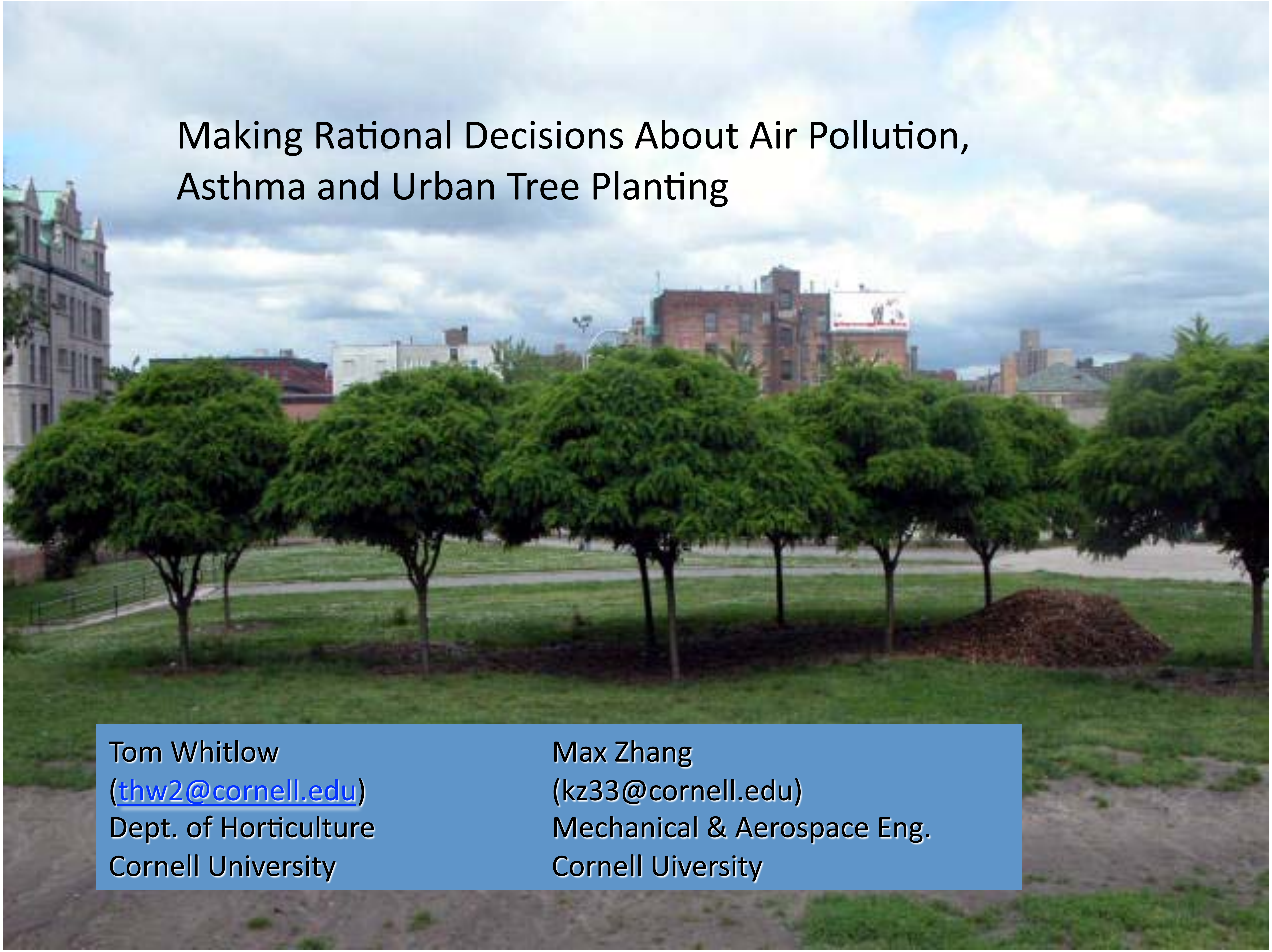
Making Rational Decisions About Air Pollution, Asthma and Urban Tree Planting



Tom Whitlow
(thw2@cornell.edu)
Dept. of Horticulture
Cornell University

Max Zhang
(kz33@cornell.edu)
Mechanical & Aerospace Eng.
Cornell Uiversity

1. Motivation

2. Conceptual model

3. Field observations
   Stochastic processes

4. Theoretical grounding
   Deterministic relationships

5. Application

6. Policy formulation?

Modeling Opportunities

1. What are the relative contributions of different sources to the PM load?

2. How does land use correlate with PM load?

3. How do trees affect PM load experienced by humans?

4. What are appropriate response metrics?

Motivation: Human health

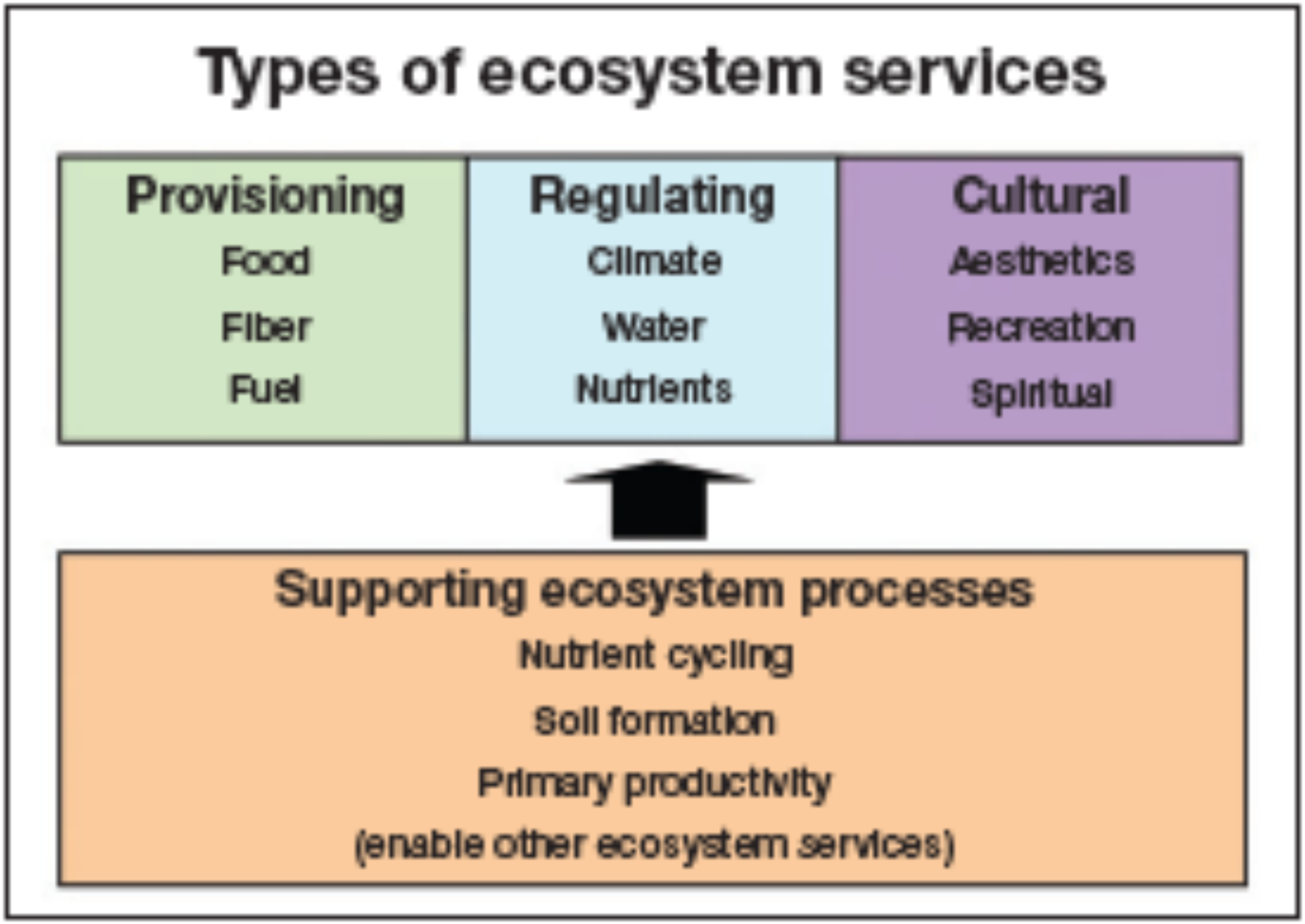
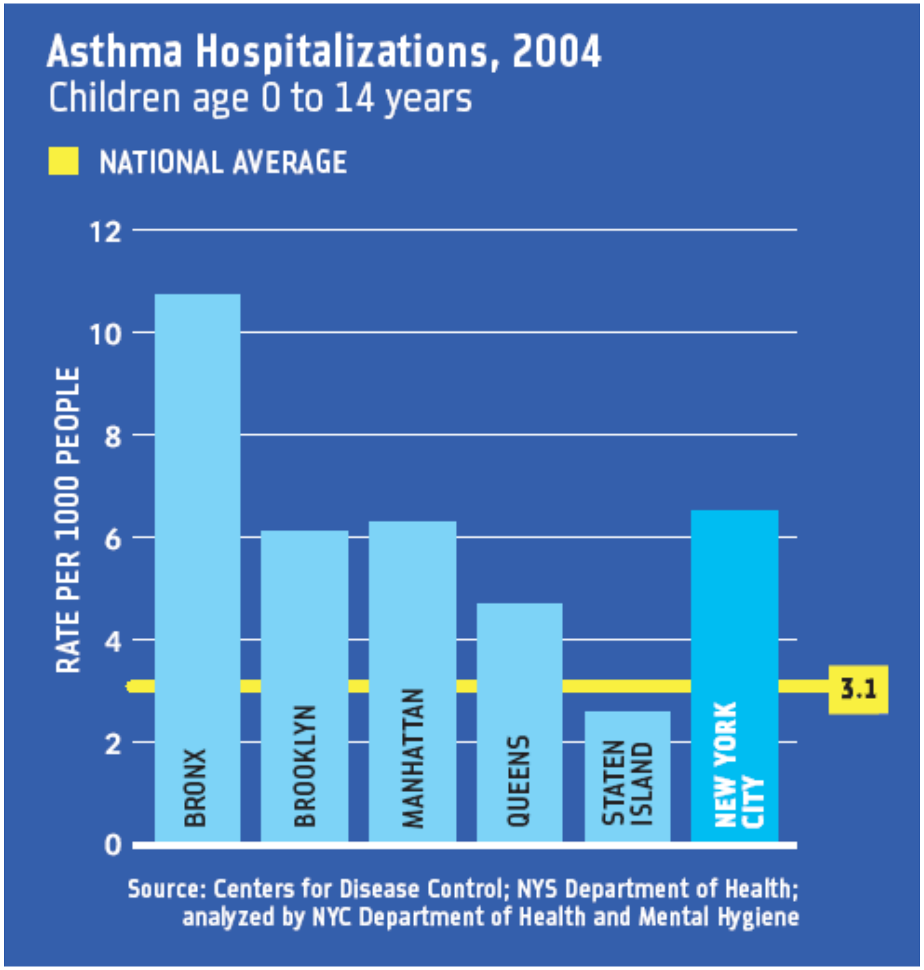
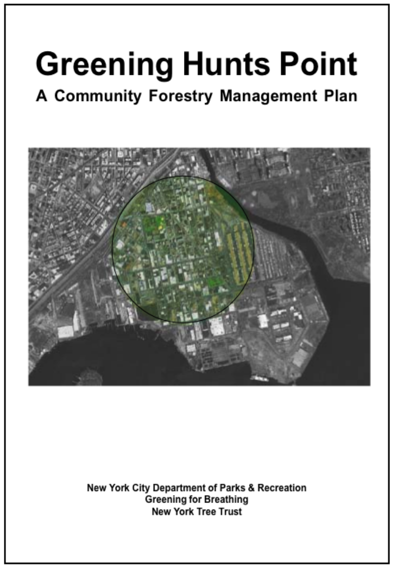


Figure 1. Ecosystem-services framework based on the Millennium Ecosystem Assessment (MA 2003).

