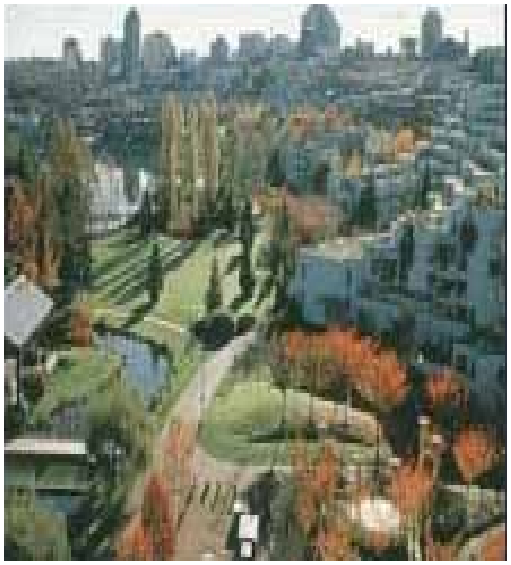
Urban sustainability engineering

Julian Marshall
Assistant Professor of Environmental Engineering
Department of Civil Engineering, University of Minnesota
julian@umn.edu
MPCA, December 4, 2008


Cities: the vision

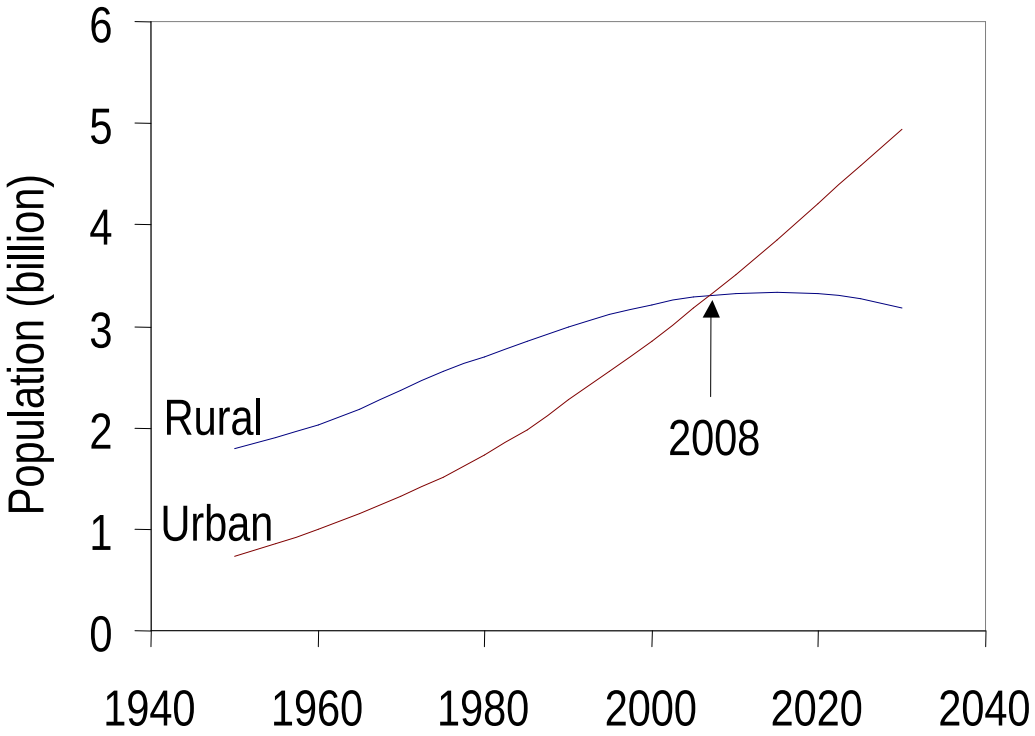
The cities will be part of the country;

I shall live 30 miles from my office in one direction, under a pine tree; my secretary will live 30 miles away from it too, in the other direction, under another pine tree. We shall both have our own car.

We shall use up tires, wear out road surfaces and gears, consume oil and gasoline. All of which will necessitate a great deal of work ... enough for all.

— 1930's USSR propaganda film, cited in *The Radiant City* (Le Corbusier, 1967)

