

# **ASSESSMENT OF A NEW SCREENING MODEL FOR USE IN SITING NEAR-ROAD NO<sub>2</sub> MONITORS**

## **FINAL PROJECT REPORT**

by

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<b>16. Abstract</b> <p>Near-road monitoring of nitrogen dioxide (NO<sub>2</sub>) in major urban areas in the U.S. will be required by 2013. It is not yet known exactly how many urban areas will be in attainment of the new NO<sub>2</sub> air quality standard, due to a lack of historical near-road monitoring information. The answer is sensitive to the exact siting of these monitors with respect to the roadway and EPA's siting guidance for near-road NO<sub>2</sub> monitors is not yet officially established.</p> <p>In this project we will test the feasibility of a relatively new air quality model, the Quick Urban Industrial Complex (QUIC) model as a practical and economical screening tool for assessing near-road NO<sub>2</sub> monitoring sites in a complex urban environment. Using the QUIC model, predictions of nitrogen oxides concentrations will be made at locations near Interstate 5 in Seattle. Model performance will be assessed by comparing predictions with accompanying measurements using a mobile monitoring platform.</p>			
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# Chapter 1 Introduction

## *Problem Statement*

Recent research has identified the public health importance of air pollution exposures near busy roadways. As a result, EPA significantly revised its NO<sub>2</sub> air quality standard in 2010. The current regulatory focus has shifted from assessment of longer-term (annual average) NO<sub>2</sub> concentrations measured at locations away from busy roads to shorter-term (1-hour average) concentrations measured at locations near busy roads. Near-road monitoring in major urban areas is required by 2013. It is not yet known exactly how many urban areas will be in attainment of the new standard due to a lack of historical near-road monitoring information. The answer is sensitive to the exact siting of these monitors with respect to the roadway. Current siting approaches include but are not limited to: 1) deploying saturation sampling devices to identify locations of interest; 2) using nearby traffic volume estimates to distinguish one near-road monitoring location from another; and 3) using simple downwind plume models that include traffic emission estimates. Saturation sampling is costly, traffic volume estimates by themselves ignore prevailing meteorology, and simple dispersion models ignore the effect of nearby buildings and adjacent roadway structures on downwind plume dispersion. Given the potential importance of near-road exposures in built-up urban areas, additional siting approaches are needed that are relatively user-friendly and inexpensive, includes traffic volumes, considers prevailing meteorology, and incorporates the effects of the urban form on predictions of near-road pollutant concentrations.

# Chapter 2 Literature Review

## *Background*

Even though EPA has developed extensive guidelines for siting traditional air quality monitors that are located relatively far from roads, their siting guidance for near-road NO<sub>2</sub> monitors is not yet officially established. A draft document entitled “Near-Road NO<sub>2</sub> Monitoring Technical Assistance Document” (herein referred to as the TAD report ) was released in December, 2011 by EPA in collaboration state and local air agencies as well as state and federal transportation agencies (<http://www.epa.gov/ttnamti1/files/nearroad/20111221tad.pdf> ). Various siting approaches are detailed in the TAD report, including the use of mobile monitoring and the assessment of nearby traffic characteristics. The report also mentions non-traffic related data considerations, specifically roadway design (including related roadside structures), terrain, and meteorology. Data from Baldauf et al (2009) and Heist et al (2009) are cited to provide some general guidance for the diluting effect of noise barriers and the effect of depressed or elevated vs. at-grade roadways. No mention is made of other nearby urban structures that might affect dispersion of roadway emissions, and no quantitative models are suggested to account for such effects.

The Quick Urban Industrial Complex (QUIC) model has the potential to quantitatively address the effect of nearby urban structures on the impacts of roadway emissions (Williams, 2002). However, this model has not been applied to the NO<sub>2</sub> siting problem. The model was originally developed at Los Alamos National Laboratories for studying the fate of air releases in a built-up urban area (<http://www.lanl.gov/projects/quic/>). It accounts for the influence of downwind urban structures on the dispersion of pollutants. The model can be used to model dispersion of plumes from roadways as they interact with nearby structures. It has not been extensively tested as a roadway model. We have a license to use this model for research applications.