Reason for concern



From: www.nyas.org/asthma 1/21/08



Greening Hunts Point

A Community Forestry Management Plan

New York City Department of Parks & Recreation
Greening for Breathing
New York Tree Trust

Urban Respiratory Health in Crisis

Community Health

Asthma is a significant problem for children in the community. Hospitalization rates for children aged 0-14 are 23.2%, exceeded in New York City only by East Harlem (which has a rate of 23.3 %).[4] There has been a rise in asthma, particularly among children—who are most vulnerable to developing asthma—that corresponds with a rise in asthma-causing pollution emissions due to energy production, fertilization and increased vehicle use. In New York City, asthma hospitalization rates almost doubled between 1988 and 1997, a change most strongly felt in the Bronx, where rates fully doubled during this period.

A potential solution……….

Urban tree-planting reduces pollutants

EARTH TALK

Questions & Answers About Our Environment

Dear EarthTalk: Do urban trees really help reduce pollution and clean the air?

John Alderman, Washington, D.C.

In 1872, Frederick Law Olmsted, the granddaddy of American landscape architecture and the designer of New York's Central Park, proclaimed trees the "lungs of the city."

While Olmsted's statement may have been more philosophical than scientific, researchers have since found that city trees do indeed form important environmental functions like soaking up ground-level pollution and storing carbon dioxide, which helps offset global warming.

Each year in Chicago, for example, the windy city's urban tree canopy removes 15 metric tons of carbon monoxide, 84 metric tons of sulfur dioxide, 89 tons of nitrogen dioxide, 191 metric tons of ozone and 212 metric tons of particulates, according to David Nowak, project leader of the U.S. Forest Service's Urban Forest Ecosystem Research Unit. Trees absorb these gaseous pollutants via the tiny pores in their leaves and break them down into less-harmful molecules during photosynthesis.

In Sacramento, Calif., a public-private partnership called Sacramento Shade spearheaded the planting of more than 200,000 trees around the city in the mid-1990s. In a study assessing Sacramento's bolstered tree cover, Greg McPherson of the Western Center for Urban Forest Research found that the region's urban forest removes more than 200,000 metric tons of carbon dioxide from the atmosphere each year, saving taxpayers as much as $3 million annually in pollution costs.

Meanwhile, the tree cover in New York City helps remove enough airborne toxins to save taxpayers as much as $10 million a year in pollution mitigation costs, according to Nowak.

The Big Apple's five boroughs are home to more than five million trees, covering nearly 17 percent of its public and private land, he adds.

Gary Moll, a vice president at the nonprofit group American Forests, asserts that trees are the "ultimate urban multi-taskers, absorbing carbon dioxide and acting as filters, sponges, humidifiers, heat shields and wind blockers. Under Moll's supervision, American Forests is assessing the costs and benefits of tree cover across the country. The group uses a combination of satellite data, field surveys and computer modeling technology to measure regional tree canopy and calculate its dollar value.

All told, Olmsted was right in his assessment of the importance of city trees. Indeed, planting trees in urban environments may be one of the best medicines available to help restore our ailing cities.

Contacts: U.S. Forest Service Urban Forest Ecosystem Research Unit, (315) 448-3200, www.fs.fed.us/ne/syracuse; Sacramento Shade, (916) 924-TREE (8733), www.sactree.com; Western Center for Urban Forest Research, (530) 752-7636, http:// wcufre.ucdavis.edu; American Forests, (202) 955-4500, www.amfor.org.

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Got an environmental question? Send it to EarthTalk, c/o E/The Environmental Magazine, P.O. Box 5098, Westport, CT 06881; submit your question at www.emagazine.com, or e-mail earthtalk@emagazine.com.

The over-built landscape of the South Bronx dominated by commercial and industrial land use

From the House version of the Climate Bill

The Congress finds that
(4) Shade trees have significant clean air benefits associated with them;

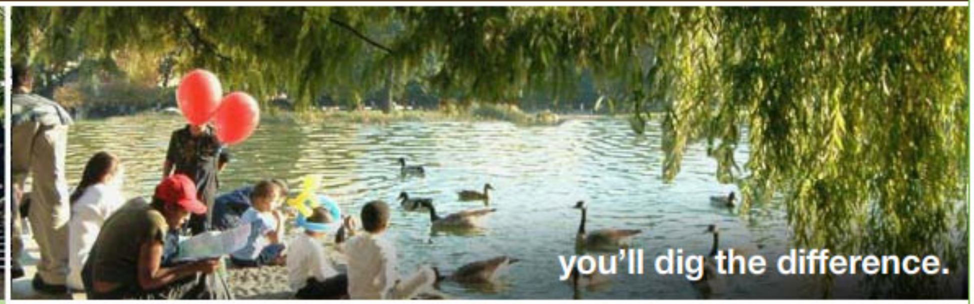
(5) Every 100 healthy trees removes about 300 pounds of air pollution (including particulates and ozone) and about 15 tons of carbon dioxide from the air each year;

(7) In over a dozen cities across the United States, increasing urban tree cover has generated between two and five dollars in savings for every dollar invested in such tree plantings

www.govtrack.us/congress/bill.xpd?bill=h111-2454

milliontreesNYC

A PLANYC INITIATIVE WITH NYC PARKS AND NEW YORK RESTORATION PROJECT



Support **MillionTreesNYC**

BUY A TREE **TODAY!**

- I want a tree on my street!
- I just planted a tree!
- I know a good place for a tree!
- I want to dig in and volunteer!
- I want to make a donation!
- I want to be a tree steward!

3 | weeks to spring planting season!

Trees Planted:
0 4 3 0 7 9 0

Happening Now

View All Page 1 2

Spring Volunteer Planting Events
Help plant 20,000 new trees in city parks during our spring volunteer

New York ReLeaf

After the Storm ReLeaf Workshop
The NYC ReLeaf Committee is sponsoring a spring workshop to bring

Adopt-a-Tree Online
Find a tree to care for and record your volunteer work with our online system.

Conceptual Model

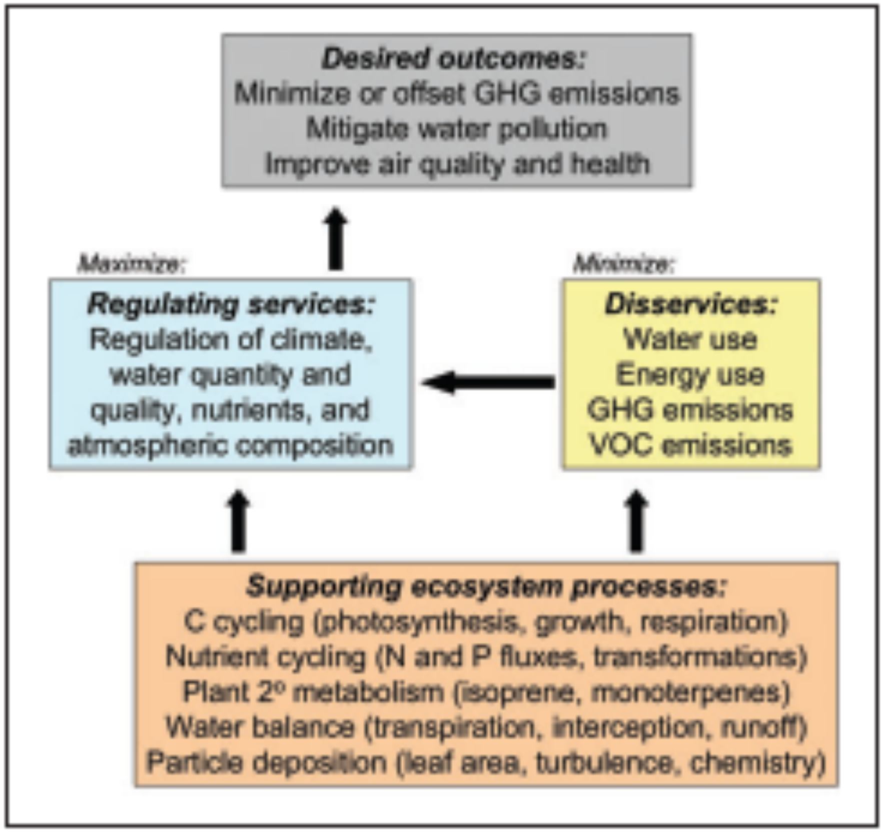


Figure 2. Framework for incorporating ecosystem services into improving environmental outcomes in cities. Both ecosystem services and disservices (benefits and costs of green space, respectively) must be identified for a given desired outcome. To quantify these services and disservices, we must further relate them to measurable supporting ecosystem processes.

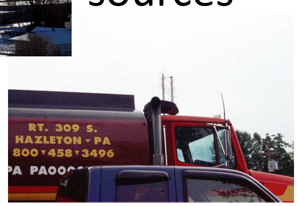
Presumed Causal Chain

Regional

Local

Point sources

Mobile sources



Geological weathering, fire, agriculture

Urban landscape, deficient in ecosystem services

Asthma!

Ecosystem services rendered by the urban forest

Respiratory health

Field Observations

Modeling Opportunities

1. What are the relative contributions of different sources to the PM load?

Problems

Stochastic variations in local and regional sources have different temporal scales

Autocorrelations

Existing samplers are biased against local sources

    Need for additional monitors?

    Need to correlate existing monitors with ground level monitors?

