Impacts of Solid Noise Barriers and Roadside Vegetation on Near-Road Air Quality

Rich Baldauf, Jon Steffens, Vlad Isakov, Sue Kimbrough
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Background on Health Concerns

- Populations living, working and going to school near highways and large arterial roads have increased risks for many adverse health effects (e.g. asthma, cardiovascular disease, premature mortality)
- Elevated concentrations of air pollutants exist near large roads
- Significant portion of US population exposed, including residential and children at school
- Interest in methods to understand and mitigate these traffic emission exposures and adverse health effects

Transportation and land use planning mitigation options include:
- Reduce emissions through vehicle standards and voluntary programs
- Reduce vehicle activity/Vehicle Miles Travelled (VMT)
- Recommend or enforce buffer/exclusion zones
- Use roadway design and urban planning
  - Road location and configuration
  - Roadside noise barriers and vegetation
Why study roadside barriers?

- Roadside barriers alter air pollution transport and dispersion
- Roadside barriers may already be present and affecting exposures
- Roadside barriers often have other positive benefits
- Few other “short-term” mitigation options
  - Emission reductions take long to implement (fleet turnover required)
  - Planning and zoning involved in rerouting/VMT reduction programs
  - Buffer/exclusion zones may not be feasible, especially in urban areas
Research Methodology

• EPA has initiated studies to examine how roadside features affect near-road air pollutant exposures

• Using modeling and measurements to characterize the impact of roadway features on near-road air quality
  – Wind tunnel assessments
  – CFD modeling
  – Field studies

• Developing new model algorithms to evaluate impacts of roadway features
  – Determine potential mitigation opportunities
  – Air quality characterization
  – Exposure assessment and characterization
Wind tunnel simulations show roadway design impacts on pollutant transport and dispersion. Highest levels occur with at-grade and elevated fill roads; lowest levels occur with cut sections and noise barriers.
Computational Fluid Dynamics (CFD) modeling suggests:

- Decreased concentrations downwind of barrier
- Increased concentrations on-road due to upwind trapping
- The higher the barrier, the greater the downwind reduction and on-road increase
• Pollutant can wrap around barrier edges (top and sides)
• Modeling estimates effect <50m from side edges
• Higher open area concentrations can occur within ~20m

Hagler et al. (2011)
Tracer gas experiments show downwind pollutant reductions under all stability classes; more variability with stable, calm wind conditions.
Noise Barriers & Air Quality

- Reductions of over 50% observed under downwind conditions
- Upwind pollutant trapping and wrapping around edges can occur

Baldauf et al. (2008)
Noise Barriers & Air Quality

Impacts on NO$_2$ concentrations

Baldauf et al., (2016)

Phoenix, Arizona

East Section (Afternoon)

West Section (Morning)
Reduced UFP concentrations

East Section (Afternoon)

West Section (Morning)
• Noise barriers reduced PM levels compared with a clearing

Vegetation with noise barriers provided a further reduction of PM concentrations and gradients

(Baldauf et al., 2008a; 2008b)
Vegetation Effects

- Ultrafine PM number count generally reduced downwind of a vegetation stand.
- Higher reductions most often occurred closer to ground-level.
- Variable winds caused variable effects.

Steffans et al. (2012)
Vegetation Effects

- Smaller size PM have higher removal rate
- Removal increases at lower wind velocities
- Branch/leaf shape and size affect removal

Cahill et al., (2010)
Vegetation Effects

- For thin tree stands, variable results seen under changing wind conditions (e.g. parallel to road, low winds)
- Gaps/dead trees can lead to higher downwind concentrations

Hagler et al. (2011)
San Francisco Area Vegetation Study

- On-road and near-road mobile and fixed measurements to evaluate varying vegetation types
  - Bush/tree combinations with varying porosity (Woodside, CA)
  - Manicured hedges (Palo Alto, CA)
Woodside Vegetation Study

- Initial results suggest the importance of thickness, porosity and full coverage

- All wind directions
- ~10k data pts/stop
- ~10min/stop/day

\[ \text{NO}_2 \]
Woodside Vegetation Study

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- All wind directions
- ~10k data pts/stop
- ~10min/stop/day
Vegetation Model Algorithm

- CFD modeling highlights PM removal from vegetation, especially for smaller, ultrafine particles

Tong et al (2015)
Summary – Noise Barriers

- Research shows noise barrier design characteristics that can reduce downwind pollutant levels
  - The higher the barrier, the higher the downwind pollution reduction
    - Most studies conducted with barriers ≥ 4m
    - Pollutants can meander around edges
      - Sensitive areas should be ≥ 50m from edges
      - Sensitive areas should be below barrier top
  - Pollutants can be trapped on the upwind side of the barrier
    - “Upwind” sources need to be considered
    - May lead to increased levels on the road
  - Barrier should be close to the road
    - Most studies had barriers ≤5m of travel lane
Summary - Vegetation

