Effects of Roadside Barriers on Near-Road Air Pollutant Dispersion and Concentration

Requested by
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June 28, 2018

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Executive Summary

Background

Near-road air quality continues to be an important issue for transportation agencies. National and international researchers have found that roadside barriers such as sound walls can provide a benefit for near-road air quality by deflecting the pollutant, increasing dispersion and reducing the concentration for receptors behind the barrier.

Currently, there is no air quality dispersion model that quantifies the effect of roadside barriers and also meets federal guidelines for regulatory use. The lack of a federally acceptable dispersion model or computational algorithm to analyze roadside barrier benefits prevents Caltrans and other transportation agencies from receiving air quality improvement credit for barriers when determining conformity to air quality standards on transportation projects.

Caltrans is interested in learning about current efforts to develop a model or algorithm that quantifies the benefits of roadside barriers in improving air quality along the roadway and also complies with federal modeling requirements. To assist Caltrans with this effort, CTC & Associates compiled information gathered from consultations with experts and related research on this topic.

Summary of Findings

Below is a summary of findings in two topic areas:

- Consultations with experts.
- Related research.

Consultations With Experts

Before summarizing our consultations with experts, we present a brief background of the issue that describes AERMOD, U.S. Environmental Protection Agency's (EPA's) preferred dispersion model for project-level conformity analyses, and Caltrans' interest in a dispersion algorithm to quantify the effects of roadside barriers. The algorithm would be compatible with AERMOD and also comply with federal modeling guidance, which requires vetting through a scientific peer review and evaluation using a field database that provides the data with which to evaluate the algorithm's or model's performance.

U.S. Environmental Protection Agency Scientists

We corresponded with two EPA scientists who described current agency efforts and future plans for roadside barrier-related modeling. We sought information about Research LINE (R-LINE), EPA's research dispersion modeling tool for near-roadway assessments.

According to EPA's current plan, the roadside barrier algorithm included in the next release of R-LINE would be based on the work of Venkatram's research group and other research efforts conducted at EPA (see citations beginning on page 11 of this Preliminary Investigation). EPA plans to add the roadside barrier algorithm in R-LINE to AERMOD as an alpha release, which will allow for testing and evaluation. Addition as an alpha release means the roadside barrier algorithm cannot be used for regulatory applications to address areas where conformity requirements apply. An evaluation of the roadside barrier algorithm in R-LINE against data from wind tunnel studies is planned for 2018. The agency expects to submit a journal article describing that work in late 2018, with journal peer review anticipated in early 2019.

Other Researchers

We contacted Max Zhang, associate professor, Cornell University, to learn more about his research group's efforts to develop an algorithm to assess the impact of roadside solid barriers on near-road air quality. Zhang's research group presented its results in a 2017 Transportation Research Board annual meeting paper (see page 14 of this Preliminary Investigation for this paper's citation) that will be submitted for journal publication. Zhang has no plans to seek alternative model approval from EPA and noted that the most likely use of his group's algorithm will be incorporation into an existing modeling framework.

Related Research

EPA Modeling and Guidance focuses on EPA's development of AERMOD and R-LINE, and the research efforts that have informed that development. Information about federal modeling guidelines is also included. **Other Modeling Efforts** offers conference papers and journal articles that describe the conduct of field studies, laboratory experiments and computational fluid dynamics (CFD) simulations that examine the impact of roadside barriers on near-road air quality.

Two publications are given in **Model Comparisons**: An October 2015 conference paper describes three studies of near-road barrier dispersion used to evaluate and compare two dispersion models—R-LINE and ADMS (Atmospheric Dispersion Modeling System), a model developed by Cambridge Environmental Research Consultants, a company based in the United Kingdom. A December 2013 journal article compares four dispersion models using two tracer studies.

Publications in **Wind Tunnel and Tracer Studies** highlight several studies: A January 2010 journal article describes a roadway toxics dispersion study conducted at Idaho National Laboratory; an October 2009 journal article presents results of a wind tunnel experiment that modeled 12 different configurations. A 2014 journal article also analyzes wind tunnel experiments of 12 different roadway configurations but uses a large-eddy simulation (LES) model. **International Research Efforts** presents research in Kazakhstan and the Czech Republic that examines CFD and LES models, respectively.

Gaps in Findings

We uncovered no preferred model or algorithm that quantifies the benefits of roadside barriers in improving air quality along the roadway and also complies with federal modeling requirements. EPA will continue its development of a roadside barrier algorithm. Max Zhang, a prominent researcher in this field, has no plans to seek alternative model approval from EPA for the model his research group has developed.

While we did not uncover efforts underway to conduct the field database collection study needed to evaluate the roadside barrier models in development, such an effort could be planned or in process by individuals or groups we did not query for this Preliminary Investigation.

Next Steps

Moving forward, Caltrans could consider:

- Consulting with EPA scientists to learn more about agency efforts to develop a roadside barrier algorithm.
- Contacting the Cornell University research group led by Max Zhang to learn more about this research effort.
- Identifying and consulting with researchers and organizations with an interest in this topic to discuss how to encourage or advance the field database study needed to evaluate the air quality dispersion models in development.

Detailed Findings

Consultations With Experts

We contacted selected experts to learn more about efforts to develop a model or algorithm that quantifies the benefits of roadside barriers in improving air quality along the roadway and that also complies with federal modeling requirements. These contacts include:

- **U.S. Environmental Protection Agency scientists**. Contacts to several U.S. Environmental Protection Agency (EPA) staff members resulted in email exchanges with two EPA research scientists who described current agency efforts and future plans for roadside barrier-related modeling.
- **Other researchers**. We contacted Max Zhang, leader of a Cornell University research group, to learn more about his group's development of an algorithm to assess the impact of solid roadside barriers on near-road air quality.

We begin below with a discussion of current efforts to model near-road air quality and Caltrans' interest in modeling to assess the benefits of roadside barriers. This background is followed by summaries of our consultations with the experts described above.

Background

Near-Road Air Quality Modeling

Near-road air quality continues to be an important issue for transportation agencies. National and international researchers have found that roadside barriers such as sound walls can provide a benefit for near-road air quality by deflecting the pollutant, increasing dispersion and reducing the concentration for receptors behind the barrier.

Currently, there is no air quality dispersion model that quantifies the effect of roadside barriers and also meets federal guidelines for regulatory use. American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD), EPA's preferred dispersion model for project-level conformity analyses (see the note below), including particulate matter (PM) and carbon monoxide "hot-spot" analyses, does not consider the physical effects of roadside barriers on air flow and pollutant dispersion.