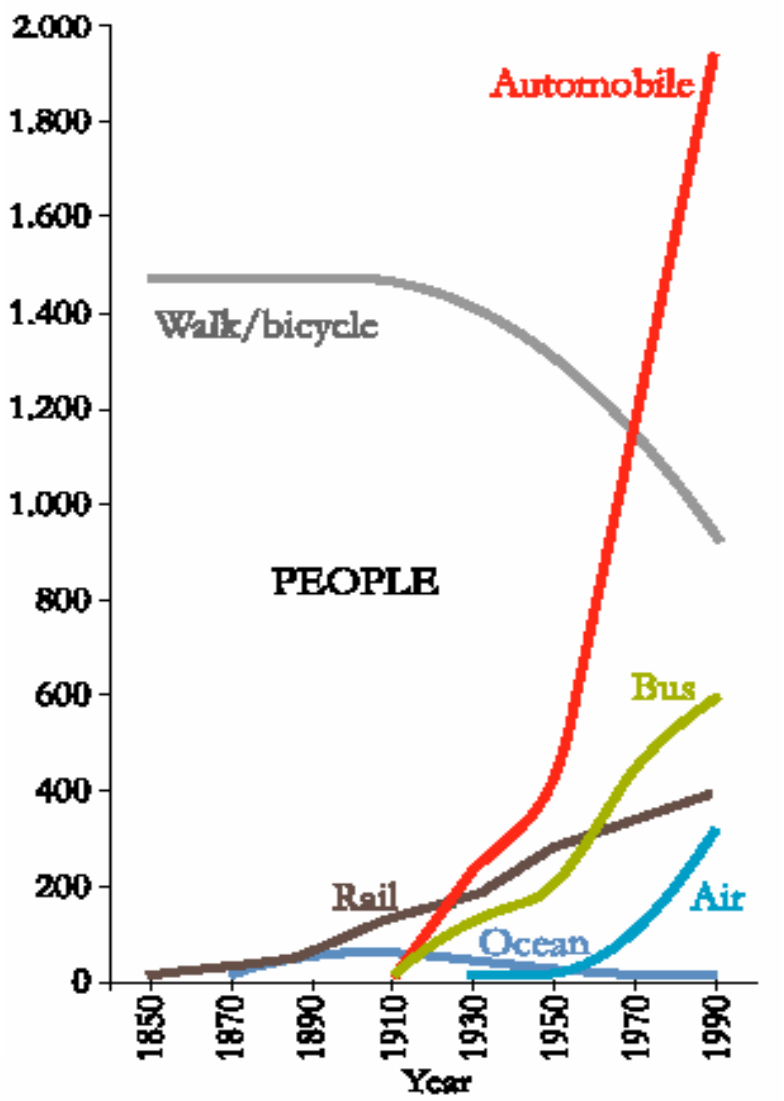
Urbanization



Source: United Nations, 2007

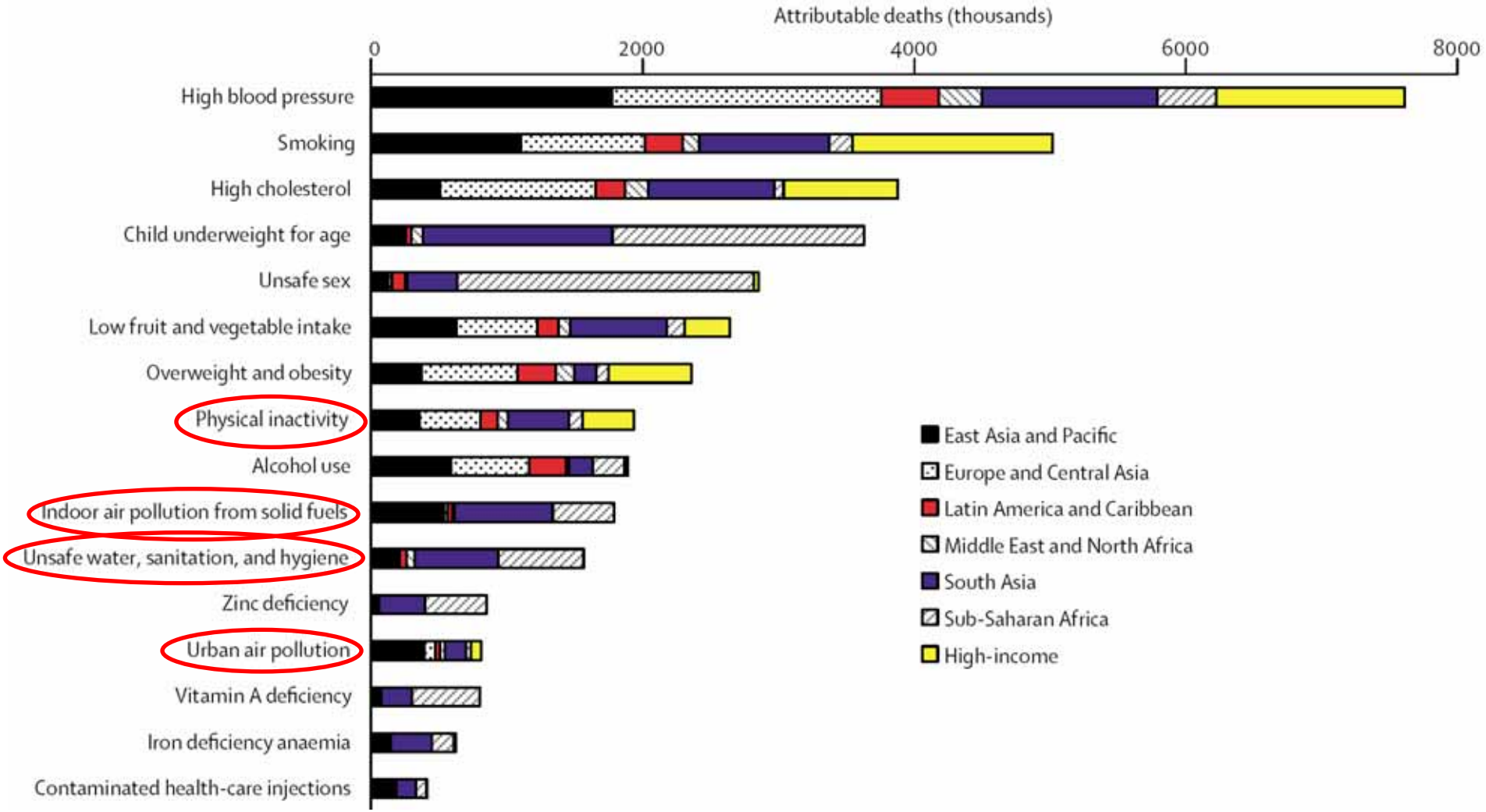
Automobility

Kilometers per person per year



Source: Center for Sustainable Transportation.