Mobile monitoring of nitrogen oxides is one of several monitoring methods that have gained more interest in recent years. The TAD report states that “these studies will likely increase with the availability of new real-time NO<sub>2</sub> monitors” but also notes that care should be used when assessing the data from such systems in order to account for spatio-temporal interaction, citing work by Hagler et al (2010) and others.

## **Chapter 3 Study Site/Data**

### ***Objectives***

The objectives of this study were: 1) to implement the QUIC model and predict NO<sub>2</sub> concentrations in a complex urban environment; 2) to test the feasibility of implementing the QUIC model as a practical and economical screening tool for assessing candidate near-road NO<sub>2</sub> monitoring sites at locations near Interstate 5 in downtown Seattle.

### ***Approach***

Information was gathered on traffic flows, traffic emissions, building geometries and hourly meteorology in order to implement the QUIC model near Interstate 5 in downtown Seattle. Model predictions of near roadway downwind concentration patterns were compared with those from the more traditional EPA Aermოდ dispersion model. In addition, QUIC model performance was assessed by comparing the locations of model predicted “hot spots” with a limited number of short term measurements using a mobile monitoring platform to survey the study area.

## **Chapter 4 Method**

### ***Methodology***

#### ***Dispersion models***

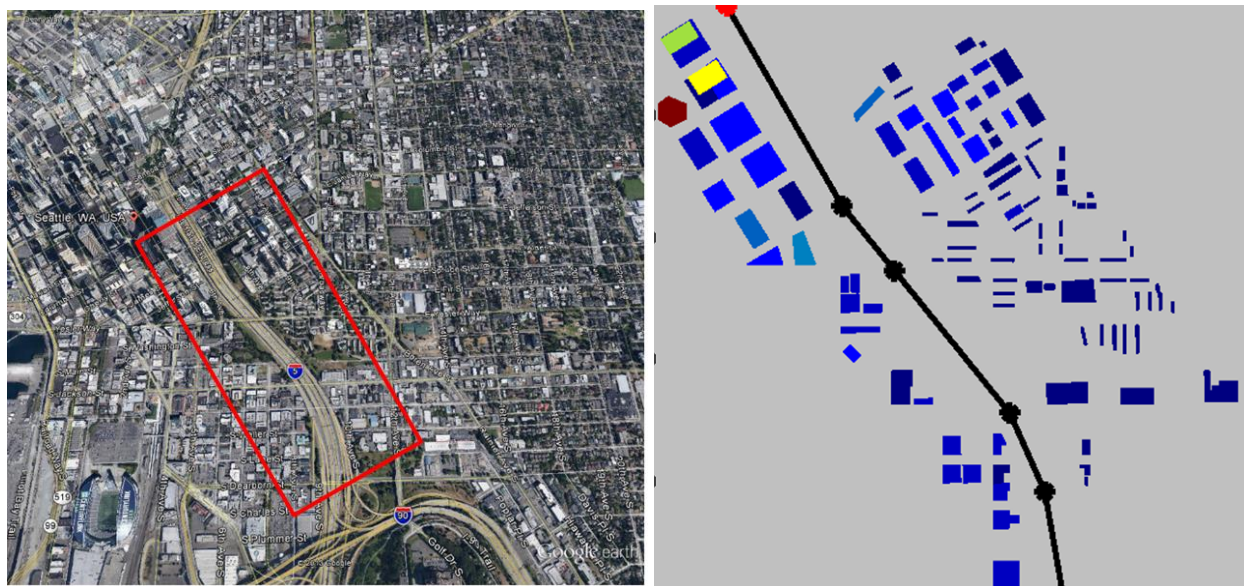
QUIC is a 2-D Lagrangian random walk dispersion model that includes both a mean wind field and flow separation regions due to both individual buildings as well as larger scale street canyons. It also includes a building cavity recirculation model and a 3-D street canyon vortex model to account for directional effects within the canyon. The original model was developed by Rockle (1990) and later by Kaplan and Dinar (1996) The current model is

maintained by Los Alamos National Laboratory ( see [https://www.lanl.gov/projects/quic/open\\_files/QUICURB\\_UsersGuide.pdf](https://www.lanl.gov/projects/quic/open_files/QUICURB_UsersGuide.pdf) for additional details on the model formulation, and <http://www.lanl.gov/projects/quic/> for further information on the model implementation). QUIC accounts for the non-gaussian distribution of downwind, polluted air parcels due to preferential capture within building wakes and thus for possible “hot spots” that are not predicted by traditional Gaussian dispersion models such as CalRoads or Aermod.