Note: A February 2017 Federal Highway Administration publication describes transportation conformity and where it applies (see page 1 of the report available at https://www.fhwa.dot.gov/ENVIRonment/air_quality/conformity/2017_guide/fhwahep17034.pdf):

> **What is Transportation Conformity?**
> Transportation conformity is required under CAA [Clean Air Act] Section 176(c) to ensure that Federally-supported transportation activities are consistent with ("conform to") the purpose of a State's SIP [state implementation plan]. Transportation conformity establishes the framework for improving air quality to protect public health and the environment. Conformity to the purpose of the SIP means Federal Highway Administration (FHWA) and Federal Transit Administration (FTA) funding and approvals are given to highway and transit activities that will not

cause new air quality violations, worsen existing air quality violations, or delay timely attainment of the relevant air quality standard, or any interim milestone.

Where Does Transportation Conformity Apply?
Conformity requirements apply in areas that either do not meet or previously have not met national ambient air quality standards (NAAQS) for ozone (O_3), carbon monoxide (CO), particulate matter (PM_{10} and $PM_{2.5}$) or nitrogen dioxide (NO_2). These areas are known as "nonattainment areas" and "maintenance areas," respectively.

Any effort to develop a dispersion algorithm to quantify the effects of roadside barriers must be done in compliance with federal modeling guidelines to ensure that the air quality improvement benefit provided by the barrier is acceptable for environmental analysis on federally funded or supported transportation projects. Federal modeling guidelines require vetting through a scientific peer review and evaluation using a field database that provides the data with which to conduct performance evaluations of the algorithm or model.

Caltrans' Interest in Modeling Efforts

California has the largest number of sound wall roadside barriers in the nation. Caltrans would like to receive air quality improvement credit for these and other barriers constructed in the future when determining conformity to air quality standards. However, Caltrans is unable to account for the secondary air quality benefit these roadway assets provide in a manner that meets the rigorous federal modeling requirements. The lack of a federally acceptable dispersion model or computational algorithm to analyze the benefits of roadside barriers prevents Caltrans and other transportation agencies from receiving air quality improvement credit for barriers when determining conformity on transportation projects.

A dispersion algorithm that is compatible with AERMOD and complies with federal modeling guidance would allow Caltrans to quantify roadside barriers' effect as an air quality mitigation measure and validate the air quality benefit the barriers provide to nearby residences.

U.S. Environmental Protection Agency Scientists

We contacted several EPA representatives about the efforts underway within the agency in connection with AERMOD, EPA's preferred dispersion model, and Research LINE (R-LINE), a modeling tool that the agency is developing. Information provided by two EPA scientists is summarized below.

Background

AERMOD is described in a 2017 conference paper (see page 1 of the PDF available at https://www.e3s-conferences.org/articles/e3sconf/pdf/2017/10/e3sconf_asee2017_00149.pdf):

> AERMOD is an air pollutant dispersion model developed by the American Meteorological Society (AMS)/Environmental Protection Agency (U.S. EPA) for regulatory purposes in the near field studies (up to 50 km) and complex terrain. It is a steady-state model, in which the plume of emitted pollutants spreads both horizontally and vertically in accordance with the Gaussian distribution.

Currently, AERMOD does not contain algorithms to account for dispersion around solid noise barriers near roadways and roadways within a depression.

R-LINE, EPA's research dispersion modeling tool for near-roadway assessments, is based on a steady-state Gaussian formulation (a continuous probability distribution). The model is currently formulated for near-surface releases and accounts for plume meander under low-wind conditions. See page 9 of this Preliminary Investigation for more information about R-LINE.

Current EPA Efforts

R-LINE and its algorithms are currently under development, including roadway configurations for roadside barriers and depressed roadways. EPA's current plan is to base the roadside barrier algorithm included in the next release of R-LINE on the work of Venkatram's research group and other research efforts conducted at EPA. (This work is described in three journal articles published in *Atmospheric Environment* in 2017, 2016 and 2014; citations for these articles begin on page 11 of this Preliminary Investigation.) An evaluation of the roadside barrier algorithm in R-LINE against data from wind tunnel studies is planned for 2018. The agency expects to submit a journal article describing that work in late 2018, with journal peer review anticipated in early 2019.

Adding the RLINE Source Type to AERMOD

An RLINE source type will be added as a beta release within AERMOD, with an internal draft of the R-LINE integration available by late 2018 or early 2019. A September 2017 EPA white paper provides further details (see page 31 of the PDF available at https://www3.epa.gov/ttn/scram/models/aermod/20170919_AERMOD_Development_White_Papers.pdf):

> This work will implement the current R-LINE algorithms to simulate dispersion from line sources, such as roadways. The RLINE source type will contain the newly formulated surface dispersion parameterizations and will have features tailored to roadways. Incorporation of R-LINE will include model functionality extensions to utilize AERMOD's emissions processing for temporally variable emissions. This RLINE source type will be added as a beta option. [When added as a beta option, the new source type will be available for regulatory applications.]

Unlike the RLINE source type, which will be added to AERMOD as a beta option, EPA plans to add the roadside barrier algorithm to AERMOD as an alpha release, which will allow for testing and evaluation. Addition as merely an alpha release means the roadside barrier algorithm cannot be used for regulatory applications to address areas where conformity requirements apply. See page 9 of this Preliminary Investigation for the publications recommended by EPA that provide current conformity guidance.

Roadside Barrier Algorithm and Alternative Regulatory Model

EPA continues to take wind tunnel measurements to refine and improve the roadside barrier algorithm and plans to subject the model to a peer review in early 2019.

Generally, EPA includes data sets collected by industry and federal and state partners in its evaluation of the roadside barrier algorithm. As Chris Owen, physical scientist, EPA, noted, "In just the last few years, we relied heavily on the Caltrans [Highway] 99 field study to satisfy this requirement for mobile sources. The Caltrans [Highway] 99 study was a joint effort between FHWA and Caltrans to collect data around a roadway along Highway 99 in Sacramento, CA" (see the December 2013 article cited on page 18 of this Preliminary Investigation for more information about the Caltrans Highway 99 study). Owen also noted that for approval of an alternative model, "[I]t is actually the responsibility of the entity seeking the alternative model approval to provide the appropriate database, rather than something the EPA would supply."

