Integrating Vegetation and Green Infrastructure into Sustainable Transportation Planning

RICHARD BALDAUF, GREG McPHERSON, LINDA WHEATON, MAX ZHANG, TOM CAHILL, CHAD BAILEY, CHRISTINA HEMPHILL FULLER, EARL WITHYCOMBE, AND KORI TITUS

Baldauf is Senior Scientist, Office of Research and Development, U.S. Environmental Protection Agency (EPA), Research Triangle Park, North Carolina. McPherson is Research Forester, U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Davis, California. Wheaton is Assistant Director for Intergovernmental Affairs, California Department of Housing and Community Development, Sacramento. Zhang is Associate Professor, Mechanical and Aerospace Engineering, Cornell University, Ithaca, New York. Cahill is Professor Emeritus of Physics, University of California–Davis. Bailey is Physical Scientist, U.S. EPA, Ann Arbor, Michigan. Fuller is Assistant Professor, School of Public Health, Georgia State University, Atlanta. Withycombe is Air Quality Consultant, and Titus is CEO, Breathe California of Sacramento–Emigrant Trails, Sacramento.

An international consensus has emerged that people living, working, and going to school near roads with high volumes of traffic face increased risks for adverse health effects (*1*), most likely from acute and chronic exposures to elevated levels of air pollution, including particulate matter (PM), gaseous criteria pollutants, and air toxics.

Field measurements conducted in the United States and throughout the world have shown that air pollution levels are highly elevated near high-volume roadways (*2*). Pollutant concentrations are often highest within the first 100 to 150 meters of the road, and some pollutants are found in concentrations that have increased by an order of magnitude. Pollutant concentrations from traffic emissions can remain elevated as far as 300 to 500 meters or more from the road (*1, 2*).

Urban Form and Air Quality

With increased urbanization worldwide, the number of people exposed to traffic emissions near high-volume roadways continues to increase. Moreover, urban form indirectly affects air quality and global climate conditions (*3*).

Public transportation and land use policies and practices increasingly support sustainable development patterns by promoting compact growth in infill locations along major transportation corridors. An example is transit-oriented development, a mix of housing and supportive land uses near transit, with access to jobs and services, intended to capture the benefits of location efficiency (*4*).

The U.S. Environmental Protection Agency (EPA) is implementing policies to address the impacts of major roads on nearby air quality. Recent revisions to

Example of a vegetation barrier along a highway; roadside vegetation barriers have been shown to improve near-road air quality. Questions remain on the optimal design features for effectiveness.

Photo: Arlington County

The Clarendon neighborhood of Arlington, Virginia, just outside of Washington, D.C., features a mix of housing and business land uses within walking distance of Metro rail and bus stops.

the monitoring rules for the National Ambient Air Quality Standards (NAAQS) require monitors for PM, carbon monoxide (CO), and nitrogen dioxide (NO_2) near high-traffic roads in large metropolitan areas.

EPA's transportation conformity rule requires the modeling of hot-spot concentrations of PM in the immediate vicinity of large federal highway or transit projects in nonattainment and maintenance areas that have high levels of heavy-duty diesel vehicle traffic. Projects are required to model concentrations at or below the NAAQS or to model the concentrations to be at lower levels after the project is built than they were before the project.

In California, three recent state laws have given impetus to sustainable development patterns.[1–3] Under California Senate Bill 375, regional transportation plans of metropolitan planning organizations must include "sustainable community strategies."[2] These strategies forecast development patterns integrated with the transportation network and other transportation measures and policies to reduce regional greenhouse gas (GHG) emissions from automobiles and light trucks; the goal is to achieve regional GHG emission reduction targets by 2020 and 2035 (*5, 6*).

Reducing Exposures

Although development patterns that limit urban sprawl and vehicle miles traveled can have a major impact on reducing GHG emissions, these plans, as well as similar proposals in other localities, concentrate development along major transit corridors. The result is to increase the local population's exposure to emissions generated from the high-volume freeways.

Transit-oriented development and similar policies increase the population's access to services and transportation options and lead to regional reductions in vehicle miles traveled and air pollution. Nonetheless, these practices often bring people closer to the sources of air pollutant emissions, such as traffic activity. As a result, ways to reduce the exposure of people residing and working near high-volume roadways are needed.

A workshop in Sacramento, California, on June 5–6, 2012, gathered a multidisciplinary group of researchers and policy makers to discuss roadside vegetation as an option for mitigating the health impacts of air quality near roads. The following is a summary of the workshop discussions, including an overview of the role that roadside vegetation may play in reducing population exposures to air pollutants emitted by traffic. Roadside vegetation also is examined as a sustainable mitigation option in the context of other potential benefits and disbenefits.

Vegetation Barriers

Research studies measuring and modeling the impacts of vegetation barriers on near-road air quality suggest that a barrier can lead to reductions in pollutant concentrations. Field measurements comparing pollutant concentrations behind roadside vegetation with the concentrations in a clearing at the same distance and along the same stretch of limited-access highway generally show lower pollutant concentrations downwind of the vegetative barrier, as illustrated in the example in Figure 1 (below).

