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EVALUATION AND DEVELOPMENT OF TOOLS TO QUANTIFY THE IMPACTS OF ROADSIDE VEGETATION BARRIERS ON NEAR-ROAD AIR QUALITY

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Abstract: Regulatory and urban planning programs require an accurate evaluation of how traffic emissions transport and disperse from roads to fully determine exposures and health risks. Roadside vegetation barriers have shown the potential to reduce near-road air pollution concentrations; however, the characteristics of these barriers needed to ensure pollution reductions are not well understood. U.S. EPA conducted several field experiments to understand the effects of vegetation barriers on dispersion of pollutants near roadways (e.g. 2008 mobile monitoring study in Chapel Hill, North Carolina and 2014 mobile monitoring study in San Francisco Bay Area, California). The results of these field studies were used to evaluate dispersion models in simulating the effects of near road barriers and to develop recommendations for model improvements. The improved models can be used for evaluating the effectiveness of vegetation barriers as a potential mitigation strategy to reduce exposure to traffic-related pollutants and their associated adverse health effects. This paper presents the results of the analysis of the field studies and discusses the applicability of dispersion models to simulate the impacts of vegetation barriers.

Key words: *Roadways, Barriers, Vegetation, Dispersion, Models.*

INTRODUCTION

There is a strong international consensus on elevated health risks for populations living, working, or going to school near large roadways. The health concerns have been linked to elevated levels of air pollution caused by traffic emissions. Public health concerns have raised interest in methods to mitigate these traffic emission impacts. Traditionally, transportation and land use planning options have been focusing on vehicle emission standards and reduction in vehicle activity, and also establishing buffer or exclusion zones. These options are typically “long-term” since emission reductions take long to implement and planning and zoning is involved in rerouting and vehicle miles travelled reduction programs. Other options to mitigate the impacts of traffic emission focus on roadway design and urban planning that includes road location and configuration, and roadside noise barriers and vegetation. The advantage of the roadside barriers option is that it provides an opportunity for a “short-term” solution and also because roadside features may already be present. Also, the roadside barriers often have other positive benefits. Thus, appropriately selected and planted roadside vegetation may reduce traffic-related air pollution concentrations by providing a way of reducing exposures to traffic emissions. While roadside vegetation barriers have shown the potential to reduce near-road air pollution concentrations, the characteristics of these barriers needed to ensure pollution reductions are not well understood. Therefore, models and more supporting field measurement data are needed to fully assess these impacts. U.S. EPA has initiated studies to examine how roadside vegetation barriers affect near-road air pollutant exposures. The studies used a combination of modeling and monitoring to characterize the impact of roadway features on near-road air quality. The 2008 mobile monitoring study Chapel Hill, North Carolina and 2014 mobile monitoring study in Woodside, California provided data to evaluate dispersion models in simulating the effects of near road barriers and to develop recommendations for model improvements.

CHAPEL HILL ROADSIDE BARRIER FIELD STUDY

The Chapel Hill, North Carolina field study was conducted in fall of 2008 along U.S. Route 15–501. The Geospatial Monitoring of Air Pollution (GMAP) electric car provided real-time mapping of PM, NO_2, and CO by repeatedly driving a specified route at each study site. Thus, mobile monitoring provided spatially-resolved air quality data behind the barrier in in the clearing. Details of the experimental setup can be found in (Hagler et al., 2012). The vegetation barrier consists around 10% of deciduous trees (Maple tree), and 90% of coniferous trees (Leyland Cypress and Morella cerifera) approximately 4-8 m in height and 2-5 meters thick (Fig. 1). A four lane highway, US 15-501, passed next to the vegetation barrier.

Figure 1. Pictures of vegetation barriers in Chapel Hill, NC next to highway (left) and behind the barrier (right)

