Vegetation and Other Development Options for Mitigating Urban Air Pollution Impacts

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Contents

Keywords
Urban air quality • Vegetation • Noise barriers • Mitigation • Urban design

Definition

While air pollution control devices and programs are the primary method of reducing emissions, urban air pollution can be further mitigated through planning and design strategies, including vegetation preservation and planting, building design and development, installation of roadside and near-source structures, and modification of surrounding terrain features.

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Bill Freedman (ed.), *Global Environmental Change*,
DOI 10.1007/978-94-007-5784-4_23,

Introduction

Emission control techniques and programs that reduce air pollution are an important component of air quality management strategies; however, options that directly remove pollution or reduce exposures also exist that can further mitigate the impacts of air pollution in urban areas. These methods can complement existing pollution control programs or provide measures to minimize impacts from sources difficult to mitigate. Since air pollution control techniques, emission standards, and urban planning strategies to reduce urban air pollution impacts are discussed in other sections of this handbook, this section focuses on options that developers, transportation designers, and urban planners can implement to reduce concentrations and population exposures to harmful air contaminants.

Urban Development Mitigation Opportunities

In addition to conventional air quality management programs that reduce or eliminate air pollution emissions from the source, other options exist for planners and developers to further reduce an urban population's exposure to harmful concentrations of air pollutants. Given the significant impact of vehicular traffic on air pollution in most urban areas of the world, this section emphasizes and provides examples of opportunities to mitigate impacts from vehicular sources in particular. These options include the preservation and planting of vegetation, the development of roadside or near-source structures, and the modification of terrain surrounding roadways or other pollutant emission sources.

Vegetation

Vegetation in urban areas, particularly trees, directly removes air pollution and can also provide barriers between sources and exposed populations. Stands of vegetation have been used for many years in agricultural applications to provide wind breaks to prevent soil erosion. In recent years, the use of vegetation as a means to reduce population exposures to urban air pollution has been investigated (Smith 1990; Nowak et al. 2006; Brode et al. 2008).

Trees remove gaseous air pollution primarily by uptake via leaf stomata, though some gases are removed by the plant surface (Smith 1990). Trees also remove pollution by intercepting airborne particles. The intercepted particle often is resuspended to the atmosphere, washed off by rain, or dropped to the ground with leaf and twig fall (Smith 1990). Consequently, vegetation may only be a temporary retention site for many atmospheric particles. Pollution removal by trees can improve air quality by reducing pollution concentrations. Pollution removal by urban trees in the United States has been estimated at 711,000 tonnes per year or about 11 g per square meter of canopy cover (Nowak et al. 2006). The average percent of air quality improvement in cities due to pollution removal by trees during the daytime of the vegetation in-leaf season is typically less than 1 % but can be as high as 16 % in areas with dense trees (Nowak et al. 2006).

The complex and porous structure of trees and bushes can increase air turbulence and promote mixing and particle impaction as air flows through and around the vegetation. However, tree canopies can also reduce wind speed and boundary layer heights, which can reduce dispersion and potentially increase concentrations in certain areas (Nowak et al. 2000). These vegetation properties impact air pollutant concentrations at local and urban scales by affecting local- and regional-scale meteorology.

Modeling, wind tunnel, and field measurements have evaluated the role of vegetation on pollutant concentrations near roadways (Baldauf et al. 2011). Variables such as the vegetation type, height, and thickness influence the extent of mixing and pollutant deposition experienced at the site, although specific interrelationships of these factors have not been identified. In addition, the porosity of vegetation relative to solid structures may promote wind flow off the road and reduce on-road pollutant concentrations, although the resulting effect on downwind concentrations may be variable. Changes in surface roughness for a single location will also affect local meteorology, influencing dispersion from all nearby air pollutant sources (Brode et al. 2008).

In addition to roadside vegetation, vegetation designs throughout an urban area can help reduce exposures to existing and planned emissions from traffic and other air pollutant sources. Surface characteristics, such as tree cover, also influence the magnitude and extent of urban heat islands, which consequently affects air quality (Stone and Norman 2006). These broad-scale vegetation effects can be integrated into urban air quality planning (Nowak 2005). For example, the US Forest Service and numerous partners have developed a suite of tools, called i-Tree, that allow urban planners to survey and assess tree populations and estimate pollution removal, carbon uptake, and other ecosystem services and values (www.itreetools.org). In terms of pollution removal, these tools address atmospheric pollutants transported and deposited upon the tree canopy at the urban scale, and not the horizontal capture of localized roadway emissions. Nevertheless, users can apply information about the filtration capacity of vegetation types to near-road conditions.