Global burden of disease



Source: Lopez et al., 2006

Solutions…

the ONION


the ONION

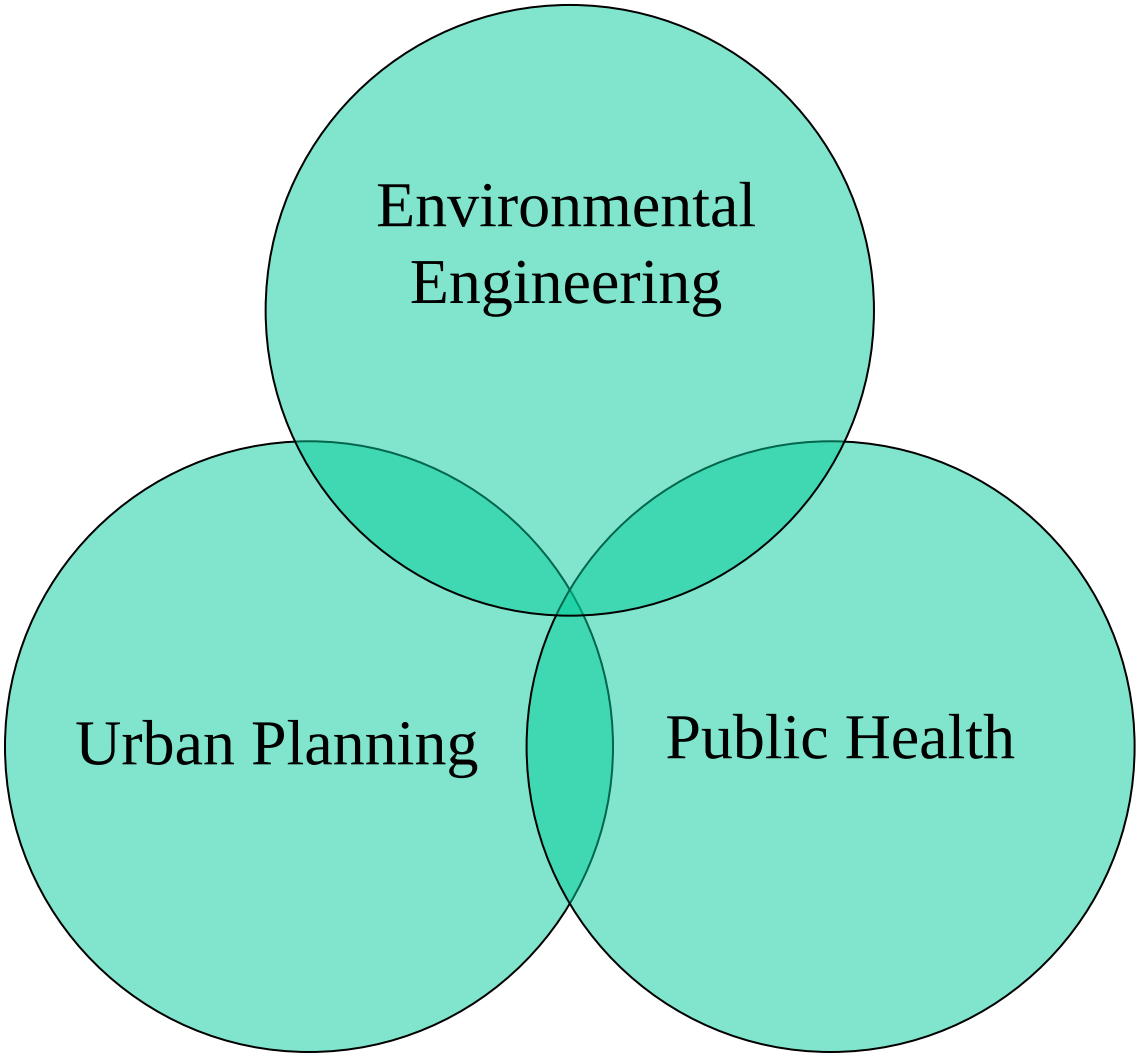
Report: 98 Percent Of U.S. Commuters Favor Public Transportation For Others

98% of US commuters favor public transportation for others.

“Take the bus… I’ll be glad you did.”