Other Research Efforts

The EPA scientists we contacted are not aware of other researchers or research groups developing algorithms or models that quantify the effects of roadside barriers on air pollutants, or efforts to conduct a field database study to collect the data needed to evaluate those algorithms or models.

Contacts

David Heist, Research Physical Scientist, National Exposure Research Laboratory, U.S. Environmental Protection Agency, heist.david@epa.gov.

R. Chris Owen, Physical Scientist, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, 919-541-5312, owen.chris@epa.gov.

Other Researchers

We contacted Max Zhang, associate professor, Cornell University, to learn more about his research group's efforts to develop an algorithm to assess the impact of roadside solid barriers on near-road air quality. Zhang's university profile describes the model developed by his research group (see http://www.eas.cornell.edu/people/profile.cfm?netid=kz33):

> Dr. Zhang's group has developed CTAG (which stands for **C**omprehensive **T**urbulent **A**erosol dynamics and **G**as chemistry), an environmental turbulent reacting flow model, to simulate the transport and transformation of multiple pollutants in complex environments. In particular, he aims to develop a mechanistic understanding on 1) near-road air pollution and its potential mitigation strategies, 2) the effects of turbulent mixing on particulate emission measurements, and 3) the impacts of plume processing on regional air quality and climate simulations.

Zhang reported that his research group presented its results in a 2017 Transportation Research Board annual meeting paper (see page 14 of this Preliminary Investigation for this paper's citation). He plans to submit the paper for journal publication but has not done so yet. Zhang's group is also working on parameterizing the effect of roadside vegetation barriers, which he described as "more difficult than solid barriers." Zhang does not have plans to seek alternative model approval from EPA, and noted that "the most likely path is to incorporate our algorithm into an existing modeling framework such as R-LINE or CALINE4" [CAlifornia LINE Source Dispersion Model, described as "a dispersion model that predicts carbon monoxide (CO) impacts near roadways"].

Contact

Max Zhang, Associate Professor, Department of Mechanical and Aerospace Engineering, Cornell University, 607-254-5402, kz33@cornell.edu.

Related Research

The publications cited below are organized into five categories:

- EPA modeling and guidance.
- Other modeling efforts.
- Model comparisons.
- Wind tunnel and tracer studies.
- International research efforts.

EPA Modeling and Guidance

The citations below focus on EPA's development of AERMOD and R-LINE and the research efforts that have informed that development.

"R-LINE: A Research LINE-Source Dispersion Model for Near-Surface Releases," Community Modeling and Analysis System (CMAS), Institute for the Environment, University of North Carolina at Chapel Hill, undated.
https://www.cmascenter.org/r-line/
The R-LINE dispersion model is described by EPA as using "state-of-the-art Gaussian dispersion algorithms, similar to AERMOD," and containing "a 'true' line source algorithm based on Romberg integration of point sources." The model, developed for use with roadways, considers plume meander under low-wind conditions. This web site maintained by an EPA partner provides information and resources associated with R-LINE, including access to the latest version (version 1.2), user documentation and related research.

Note: The CMAS web site notes that R-LINE is not appropriate for use in connection with regulatory applications and directs readers to EPA's Guideline on Air Quality Models (Appendix W to 40 CFR Part 51) and EPA's December 2010 publication, Transportation Conformity Guidance for Quantitative Hot-Spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas. See *Related Resources* below for more information about these publications.

Related Resources:

2017 Appendix W Final Rule, Support Center for Regulatory Atmospheric Modeling (SCRAM), U.S. Environmental Protection Agency, May 26, 2017.
https://www3.epa.gov/ttn/scram/appendix_w-2016.htm
This web site provides a range of resources associated with a final rule that revises the Guideline on Air Quality Models (Appendix W to 40 CFR Part 51), including technical support material and final model updates related to the revised final rule. The site also provides background information about the rule and its revised effective date*:*

Final Rule Information
On December 20, 2016, the Administrator signed a final rule that revises the *Guideline on Air Quality Models*. The *Guideline* provides EPA-recommended models and other techniques, as well as guidance for their use, for predicting ambient concentrations of air pollutants. EPA's finalized changes enhance the formulation and application of the

> agency's AERMOD dispersion model, prescribe modeling techniques for secondarily formed fine particle and ozone pollution for single sources and [make] various editorial improvements. The final rule was published in the Federal Register on January 17, 2017, and the effective date of this action has been deferred to May 22, 2017.

The full text of Appendix W is available at https://www3.epa.gov/ttn/scram/appendix_w/2016/AppendixW_2017.pdf.

Transportation Conformity Guidance for Quantitative Hot-Spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, December 2010.
https://www3.epa.gov/ttn/naaqs/aqmguide/collection/cp2/20101201_otaq_epa-420_b-10-040_transport_conform_hot-spot_analysis.pdf
From the introduction:

> This guidance describes how to complete quantitative hot-spot analyses for certain highway and transit projects in $PM_{2.5}$ and PM_{10} (PM) nonattainment and maintenance areas. This guidance describes transportation conformity requirements for hot-spot analyses, and provides technical guidance on estimating project emissions with the Environmental Protection Agency's (EPA's) MOVES [MOtor Vehicle Emission Simulator] model, California's EMFAC [EMission FACtors] model and other methods. It also outlines how to apply air quality models for PM hot-spot analyses and includes additional references and examples.

Report appendices are available at https://www3.epa.gov/ttn/naaqs/aqmguide/collection/cp2/20101201_otaq_epa-420_b-10-040_transport_conform_hot-spot_analysis_appx.pdf.

Air Quality Dispersion Modeling—Preferred and Recommended Models, Support Center for Regulatory Atmospheric Modeling (SCRAM), U.S. Environmental Protection Agency, April 2018.
https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models
This EPA web site describes the refined dispersion models that are listed in Appendix W to 40 CFR Part 51 (Guideline on Air Quality Models), including AERMOD and CALPUFF (recommended by EPA for applications involving long-range transport over distances beyond 50 km).

EPA White Papers on Planned Updates to AERMOD Modeling System, Air Quality Modeling Group, U.S. Environmental Protection Agency, September 2017.
https://www3.epa.gov/ttn/scram/models/aermod/20170919_AERMOD_Development_White_Papers.pdf
This publication includes six white papers that address the areas planned for update in the AERMOD modeling system. AERMOD is described by EPA as a "steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain." Each white paper provides an overview, literature review and agency plans for moving forward. Among the issues addressed are agency efforts to "integrate R-LINE into the AERMOD dispersion model for future consideration as an EPA preferred model."