- Research shows roadside vegetation can reduce downwind pollutant concentrations near roads
- What the research shows related to design:
  - The higher and thicker the vegetation, the higher the downwind pollution reduction
  - Vegetation affects pollutant transport and dispersion as well as removes particulates and select gases (e.g. NO2)
  - Pollutants can meander around edges or through gaps
    - Existing vegetation with gaps may lead to increased concentrations/exposures
    - Areas targeted for reductions should avoid edge effects
    - Vegetation must be well maintained to avoid gaps and insure pollutant reductions
Summary - Vegetation

- Areas desired for reduced pollutant concentrations should avoid gaps and edge effects
  - Vegetation barrier needs to provide coverage from the ground to the top of canopy
  - Barrier thickness should be adequate for complete coverage to avoid gaps

- Pine/coniferous trees and thick bushes may be good choices
  - No seasonal effects
  - Complex, rough, waxy surfaces
  - Mix of species may increase coverage

*Examples of full coverage, pine barriers*
Summary - Vegetation

- Pollutants can meander around edges or through gaps
- Barrier thickness should be adequate for complete coverage to avoid gaps
  - No spaces between or under trees
  - No gaps from dead or dying vegetation; maintenance important

Examples of inadequate barriers due to gaps
Summary - Vegetation

• Vegetation more complex than noise barriers
  – Non-uniform in height, width, thickness
  – Must be appropriate for the location of use
  – Effectiveness dependent on species type and maintenance
  – Vegetation grows and changes over time

• Vegetation also has many other benefits that make this technique worth pursuing, including:
  – Storm-water runoff and water quality improvement
  – Carbon sequestration
  – Heat relief
  – Aesthetic value
  – Health benefits
Summary – Combination Barriers

• Combination of noise and vegetative barriers may provide the most benefit
  – Provides opportunity for pollutant dispersion and removal
  – May be solid barrier with vegetation behind and/or in front (research had vegetation behind barrier)
  – Use of climbing vegetation and hedges with solid barrier may also provide benefits (studies with CFD only)
    • Field study results mixed
    • Vegetation on solid wall should extend enough to allow air to flow through

Examples of solid/vegetation barriers
Best Practices for Reducing Near-Road Pollution Exposure at Schools

- Developed to provide practical solutions to mitigate traffic-related pollution based on issues in the School Siting Guidance
- Document for schools and parents
- Types of solutions provided:
  - Building Design and Operation Strategies
    - Ventilation, Filtration, and Indoor Air
    - Building Occupant Behavior
  - Site-Related Strategies
    - Transportation Policies
      - Anti-Idling and Idle Reduction Policies
      - Upgrade Bus Fleets
      - Encourage Active Transport
  - Site Location and Design
  - **Roadside Barriers**
    - Noise Barriers
    - Vegetation

https://www.epa.gov/schools/best-practices-reducing-near-road-air-pollution-exposure-schools
Best Practices for Planners

- EPA’s Office of Sustainable Communities developing draft recommendations for Near-Road development
  - Encompasses Corridor Management, Building Design and Operations, Site Design and Layout, and Barrier Use
  - Site Layout: Development can be implemented so that sensitive land uses are farthest from the road
  - Barriers can provide added benefits

Note: Drawing not to scale
EPA has developed recommendations for designing and planting roadside vegetation

- Developed for implementing the Oakland and Detroit pilot studies
- Includes vegetation alone and vegetation in combination with solid barriers
- Maximize the potential for near-road air pollution reduction
- Avoid unintended consequences such as increased downwind pollution concentrations due to gaps in the vegetation

EPA planning to develop similar set of recommendations for solid barriers in cooperation with FHWA
Conclusions

• With the increase in near-road public health concerns, comprehensive mitigation strategies are needed

• Solid noise barriers and roadside vegetation can affect local pollutant transport and dispersion, providing an opportunity for air pollution mitigation
  – Design characteristics have been identified that lead to downwind pollutant reductions and potential pollutant increases
  – Model algorithms have been developed to quantify barrier impacts under certain design conditions

• Research still needed to understand the range of options and reductions available from roadside barriers

• Models still need to be developed and/or evaluated to quantify reduction benefits and identify potential unintended consequences under range of designs
For More Information

• Websites:
  – http://www.epa.gov/nrmrl/appcd/nearroadway/workshop.html
  – http://www.epa.gov/ord/ca/quick-finder/roadway.htm

• References
  – Bowker, G.E., R.W. Baldauf, V. Isakov et al. 2007. Atmos. Environ. 41, 8128-8139
  – Finn D., K.L Clawson, R.C Carter et al. 2010. Atmos. Environ. 44, 204-214

• Contact Information: Rich Baldauf (Baldauf.Richard@epa.gov)