Source: The Onion, 29 Nov 2000

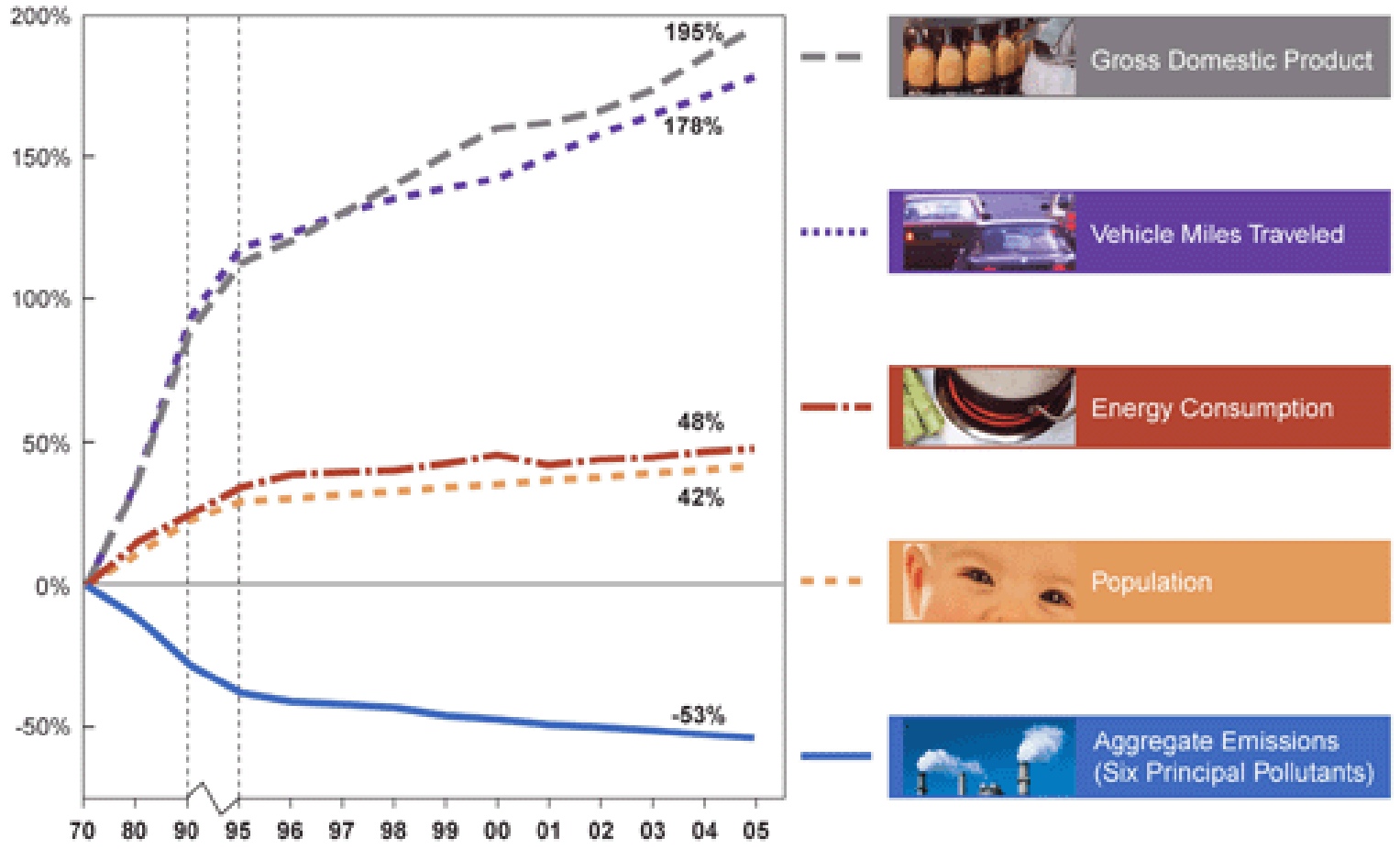
Urban sustainability engineering: “Science of cities”



Today's agenda: Air Quality (AQ) Engineering

- Background: AQ and health
- Case studies
  1. Intake fraction
  2. Walkability & AQ (2 slides)
  3. Urban growth: a scaling rule (3 slides)
  4. AQ and urban form: evidence from satellite data
  5. Strategies for improving AQ