Below is an excerpt from White Paper 5, Mobile Source Dispersion Modeling (see page 31of the PDF):

> **Considerations for Updates in Model System**
> The EPA is currently working with the Federal Highway Administration (FHWA) on a joint initiative through a formal Interagency Agreement (IA) to advance several aspects of air quality dispersion modeling for mobile sources. In particular, the IA is the primary funding mechanism for a project to incorporate the R-LINE algorithms into AERMOD. The IA also provides funding to EPA's ORD [Office of Research and Development] to supplement existing efforts to conduct wind tunnel studies to further refine and develop solid barrier algorithms.
>
> The primary focus of the IA is the creation of a new "RLINE" source type into the AERMOD modeling system. This work will implement the current R-LINE algorithms to simulate dispersion from line sources, such as roadways. The RLINE source type will contain the newly formulated surface dispersion parameterizations and will have features tailored to roadways. Incorporation of R-LINE will include model functionality extensions to utilize AERMOD's emissions processing for temporally variable emissions. This RLINE source type will be added as a beta option. EPA plans to have an internal draft of the R-LINE integration by mid-2018, with a potential beta release in the public version of AERMOD in late 2018.
>
> R-LINE and its algorithms are still being researched and developed, especially the roadway configurations for barriers and depressed roadways. EPA's ORD, partly in coordination with the FHWA IA, continues to take wind tunnel measurements to refine and improve these algorithms, but a database of relevant field studies highlighting these source configurations is needed. Once these algorithms have been thoroughly tested they could be incorporated into the RLINE source type. Their initial incorporation will be in an alpha form to allow testing and evaluation before they would be publicly released as a beta option(s) in AERMOD. The alpha (or beta) options would be available with the new RLINE source in AERMOD, so will potentially be available for public release in late 2018.
>
> Any future release of AERMOD alpha and/or beta options would be available for testing and comment by the user community, and potential future incorporation into AERMOD for regulatory purposes.

Note: David Heist, research physical scientist at EPA's National Exposure Research Laboratory, indicated that EPA's current plan is to base the roadside barrier algorithm in the next release of R-LINE on the work described in the following three *Atmospheric Environment* journal articles. See page 6 of this Preliminary Investigation for more information about EPA's plans for the roadside barrier algorithm.

"Reduction of Air Pollution Levels Downwind of a Road With an Upwind Noise Barrier,"
Faraz Enayati Ahangar, David Heist, Steven Perry and Akula Venkatram, *Atmospheric Environment*, Vol. 155, pages 1-10, April 2017.
Citation at https://doi.org/10.1016/j.atmosenv.2017.02.001
From the abstract:

> *Highlights*
>
> - Upwind barrier reduces downwind near-road pollutant concentrations.
> - Dispersion model accounts for upwind barrier.

- Recirculation behind barrier pushes emissions upwind.
- Can be as effective as downwind barrier.
- Increases impact of downwind barrier.

Abstract: We propose a dispersion model to estimate the impact of a solid noise barrier upwind of a highway on air pollution concentrations downwind of the road. The model, based on data from wind tunnel experiments conducted by Heist et al. (2009), assumes that the upwind barrier has two main effects: 1) it creates a recirculation zone behind the barrier that sweeps the emissions from the highway back towards the wall, and 2) it enhances vertical dispersion and initial mixing. By combining the upwind barrier model with the mixed wake model for a downwind barrier described in Schulte et al. (2014), we are able to model dispersion of emissions from a highway with noise barriers on both sides. The model provides a good description of measurements made in the wind tunnel. The presence of an upwind barrier causes reductions in concentrations relative to those measured downwind of a road with no barriers. The reduction can be as large as that caused by a downwind barrier if the recirculation zone covers the width of the highway. Barriers on both sides of the highway result in larger reductions downwind of the barriers than those caused by a single barrier either upwind or downwind. As expected, barrier effects are small beyond 10 barrier heights downwind of the highway. We also propose a tentative model to estimate on-road concentrations within the recirculation zone induced by the upwind barrier.

Related Resource:

RW1, Environmental Dataset Gateway, U.S. Environmental Protection Agency, undated.
https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7BF7222CCC-2CC1-4B66-9BFA-49FD1B219A46%7D
This link provides information about the data set associated with the publication cited above.
From the abstract:

Wind tunnel measurements of flow and dispersion from a simulated roadway with near-road solid barriers. This dataset is associated with the following publication: Ahangar, F., D. Heist, S. Perry and A. Venkatram. Reduction of air pollution levels downwind of a road with an upwind noise barrier. ATMOSPHERIC ENVIRONMENT. Elsevier Science Ltd, New York, NY, USA, 155: 1-10, (2017).

"Using Models to Interpret the Impact of Roadside Barriers on Near-Road Air Quality,"
Seyedmorteza Amini, Faraz Enayati Ahangar, Nico Schulte and Akula Venkatram, *Atmospheric Environment*, Vol. 138, pages 55-64, August 2016.
Citation at https://doi.org/10.1016/j.atmosenv.2016.05.001
From the abstract:

Highlights

- Roadside barriers produce effective mitigation of the impact of emissions.
- Real-world barrier effects can be described with simple model.
- Roadside barrier effects are equivalent to shifting source upwind.
- Model can be used to design roadside barriers.
- Model can be used to estimate UFP [ultrafine particle] emission factors.

Abstract: The question this paper addresses is whether semi-empirical dispersion models based on data from controlled wind tunnel and tracer experiments can describe data collected downwind of a sound barrier next to a real-world urban highway. Both models are based on the mixed wake model described in Schulte et al. (2014). The first neglects the effects of stability on dispersion, and the second accounts for reduced entrainment into the wake of the barrier under unstable conditions. The models were evaluated with data collected downwind of a kilometer-long barrier next to the I-215 freeway running next to the University of California campus in Riverside. The data included measurements of 1) ultrafine particle (UFP) concentrations at several distances from the barrier, 2) micrometeorological variables upwind and downwind of the barrier, and 3) traffic flow separated by automobiles and trucks. Because the emission factor for UFP is highly uncertain, we treated it as a model parameter whose value is obtained by fitting model estimates to observations of UFP concentrations measured at distances where the barrier impact is not dominant. Both models provide adequate descriptions of both the magnitude and the spatial variation of observed concentrations. The good performance of the models reinforces the conclusion from Schulte et al. (2014) that the presence of the barrier is equivalent to shifting the line sources on the road upwind by a distance of about HU/u_* where H is the barrier height, U is the wind velocity at half of the barrier height, and u_* is the friction velocity. The models predict that a 4 m barrier results in a 35% reduction in average concentration within 40 m (10 times the barrier height) of the barrier, relative to the no-barrier site. This concentration reduction is 55% if the barrier height is doubled.