Vegetation in urban settings can provide numerous benefits beyond air quality improvements, including temperature and stormwater regulation, noise reduction, aesthetic improvements, and environments conducive to physical exercise and experiencing nature. These co-benefits or ecosystem services have been associated with improved physical and mental health and community vitality. Positive associations between physical or visual access to green space and personal health have been observed particularly in children, the elderly, populations with limited mobility, and families in military and low-income housing. The services provided by urban vegetation can yield significant concomitant economic returns such as energy and medical costs averted, increased worker productivity, and increased property values (Nowak and Dwyer 2007).

Potential dis-benefits may also be associated with near-road and other urban vegetation. Issues of concern include pollen production, maintenance costs, water demand, channeling or introduction of invasive pests and fire into the urban environment, and exacerbation of sprawl by distancing buildings and other land use activities from roadways. Trees may also cause trapping of pollutants behind the barrier due to decreased wind flow, obstruct visibility on the road, cause damage or injury by falling, and create slippery conditions from dropped debris. Consideration of the social and physical environmental contexts of vegetation is critical to optimizing the benefits related to designing roadside or near-source vegetation barriers and other urban vegetation designs to improve air quality. Ideally, a myriad of vegetation costs and benefits would be considered in designing optimal landscapes to protect human health and promote sustainable, vibrant communities (Baldauf et al. 2011).

Roadside Features

In addition to vegetation, other structures (e.g., noise barriers, buildings) may also impact pollutant transport and dispersion near roadways and other air pollutant sources. These features also affect pollutant concentrations around the structure by blocking initial dispersion and increasing turbulence and mixing of the emitted pollutants downwind of the road. These barriers increase vertical mixing due to the upward deflection of air flow caused by the structure. Studies suggest that this upward deflection of air can create a recirculation cavity downwind of the barrier that contains a well-mixed, and often lower, zone of pollution concentrations. Air quality impacts from noise barriers have been identified in modeling, wind tunnel, and field studies (Baldauf et al. 2008, 2009; Heist et al. 2009; Naser et al. 2009; Hagler et al. 2011). However, some studies suggest that noise barriers and other solid structures adjacent to a road may also inhibit air movement off the road, leading to elevated pollutant concentrations on the upwind side of the structure (Bowker et al. 2007; Finn et al. 2010). As previously noted, vegetation may not have these same effects due to the porosity of the structure, but can also create turbulent mixing and potential zones of lower pollutant concentrations downwind from the roadside barrier (Fig. 56.1). Compared to vegetation, solid structures will typically have a significantly lower removal rate for pollution, although research has begun on surface coatings (e.g., titanium oxides) that may help improve pollution uptake by solid structures for some contaminants.

Roadway or Pollution Source Configuration

The physical location of a roadway or other air pollutant source relative to its surrounding terrain and buildings can also affect nearby air quality and population exposures (Fig. 56.2). Wind tunnel assessments and field measurements have been reported that compared a number of roadway configuration scenarios

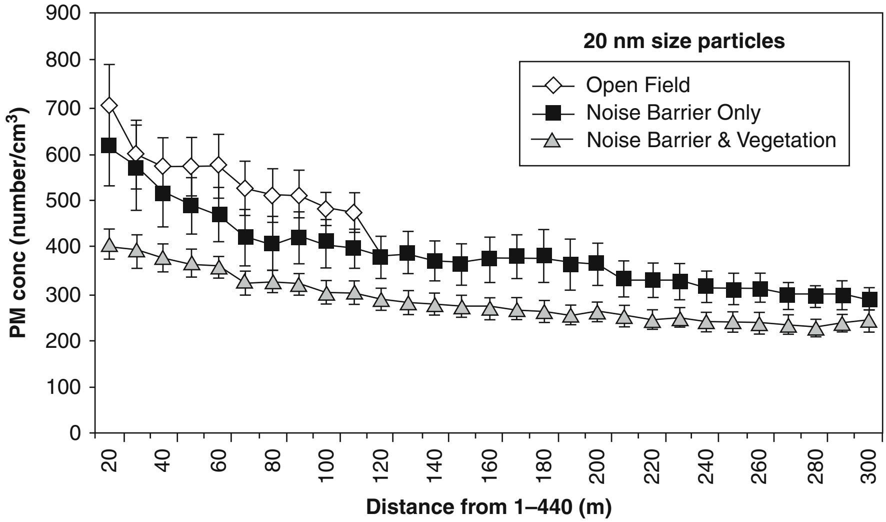

Fig. 56.1 Change in particulate matter concentration downwind from a highway due to various barriers. Increased mixing and turbulence caused by roadside features can reduce near-source concentrations of particulate matter and other pollutants. Vegetation may also provide a mechanism for pollutant removal in addition to increased dispersion (Baldauf et al. 2008)