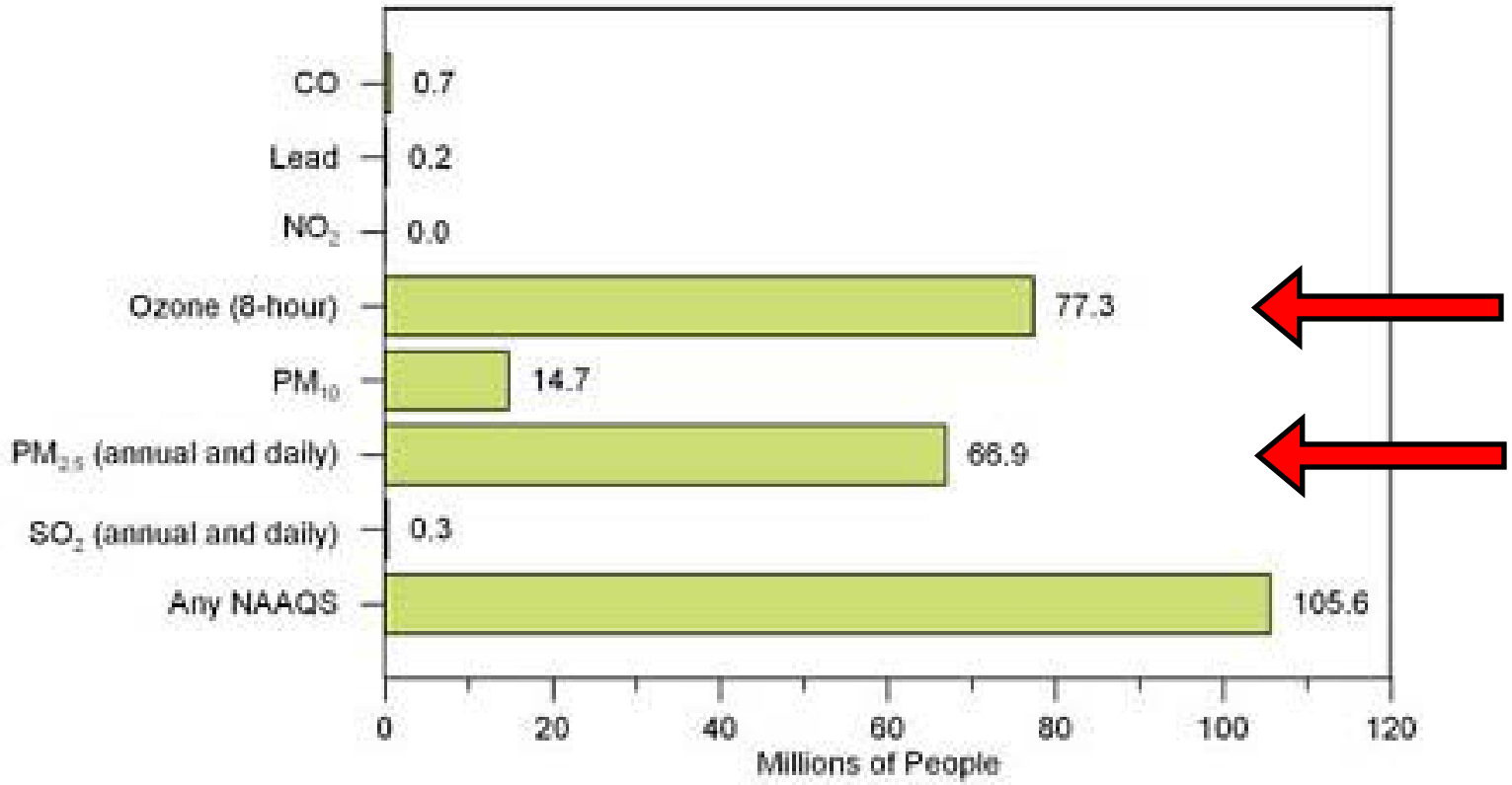
AQ: Progress



Source: US EPA, 2006

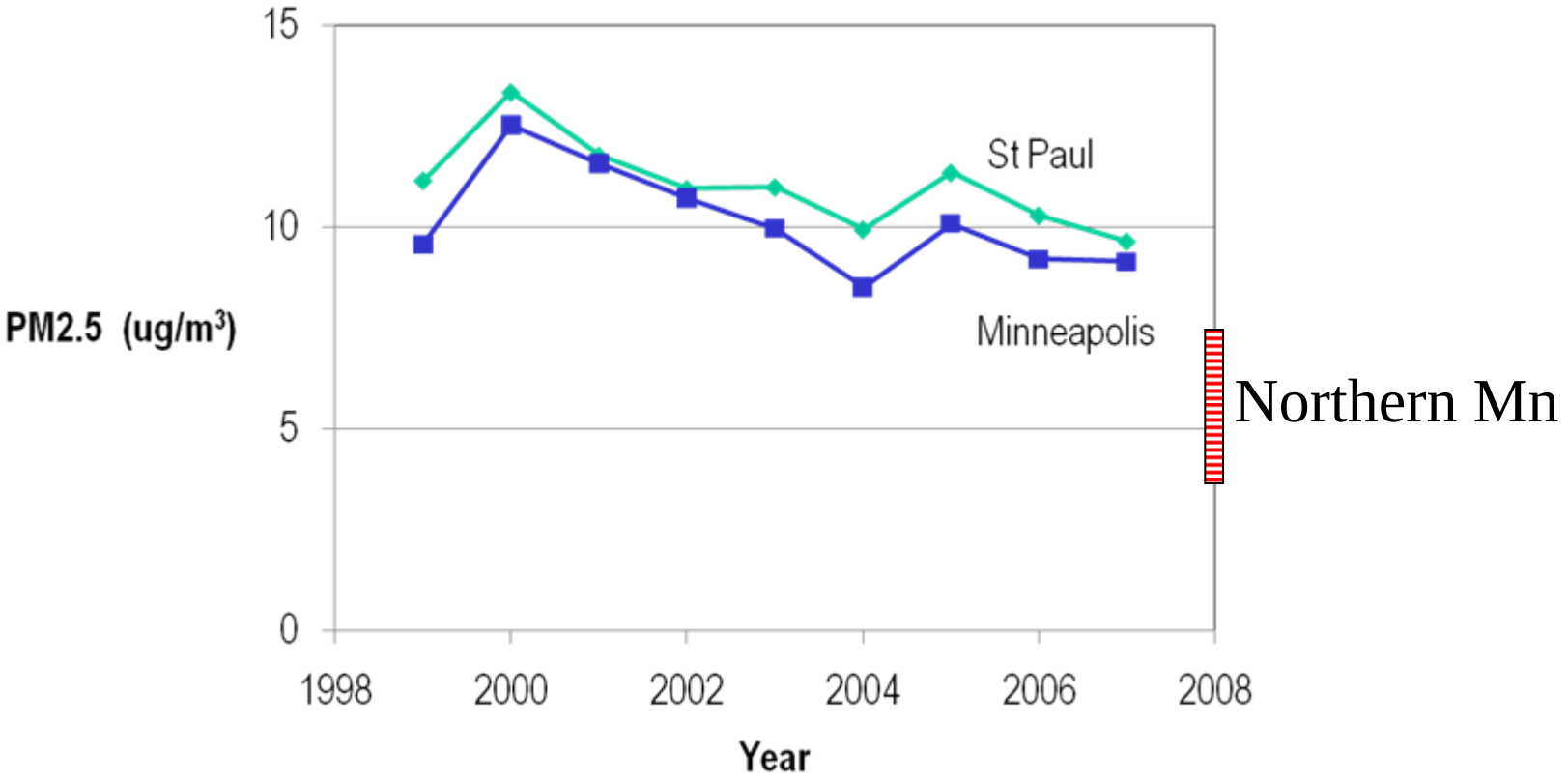
AQ: Current status

Number of people living in counties with air concentrations above NAAQS, 2006



Source: US EPA, 2007

AQ: Twin Cities



US EPA standard: 15 μg/m^3
CalEPA standard: 12 μg/m^3

Source: US EPA

Health benefits from reducing $PM_{2.5}$ (Twin Cities)

"Each 10 μg m^{-3} $PM_{2.5}$ [is] … associated with approximately a 4%, 6%, and 8% increased risk of all-cause, cardiopulmonary, and lung cancer mortality, respectively."
Pope et al., JAMA, 2002.