TEOM* samplers maintained by regulatory agencies are located on roof tops

Above level of near ground boundary layer

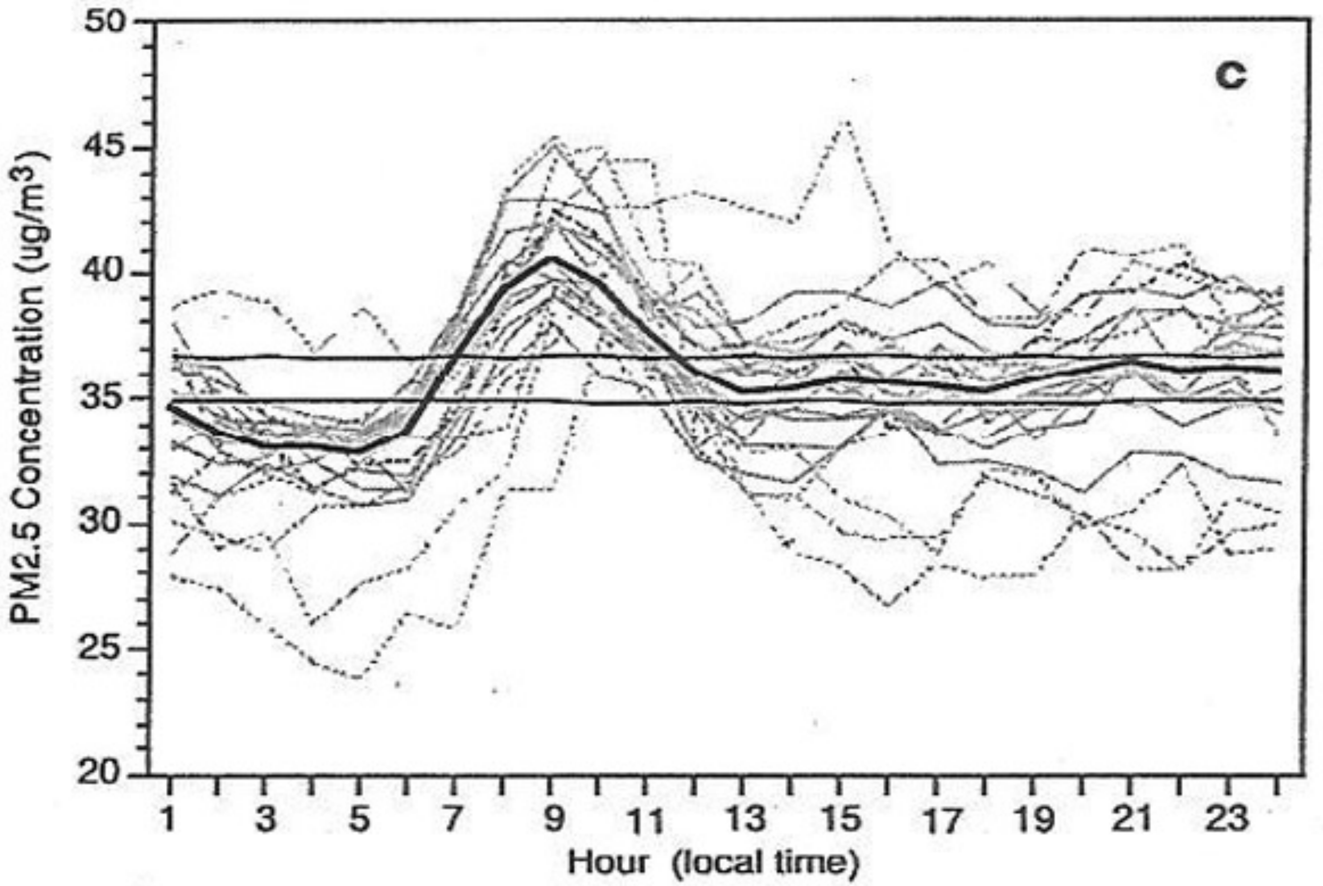
- Relatively well-mixed
- Less vulnerable to local variation

Less vulnerable to vandalism

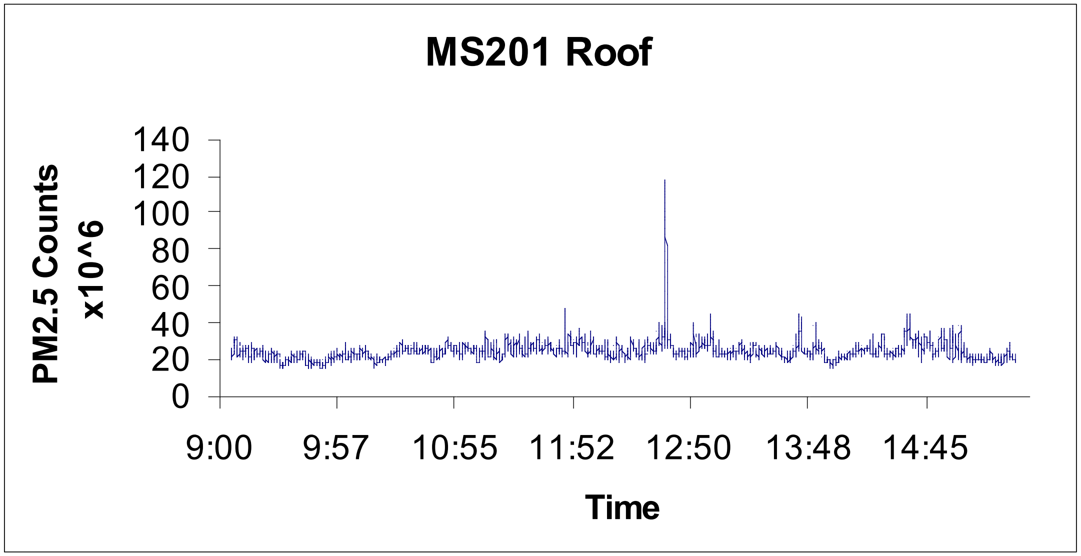
Hourly averages: coarse time integral

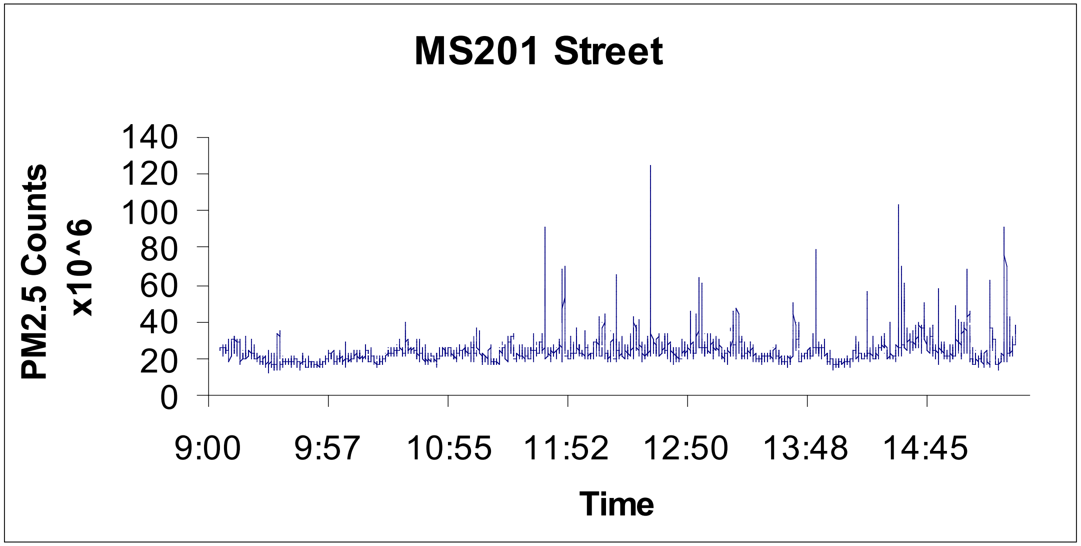
* **T**apered **E**lement **O**scillating **M**icrobalance

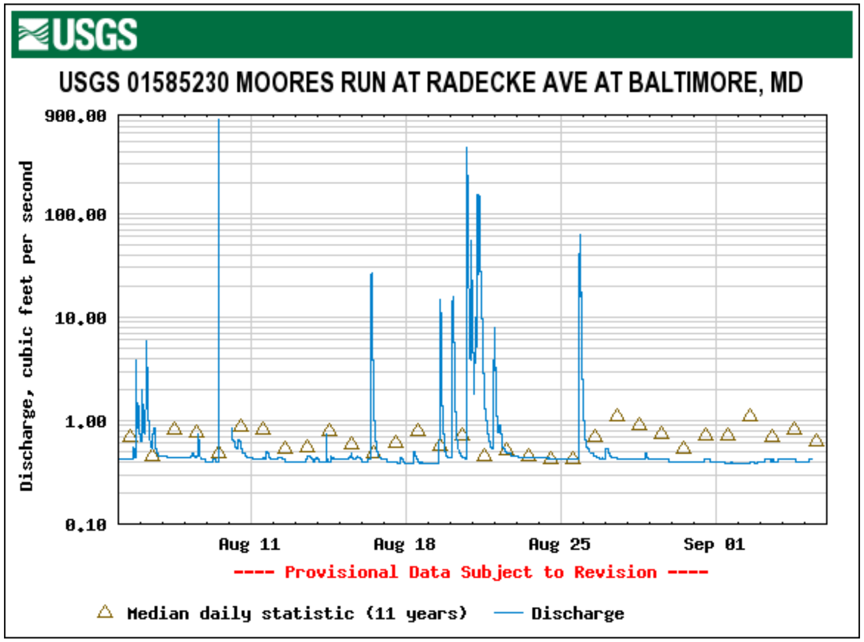
Average [PM 2.5] for monitoring stations in NYC