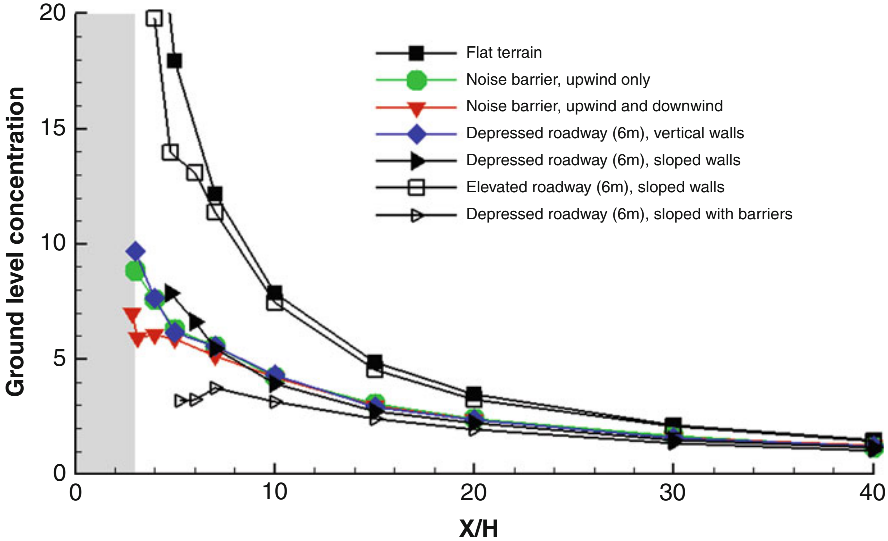

Fig. 56.2 Downwind pollutant concentrations vary under multiple roadway design scenarios. For this figure, the distance from the road is scaled to the height of the noise barrier evaluated (6 m in the example shown); thus, the distances listed along the x-axis should be multiplied by a factor of 6 to get the actual distance (in meters) from the road edge. The figure suggests that traffic emissions in a cut section with a noise barrier (6 m in height) at the top resulted in the lowest downwind air pollutant concentrations for the scenarios evaluated (Baldauf et al. 2009)

(Heist et al. 2009; Baldauf et al. 2009). These studies indicate that at-grade roadways experience the least amount of pollutant mixing when structures are not present near the road. However, cut section roads, where the road surface is below the level of the surrounding terrain, will increase the turbulence in air flow resulting from winds into and along the cut section, increasing pollutant mixing and dispersion, and resulting in lower air pollutant concentrations near the source. In addition, as winds flow up and out of a cut section, the plume will be elevated compared with at-grade road conditions. For other air pollutant sources located below the surrounding terrain, consideration must be given to the release height of emissions to determine the likelihood for decreased downwind pollutant concentrations and exposures.

Elevated roadways, whether on bridges or on top of solid fill sections, can also alter downwind pollutant concentrations. Air pollutant sources elevated above the surrounding terrain can lead to equal or slightly higher downwind pollutant concentrations compared with at-grade sources at a distance when the plume reaches ground level. In addition to affecting wind flow, studies suggest that changing roadway configurations may also affect the momentum and buoyancy of the traffic emissions due to vehicle-induced turbulence and vehicular exhaust heat (Heist et al. 2009).

Conclusions

A number of urban design features, including vegetation, solid structures, and road configuration, have the potential to mitigate air pollutant source impacts. These features can be implemented with other air pollutant control strategies to maximize reductions in the population's exposures to urban air pollution. However, further research is still needed to fully understand the benefits, and potential consequences, of these urban design techniques.

Acknowledgments The authors wish to thank their colleagues who helped organize and execute the near-road vegetation workshop, which include Gayle Hagler, Laura Jackson, Rich Cook, Chad Bailey, and Vlad Isakov of the US Environmental Protection Agency; Greg McPhersion of the US Forest Service; Tom Cahill of the University of California-Davis; and K. Max Zhang of Cornell University. The authors also wish to thank Steve Perry and David Heist of the US Environmental Protection Agency for their wind tunnel and fluid dynamic modeling work on roadside features.

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Additional Recommended Reading

The following websites provide additional information on the subject of this chapter:

I-Tree toolkit (www.itreetools.org)

Workshop: The Role of Vegetation in Mitigating Air Quality Impacts from Traffic Emissions (https://www.epa.gov/nrmrl/appcd/nearroadway/workhop.html)

Dutch Air Quality Innovation Programme (https://www.ipl-airquality.nl/project.php?name=schermwerking)