We used a combination of measurement and modeling to evaluate the impact of vegetation barriers and developing recommendation for improved dispersion modeling algorithms based on solid barrier algorithms to be applicable for vegetation barriers. We used the Comprehensive Turbulent Aerosol Dynamics and Gas Chemistry (CTAG) model with Large Eddy Simulation (LES) to simulate the impacts of vegetation barriers on dispersion ultrafine particulates near roadway and evaluated model results against the Chapel Hill field study data (Tong et al., 2016). The results of CTAG with LES model simulations compared well with observations behind the vegetation barrier and the model was able to capture the trend observed in the experiment (Steffens et al., 2012). The results of model evaluation against the Chapel Hill data provided us with the confidence in CTAG with LES to simulate other scenario. Next, we used the model to explore the effects of vegetation barriers on near-road particle concentrations using six common near-road configurations: 1) a no-barrier scenario for comparison with other configurations; 2) a wide vegetation barrier located next to the road; 3) a solid barrier configuration; 4) a "green wall" configuration, which is a combination of solid barrier and vegetation cover; 5) a "vegetation–solid barrier combination" scenario where a tall vegetation barrier is behind a solid wall; 6) configuration where both upwind and downwind vegetation barriers are present. The near-road air quality is primarily driven by two physical mechanisms, i.e., dispersion and deposition, and deposition only occurs in the presence of vegetation. The results of model simulations highlight the removal from vegetation, especially for smaller, ultrafine particles. The modeling suggests two potentially viable design options as a potential mitigation option for near-road particulates: 1) a wide vegetation barrier with high Leaf Area Density, and 2) vegetation–solid barrier combinations, i.e., planting trees next to a solid barrier. However, these recommendations for vegetation barrier designs are based on model simulations for a few generic configurations, and therefore future implementation needs to take into account site-specific characteristics, given the complexity of urban landscapes.

CALIFORNIA ROADSIDE BARRIER FIELD STUDY

The California Roadside Barrier study was conducted to determine the influence of vegetation barriers on near-road pollutant concentrations. The study was conducted in San Francisco Bay area along Interstate-280 near Woodside, CA. Measurements were conducted near a roadway with varying vegetation types – bush/tree combinations with varying porosity and manicured hedges (Fig. 2). The study was conducted for approximately one month, from late August until late September, 2014 for approximately three hours each day during either morning or afternoon time periods. Data collected included traffic counts and speed, meteorology, and air quality for multiple pollutants. Concentrations of NO_2, CO, ultrafine particles (UFP), and black carbon (BC) were measured using the Geospatial Monitoring of Air Pollution (GMAP) electric car and fixed sites along two limited-access stretches of highway that contained a section of the vegetation barrier and a section with no noise barrier at-grade with the surrounding terrain.

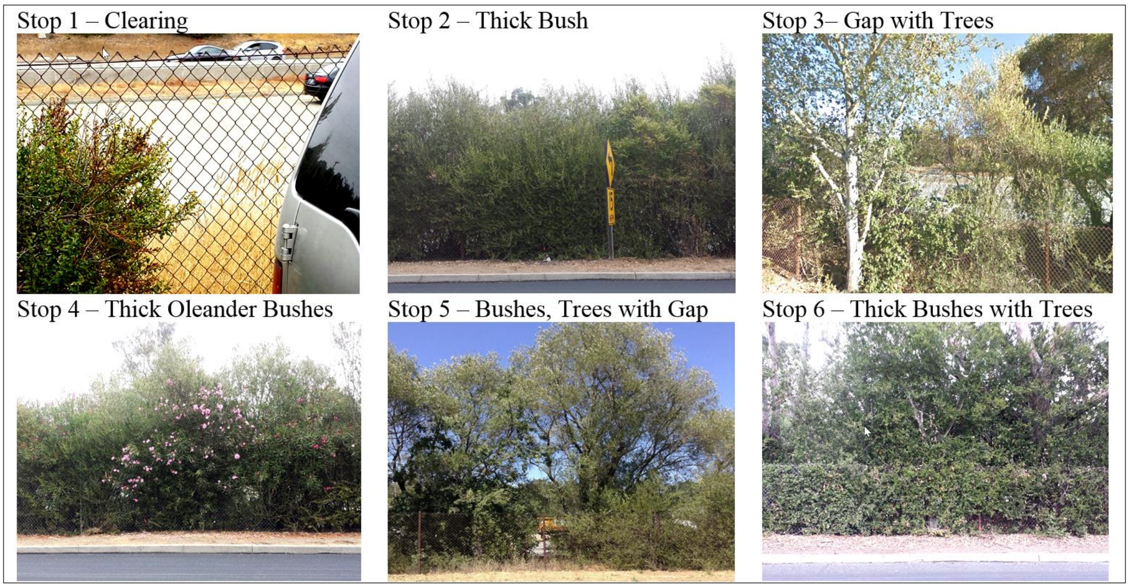

Figure 2. Examples of varying near-roadway vegetation types in Woodside, CA

The GMAP measurements were conducted across six locations behind the barrier with different characteristics: Stop 1 – clearing; Stop 2 - behind bushes; Stop 3 - gap with trees; Stop 4 - behind thick oleander bushes; Stop 5 - gap with trees; Stop 6 - behind thick bushes and trees (Fig.3). These measurements and analysis are critical for the development of improved model algorithms capable of simulating pollutant transport and dispersion of near-surface releases in the presence of roadside barriers.