"Effects of Solid Barriers on Dispersion of Roadway Emissions," Nico Schulte, Michelle Snyder, Vlad Isakov, David Heist and Akula Venkatram, *Atmospheric Environment*, Vol. 97, pages 286-295, November 2014.
Citation at https://doi.org/10.1016/j.atmosenv.2014.08.026
From the abstract:

Highlights

- Roadside barriers mitigate the impact of vehicular emissions on near road air quality.
- The concentration reduction is largest during stable conditions.
- The primary effect of barriers is to mix pollutants over the barrier height.
- A simple model that incorporates enhanced mixing describes observations.

From the abstract: Field studies, laboratory experiments and numerical simulations indicate that roadside barriers represent a practical method of mitigating the impact of vehicle emissions because near road concentrations are significantly reduced downwind of a barrier relative to concentrations in the absence of a barrier. These studies also show that the major effects of barriers on concentrations are: 1) the concentration is well mixed over a height roughly proportional to the barrier height, and this effect persists over several barrier heights downwind, 2) the turbulence that spreads the plume vertically is increased downwind of the barrier, 3) the pollutant is lofted above the top of the barrier. This paper ties these effects together using two semi-empirical dispersion models. These models provide good descriptions of concentrations measured in a wind tunnel study and a tracer field study. Their performance is best during neutral and stable conditions. The models overestimate concentrations near the barrier during unstable conditions. We illustrate an application of these models by estimating the effect of barrier height on concentrations during neutral, stable and unstable conditions.

Other Modeling Efforts

Note: The conference paper cited below describes the work of Max Zhang's Cornell University research group. See page 8 of this Preliminary Investigation for more information about Zhang's future plans for this research.

"A Multi-Regime Approach to Parameterize the Effects of Noise Barriers on Near-Road Air Quality," Jonathan T. Steffens, Chunli Yuan and K. Max Zhang, *TRB 96th Annual Meeting Compendium of Papers*, Paper #17-03847, 2017.
Citation at https://trid.trb.org/view/1438527
From the abstract: This paper presents the development and evaluation of a parameterized model capable of predicting near-road concentrations of inert species in the vicinity of a solid barrier using a multi-regime approach. Derived based on studying the flow structures and the underlying physics, the multi-regime approach describes 1) concentration profiles outside of the wake created by the barrier (referred to as the "far field" regime) by a standard Gaussian plume dispersion model with a vertically and horizontally shifted source, 2) the concentrations within the wake as nearly uniform (referred to as the "wake" regime), and 3) creates a third regime (referred to as the "transition" regime) to smoothly merge the far field concentration to the wake concentration. A high-fidelity Large-eddy simulation (LES) model is employed to create a wide range of conditions to generate robust empirical constants. The performance from this multi-regime model is evaluated against wind tunnel and field measurement data, which shows good agreement. An important feature of our approach is that the parameterization is developed entirely based on numerical experiments, and evaluated against independent datasets, i.e., datasets are not used for parameterization. In comparison, previous parameterization efforts typically developed and evaluated the model based on the same datasets. Therefore, the parameterization presented in this paper is potentially more robust.

"CFD Simulation of Highway Contaminant Dispersion," Liyuan Gong and Xiuling Wang, *American Society of Mechanical Engineers 2016 International Mechanical Engineering Congress and Exposition*, November 2016.
Citation at
http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=2602642
From the abstract: Studies of highway contaminants['] influence have been carried out by different methods, such as field study, wind tunnel and computational fluid dynamics (CFD). Among all the methods, CFD is respectively both economical and accurate. For CFD method, in order to have a most accurate result, all the factors including terrain, wind profile and other features in the studied area should be included. In this study, noise barrier effect is the main feature being analyzed. Different barrier heights were modelled and simulated in order to see the effect of barrier height. Situations with and without barriers were compared to get the general influence of noise barriers. Simulations were accomplished by using commercial software ANSYS 15.0. Simulated species are nitrogen oxides (NOx), including NO and NO_2, carbon monoxide (CO). Double barriers configuration were modelled. A model of local high school system was built to see the difference of concentration in far wake region behind the barriers. Comparison has been made between with and without barriers. As the results of this study [indicate], a significant reduction was found in far wake area due to noise barriers. Effected flow distribution and contaminants concentration was found due to different barriers['] heights. Flow distribution and pollutants concentration has been depicted and analyzed. The effect has been analyzed by studying flow and wind velocity distribution.

"Modeling the Impact of Solid Noise Barriers on Near Road Air Quality," Akula Venkatram, Vlad Isakov, Parikshit Deshmukh and Richard Baldauf, *Atmospheric Environment,* Vol. 141, pages 462-469, September 2016.
Citation at https://doi.org/10.1016/j.atmosenv.2016.07.005
From the abstract:

Highlights

- Developed a dispersion model algorithm for noise barriers in unstable meteorology.
- Account for the lofting of the plume above the height of the barrier.
- Simulate the entrainment of the elevated plume into the cavity behind the barrier.
- Model compared to field measurement data in Phoenix, Arizona, USA.
- Model predicted reductions similar, but slightly lower, than field measurements.

Abstract: Studies based on field measurements, wind tunnel experiments and controlled tracer gas releases indicate that solid, roadside noise barriers can lead to reductions in downwind near-road air pollutant concentrations. A tracer gas study showed that a solid barrier reduced pollutant concentrations as much as 80% next to the barrier relative to an open area under unstable meteorological conditions, which corresponds to typical daytime conditions when residents living or children going to school near roadways are most likely to be exposed to traffic emissions. The data from this tracer gas study and a wind tunnel simulation were used to develop a model to describe dispersion of traffic emissions near a highway in the presence of a solid noise barrier. The model is used to interpret real-world data collected during a field study conducted in a complex urban environment next to a large highway in Phoenix, Arizona, USA. We show that the analysis of the data with the model yields useful information on the emission factors and the mitigation impact of the barrier on near-road air quality. The estimated emission factors for the four species, ultrafine particles, CO, NO_2, and black carbon, are consistent with data cited in the literature. The results suggest that the model accounted for reductions in pollutant concentrations from a 4.5 m high noise barrier, ranging from 40% next to the barrier to 10% at 300 m from the barrier.