Data: 766 deaths per 100,000 people per year.

Example: For 3 million people, reduce $PM_{2.5}$ by 2 μg m^{-3} (~ 20%).

Calculation: Deaths decline 0.8% (6 deaths per 100,000 per year).

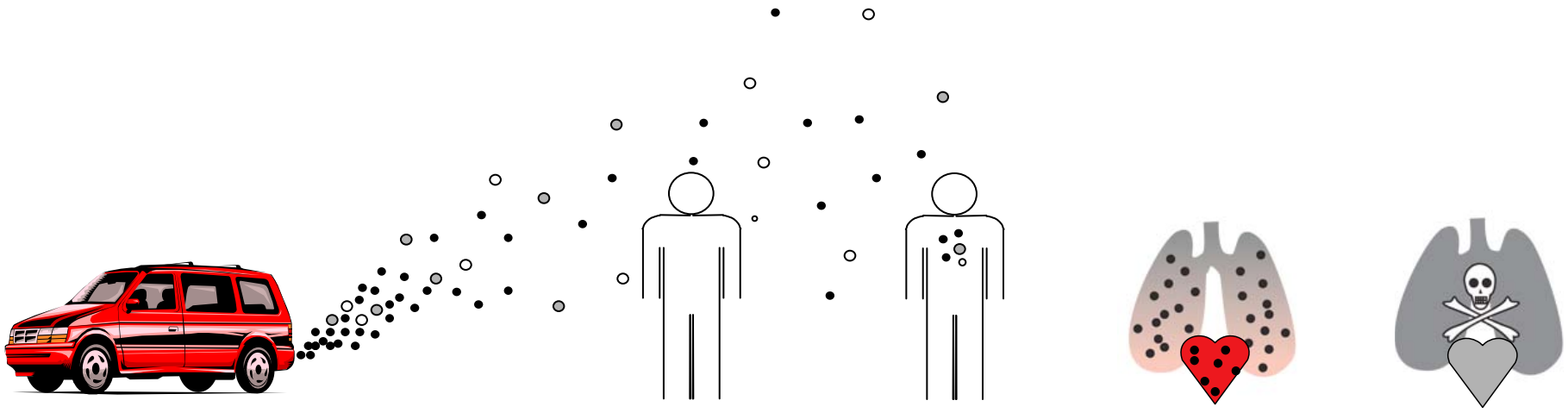
Conclusion: 180 fewer deaths per year.

Challenge

- Air pollution harms human health
- Problems are best controlled at the source
- Some emissions are inevitable

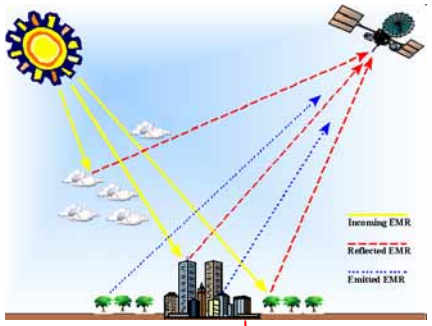
- Which emissions should be controlled?
- … and to what extent?