Aermod is an EPA model that was developed for stationary sources and later applied to roadways. It uses a continuous parameterization of boundary layer turbulence to predict downwind dispersion. In this case, we implemented the model by assuming that each lane of I-5 acted as a well mixed volume source with the on-road mixing height of 1.8 meters as is assumed in the traditional EPA CalRoads roadway dispersion model. We also used a dense set of uniform rectangular gridded receptors in order to observe the resulting concentration patterns downwind of the roadway.

### *Building profiles*

QUIC requires information on building geometries in order to account for their effect on localized wind flow patterns and downwind dispersion. The area of interest is along the I-5 in Downtown Seattle, from Marion St. to S Dearborn St. The focus is on near-road NO<sub>2</sub> emission from vehicles on I-5, so only the buildings are within two blocks from I5 are considered in the modeling process. The area is about 1200m by 1200m as outlined in the red rectangle in the figure below.



QUIC-URB is able to load shapefiles into its City Builder utility, as long as the Origin XY coordinates are set. The shapefiles for building outlines and arterials are available from the database of City of Seattle (courtesy of University of Washington Library System). We used

ArcGIS to separate the buildings in the neighborhood of Yesler Terrace. Since the projection system in QUIC is UTM and the unit is meters, the first step is to project the building outlines and arterials to UTM (NAD\_1983\_HARN\_UTM\_Zone\_10N for Washington State) and then convert the unit from feet to meters. The buildings in City Builder were geo-referenced once the Origin XY coordinates were set.

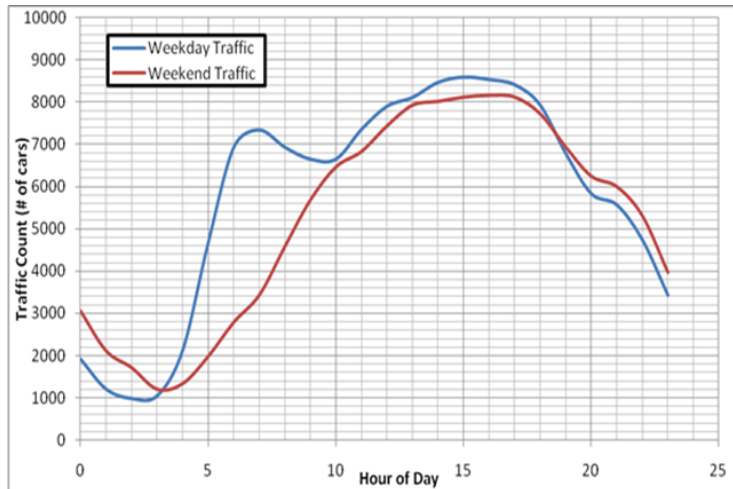
In the shapefiles downloaded from City of Seattle, there's no information about the building height. Therefore we used the elevation in Google Earth to find the height for each building, manually entered the values into a shapefile using ArcGIS and imported the shapefile information into City Builder. Some of the building heights can be found through websites, such as <http://www.emporis.com>, but these are only available for the taller commercial buildings that reside mainly to the north of the study area.

### *Roadway Emissions and Geometry*

The emissions of NO<sub>x</sub> and NO<sub>2</sub> directly from the interstate were computed using emission factors computed by the EPA MOVES model for King County restricted roadways for 2012. The resulting emission factors were 0.37 and 1.74 grams per vehicle –mile for NO<sub>2</sub> and NO<sub>x</sub>, respectively. Given that we were examining near road concentrations of NO<sub>2</sub>, our primary analysis considered both NO<sub>2</sub> (as well as NO<sub>x</sub>) as a non-reacting species. Sensitivity analysis using the plume volume molar ratio method (Hanrahan 1999a, b) and the nearby hourly ozone measurements taken at the Beacon Hill urban site southeast of the study area indicated that the assumption of a constant downwind ratio of NO<sub>2</sub> to NO<sub>x</sub> of  $0.37/1.74 = 0.21$  is reasonable for the small plume travel times within study area .

