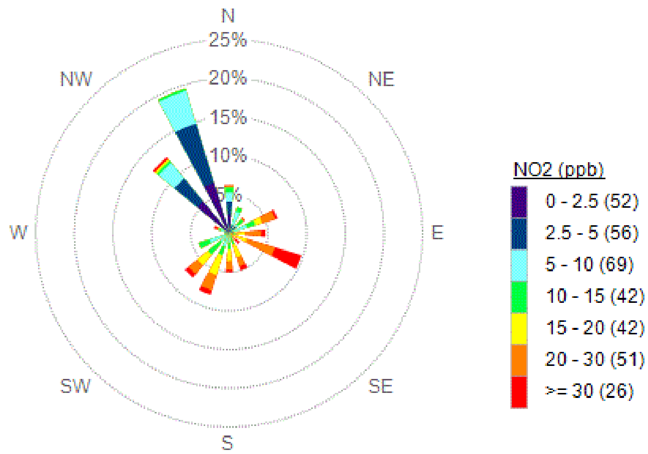


Figure 3-15. The frequency of NO_2 concentrations as a function of wind direction measured during the winter of the US 95 study (Las Vegas, NV). Only measurements collected at wind speeds equal to or greater than 2 ms^{-1} are included. See text for instructions on interpreting a pollution rose.

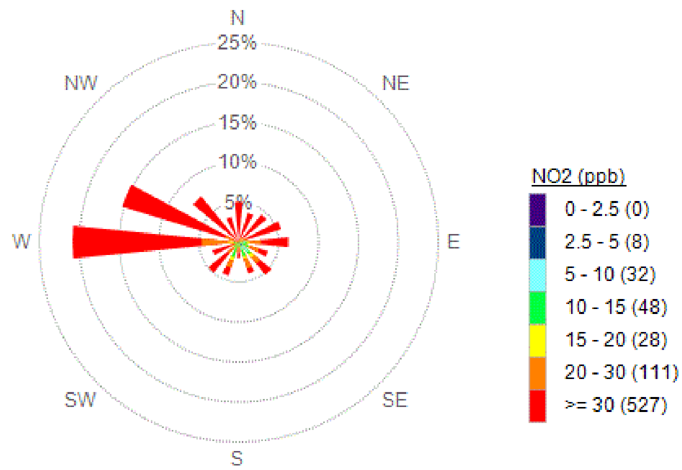


Figure 3-16. The frequency of NO_2 concentrations as a function of wind direction measured during the I-710 winter intensive study (Los Angeles, CA). See text for instructions on interpreting a pollution rose.

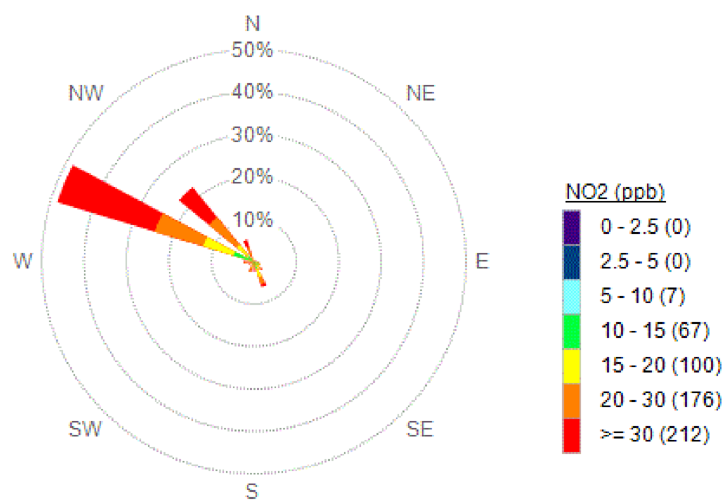


Figure 3-17. The frequency of NO_2 concentrations as a function of wind direction measured during the I-710 summer intensive study (Los Angeles, CA). See text for instructions on interpreting a pollution rose.

