Science of the Total Environment 419 (2012) 7–15

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Field investigation of roadside vegetative and structural barrier impact on near-road ultrafine particle concentrations under a variety of wind conditions

Gayle S.W. Hagler [a,*], Ming-Yeng Lin [b], Andrey Khlystov [b], Richard W. Baldauf [a,c], Vlad Isakov [d], James Faircloth [a], Laura E. Jackson [e]

[a] US EPA, Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, NC, USA
[b] Duke University, Civil and Environmental Engineering, Durham, NC, USA
[c] US EPA, Office of Air and Radiation, Office of Transportation and Air Quality, National Vehicle and Fuel Emissions Laboratory, Ann Arbor, MI, USA
[d] US EPA, Office of Research and Development, National Exposure Research Laboratory, Research Triangle Park, NC, USA
[e] US EPA, Office of Research and Development, National Health and Environmental Effects Laboratory, Research Triangle Park, NC, USA

ARTICLE INFO

Article history:
Received 30 September 2011
Received in revised form 2 December 2011
Accepted 2 December 2011
Available online 26 January 2012

Keywords:
Near-road
Noise barrier
Tree stands
Vegetation
Ultrafine
Particulate matter

ABSTRACT

Roadside barriers, such as tree stands or noise barriers, are prevalent in many populated areas and have been shown to affect the dispersion of traffic emissions. If roadside noise barriers or tree stands are found to consistently lower ground-level air pollution concentrations in the near-road environment, this may be a practical strategy for reducing exposures to air contaminants along populated traffic corridors. This study measured ultrafine particle (UFP) concentrations using an instrumented mobile measurement approach, collecting data on major roadways and in near-road locations for more than forty sampling sessions at three locations in central North Carolina, USA. Two of the sampling sites had relatively thin tree stands, one evergreen and one deciduous, along a portion of the roadway. The third sampling site had a brick noise wall along a portion of the road. At 10 m from the road, UFPs measured using a mobile sampling platform were lower by approximately 50% behind the brick noise wall relative to a nearby location without a barrier for multiple meteorological conditions. The UFP trends at the vegetative barrier sites were variable and the barrier effect is uncertain. In some cases, higher concentrations were observed behind the vegetative barrier, with respect to the clearing, which may be due to gaps in the thin tree stands allowing the transport of traffic-related air pollution to near-road areas behind the vegetation. On-road sampling revealed no consistent difference in UFP levels in on-road portions of the road with or without a roadside barrier present. These findings support the notion that solid roadside barriers may mitigate near-road impact. Given the co-benefits of vegetative barriers in the urban landscape, research regarding the mitigation potential of vegetative barriers of other configurations (e.g., greater density, wider buffer) is encouraged.

Published by Elsevier B.V.

1. Introduction

Near-road air quality is a pressing issue of concern for densely developed urban regions worldwide. In response to field studies documenting significant increases in air pollutant concentrations in the roadside environment relative to areas several hundred meters downwind (Karner et al., 2010 and references therein), a number of health-advocacy groups have issued recommendations to reduce exposure risk. For example, the state of California advises a distance of 500 ft (~150 m) from urban roadways with more than 100,000 vehicles per day or rural roadways with over 50,000 vehicles per day for locating new schools (California Environmental Protection Agency, 2005). The American Academy of Pediatrics has also issued a policy statement suggesting that new school and childcare facilities should take proximity to roadways into account (Shannon et al., 2004). Implementing such recommendations may lower the risk of exposure to high concentrations of traffic-related pollutants; however, this strategy can have limited utility for existing developments and may encourage environmentally-unfriendly urban sprawl, longer commutes for children attending school at locations far from their neighborhoods, and other unintended consequences.

One practical potential mitigation strategy undergoing investigation through field and modeling studies is the reduction of near-road air pollution by roadside barriers, such as solid noise barriers or tree stands. Noise barriers and tree stands are already appreciated as mechanisms of noise control and aesthetic improvement in urban landscapes. In addition, even relatively sparse vegetation has been documented to provide a number of benefits to health; views of greenery have been related to faster healing (Ulrich, 1984), improved cognitive development (Wells, 2000), and reduced domestic violence (Sullivan and Kuo, 1996) and aggression (Moore and Arch, 1981). Urban vegetation can also provide shade, reducing the urban heat-island effect as well

* Corresponding author.
E-mail address: hagler.gayle@epa.gov (G.S.W. Hagler).

0048-9697/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.scitotenv.2011.12.002

as building energy costs and greenhouse gas emissions from air conditioning. Near-road vegetative buffers can also filter and slow polluted stormwater runoff from roadways. These and potential near-road air quality benefits may be offset by potentially undesirable effects such as pollen production and habitat for invasive pest species.

Roadside barriers may augment near-road air quality through altering dispersion as well as by capturing air pollutants. Past research studying roadside barrier effects on local air pollution has generally focused on two types of road configurations — (1) street canyon environments typical of highly populated cities with densely located tall buildings and (2) open street environments that have lower density single- to triple-story buildings and are common urban sprawl layouts found in moderate-sized cities or suburban areas of large cities in the United States. While this present research is focused primarily on open street configurations, it is important to point out that the findings may not be simply translated to complex street canyon environments. For example, a recent modeling study found that trees within a street canyon environment may have a positive or negative effect on within-canyon pedestrian air quality, depending on the placement of the trees and on which side of the road the pedestrians are located (Buccolieri et al., 2009). Meanwhile, past field and modeling studies evaluating the open street environment have consistently estimated lower air pollutant concentrations in roadside zones (0–50 m) in the lee of a solid noise barrier (Bowker et al., 2007; Baldauf et al., 2008a, b; Finn et al., 2010; Ning et al., 2010; Hagler et al., 2011a); however, the comparison between barrier-protected versus open roadsides was inconsistent among studies at distances further away from the road.