The geometry of I-5 was represented by 5 straight line segments as shown in Figure xx, We used the measuring tool in Google Earth to determine the length and the relative angle of each segment. We assumed daily and peak hourly traffic counts of 6,000 and 8000 vehicles/hour, respectively, which is representative of the two mobile air monitoring periods and also is the peak daily traffic count on this section of I-5 (TDAD database, UW ITS Research Program) shown in the figurebelow.





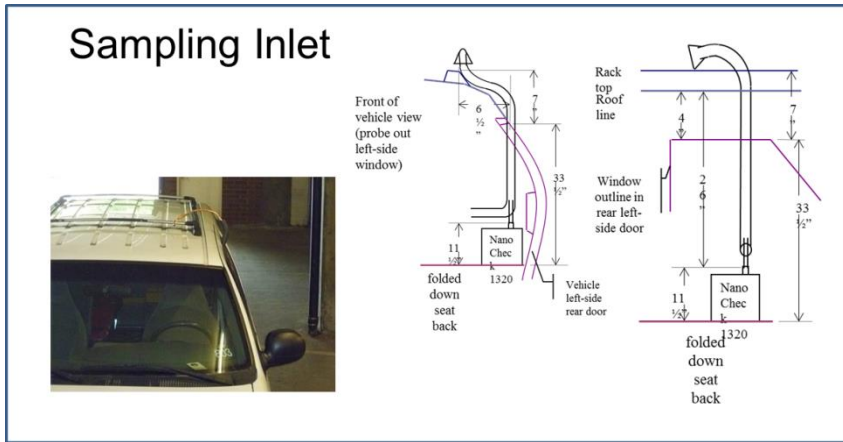
## *Meteorology*

The QUIC model requires a single, overlying wind direction (specified by sector), an average wind speed at reference height, and an associated vertical wind speed profile. The effect of classic stability category on downwind dispersion of emission is less important than the flow disturbances created by nearby structures. Therefore for input to this model we used appropriate hourly wind direction and wind speed values based upon National Weather Service data from nearby Boeing Field (National Climatic Data Center WBAN Station ID # 24208).

The Aermid model requires surface and upper air files for each hour. These were generated by Aermet. The surface files were based on input data from nearby Boeing Field in Integrated Surface Hourly Data (ISHD) TD3505 format (<http://www1.ncdc.noaa.gov/pub/data/noaa>). The upper air files were based on input data from Sea-Tac airport taken from the ESRL Radiosonde Database (<http://esrl.noaa.gov/raobs>).

## ***NO<sub>2</sub> Mobile Monitoring***

Continuous 10 second average concentrations of NO<sub>2</sub> were measured on a moving platform using a Cavity Attenuation Phase Shift (CAPS) monitor (Aerodyne Research Inc., Billerica, MA). The monitor relies on absorption of blue laser light at 450nm in a mirror cavity and is essentially free of interferences from other compounds (there are minor interferences from dicarbonyl species). This particular model instrument has been shown to agree very well with the EPA equivalent NO<sub>2</sub> monitoring method (Kebabian et al, 2008). A schematic of the mobile platform sampling inlet is shown in the Figure below. Simultaneous GPS location information was also obtained, allowing us to plot measurements on a map. All measurements were made during afternoon rush hour to avoid the effect of temporal variations due to rapidly changing morning mixing depth that can obscure the spatial patterns.