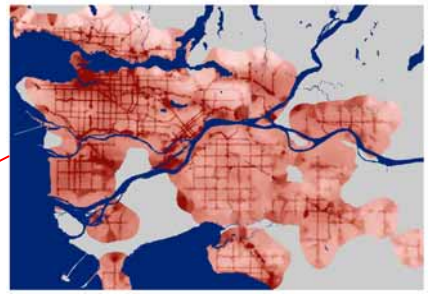
AQ: emission-to-effect

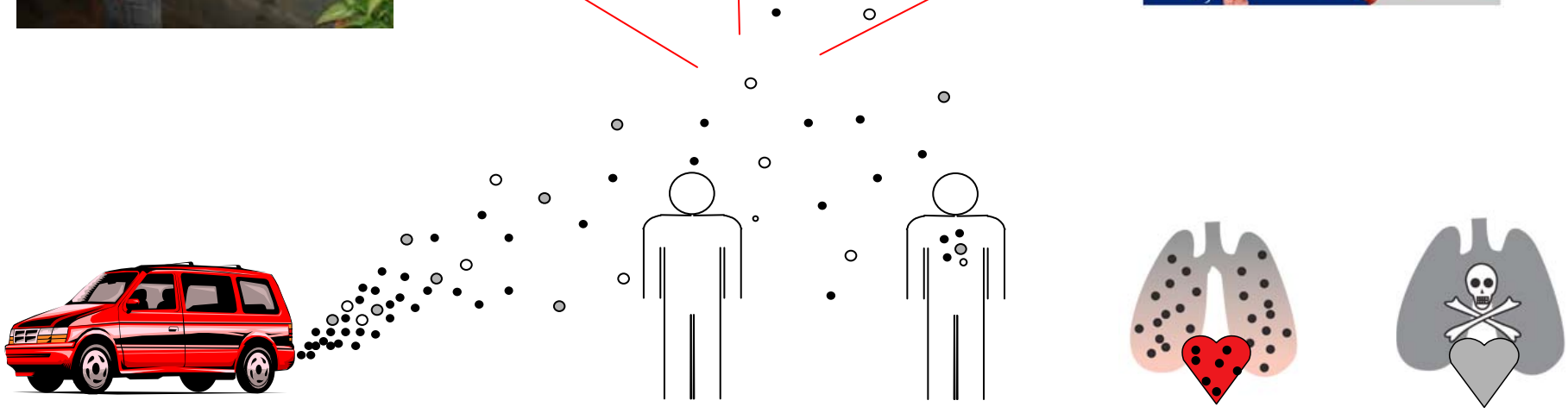


emissions → concentration → exposure → intake → dose → health effects

AQ: emission-to-effect

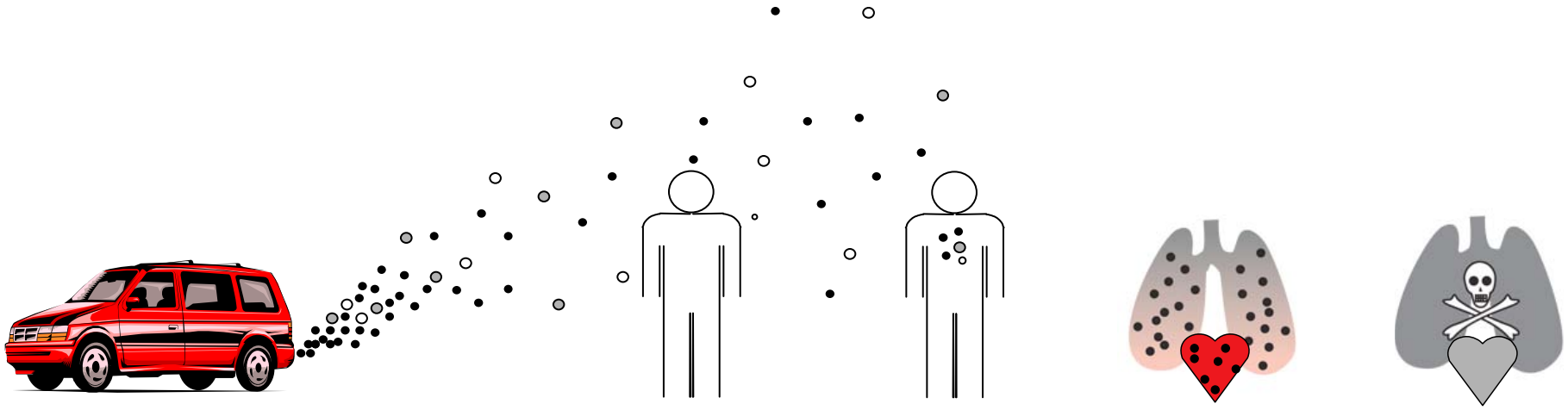






emissions → concentration → exposure → intake → dose → health effects

1. Intake fraction



emissions → concentration → exposure → intake → dose → health effects

emissions ⟶ intake

$$\text{intake fraction} = \frac{\text{intake rate}}{\text{emission rate}}$$

Use of intake fraction

Health impact ~ Emissions $\times$ Intake fraction $\times$ Toxicity

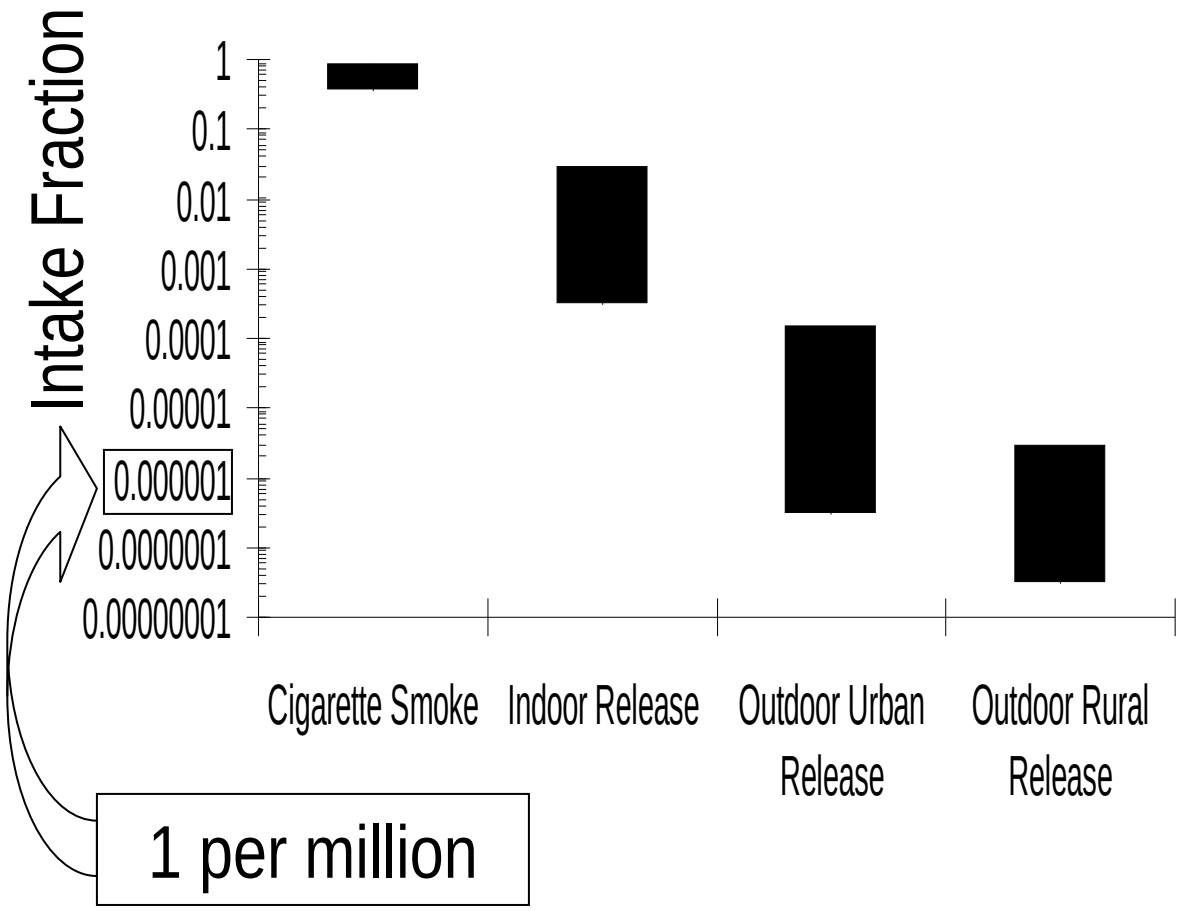
units :

