Particulate Matter Modeling of Near-Road Vegetation Environments

UC DAVIS Air Quality Project — Caltrans

Motivation

- Concern over near-road pollutant concentrations
- Potential for vegetation to reduce pollution
- Ability to leverage existing Caltrans installation and maintenance of roadway landscape enhancements

Methods

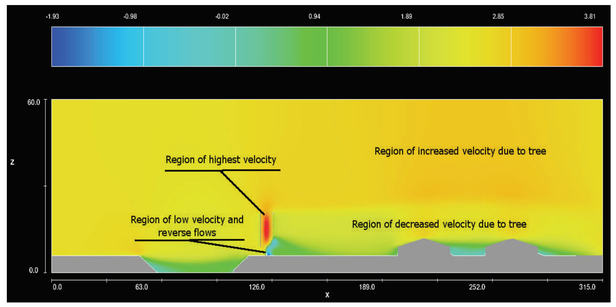
- Applied a computational fluid dynamics model to tree plantings in the near-road environment
- Solved for steady-state airflow in order to calculate particulate matter flows within three tree canopy configurations
- Approximated particulate matter capture based on a probabilistic calculation of the number of particles impacting the tree surface

Modeling Parameters

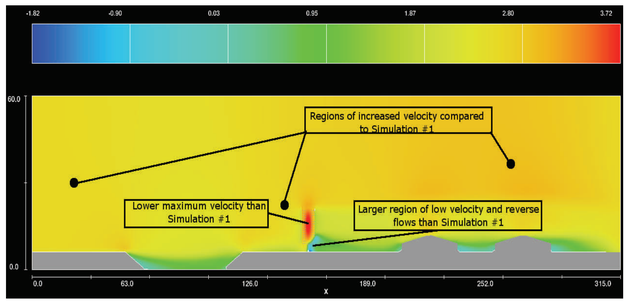
- Computational fluid dynamics (CFD) is a mathematical way in which to analyze the dynamics of fluid flows
- CFD modeling generally entails the following steps: pre-processing, solving, and post-processing
- Considered the transport of 100 particles from a depressed freeway section
  - ➢ Particle diameter equal to 1 micron
  - ➢ Particle density equal to 2.6 kg/m^3
  - ➢ Particle assumed to lose all kinetic energy in a particle-surface collision
- Time constraints
  - ➢ Steady-state airflow reached by 300 seconds
  - ➢ Particles initialized in steady-state and transported for 150 seconds
  - ➢ Total time of 450 seconds sufficient to allow particles to pass through vegetation and past school buildings
- Leaf Area Index equal to 6

Simulation Results

Simulation #1: one tree at 75m



Simulation #2: one tree at 50m



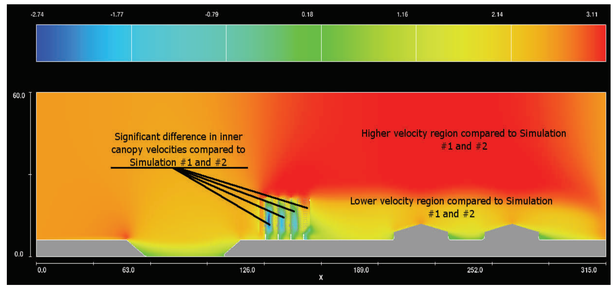
X-velocity in meters per second

Particulate Impaction to tree surface: 43%

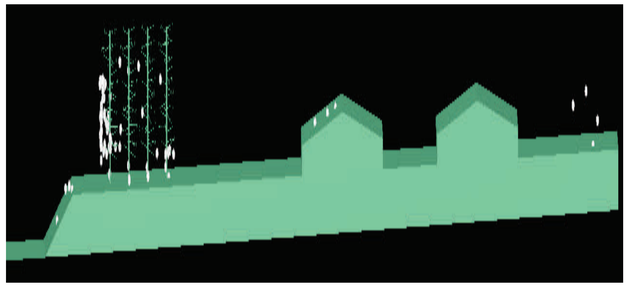
Particulate Impaction to tree surface: 44%