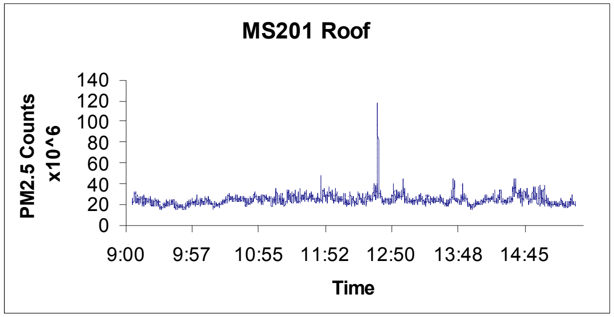
PM2.5 events are spiky and stochastic





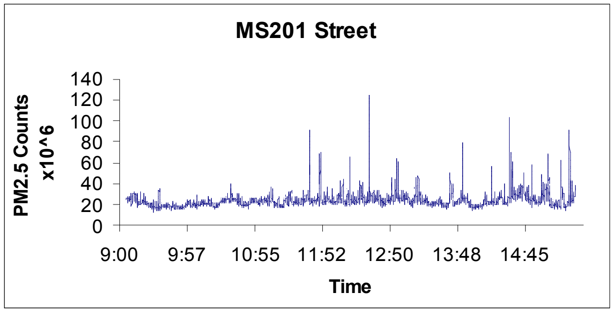


A hydrograph

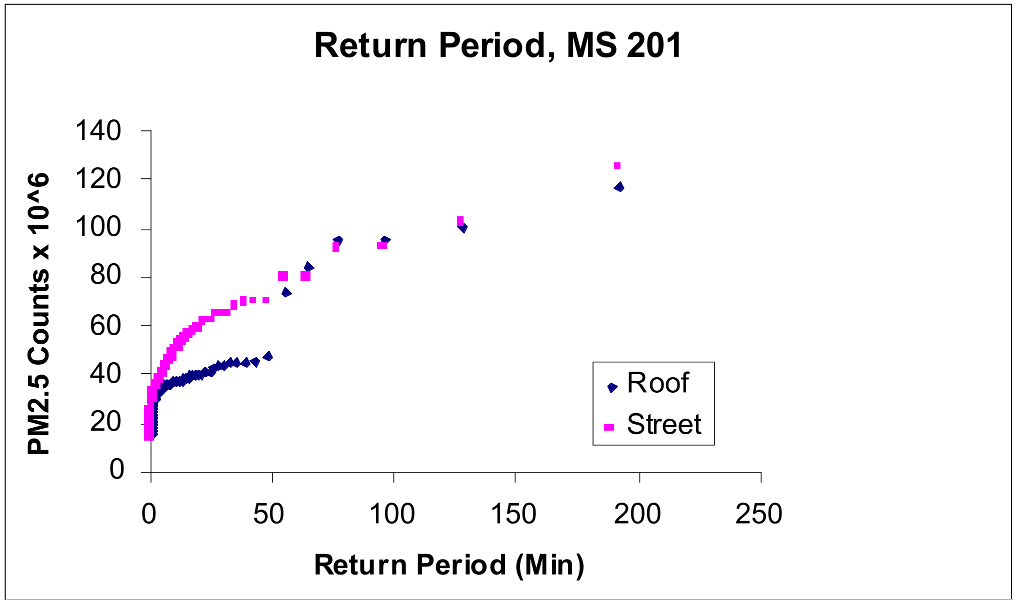


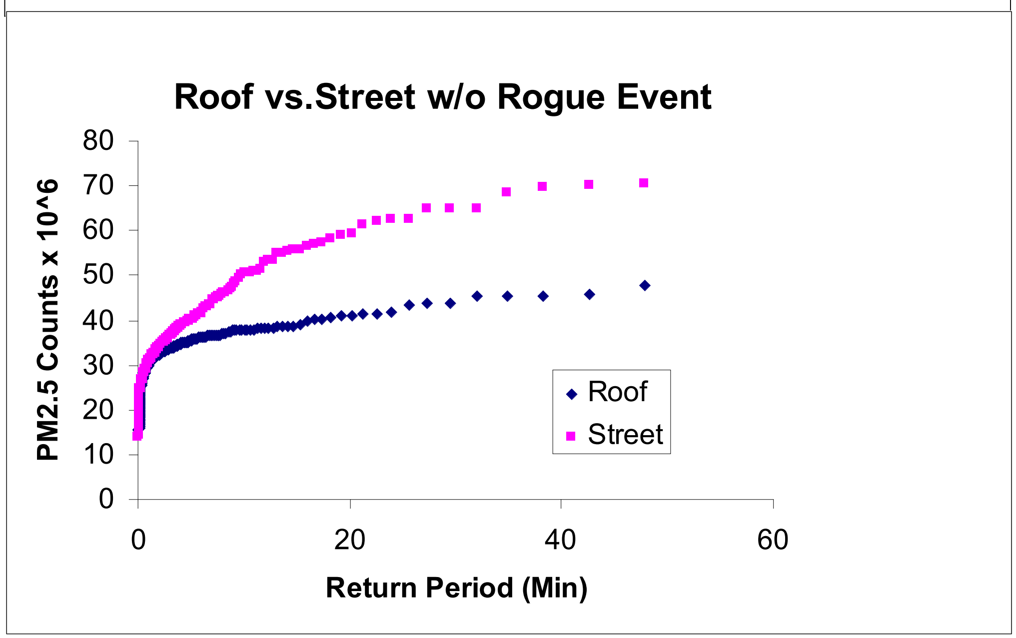
A *Koniograph*

Fr. Greek, *konia*: soot or dust



Return Period, Street vs. Rooftop





Modeling Opportunities

2. How does land use correlate with PM load?

Problems

Distance from sources varies

Wind modifies direction and severity of effect

Local variation in biophysical structure affects dispersion and mixing

What is an appropriate typology to capture these effects?

A priori or developed as part of the study?

Modeling Opportunities

3. How do trees affect PM load?

Problems

At least 2 processes occurring simultaneously

- Deposition: removal from the air
- Dispersion: rearranging where the PM occurs

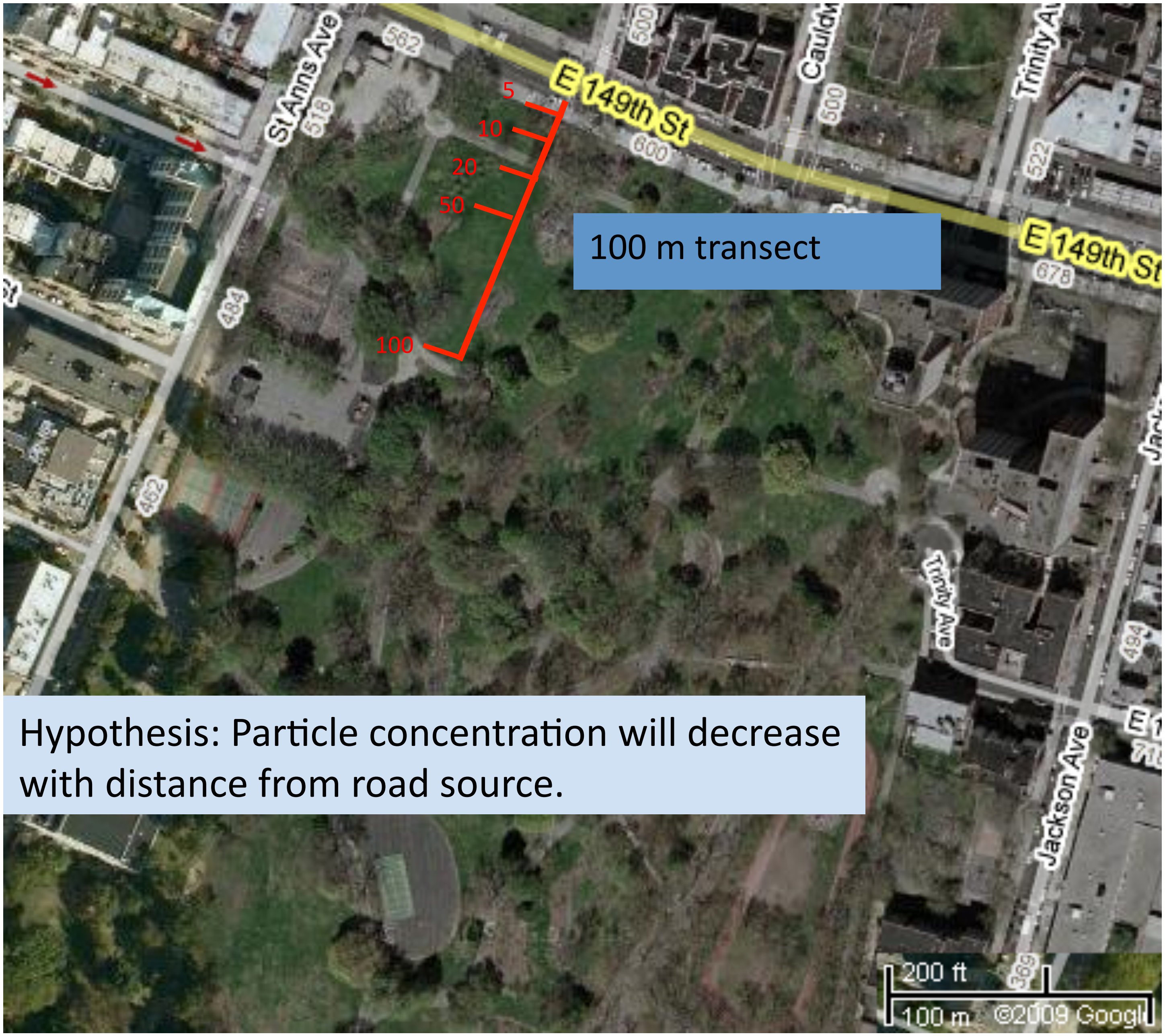
Different particle sizes behave differently

- Clean Air Act standards are based on aggregate size classes, PM 10 and PM2.5
- NO current standards for ultrafine PM

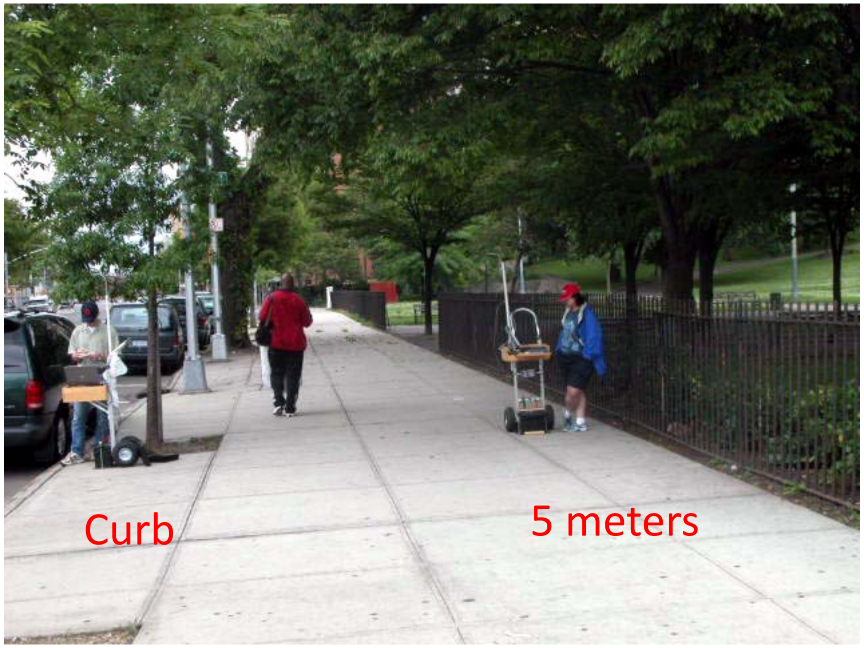
Monitoring occurs on rooftops, where humans typically are not present

Case Study: The South Bronx

An over-built landscape dominated by commercial, industrial and warehouse land use. Heavy diesel truck burden.