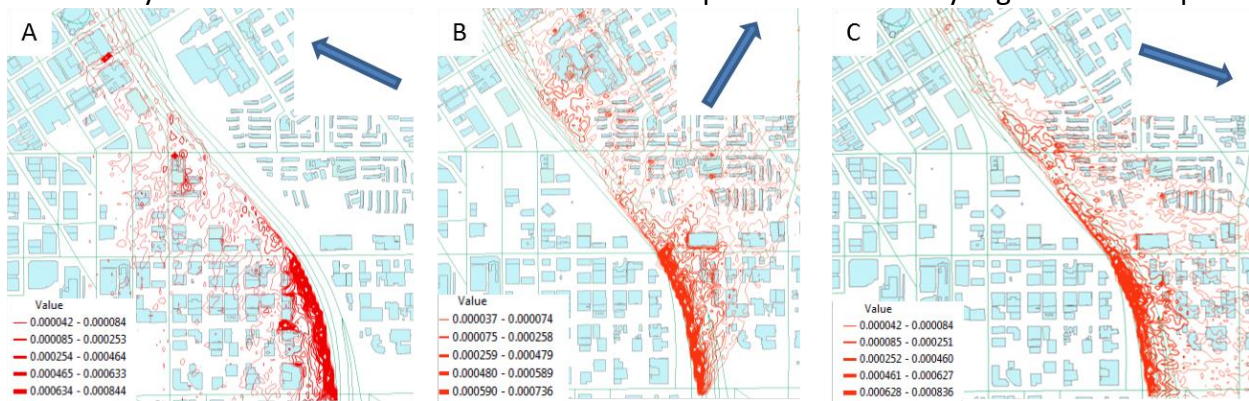


## Chapter 5 Results

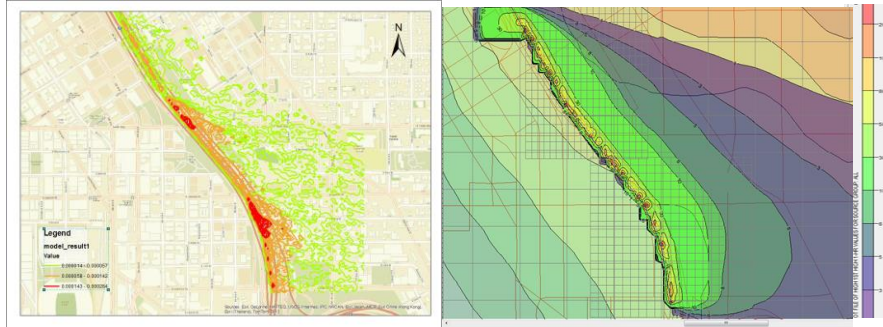
### Findings

#### *Predicted dispersion patterns*

The Figure below shows the typical dispersion patterns predicted by the QUIC model for different overlying wind directions measured at Boeing Field for a given hour. For the period of southeasterly winds observed in February 2013 (figure A, below), QUIC predicts the highest concentrations (darkest red patterns) in the southern part of the study area on the western (downwind) side of I-5. For the periods of southwesterly (figure B) and westerly (figure C) winds during May 2013, QUIC also predicted the highest concentrations at the southern part of the study area. These results are consistent with the fact that this southernmost area is more confined by structures near I-5 whereas the northern portion of the study region is more open.