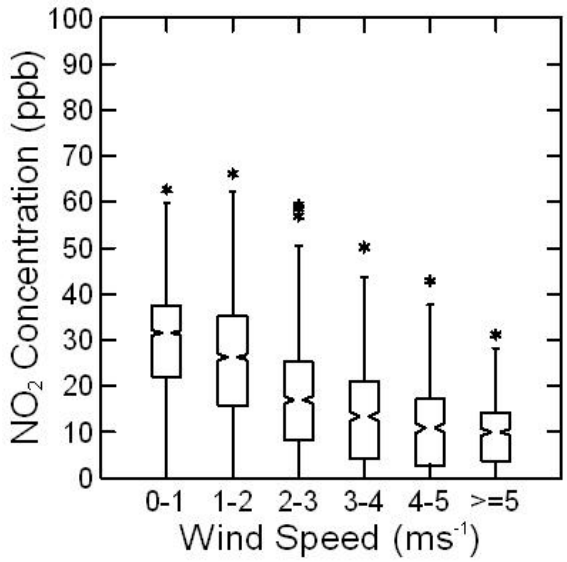


Figure 3-18. NO_2 concentrations against wind speed at Fyfe Elementary School in Las Vegas, NV, next to US 95. The measurements used were made between September 2007 and September 2008.

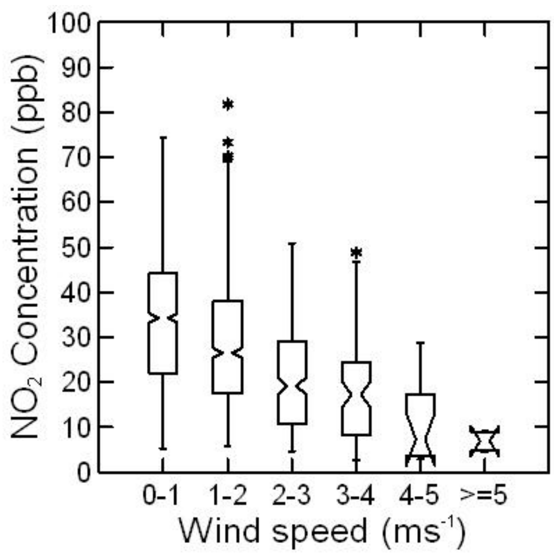


Figure 3-19. NO_2 concentrations against wind speed at the West (15 m) measurement site in Los Angeles CA, next to I-710. The measurements used were made during January, February, July, and August 2009.