There are several key unknowns regarding barrier effects in open street configurations, where field data in particular are lacking. One unknown is the effect of wind direction on the dispersion of traffic emissions — the majority of research to date has focused primarily on solid barrier effects under winds perpendicular to the road. The effect of roadside vegetation on near-road air pollution has received less attention and may be even more difficult to quantify given the added complexities of vegetation type and seasonal effects in addition to physical characteristics such as height, width, and length. Baldauf et al. (2008b) showed measurable reductions in UFP number concentrations when mature and extensive vegetation was present along with a noise barrier compared with a noise barrier-only section of the roadway; however, the site configuration prevented the vegetation effect alone from being isolated. In agriculture environments, vegetation has been used as natural windbreaks and demonstrated to reduce the length of livestock odor plumes by 22% (Lin et al., 2007). In addition, the capacity of urban trees to capture ambient air pollutants has been documented in multiple locations (e.g., Beckett et al., 1998; Nowak et al., 2006) as well as in wind tunnel experiments (Beckett et al., 2000; Lin and Khlystov, 2012). These past findings, as well as previous research regarding roadside structural barriers, provide a basis for hypothesizing that near-road vegetation in open street environments may capture vehicular air pollutants as well as enhance dilution.

This study presents results from a recent field study quantifying the impact of a narrow roadside tree stand or a solid noise barrier on near-road and on-road air pollution, expanding on previous findings in several ways: 1) exploring whether vegetative barriers (trees, hedges) alone lower air pollutant concentrations in the roadside environment, 2) quantifying the impact of both structural and vegetative barriers under multiple wind conditions, and 3) exploring whether on-road concentrations are significantly different with barriers present.

2. Methods

2.1. Field campaign locations and schedule

This field study, named the Triangle Area Barriers Study (TABS), took place at three roadside locations in central North Carolina, located in the southeastern United States (Fig. 1). The road sampling sites were selected based on roadside barrier properties: a stretch of roadway having a vegetative buffer or structural noise wall as well as an adjacent roadside area without a barrier for comparison and moderate to heavy traffic during morning commute periods. In addition, relatively thin vegetative buffers were sought (<10 m in thickness) in order to relate the results of this study most closely to the utility of vegetative buffers in mitigating near-road impact for developments located immediately adjacent to roadways. A final site requirement was a low degree of side road traffic, so that the effect of the barrier on highway emissions impact could be isolated.

The three sites sampled include Mebane, which had a primarily deciduous tree stand and was located along an interstate highway (I-40/I-85 combined) that connects several major population centers of North Carolina; Chapel Hill, which had a primarily evergreen tree stand and was located along an expressway (U.S. Route 15–501); and, Raleigh, which has a brick noise barrier and is located along an interstate highway (I-440) that loops around the city of Raleigh. All sites were characteristic of a typical open street environment; Mebane and Chapel Hill roadways were bordered by residential zones with one- and two-story houses, while the Raleigh site had a mixture of one- and two-story residential and commercial buildings in the near-road area. Further details on each site are provided in Table 1 and a closer look at the sampling locations is available in Fig. 1. The Chapel Hill and Raleigh side roads measured for barrier/clearing comparisons were at-grade with the highway of interest. The Mebane side road adjacent to the highway had slight rolling hills, with the clearing position approximately 1 m above the highway and the barrier position approximately 2 m above the highway, estimated by the mobile car's global positioning system (GPS) elevation data. At all sites, background areas were designated as residential locations with minimal traffic and located at least 200 m from the major roadway (Fig. 1). While these are the first near-road measurements conducted at the Mebane and Chapel Hill locations, the Raleigh site had been previously used to study barrier effects on near-road air pollution and is further described in other studies (Bowker et al., 2007; Baldauf et al., 2008a, b).

Sampling was conducted using instrumented vehicular platforms — one mobile electric vehicle (Li-Ion Motors Corp), one parked sports utility vehicle with on-board battery supply, and one parked van with on-board battery supply and a mast allowing for sampling at heights up to 7 m. The electric vehicle driving route and stationary sampling locations are shown in Fig. 1. Sampling was conducted during the early-fall to winter, 2008, with the three vehicles sampling at each location during weekday morning commute periods (7–9 AM) for a consecutive series of approximately 6–10 days over a two week period. Two sampling sessions were conducted for each of the vegetative barrier sites – in the early-fall and then again in the late-fall/winter – to observe the impact of reduced leaf coverage on near-road air pollution. One sampling session was conducted at the Raleigh site with the brick noise barrier during the mid-fall season.

2.2. Measurements

Air pollution monitoring measurements were collected onboard the two stationary vehicles — the SUV situated in a clearing and the van with a mast situated behind the barrier of interest. In addition, the stationary vehicles each were equipped with three-dimensional (3D) ultrasonic anemometers monitoring wind speed and direction. The vehicle located behind the barrier measured particle number (PN) and wind speed/direction at two heights – 3 m and 7 m – and sampled CO continuously at 3 m. The two sampling heights were selected for an improved observation of the air flow transport with a barrier present. The stationary vehicle located in the clearing continuously measured PN, CO, and wind at 3 m. More information on the instrumentation is