5
10
20
50
100
E 149th St
St Anns Ave
Trinity Ave
Jackson Ave
100 m transect
Hypothesis: Particle concentration will decrease with distance from road source.
200 ft
100 m
©2009 Google


Curb
5 meters

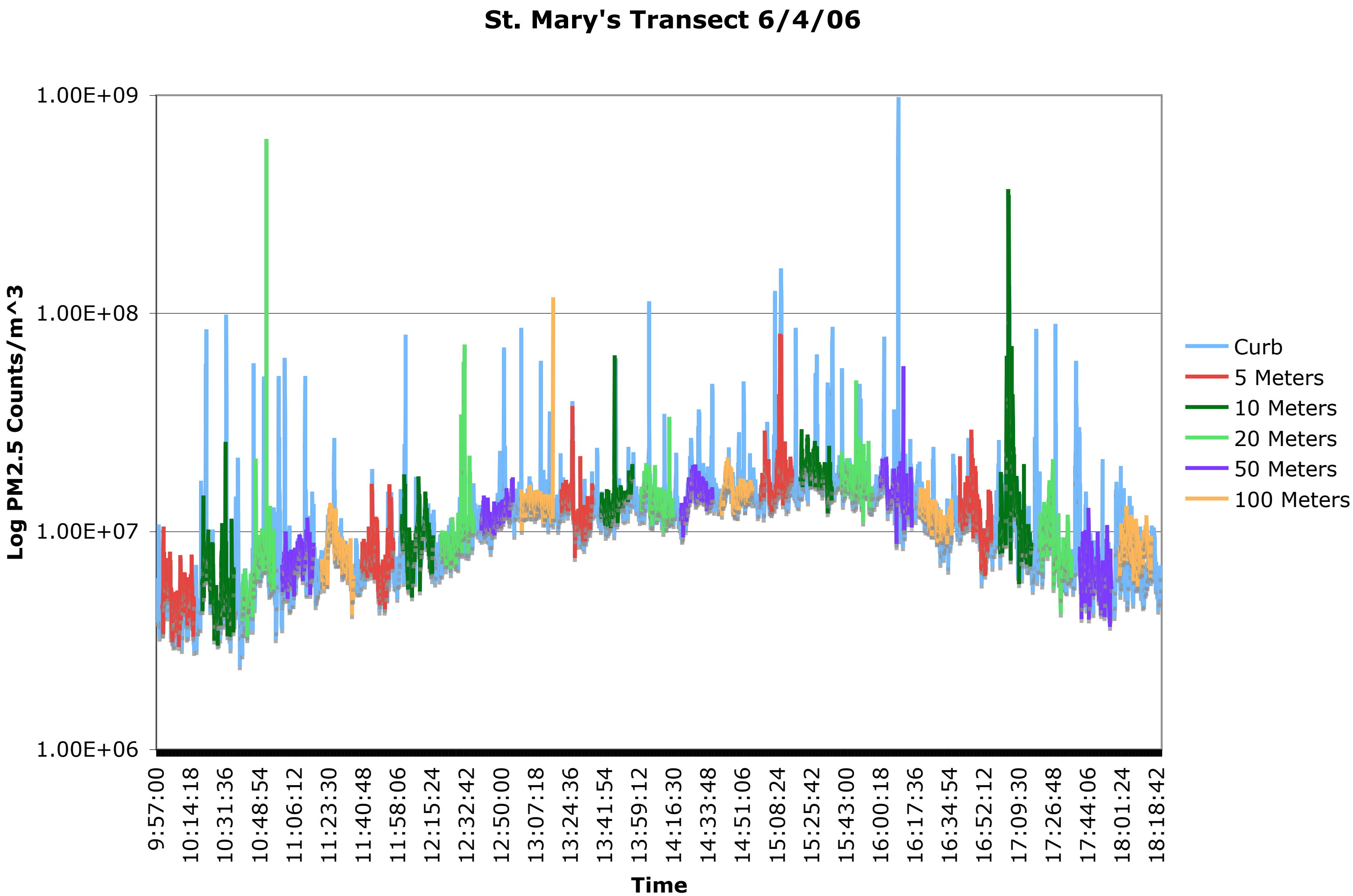

ca-Cola
20 meters


50 meters

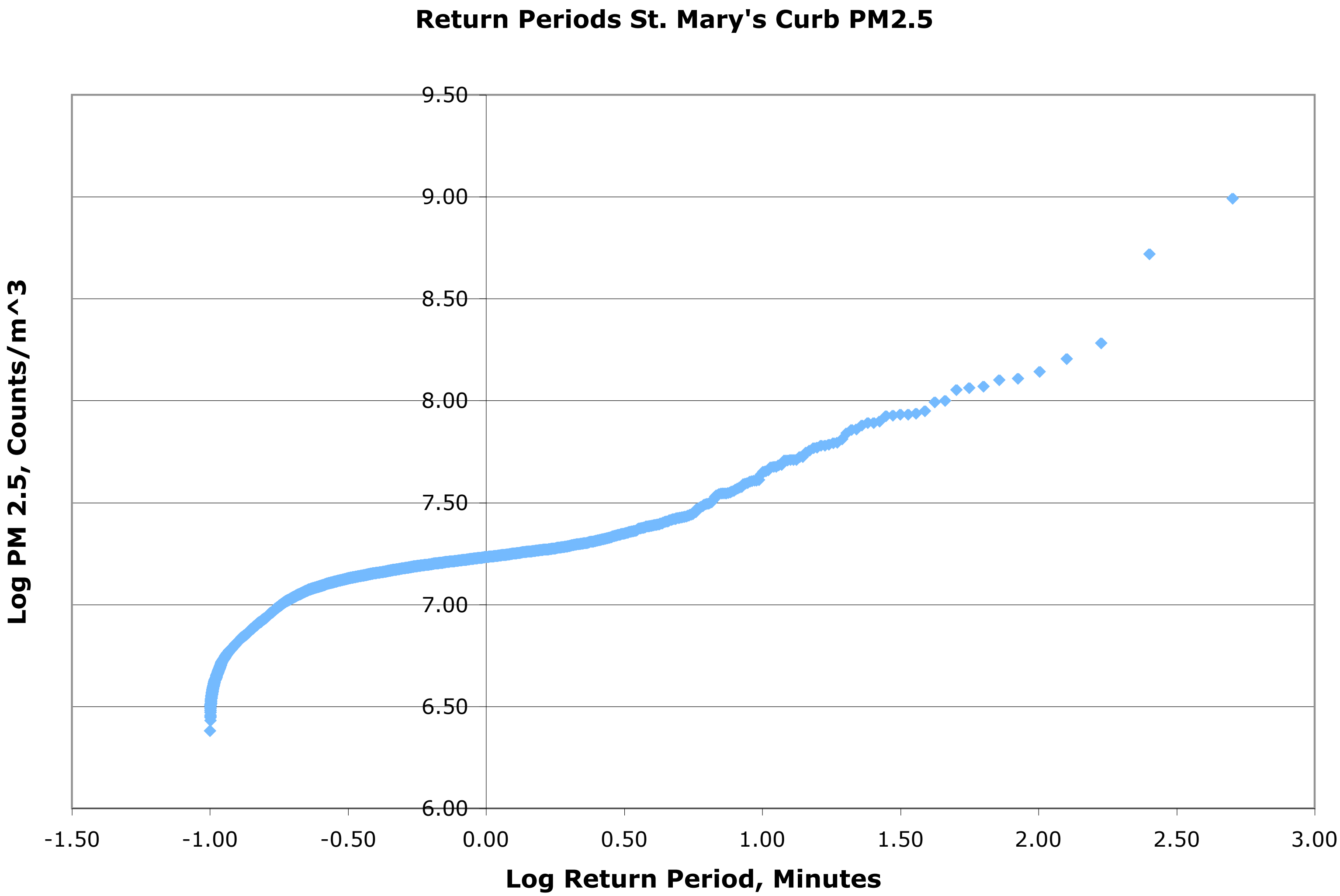

100 meters

A *koniograph* of PM2.5 events: **spikey, stochastic**

Is there a story here?

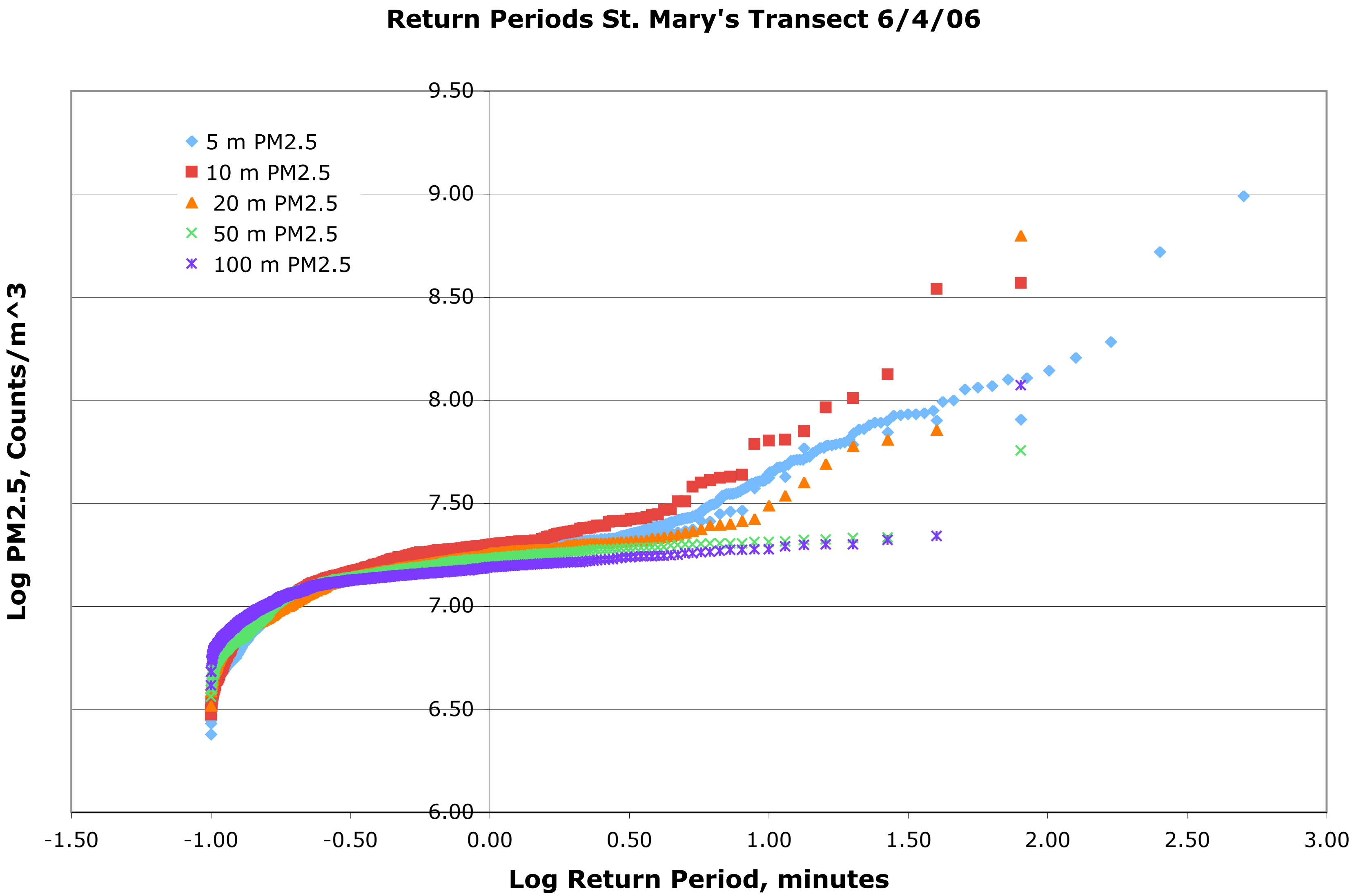


Return Period: analogous to the 100 year storm.
Summarizes, makes randomness informative.