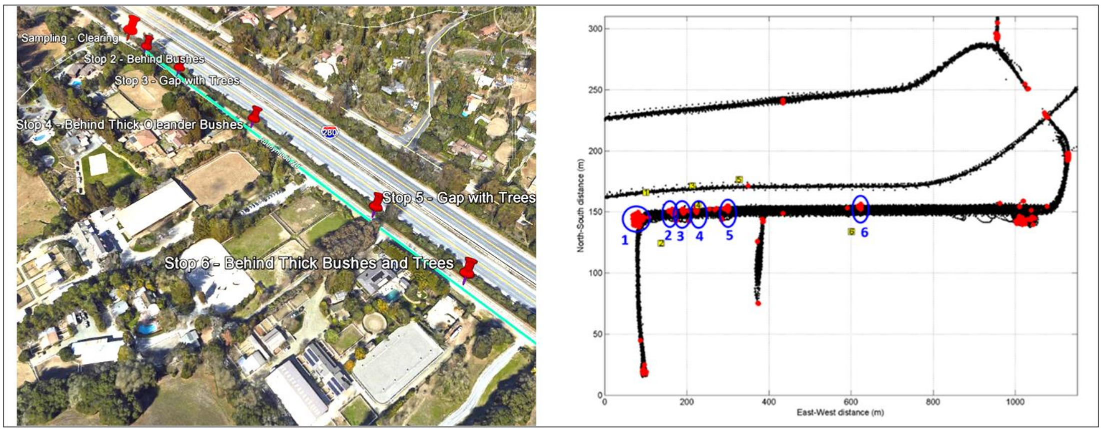

Figure 3. Aerial view of the study site in Woodside, CA (left) and a map of mobile measurement locations (right) at selected 6 stops along the vegetation barriers where GMAP measurements were taken.

The results of GMAP measurements at Woodside location for CO and UFP are shown in Figure 4. Distributions of observed concentrations from all 1-second measurements in Woodside are compared across six locations behind the barrier with different characteristics. Each distribution is based on a roughly ten thousand observations during the entire field campaign. This, the distributions represent a longer-term exposure over the range of varying meteorological conditions. The results indicate the reduction in concentrations behind the barrier. The median values of the distribution behind the barrier with different characteristics (stops 2 and 3 – bushes, stops 5 and 6 –trees) are generally lower that in the clearing. One exception is stop 3, which is a gap in the barrier. This is consistent with the findings from other studies that have shown that spaces and gaps between roadside vegetation can lead to increased pollutant concentrations along and away from the road. Therefore, vegetation must be thick and without gaps to be considered as a potential mitigation option.

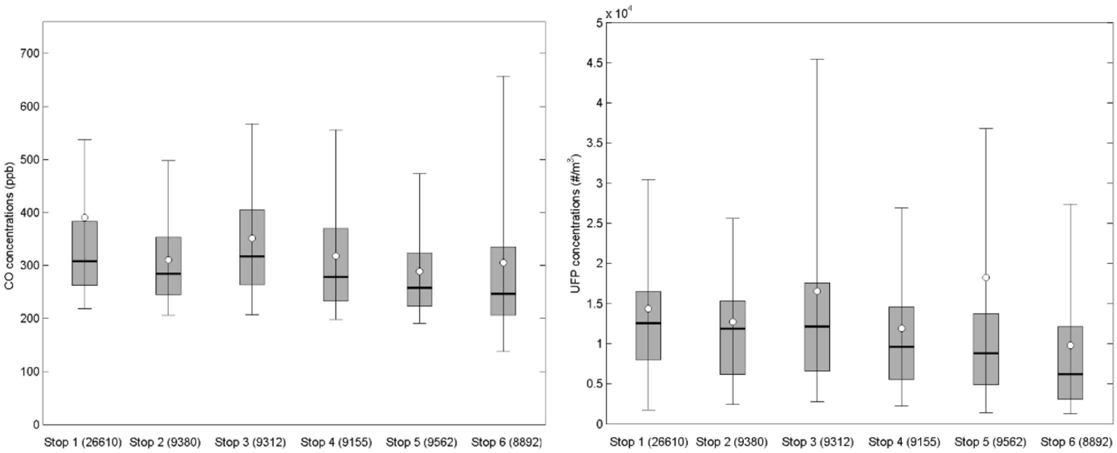

Figure 4. Distributions of observed CO (left) and UFP (right) concentrations from all mobile measurements in Woodside. Each distribution is based on n observations (shown below). The middle line represents the median, the box the 25th and 75th percentiles, and the whiskers the 5th and 95th percentiles. The point represents the mean value of the distribution.