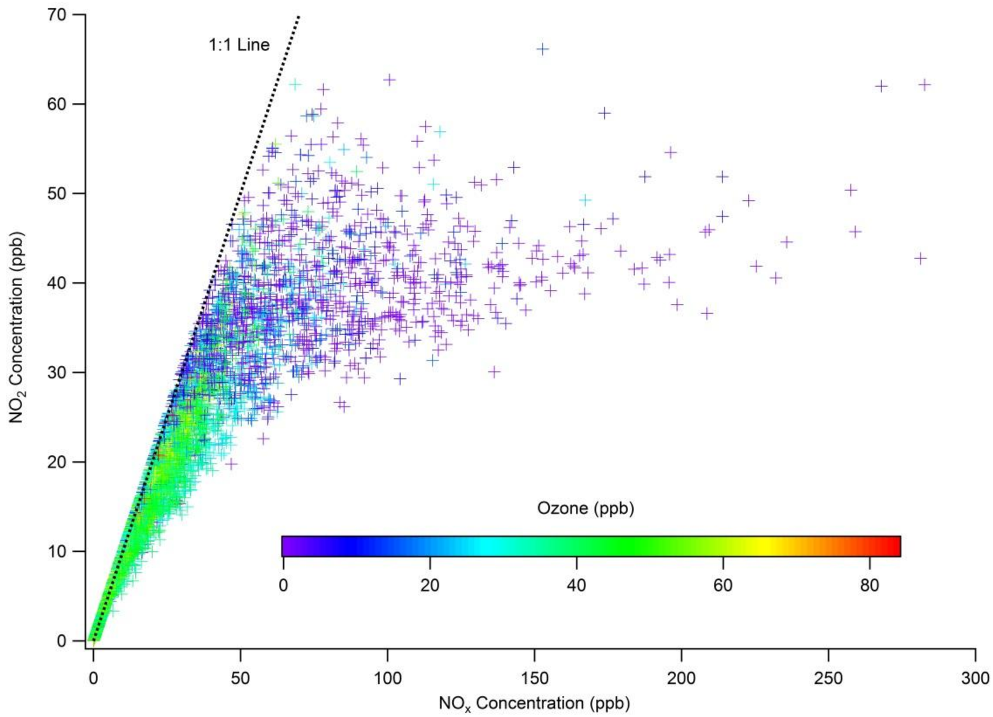


Figure 3-20. The relationship between NO_2, NO_x, and ozone next to US 95 (Las Vegas, NV) between September 2007 and September 2008.

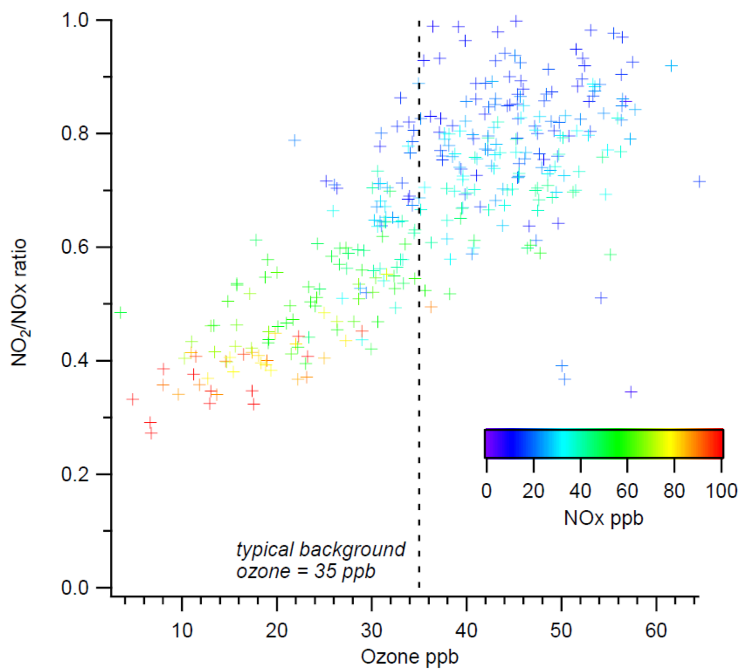


Figure 3-21. The relationship between NO_2/NO_x ratio and ozone concentration next to US 95 at Las Vegas, NV, between September 2007 and September 2008.

4. Conclusions and Implications

The 98th percentile of maximum 1-hr concentrations measured at both Las Vegas and Los Angeles were below 100 ppb. This is particularly interesting from a regulatory perspective at the I-710 site, where the measurements were collected throughout approximately two years and nine months. The FE-AADT of I-710 is approximately 500,000 vehicles per day (if HD_m=10). Therefore, the question could be raised that if this location is below the NAAQS, despite having much higher volumes of truck traffic than is typical for most US highways, how many other locations across the country will be above the standard?

Although the 98th percentiles of the measured concentrations were below the level specified in the current 1-hr NO_2 NAAQS, EPA did propose a range of NO_2 concentrations (80 to 100 ppb) based on advice by the Clean Air Science Advisory Committee (CASAC) and public comments on the proposed rule. EPA also requested comments on a limit as low as 65 ppb. Although the EPA administrator selected a 100 ppb maximum allowable 98th percentile 1-hr concentration for the current standard, it is conceivable that a lower NAAQS could be adopted in the future. If a limit as low as 80 ppb were chosen, and the 98th percentile form retained, the I-710 location could fail to comply with the lower standard. This then leads to the question of what other locations might fail to comply with the NAAQS if the standard were revised and set somewhere between 65 and 100 ppb? The Las Vegas site would probably only be below the NAAQS if it were lowered to at least 48, which is unlikely given EPA's proposals. Other sites in Los Angeles which have FE-AADT up to 40% higher than the I-710 measurement sites may already have compliance issues which would be exacerbated by a standard between 80 and 100 ppb (South Coast Air Quality Management District, 2012, Table 7).