Events frequency: 5m = curb < 10 m > 20,50,100m

You need to be 50 m back to be "decoupled" from street conditions



Deterministic Theory

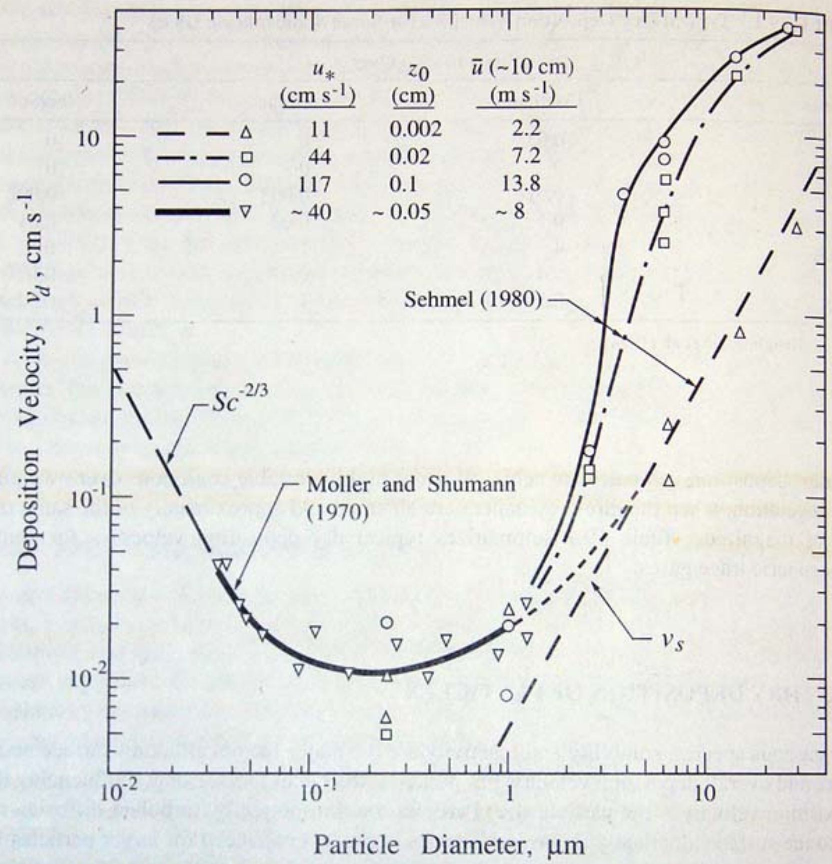


FIGURE 19.3 Particle dry deposition velocity data for deposition on a water surface in a wind tunnel (Slinn et al., 1978).

For the dry deposition of 0.1 to 1.0 μm diameter particles, uncertainties of at least an order of magnitude exist even for their deposition to simple vegetative canopies (e.g., see Allen et al., 1991); greater uncertainties exist for forest canopies (e.g., see Peters and Eiden, 1992). For deposition of 0.1 to 1.0 μm diameter particles to the sea surface, no particle-size-dependent data appear to be available (e.g., see Rojas et al., 1993). Numerical studies have examined problems with modifying available dry deposition formulations for use in global models (e.g., Giorgi, 1988); the lack of mesoscale, particle-size-specific field studies for dry deposition to inhomogeneous vegetation and to the ocean result in, at best

Accepted Theory

Einstein- Stokes Relation

$$D = \frac{kT}{6 \pi \eta R}$$

D = diffusivity

K = Boltzmann constant

η = viscosity

R = particle radius

Fick's 1st Law of Diffusion

$$J_j = -D_j \frac{\delta c_j}{\delta x}$$

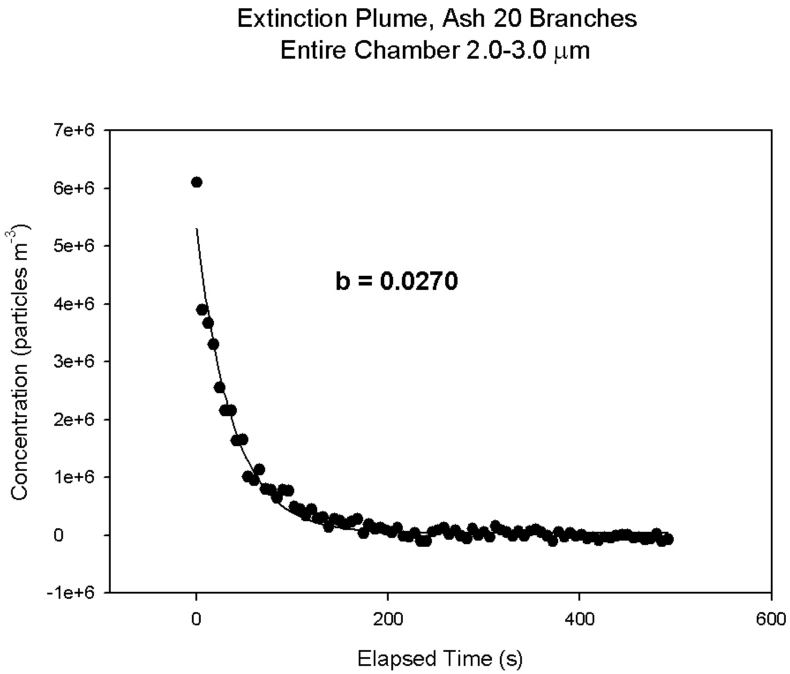
J_j = flux (mol m^{-2} s^{-1})

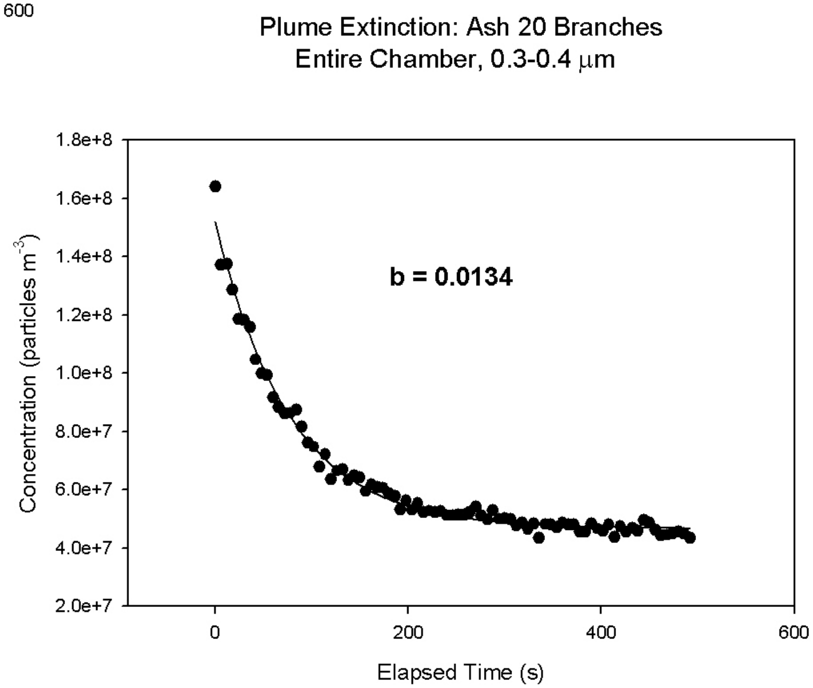
D_j = diffusion coefficient

c_j = conc. (mol m^{-3})

x = distance

Comparing particle behavior at extremes of PM2.5

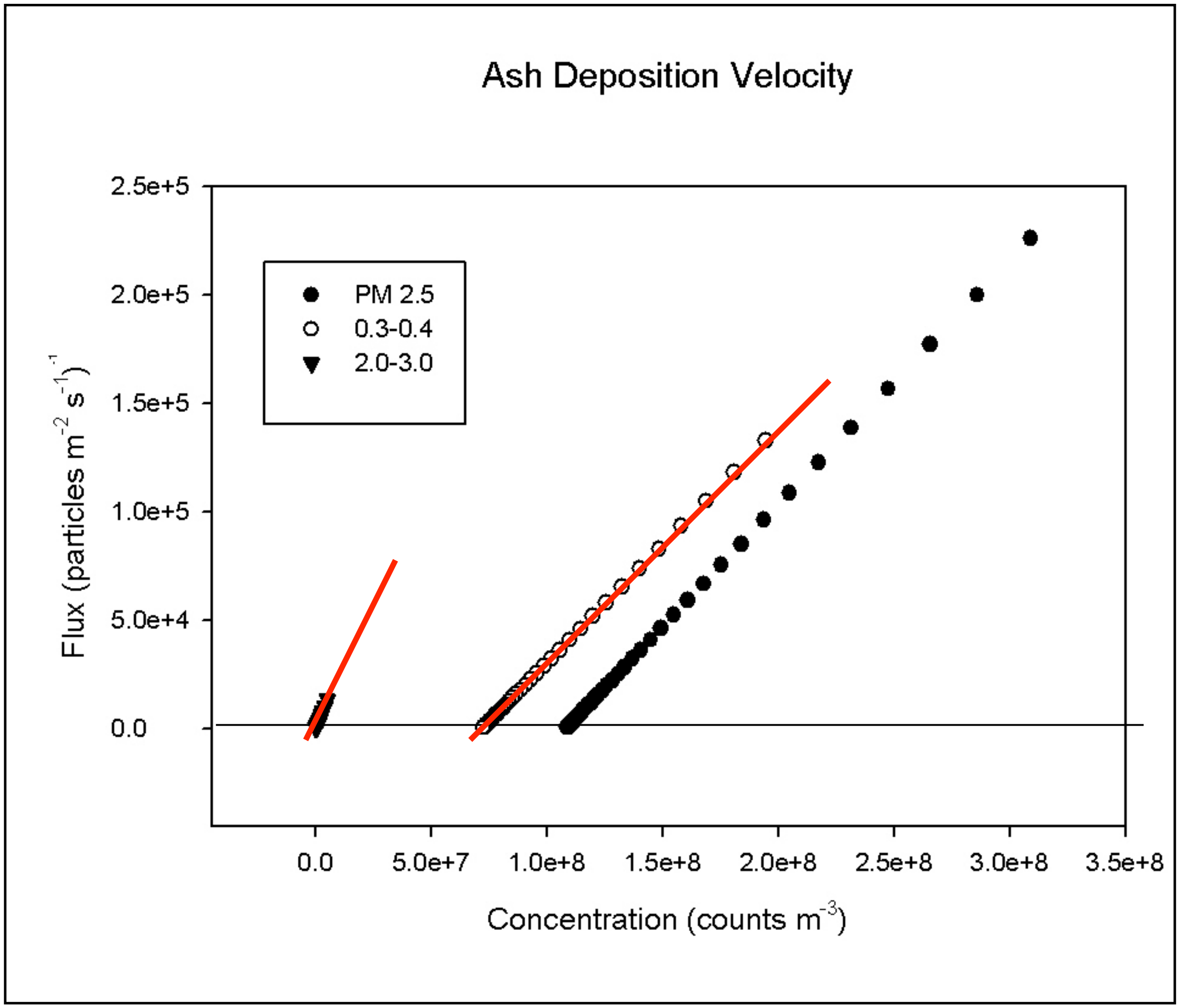




V_d, deposition velocity : slope of Flux vs. ambient concentration

2.0-3.0 > 0.3-0.4, so at a given concentration, larger particles deposit faster than smaller

Contradicts Fick's first Law



Can we model on a shaky theoretical foundation?