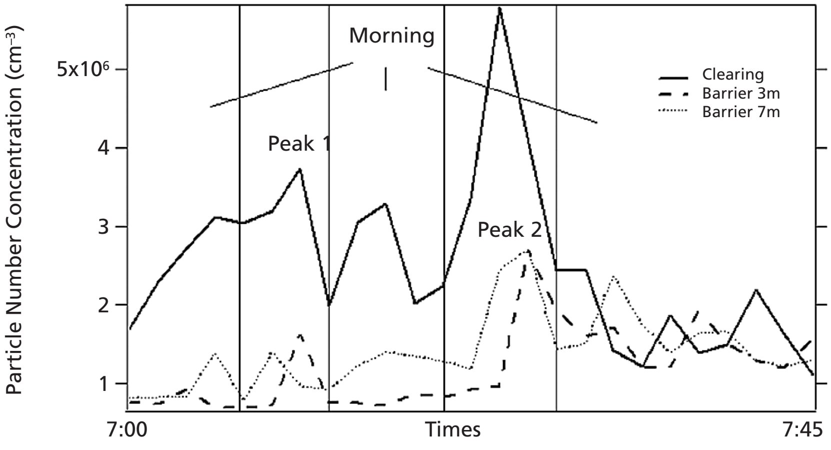

FIGURE 1 **A study in North Carolina measured PM concentrations at a clearing and behind a vegetation stand along the same stretch of highway and the same distance from the nearest pavement edge. Substantial reductions in PM concentrations occurred during morning time periods with light winds from the road; however, as winds became variable, the vegetation did not effectively reduce PM concentrations, with some instances of higher concentrations behind the vegetation than at the clearing (*7, 8*).**

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[1] California Assembly Bill 32, Global Warming Solutions Act (2006), and Climate Change Scoping Plan (2008).

[2] California Senate Bill 375, Sustainable Communities and Climate Protection, Ch. 728 (2008).

[3] California Assembly Bill 1358, Complete Streets Act, Ch. 657 (2008).

Photo: North Carolina DOT

Wildflowers at I-40 and US-421 in Forsyth County, North Carolina. Besides aesthetic benefits, native vegetation along highways improve ecosystems, air quality, and stormwater regulation.

The measurements suggest that the barrier led to an increase in air mixing, resulting in lower behind-barrier concentrations at ground level. Field and wind tunnel studies also suggest an enhanced capture of PM by the vegetation; generally, the concentrations of ultrafine and coarse-mode PM decrease, with limited reductions in fine-particle $PM_{2.5}$ mass.

The field measurements, however, also indicated that under certain meteorological and design conditions, the PM concentrations could be higher behind a vegetative barrier than in a clearing. These results suggest that higher pollutant concentrations could occur behind a vegetation stand when wind speeds are low and the winds are parallel to or toward the road. In addition, gaps in the barrier from dead trees or natural openings could cause wind stagnation, leading to higher downwind concentrations behind the vegetation (*9*).

Too-heavy tree canopy can obstruct roadway visibility and trap source particles.

Photo: Virginia Travis, Flickr

Computational Models

Researchers have incorporated the representations of the aerodynamic and deposition effects of vegetation barriers on transportation air quality into a computational model based on fluid dynamics. To explore the effects of vegetation barriers on near-road air quality, the simulation results were compared with the data collected from field studies (*7, 8*).

The models consistently reproduced the spatial variations of pollutants behind barriers under different atmospheric stability conditions. With the accuracy of the three-dimensional, detailed modeling verified, researchers are examining the effects of different barrier designs, wind speeds, and turbulence environments (*10*).

Cobenefits and Disbenefits

Urban forestry and landscape ecology offer insights on potential additional advantages and disadvantages of implementing vegetation to mitigate near-road air quality impacts. Vegetation in urban settings can provide benefits beyond improvements in air quality—these include carbon sequestration, temperature and storm water regulation, noise reduction, aesthetic improvements, and opportunities for physical exercise and the experience of nature. These cobenefits, known as ecosystem services, have been associated with improved physical and mental health and community vitality.

Positive associations between personal health and physical or visual access to green space have been observed in children, the elderly, persons with limited mobility, and families in military and low-income housing. Trees also have been shown to have direct health benefits (*11*). In addition, the services provided by urban vegetation can yield significant economic returns, such as averted energy and medical costs, increased worker productivity, and increased property values (*9*).

Near-road vegetation, however, has some potential disbenefits, such as pollen production, water demand, introduction of invasive or nonnative species, channeling of invasive pests and fire into the urban environment, and expanding the urban footprint by distancing buildings and other land use activities from roadways. Trees also may obstruct roadway visibility, cause damage or injury by falling, and create slippery conditions from dropped debris.

Barrier Design Considerations

Meeting participants agreed that further exploration of vegetative barriers to mitigate adverse air quality is worth pursuing; the design process should maximize the potential benefits and avoid the disbenefits to the extent feasible. Successful designs would match plant species with each site and with the site's purpose, to achieve optimal performance for the service life of the project. Many sites and designs are unique, with no single recipe for effectiveness.