"Influence of Solid Noise Barriers on Near-Road and On-Road Air Quality," Richard W. Baldauf, Vlad Isakov, Parikshit Deshmukh, Akula Venkatram, Bo Yang and K. Max Zhang, *Atmospheric Environment*, Vol. 129, pages 265-276, March 2016.
Citation at https://doi.org/10.1016/j.atmosenv.2016.01.025
From the abstract:

Highlights

- Mobile monitoring measured near-road air quality impacts of a solid noise barrier.
- Downwind concentration reductions of up to 50% occurred behind the barrier.
- Downwind reductions were highest within the first 50 m from the road.
- Reductions extended as far as 300 m from the road.
- On-road levels did not increase in front of barrier, contrary to model predictions.

From the abstract: A field study was conducted to determine the influence of noise barriers on both on-road and downwind pollutant concentrations near a large highway in Phoenix, Arizona, USA. Concentrations of nitrogen dioxide, carbon monoxide, ultrafine particles, and black carbon were measured using a mobile platform and fixed sites along two limitedaccess stretches of highway that contained a section of noise barrier and a section with no noise barrier at-grade with the surrounding terrain. Results of the study showed that pollutant concentrations behind the roadside barriers were significantly lower relative to those measured in the absence of barriers. The reductions ranged from 50% within 50 m from the barrier to about 30% as far as 300 m from the barrier. Reductions in pollutant concentrations generally began within the first 50 m of the barrier edge; however, concentrations were highly variable due to vehicle activity behind the barrier and along nearby urban arterial roadways. The concentrations on the highway, upwind of the barrier, varied depending on wind direction. Overall, the on-road concentrations in front of the noise barrier were similar to those measured in the absence of the barrier, contradicting previous modeling results that suggested roadside barriers increase pollutant levels on the road. Thus, this study suggests that noise barriers do reduce potential pollutant exposures for populations downwind of the road, and do not likely increase exposures to traffic-related pollutants for vehicle passengers on the highway.

Effects of Sound Barriers on Dispersion From Roadways, Nico Schulte and Akula Venkatram, Draft Final Report, South Coast Air Quality Management District, June 2013.
http://www.aqmd.gov/docs/default-source/technology-research/Technology-Forums/near-road-mitigation-measures/ucr-venkatram.pdf
From the abstract: Several field studies, laboratory experiments and computational fluid dynamics simulations have been conducted to examine the impact of barriers. The objective of the research summarized in this report is to use the results from these studies to develop a semi-empirical model that can be used to design roadside barriers to reduce exposure to pollutants from vehicles. In developing this model, we have focused on a tracer study (Finn et al., 2010) and a wind-tunnel experiment (Heist et al., 2009) that were specifically designed to estimate the impact of barriers on near surface dispersion under a variety of atmospheric conditions. We have developed three semi-empirical models that incorporate the dominant physical effects of barriers. The first model treats the effect of the barrier as an upwind shift of the source, where the upwind shift depends on the height of the barrier and atmospheric stability. The second model assumes that the primary role of the barrier is to mix pollutants behind the barrier. The concentration is well mixed behind the barrier, and follows an exponential distribution above it. The third model is an adaptation of that proposed by Puttock and Hunt (Puttock et al., 1979) for predicting dispersion behind obstacles. All three models perform well in describing data from the Idaho Falls field study (Finn et al., 2010) and a wind tunnel study (Heist et al., 2009). The model that mixes pollutants behind the barrier performs the best in describing ground-level concentrations, while the PH model best describes concentrations above the barrier.

"Modeling the Effects of a Solid Barrier on Pollutant Dispersion Under Various Atmospheric Stability Conditions," Jonathan T. Steffens, David K. Heist, Steven G. Perry and K. Max Zhang, *Atmospheric Environment*, Vol. 69, pages 76-85, April 2013.
Citation at https://doi.org/10.1016/j.atmosenv.2012.11.051
From the abstract: In this study, we utilized the Comprehensive Turbulent Aerosol Dynamics and Gas Chemistry (CTAG) model to simulate the spatial gradients of SF_6 concentrations behind a solid barrier under a variety of atmospheric stability conditions collected during the Near Road Tracer Study (NRTS08). We employed two different CFD [computational fluid dynamics] models, RANS [Reynolds-averaged Navier-Stokes] and LES [large-eddy simulation]. A recirculation zone, characterized by strong mixing, forms in the wake of a barrier. It is found that this region is important for accurately predicting pollutant dispersion, but is often insufficiently resolved by the less complex RANS model. The RANS model was found to perform adequately away from the leading edge of the barrier. The LES model, however,

performs consistently well at all flow locations. Therefore, the LES model will make a significant improvement compared to the RANS model in regions of strong recirculating flow or edge effects. Our study suggests that advanced simulation tools can potentially provide a variety of numerical experiments that may prove useful for roadway design communities to intelligently design roadways, making effective use of roadside barriers.

Highlights
► The LES and *k–ε* RANS models are employed to model how a solid barrier affects dispersion. ► Modeling results are evaluated against the NRTS08 dataset. ► LES performs consistently well under all atmospheric conditions. ► The *k–ε* RANS model cannot fully capture the edge and recirculation.