Response Metrics: Human Health Outcomes

SPECIAL ARTICLE

Fine-Particulate Air Pollution and Life Expectancy in the United States

C. Arden Pope III, Ph.D., Majid Ezzati, Ph.D., and Douglas W. Dockery, Sc.D.

ABSTRACT

BACKGROUND
Exposure to fine-particulate air pollution has been associated with increased morbidity and mortality, suggesting that sustained reductions in pollution exposure should result in improved life expectancy. This study directly evaluated the changes in life expectancy associated with differential changes in fine particulate air pollution that occurred in the United States during the 1980s and 1990s.

METHODS
We compiled data on life expectancy, socioeconomic status, and demographic characteristics for 211 county units in the 51 U.S. metropolitan areas with matching data on fine-particulate air pollution for the late 1970s and early 1980s and the late 1990s and early 2000s. Regression models were used to estimate the association between reductions in pollution and changes in life expectancy, with adjustment for changes in socioeconomic and demographic variables and in proxy indicators for the prevalence of cigarette smoking.

RESULTS
A decrease of 10 μg per cubic meter in the concentration of fine particulate matter was associated with an estimated increase in mean (±SE) life expectancy of 0.61±0.20 year ($P=0.004$). The estimated effect of reduced exposure to pollution on life expectancy was not highly sensitive to adjustment for changes in socioeconomic, demographic, or proxy variables for the prevalence of smoking or to the restriction of observations to relatively large counties. Reductions in air pollution accounted for as much as 15% of the overall increase in life expectancy in the study areas.

CONCLUSIONS
A reduction in exposure to ambient fine-particulate air pollution contributed to significant and measurable improvements in life expectancy in the United States.

From the Department of Economics, Brigham Young University, Provo, UT (C.A.P.); the Harvard School of Public Health, Boston (M.E., D.W.D.); and the Harvard Initiative for Global Health, Cambridge, MA (M.E.). Address reprint requests to Dr. Pope at 142 FOB, Brigham Young University, Provo, UT 84602-2363, or at cap3@byu.edu.

N Engl J Med 2009;360:376-86.

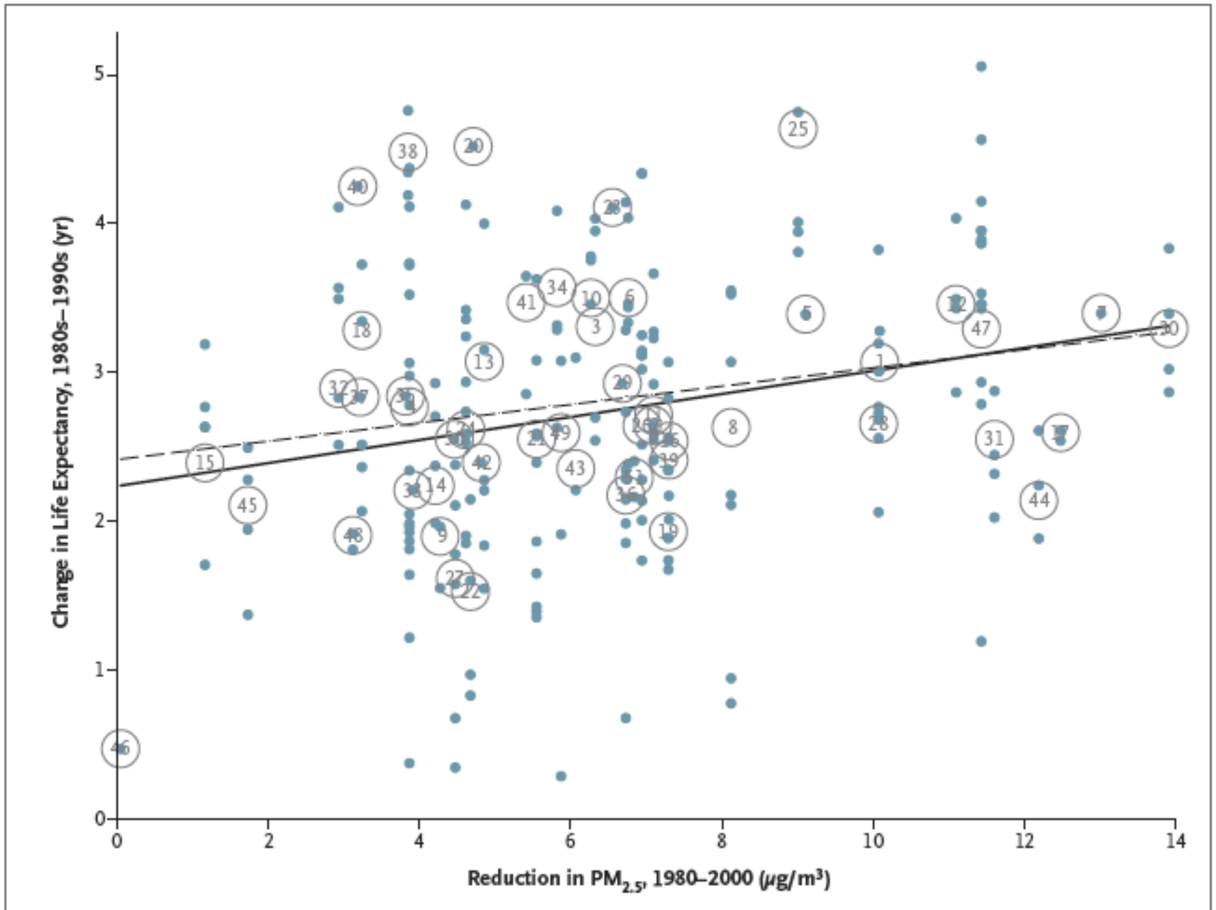


Figure 4. Changes in Life Expectancy for the 1980s–1990s, Plotted against Reductions in $PM_{2.5}$ Concentrations for 1980–2000.

For each 10µg m^3 increase in $PM_{2.5}$, life expectancy decreases by:
1978-1982 0.46 ± 0.22 yr (P= 0.039)
1997-2001 0.37 ± 0.20 yr (P= 0.091)

Pope, C.A. III, M. Ezzati, and D. W. Dockery, 2009. Fine particulate air pollution and life expectancy in the United States. New England Jour. Med. 360:376-86.

Children living in areas with more street trees have lower prevalence of asthma

G S Lovasi, J W Quinn, K M Neckerman, M S Perzanowski and A Rundle

J. Epidemiol. Community Health 2008;62;647-649; originally published online 1 May 2008;
doi:10.1136/jech.2007.071894

RESULTS

Street tree density was high in the most densely populated areas and in areas with less poverty, and was negatively correlated with the two measures of asthma burden (table 1). Higher street tree density was associated with a lower prevalence of childhood asthma even after adjustment for potential confounders (including sociodemographic characteristics, population density and proximity to pollution sources), but the association between street trees and hospitalisations as a result of asthma was no longer significant after adjustment.

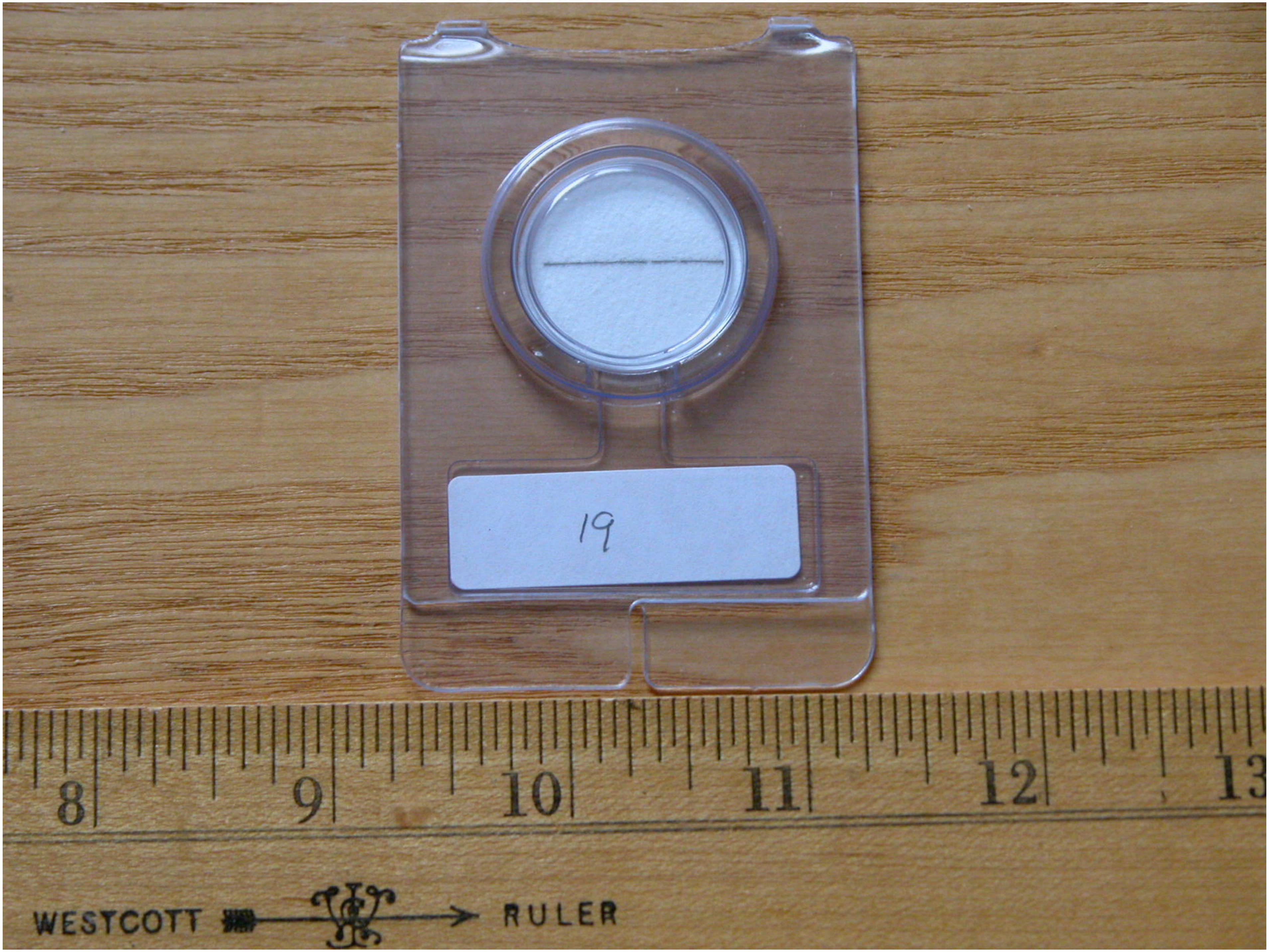
Unadjusted estimates suggest that an increase in tree density of 1 standard deviation (SD, 343 trees/km^2) would be associated with a 24% lower prevalence of asthma (relative risk (RR), 0.76 per SD of tree density; 95% CI, 0.67 to 0.91) and a 26% lower risk of hospitalisation as a result of asthma (RR, 0.74 per SD of tree density; 95% CI, 0.62 to 0.87). After adjustment for potential confounders, we estimate that the same increase in street tree density would be associated with a 29% lower early childhood prevalence of asthma (RR, 0.71 per SD of tree density; 95% CI, 0.64 to 0.79). The association between tree density and hospitalisations as a result of asthma was not significant after adjustment (RR, 0.89 per SD of tree density; 95% CI, 0.75 to 1.06). and proximity to sources of air pollution. The inverse association of street trees with hospitalisations for childhood asthma became non-significant following adjustment for the same potential confounders.