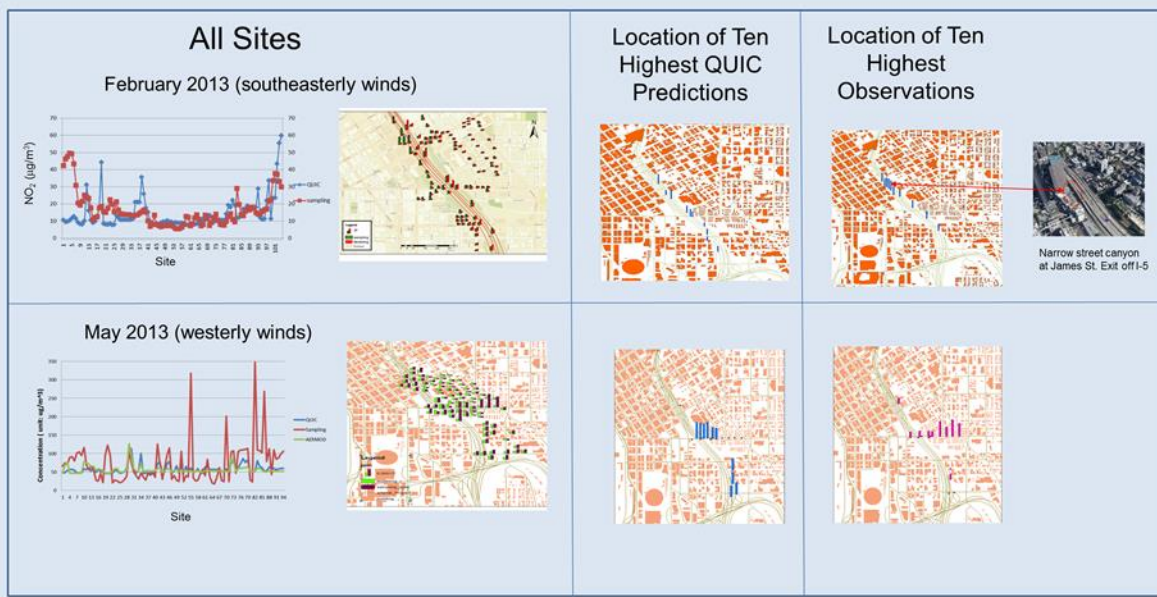
In contrast, the AERMOD model predicts a more uniform concentration pattern downwind of I-5. This is not surprising given that the AERMOD model does not include the effects of multiple building wakes. The figure below compares the QUIC (left panel) and AERMOD (right panel) dispersion patterns for the same case as figure C above.



In this implementation, QUIC predicted the dispersion of NO<sub>2</sub> directly emitted as a primary pollutant, and therefore did not include oxidation reactions of ozone with NO to form NO<sub>2</sub>. Near the freeway in downtown, confined spaces, ozone is depleted and the NO<sub>2</sub> concentrations are primarily influenced by the dispersion of roadway NO<sub>2</sub> emissions rather than the downwind oxidation of NO. On one occasion, we also measured NO<sub>x</sub> on the mobile platform (2B Technologies, Boulder, CO). The observed ratios of NO<sub>2</sub> to NO<sub>x</sub> were less than < 0.15, consistent with the above assumptions. In addition, simulations using the plume volume molar ratio option in AERMOD (Hanrahan, 1999a,b) using observed ozone concentrations at the Department of Ecology site at Beacon Hill also predicted little if any NO<sub>2</sub> oxidation due to the nature of the cross-wind integrated plume that only allows limited dispersive mixing from above. This assumption of near road NO<sub>2</sub> hot spots due to primary emission of NO<sub>2</sub> limits our analysis to using QUIC as a predictor of the relative location of near road “hot spots” as discussed below.

The figure below compares the QUIC predictions versus the observed NO<sub>2</sub> “hot spots”. These latter values were determined by a ranking of the 1 minute average mobile monitoring observations whose average locations are shown on the accompanying maps in the leftmost panels. February model predictions show reasonably good agreement with observed hot spots but fail to capture a major area of elevated NO<sub>2</sub> associated with an extremely narrow street canyon bounded by an elevated section of Interstate 5. The model predictions for the May period do a better job of identifying hot spots but systematically under-predict observed NO<sub>2</sub> levels in the southern half of the study region.

## QUIC Predictions vs. Observed NO<sub>2</sub> Hot Spots



## Chapter 6 Discussion

### *Proposed Technology Transfer Activities (Implementation Report)*

We plan to submit a paper on the results of this project for publication in a journal and also to present these results at a national transportation meeting. We will also present our findings to the air monitoring group at the Washington State Department of Ecology as they make preparations for locating an NO<sub>2</sub> monitor near I-5 in Seattle.

## Chapter 7 Conclusions and Recommendations

1. The location of observed near-road NO<sub>2</sub> hot spots (~top 10<sup>th</sup> percentile) were reasonably captured by the QUIC model during two intensive field sampling events along a section of I-5 in Seattle.
2. QUIC model predictions of absolute NO<sub>2</sub> concentrations were not as robust and therefore the model is best used as a screening tool to establish candidate monitoring sites near a busy freeway.
3. The CAPS NO<sub>2</sub> analyzer is a robust and sensitive instrument that has the potential to be deployed in a mobile mode for further comparison of candidate near road monitoring sites.

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