A consideration to make here is that as gasoline and diesel engines become increasingly advanced, NO_x emissions are decreasing, so future decreases in the NAAQS may come after significant reductions in fleet emissions of NO_2 have already been achieved. A caveat to this is that recent studies have found that although NO_x from newer diesel vehicles is decreasing, the relative fraction of direct NO_2 emissions for these newer vehicles can be considerably higher than for traditional fuels and engine configurations (Eisinger et al., 2012; Dallmann et al., 2012). Given these considerations, care should be exercised when making future predictions of near-road NO_2 concentrations for individual road segments using current fleet models.

The data suggest that several key factors were important for determining near-road NO_2 concentrations: wind direction, wind speed, proximity of the monitor to the roadway, traffic patterns, total vehicle counts, proportion of heavy-duty diesel vehicles, urban background ozone concentrations, and urban background NO_2 concentrations.

Under moderate to high wind speeds, the wind must be coming from the correct direction to allow emissions from the road to travel to the monitor. Under stagnant conditions, upwind meandering of pollutants can be caused by traffic-induced turbulence, meaning that the wind direction is not always a key factor controlling whether the roadway influences the sampling site (U.S. Environmental Protection Agency, 2012). Wind speeds strongly influenced downwind near-road NO_2 concentrations at both locations, which is to be expected because higher wind speeds increase dilution at the point of emission as well as turbulent dispersion. At

Los Angeles, the highest NO_2 concentrations were measured during winter, when ozone concentrations are generally lower than in summer, but background NO_2 concentrations are higher and dispersion conditions are generally less favorable (e.g., lower boundary layer heights, more hours with stable atmospheric conditions, and lower wind speeds). In contrast to Los Angeles, little seasonal difference was observed at Las Vegas. Seasonal variations in meteorology between the cities were thought to causing the seasonal differences in near-road NO_2 concentrations, meaning that the discoveries made in one city cannot be universally applied to all cities.

Proximity of the monitor to the roadway is important to consider when comparing data sets from two different locations. The new near-road component of the NO_2 NAAQS states only that a monitor must be within 50 m of the road. Gradients in NO_2 concentrations exist within the first 50 m from a roadway, and on a given day the gradient is determined by the wind characteristics; the background concentrations of NO_2; and the amount of ozone available for reaction with NO emitted by traffic. The concentration of NO_2 measured by a monitor will change for a given sampling location depending on how close to the roadway the monitor is placed.

Ozone is necessary for conversion of NO to NO_2. The relationships observed between NO_2, NO_x, and ozone at Las Vegas show that there are times when all the available NO is converted to NO_2 by ozone. However, there were also deviations from the expected relationship, the most important showing that the NO_2 concentrations observed at monitoring sites within 50 m of the roadway depend upon there being enough available background ozone to form NO_2 from the NO emitted by traffic. A secondary scatter around the main NO_2 vs. NO_x relationship may have existed because the photo stationary state had not been achieved by the time the air mass had arrived at the instrument inlet. Background NO_2 was an important factor controlling near-road NO_2 concentrations because it was a significant portion of the total NO_2 measured at the near-road sites. At both sites the contribution of the background NO_2 varied in strength with hour of the day, but averaged overall the contribution was typically greater than one-half of the near-road NO_2 concentrations at each site.

Traffic characteristics were an important factor influencing absolute NO_2 concentrations next to the road. NO_2 concentrations were generally higher next to I-710 despite both roads having similar AADTs (~200,000), because of the much higher percentage of HDDV traffic. Interestingly, diurnal traffic patterns observed in the near-road NO_2 concentrations were apparently driven by the urban background NO_2 concentrations. Roadway contributions from US 95 or I-710 to NO_2 did not peak during rush hour periods but instead were highest during the middle of the day, between rush hour periods.

In conclusion, this study demonstrated that while both sites were below the 1-hr NO_2 NAAQS, a reduction to 80 ppb would likely cause the Los Angeles location to be above the NAAQS. The data suggest that wind direction, wind speed, proximity of the monitor to the roadway, traffic patterns, total vehicle counts, proportion of heavy-duty diesel vehicles, urban background ozone concentrations, and urban background NO_2 concentrations were the key factors influencing near-road NO_2 concentrations.

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