"Model Evaluation of Roadside Barrier Impact on Near-Road Air Pollution," Gayle S.W. Hagler, Wei Tang, Matthew J. Freeman, David K. Heist, Steven G. Perry and Alan F. Vette, *Atmospheric Environment*, Vol. 45, No. 15, pages 2522-2530, May 2011.
Citation at https://doi.org/10.1016/j.atmosenv.2011.02.030
From the abstract: A 3-dimensional computational fluid dynamics (CFD) 6-lane road model has been developed to simulate roadside barrier effects on near-road air quality and evaluate the influence of key variables, such as barrier height and wind direction. The CFD model matches an existing wind tunnel road model and comparison with the wind tunnel data guided the selection of the optimal turbulence model (Realizeable *k–ε* turbulence model with a Schmidt number of 1.0). Under winds perpendicular to the road, CFD model simulations show that roadside barriers reduce the concentration of an inert gaseous tracer (χ), relative to a no-barrier situation, vertically up to approximately half the barrier height and at all horizontal distances from the road. At 20 m (3.3H, where H = 6 m) from the road, barriers of heights ranging from 0.5H to 3.0H reduce the maximum concentrations by 15–61% relative to a no-barrier case, with the location of the maximum shifted to occur near the top of the barrier. The near-road reduction comes at a penalty for on-road air pollutant concentrations: on-road pollution is projected to increase by a factor of 1.1–2.3 corresponding to barriers ranging from 0.5H to 3.0H. When the noise barrier is downwind of the road, a stagnant zone is formed behind the barrier and minor road emissions (e.g., 5% of the highway emissions strength) in this zone, such as a moderately traveled service road, have a magnified effect on concentrations immediately behind the barrier. Wind direction and barrier termination also play a critical role, with a spill-over of accumulated emissions upwind of the barrier strongly increasing near-road concentrations at one end of the barrier. These results imply that roadside barriers may mitigate near-road air pollution, although local meteorology, the barrier structure, and the degree of lee-side emission sources are critical factors determining the outcome.

Highlights
► Traffic emissions dispersion in the presence of a roadside barrier is evaluated using a computational fluid dynamics model. ► Under crosswind conditions, barriers reduce downwind near-road maximum concentrations, but increase on-road concentrations. ► Minor emissions (e.g., service road) in the stagnant zone downwind of a barrier can increase near-road pollution levels. ► Oblique winds can transport accumulated on-road emissions around the edge of a barrier and create a local high concentration zone.

Model Comparisons

"Evaluation of US and UK Models in Simulating the Impact of Barriers on Near-Road Air Quality," D. Heist, C. Hood, A. Venkatram, S. Perry, V. Isakov, M. Snyder, L. Brouwer, D. Carruthers, J. Stocker and S. Smith, *International Society of Exposure Science (ISES) 25th Annual Meeting*, October 2015.
Description at https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=317253
From the conference paper description: To assess the ability of two dispersion models capable of accounting for the barrier effect, three different studies of near-road noise barrier dispersion have been used for model evaluation and intercomparison purposes. This paper presents comparisons, using the three datasets, of the performance of barrier algorithms in two different dispersion models: US EPA's R-LINE (a research dispersion modelling tool under development by the US EPA's Office of Research and Development) and CERC's [Cambridge Environmental Research Consultants'] ADMS [Atmospheric Dispersion Modeling System] model (ADMS-Urban).The first study was performed in the meteorological wind tunnel at the US EPA and simulated line sources near noise barriers of different heights to investigate that aspect of barrier design in a well-controlled environment. The second was an idealized tracer field study [that] was performed in Idaho Falls, ID, USA with a 6-m high noise barrier and a finite line source. This study employed 58 samplers arrayed predominantly downwind of the source and has the advantage of being conducted in a variety of atmospheric conditions but with a controlled source of pollutants. The third is a field study performed along a major thoroughfare in Phoenix, AZ, designed to investigate the effect of a roadside barrier on traffic-generated pollutant dispersion under real driving conditions. Measurements of various pollutants were made downwind of roadway sections with and without a noise barrier. In all three studies, velocity and concentration measurements were used to characterize the effect of the barrier on dispersion.

"Estimating Near-Road Pollutant Dispersion: A Model Inter-Comparison," David Heist, Vlad Isakov, Steven Perry, Michelle Snyder, Akula Venkatram, Christina Hood, Jenny Stocker, David Carruthers, Saravanan Arunachalam and R. Chris Owen, *Transportation Research Part D: Transport and Environment*, Vol. 25, pages 93-105, December 2013.
Citation at https://doi.org/10.1016/j.trd.2013.09.003
From the abstract:

Highlights

- Gaussian dispersion models to capture near-road pollutant dispersion are compared.
- The Idaho Falls and Caltrans Highway 99 tracer studies are used in the comparison.
- Estimated downwind concentrations are mostly within a factor of two of observations.
- RLINE, ADMS and AERMOD performed similarly, while CALINE 3 and 4 had more scatter.

Abstract: A model inter-comparison study to assess the abilities of steady-state Gaussian dispersion models to capture near-road pollutant dispersion has been carried out with four models (AERMOD, run with both the area-source and volume-source options to represent roadways, CALINE, versions 3 and 4, ADMS and RLINE). Two field tracer studies are used: the Idaho Falls tracer study and the Caltrans Highway 99 tracer study. Model performance measures are calculated using concentrations (observed and estimated) that are paired in time and space, since many of the health related questions involve outcomes associated with spatially and temporally distributed human activities. All four models showed an ability to estimate the majority of downwind concentrations within a factor of two of the observations. RLINE, AERMOD-V and ADMS also have the capability to predict concentrations upwind of the roadway that result from low-speed meandering of the plume. Generally, RLINE, ADMS and AERMOD (both source types) had overall performance statistics that were broadly similar, while CALINE 3 and 4 both produced a larger degree of scatter in their concentration estimates. The models performed best for near-neutral conditions in both tracer studies, but had mixed results under convective and stable conditions.

Wind Tunnel and Tracer Studies

"Effects of Roadway Configurations on Near-Road Air Quality and the Implications on Roadway Designs," Jonathan T. Steffens, David K. Heist, Steven G. Perry, Vlad Isakov, Richard W. Baldauf and K. Max Zhang, *Atmospheric Environment,* Vol. 94, pages 74-85, September 2014.
Citation at https://doi.org/10.1016/j.atmosenv.2014.05.015
From the abstract:

Highlights

- We investigate the impacts of elevated and depressed roadways, and roadside barriers.
- All configurations reduce ground-level air pollutant concentrations near roadways.
- The elevated roadway leads to reduction in both on-road and near-road concentration.
- Adding multiple features offers diminishing returns in concentration reduction.
- The effects of design features damp out <15 multiples of the characteristic height.