Roadside vegetation barriers designed to reduce harmful PM concentrations, for example, should be tall and wide enough to enhance particle deposition and dispersion—a minimum width of 5 meters has been suggested (*12*). A closed canopy over roadways, however, can trap source particles and increase concentrations below the canopy unless prevailing winds continuously flush out the pollutants (*13*).

Vegetation barriers with a porosity of 20 to 40 percent have been suggested, because higher or lower porosities are likely to reduce efficiency in capturing pollutants (*12*). A porosity of less than 20 percent can increase turbulence, so that the vegetation acts more like a solid structure.

A multirow barrier combines shrubs along the edge to protect young trees from exposure and reduce subcanopy air flow for deciduous and coniferous trees. Plants can be staggered to eliminate gaps horizontally and from the ground level to the canopy top.

In terms of performance, conifers are superior to deciduous trees because of their year-round foliage and greater amounts of leaf and stem surface area per unit of land. Their demand for water, however, may be greater for the same reasons (*14*). A diverse mix of well-adapted species increases the barrier's long-term resilience to drought, pests, storm damage, and other urban stressors (*15*).

Barriers also may be designed to accomplish other environmental objectives, such as carbon storage, rainfall interception, and reduction of contaminated storm water runoff. Desired characteristics for trees include high wood density values, large crown projection areas, long life spans, and tolerance to inundation.

Addressing Negative Effects

An important design goal is to minimize the potential negative impacts of roadside plantings through the judicious selection and placement of species. Single-vehicle collisions with trees account for nearly 25 percent of all fixed-object fatal accidents each year (*16*). Improving driver visibility and providing a safe distance between travel lanes and trees through clear zones can alleviate this threat.

Avoiding plant species that have invasive qualities and shallow roots can reduce long-term maintenance costs. Tree species with small leaves and open crowns are less likely to clog drains during rain storms or to slow the ice melt from paved surfaces in winter.

Clustering trees within shrub borders can reduce damage from mowing. Understory plantings, however, may limit access and may conceal encampments in certain areas. When the flammability of plantings is a concern, designs should avoid continuous planting strips and "ladder fuel" plantings that allow fires to climb from the ground to the tree canopy via branches touching the ground or via high grasses and underbrush that extend into the trees.

Nut and fruit production from trees near paved surfaces also can be a nuisance. Emissions of pollen and biogenic volatile organic compounds, which are highly species-specific, can adversely affect human health and air quality (*17*). Most of these effects can be avoided.

Site Characteristics

Understanding how a site's microenvironments will change over time and influence plant growth is fundamental to good barrier design. Grading for optimal surface drainage before planting will promote the survival and growth of the vegetation. Soil sampling is an important first step, followed by subsoiling, or ripping, to reduce compaction and address the nutrient deficiencies in the soil. Chloride content, soil pH, and concentrations of metals may change with the use of deicing salts and other road- or vehicle-generated contaminants.

Designing the barrier to create and protect healthy soil over the long term often reduces maintenance while promoting survival and growth. Traffic volumes influence the dispersion of pollutants, as well as the drying effects on roadside vegetation from local turbulence. Slope and direction also influence plant stress from heat and wind and should be considered in planning and designing the barrier.

Planting Trees

Trees generally are planted into augured holes from containers or bare root stock (caliper of 2.5 centimeters or more), liners (1.2-centimeters caliper), or as seedlings (30 to 45 centimeters tall). The tree size at the time of the planting appears to be related to survival—smaller stock, although less expensive than larger stock, is more vulnerable to physical damage from mowers and animals and to competition from weeds. Larger-stock trees will provide a more immediate barrier for mitigating the impacts of pollutants soon after construction.

PHOTO: WASHINGTON STATE DOT

Newly planted trees along SR-542 in Washington State. A mix of tree varieties can balance disease and pest resistance, water use, foliage sizes, and root depths.

PHOTO: MASSACHUSETTS DOT

Massachusetts DOT replanted 20 linden trees as part of a 2010 bridge rehabilitation project. Mature trees are less likely to experience transplant shock and begin to mitigate pollution effects more quickly than young trees.

Mulch helps to conserve soil moisture around the tree. Too much mulch, however, can become a seedbed for weeds and fungus. Most trees require staking for support and protection at planting. Removing stakes after trees have become established and self-supporting is an important maintenance task because of the damage that vestigial stakes can cause to trees, through girdling and wounds.

Watering trees during the establishment period is key to long-term success, as is controlling weeds by mechanical or chemical means. In some cases, a cover crop can control weeds effectively while the woody plants become established. Care must be taken to avoid plants that are invasive or that attract deer and other animals that pose a threat to motorists. Monitoring the barriers is also critical to their performance and survival.

Pilot Studies Needed

Roadside vegetation barriers can improve near-road air quality and can affect the public health positively for populations near high-volume roadways. Although questions remain about the optimal design features for vegetation barriers, the current scientific understanding warrants pilot studies to investigate this potential strategy for mitigating air quality. Three-dimensional modeling of PM transport and deposition in roadside barriers, combined with field monitoring and verification studies, are contributing valuable new knowledge to the design and management of effective barriers.

Tree species such as oaks can produce gutter-clogging leaf drops in the fall.

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