Our cross-sectional and ecological study does not permit inference that trees are causally related to the prevalence of childhood asthma at the individual level. These observational data may be subject to residual confounding or confounding by unmeasured characteristics. Previous studies of tree density and childhood asthma have not been published to our knowledge, and our results need to be replicated by others. Future studies may be more robust if they are able to measure and control for characteristics of the home environment, such as the presence of allergens.

A natural experiment could demonstrate whether abundant street trees caused the lower prevalence of asthma observed in densely planted areas. The PlaNYC sustainability initiative (www.nyc.gov/html/planyc2030) includes a commitment to plant one million trees in New York City by the year 2017 and offers an opportunity for a large prospective evaluation. Staged tree planting by area could help identify the effects of increased tree density on childhood asthma.

An alternative, reductionistic approach


Collect particles in the field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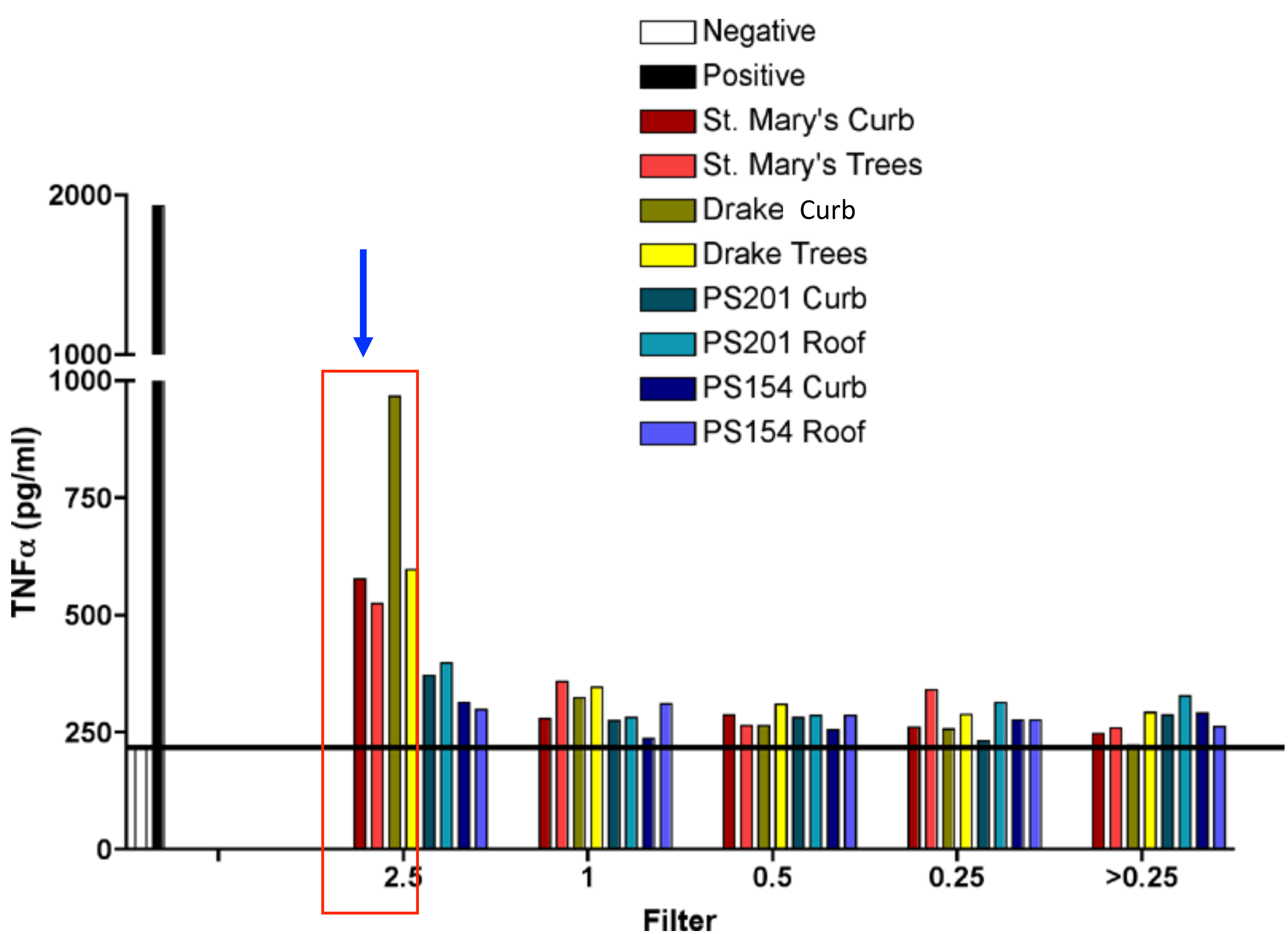
WESTCOTT
RULER

June 2007



Negative
Positive
St. Mary's Curb
St. Mary's Trees
Drake Curb
Drake Trees
PS201 Curb
PS201 Roof
PS154 Curb
PS154 Roof
TNFα (pg/ml)
2000
1000
1000
750
500
250
0
2.5
1
0.5
0.25
>0.25
Filter

Current Application: Monitoring the Effect of Peak Power Generators on Environmental Justice Communities (NYSERDA RFP)


Gowanus, Brooklyn, NYC
Coal fired peaking power plants
© 2011 Google
© 2011 Europa Technologies
Gray Buildings © 2008 Sanborn
©2009 Google
Imagery Date: Jun 18, 2010
40°39'44.72" N 74°00'19.84" W elev 0 m
Eye alt 3.11 km

Determining Impact of Emissions on Environmental Justice (EJ) Communities

1. Where should sensors be placed?

2. How many sensors are needed?

3. How long should sensors be deployed?

Policy Implications?

Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions

Diane E Pataki[1,2*], Margaret M Carreiro[3], Jennifer Cherrier[4], Nancy E Grulke[5], Viniece Jennings[6], Stephanie Pincetl[7], Richard V Pouyat[8], Thomas H Whitlow[9], and Wayne C Zipperer[6]

Urban green space is purported to offset greenhouse-gas (GHG) emissions, remove air and water pollutants, cool local climate, and improve public health. To use these services, municipalities have focused efforts on designing and implementing ecosystem-services-based "green infrastructure" in urban environments. In some cases the environmental benefits of this infrastructure have been well documented, but they are often unclear, unquantified, and/or outweighed by potential costs. Quantifying biogeochemical processes in urban green infrastructure can improve our understanding of urban ecosystem services and disservices (negative or unintended consequences) resulting from designed urban green spaces. Here we propose a framework to integrate biogeochemical processes into designing, implementing, and evaluating the net effectiveness of green infrastructure, and provide examples for GHG mitigation, stormwater runoff mitigation, and improvements in air quality and health.

Front Ecol Environ 2011; 9(1): 27–36, doi:10.1890/090220

Panel 1. Urban trees and air quality

Section 205 of HR2454, The American Clean Energy and Security Act of 2009, states:

The Congress finds that:
(4) shade trees have significant clean air benefits associated with them;
(5) every 100 healthy trees removes about 300 pounds of air pollution (including particulate matter and ozone) and about 15 tons of carbon dioxide from the air each year;
(7) in over a dozen test cities across the United States, increasing urban tree cover has generated between two and five dollars in savings for every dollar invested in such tree plantings (www.govtrack.us/congress/bill.xpd?bill=h111-2454).

One would assume from this text that (1) our knowledge of the impacts of trees on air quality is adequate to formulate "good" policy and (2) trees appreciably reduce concentrations of harmful air pollutants. However, despite simulation models demonstrating the benefits of urban trees, their effects on air pollution remain empirically unquantified.

One of the presumed benefits of trees is particulate matter (PM) deposition onto canopies, which have a large surface area. However, particle deposition is affected by particle size, landscape roughness, canopy and leaf characteristics, and atmospheric turbulence. This complexity has hampered the development of a coherent theory for particulate deposition in canopies (Grantz *et al.* 2003; Hicks 2008). Reports of particulate deposition tend to be based on assumptions, models, or theories that are untested in urban settings. It is unlikely that even optimistic estimates of pollutant removals (uptake and deposition) will appreciably affect atmospheric concentrations in polluted cities. In contrast, tree canopies may reduce dispersion, causing locally elevated PM concentrations.

A commonly used model, Urban Forest Effects (UFORE) Model (www.ufore.org), estimates the effects of urban trees on particulate pollution. For New York City (NYC), UFORE predicted that – during the growing season – the forest removes 0.47% of PM matter, based on reported deposition velocities for particulates less than 10 microns in diameter (PM_{10}) (Nowak *et al.* 2002). If NYC were to add 1 million new trees to the urban forest, as is currently proposed (www.milliontreesnyc.org), particulate pollution removal would increase to 0.55% of PM_{10} (there are currently ~6 million trees in the five-borough area). Thus, the additional 1 million trees would reduce PM by 0.02891 $\mu g\ m^{-3}$ to achieve a concentration of 36.97 $\mu g\ m^{-3}$. A decrease in $PM_{2.5}$ by 10 $\mu g\ m^{-3}$ has been estimated to add 0.61 years to human life expectancy (Pope *et al.* 2009). The net effect of planting 1 million trees would be to add 4.05 hours to the lives of NYC residents, based on PM reductions alone.

Although based on many assumptions, these calculations illustrate that assertions of the specific physical benefits of urban trees can be overstated. The pitfall in doing so is that the public receives the wrong message about how critical environmental and human-health problems must be solved. Tree-planting programs clearly have many benefits, but it is incumbent upon scientists to provide accurate and realistic estimates of both the ecosystem services and disservices of such programs.

What roles can Computational Sustainability in the complex arena?

MILLIONTREESNYC, GREEN INFRASTRUCTURE, AND URBAN ECOLOGY: BUILDING A RESEARCH AGENDA

Report from the Workshop

MillionTreesNYC Advisory Board Research & Evaluation Subcommittee