Abstract: This paper presents an analysis of wind tunnel experiments of twelve different roadway configurations and modeling of these configurations using a Large-Eddy Simulation (LES) model, aiming at investigating how flow structures affect the impact of roadway features on near-road and on-road air quality. The presence of roadside barriers, elevated fill and depressed roadways, and combinations of these configurations all reduce ground-level air pollutant concentrations immediately downwind of roadways. However, all of these cases, except the elevated fill configuration, increase pollutant concentrations on the roadway itself. For a roadside barrier with finite length, higher concentrations than those without a barrier are present in a small region near the edge of the barrier, influenced by complex flow in that region which we term "Edge Effects." The inclusion of multiple roadway features often result in lower downwind pollutant concentrations than those with single roadway features; however, adding features typically offers diminishing returns in concentration reduction. Generally, the effects on concentration, both beneficial and adverse will damp out within 15 multiples of the characteristic height, be it the barrier height or the elevation/depression height of the roadway. Thus, evaluating the trade-off between the air pollutant reductions near the ground and the air pollutant increases on the roadway and elevated above the ground will be important in designing a sustainable transportation system.

“Tracer Studies to Characterize the Effects of Roadside Noise Barriers on Near-Road Pollutant Dispersion Under Varying Atmospheric Stability Conditions,” Dennis Finn, Kirk L. Clawson, Roger G. Carter, Jason D. Rich, Richard M. Eckman, Steven G. Perry, Vlad Isakov and David K. Heist, *Atmopheric Environment*, Vol. 44, No. 2, pages 204-214, January 2010. Citation at https://doi.org/10.1016/j.atmosenv.2009.10.012
From the abstract: A roadway toxics dispersion study was conducted at the Idaho National Laboratory (INL) to document the effects on concentrations of roadway emissions behind a roadside sound barrier in various conditions of atmospheric stability. The homogeneous fetch of the INL, controlled emission source, lack of other manmade or natural flow obstructions, and absence of vehicle-generated turbulence reduced the ambiguities in interpretation of the data. Roadway emissions were simulated by the release of an atmospheric tracer (SF_6) from two 54 m long line sources, one for an experiment with a 90 m long noise barrier and one for a control experiment without a barrier. Simultaneous near-surface tracer concentration measurements were made with bag samplers on identical sampling grids downwind from the line sources. An array of six 3-d sonic anemometers was employed to measure the barrier-induced turbulence. Key findings of the study are: (1) the areal extent of higher concentrations and the absolute magnitudes of the concentrations both increased as atmospheric stability increased; (2) a concentration deficit developed in the wake zone of the barrier with respect to concentrations at the same relative locations on the control experiment at all atmospheric stabilities; (3) lateral dispersion was significantly greater on the barrier grid than the non-barrier grid; and (4) the barrier tended to trap high concentrations near the “roadway” (i.e.[,] upwind of the barrier) in low wind speed conditions, especially in stable conditions.

“A Wind Tunnel Study of the Effect of Roadway Configurations on the Dispersion of Traffic-Related Pollution,” D.K. Heist, S.G. Perry and L.A. Brixey, *Atmospheric Environment*, Vol. 43, No. 32, pages 5101-5111, October 2009.
Citation at https://doi.org/10.1016/j.atmosenv.2009.06.034
From the abstract: In this paper we examine the effect of different roadway configurations, including noise barriers and roadway elevation or depression relative to the surrounding terrain, on the dispersion of traffic-related pollutants for winds perpendicular to the roadway. A wind tunnel experiment modeling 12 different configurations was performed to study the flow fields and the concentration distributions resulting from emissions from a simulated six-lane highway. All of the configurations examined here reduced the downwind ground-level concentrations relative to that for a flat, unobstructed roadway; however, the degree to which the concentrations were reduced varied widely depending on the particular situation.

Ground-level concentration data from the cases considered in this research indicate that a constant entrainment velocity can be used over the region beginning downwind of any initial disturbance to the flow resulting from the roadway configuration (e.g., a recirculation region behind a noise barrier) and extending at least to the end of our measurements. For example, for the case of a single noise barrier on the downwind side of the road, this region extends from approximately four barrier heights downwind of the roadway to 40 barrier heights. It was also found that the virtual origin concept is useful in describing the initial mixing created by the particular roadway configuration. To effectively model the influence of the roadway configuration on the dispersion, a combination of a virtual origin and an entrainment velocity may be effective. The magnitude of the virtual origin shift appears to depend on the particular roadway configuration, while the entrainment velocity appears to be a function of the friction velocity and the roadway geometry. These results suggest that road configuration must be taken into account in modeling near-road air quality.

International Research Efforts

"Evaluation of Model for Air Pollution in the Vicinity of Roadside Solid Barriers," Desmond Adair and Martin Jaeger, *Energy and Environmental Engineering*, Vol. 2, No. 7, pages 145-152, 2014.
http://www.hrpub.org/download/20150101/EEE2-14503114.pdf
From the abstract: Roadside noise barriers and solid fences are common features along major highways in urban regions of Kazakhstan and are anticipated to have important effects on near-road air pollution through altering the dispersion of traffic emissions and resulting downstream concentrations. A 3-dimensional computational fluid dynamics (CFD) road model has been developed to simulate roadside barrier effects on near-road air quality and evaluate the influence of key variables, such as barrier height and wind direction. The CFD model is tested against experimental data and other existing models found in the literature, with several turbulence models tested to give optimal results, i.e., the standard $k-\varepsilon$ model and the realizable $k-\varepsilon$ model with different Schmidt numbers. The dispersion of a mixture of nitrogen oxides (denoted as NO_x—a mix of NO and NO_2) was computed and the barriers were assumed to be straight and infinitely long. Dispersion of NO_x was modeled for situations with no barriers along the highway, barriers on both sides, and for a single barrier on the downwind side of the highway. The modelling results are presented and discussed in relation to previous studies and the implications of the results are considered for pollution barriers along highways.

"Impact of Noise Barriers on Air-Pollution Dispersion," Josef Brechler and Vladimir Fuka, *Natural Science*, Vol. 6, pages 377-386, 2014.
https://file.scirp.org/pdf/NS_2014040813320396.pdf
From the abstract: The impact of noise barriers on gaseous air-pollution dispersion was examined using the high-resolution CLMM (Charles University LES (Large Eddy Simulation) Microscale Model). The dispersion of a mixture of nitrogen oxides (denoted as NO_x—a mix of NO and NO_2) was computed, providing the simulation in which wind direction is approximately perpendicular to the noise barriers. The barriers were assumed to be straight and infinitely long, with a height of 3 m. Dispersion of NO_x was modeled for situations with no noise barriers along the highway, barriers on both sides, and for a single barrier on the upwind and downwind sides of the highway. The modelling results are presented and discussed in relation to previous studies and the implications of the results are considered for pollution barriers along highways.