Particle distribution at t=450 seconds

Simulation #3: four trees at 50m



X-velocity in meters per second



Particulate Impaction to tree surface: 73%

Results Summary

Simulation	Maximum x-velocity	Region of maximum velocity	Minimum x-velocity	Region of minimum velocity	Sheltered region velocity	Conclusion
One tree 75 m from school buildings	3.81 m/s	Inner-canopy, centered on trunk	-1.93 m/s	Understory, behind trunk	~2.3 m/s	⇨43% impaction ⇨does not maximize deposition by diffusion
One tree 50 m from school buildings	3.72 m/s	Inner-canopy, centered on trunk	-1.82 m/s	Understory, behind trunk	~2.1 m/s	⇨44% impaction ⇨does not maximize deposition by diffusion
Four trees 50 m from school buildings	3.11 m/s	In atmosphere above school (21m ≤ z ≤60m)	-2.74 m/s	Inner-canopy, centered behind trunk	~1.8 m/s	⇨73% impaction ⇨maximizes deposition by diffusion

Note: "Sheltered region velocity" refers to the leeward area behind the trees that has reduced velocity due to the presence of the obstacle.

Recommendations

- ❖ Modeling shows that deposition by impaction is dominant on the windward side
- ❖ Multiple rows of trees should be planted if the goal is to maximize deposition by diffusion
- ❖ Trees should have the following optimal characteristics: retain foliage throughout the year, create a buffer between the source and receptor, have a low biogenic volatile organic compound emission rate, be characterized by rough and sticky surfaces, be hardy, have a long life span, have a high leaf surface area, and consist of fine, complex foliage structure (conifers)
- ❖ Optimal tree characteristics will significantly slow the in-canopy airflow, maximizing particulate residence time (and thus deposition by diffusion) within the tree canopy

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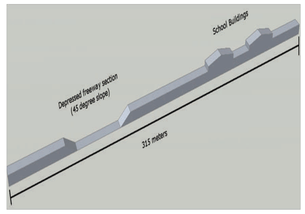
Case Study

- Willett Elementary School in Davis, CA
  - ⇨ Within 500 feet of Highway 113
- Highway 113
  - ⇨ Depressed with approximately 33,000 annual average daily trips
- Three different tree configurations were modeled (distances from school buildings)
  - ⇨ One tree placed at 50 meters
  - ⇨ One tree placed at 75 meters
  - ⇨ Four trees placed at 50 meters

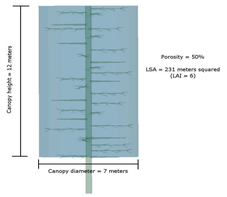
Model Representation

Aerial of Elementary

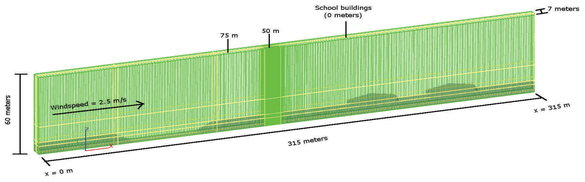


3D Site Geometry

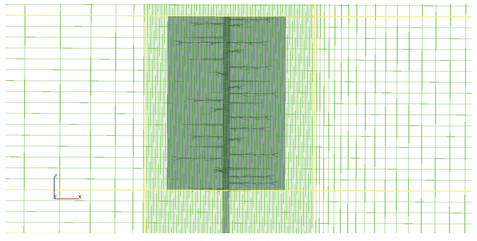
Pinus Sabiniana



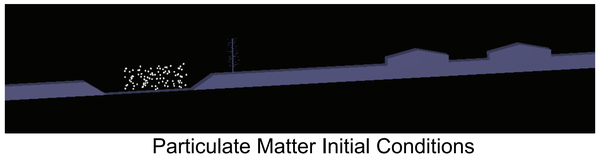
Model Tree



Simulation Domain



Tree Region Mesh



Particulate Matter Initial Conditions