We can quantify the effect of vegetation on reducing near road concentrations by estimating the height of a solid barrier that would resulted in the same reduction. The primary effect of a solid barrier is to increase vertical dispersion of the pollutants emitted from the road. A simple model of this effect adds the height of the barrier to the vertical dispersion. Then, if we assume that that the emissions from the road are distributed over the width of the road, *W*, the concentration at a distance, *d*, from the edge of the road is given by (Schulte et al.,2014):

$$C = \sqrt{\frac{2}{\pi}} \frac{q}{W\sigma_w} \ln\left(1 + \frac{W}{d + \frac{HU}{\sigma_w}}\right), \qquad (1)$$

where q is the emission rate per unit length of the road, H is the height of the barrier, σ_w is the standard deviation of the vertical velocity fluctuations, and U is the near surface wind speed. If we assume that vehicle induced turbulence enhances the vertical spread by 2 m, we can derive an expression for the solid barrier height that would have resulted in the observed concentration reduction, *R*, seen by the vegetative barrier relative to the open section:

$$H = \frac{\sigma_w}{U}\left(\frac{W}{p-1} - \mathrm{d}\right), \qquad (2)$$

where p is given by

$$p = \left(1 + \frac{W}{d + \frac{H_0 U}{\sigma_w}}\right)^R, \qquad (3)$$

where *R* is the ratio of the concentration behind the vegetative barrier to the concentration in the open section, and H_0=2 m corresponds to vehicle induced turbulence in the open section.

Table 1 presents results for the measurements made in Woodside. Here *R* refers to the mean of the reductions of the four species at each of the stops. The variables σ_w and *U* were derived from the sonic measurements made at a 3m height in the open area. All the variables used in deriving averages correspond to the wind direction blowing the emissions towards the measurement stops.

We see that the computed solid barrier heights, in the last column, are consistent with the heights of the vegetation and their coverage. This suggests that it might be possible to estimate the equivalent height of a barrier using the actual height of the vegetative barrier and its porosity. In principle, this would allow us to compute the effect of a vegetative barrier under different meteorological conditions using more established models for dispersion behind a solid barrier (Schulte et al., 2014).

Table 1. Effect of Vegetative Barriers on Concentrations

Stop Number	Height of Vegetation (m)	Description	Reduction	Equivalent Barrier Height (m)
1	0	Clear	1	2.0
2	3-4	vegetation buffer ~6-7m with approx. 75% coverage	0.77	3.5
3	3-4	Wide gap (>4m) with highly porous mix of trees and thin bushes (~6-7m with approx. 50% coverage)	1	2.0
4	3-4	vegetation buffer ~6-7m with approx. 90% coverage	0.73	3.9
5	3-4	trees ~10m, thick vegetation buffer ~7m, and 1m wide gap with little vegetation	0.85	2.8
6	3-4	trees 10-12m, vegetation buffer ~7m with approx. 90% coverage	0.71	4.1

SUMMARY

The results of the combined monitoring and modeling analysis indicate that roadside vegetation can affect downwind pollutant concentrations in both positive and negative ways. Roadside bushes and hedges can result in improved near-road air quality if designed properly. However, some other configurations such as large gaps in vegetation would not impact the dispersion or could even increase concentrations behind the barrier. Our analysis suggest the following barrier configurations that could help mitigate near-road exposures to traffic pollution: 1) Complete coverage from ground to top; 2) No gaps or dead tree areas (original planting and maintenance of vegetation); 3) Sufficient length for protecting sensitive populations/land uses.

REFERENCES

Hagler, G.S.W., E.D. Thoma, R.W. Baldauf, 2010: High-Resolution Mobile Monitoring of Carbon Monoxide and Ultrafine Particle Concentrations in a Near-Road Environment, J. *Air & Waste Manage Assoc*. **60**, 328–336

Steffens, Y.J. Wang, K.M. Zhang, 2012: Exploration of effects of a vegetation barrier on particle size distributions in a near-road environment. *Atmos. Environ.*, **50**, 120-128

Tong, Z., R.W. Baldauf, V. Isakov, P. Deshmukh, K.M. Zhang, 2016: Roadside vegetation barrier designs to mitigate near-road air pollution impacts. *Science Tot. Environ.*, **541**, 920-927

Schulte, N., Snyder, M., Heist, D. and Venkatram, A., 2014: Effects of solid barriers on dispersion of roadway emissions. *Atmos. Environ.* **97**, 286-295.

Venkatram, A., V. Isakov, P. Deshmukh, R. Baldauf, 2016: Modeling the Impact of Noise Barriers on Near Road Air Quality. *Atmos. Environ.*, (in review)