$$\text{health impact} \sim \text{grams emitted} \times \frac{\text{grams inhaled}}{\text{gram emitted}} \times \frac{\text{health impact}}{\text{gram inhaled}}$$

Determinants of Intake fraction:

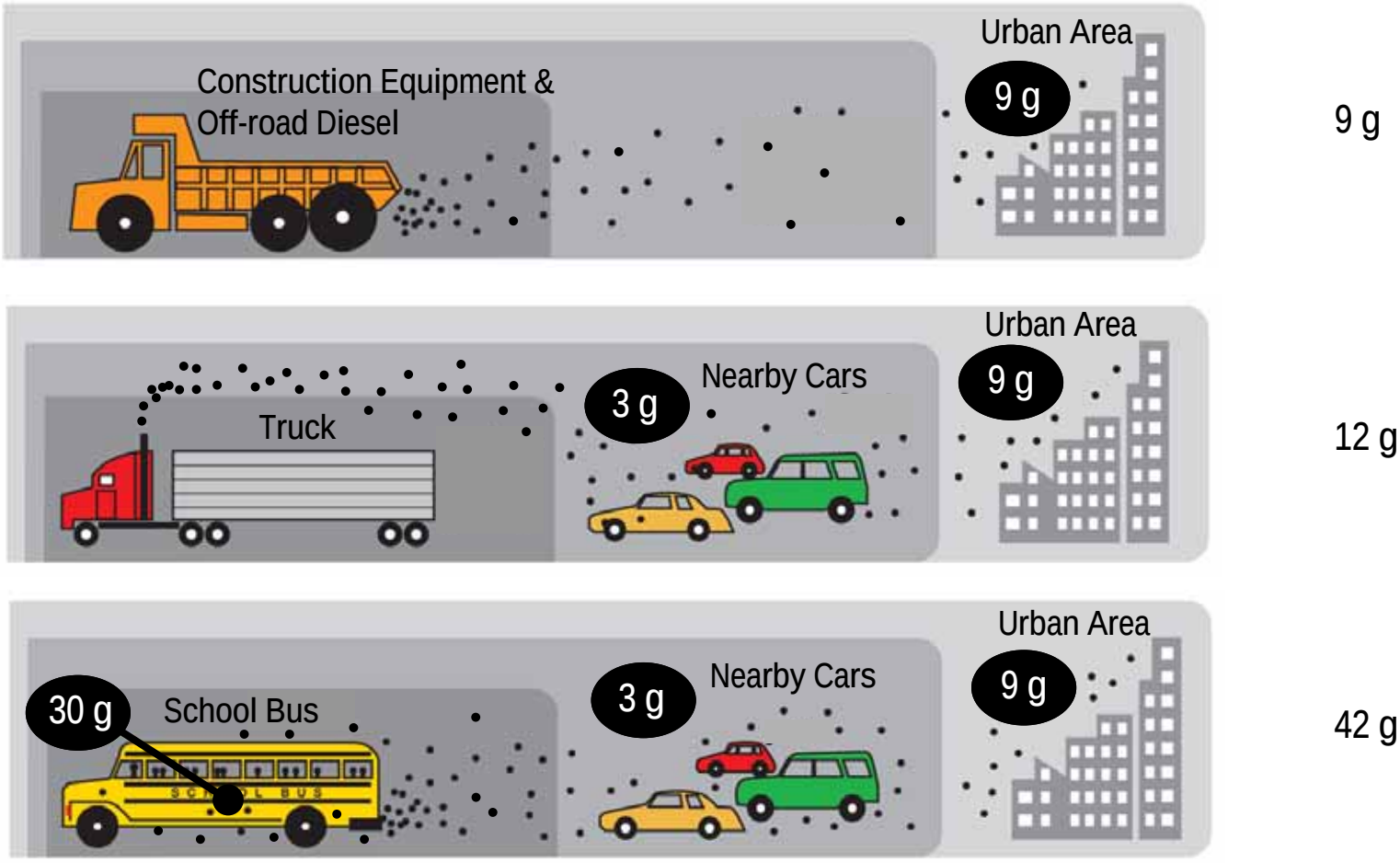
- Size of the exposed *Population*
- *Proximity* between emissions and people
- *Persistence* of the pollutant in the environment

iF: typical values

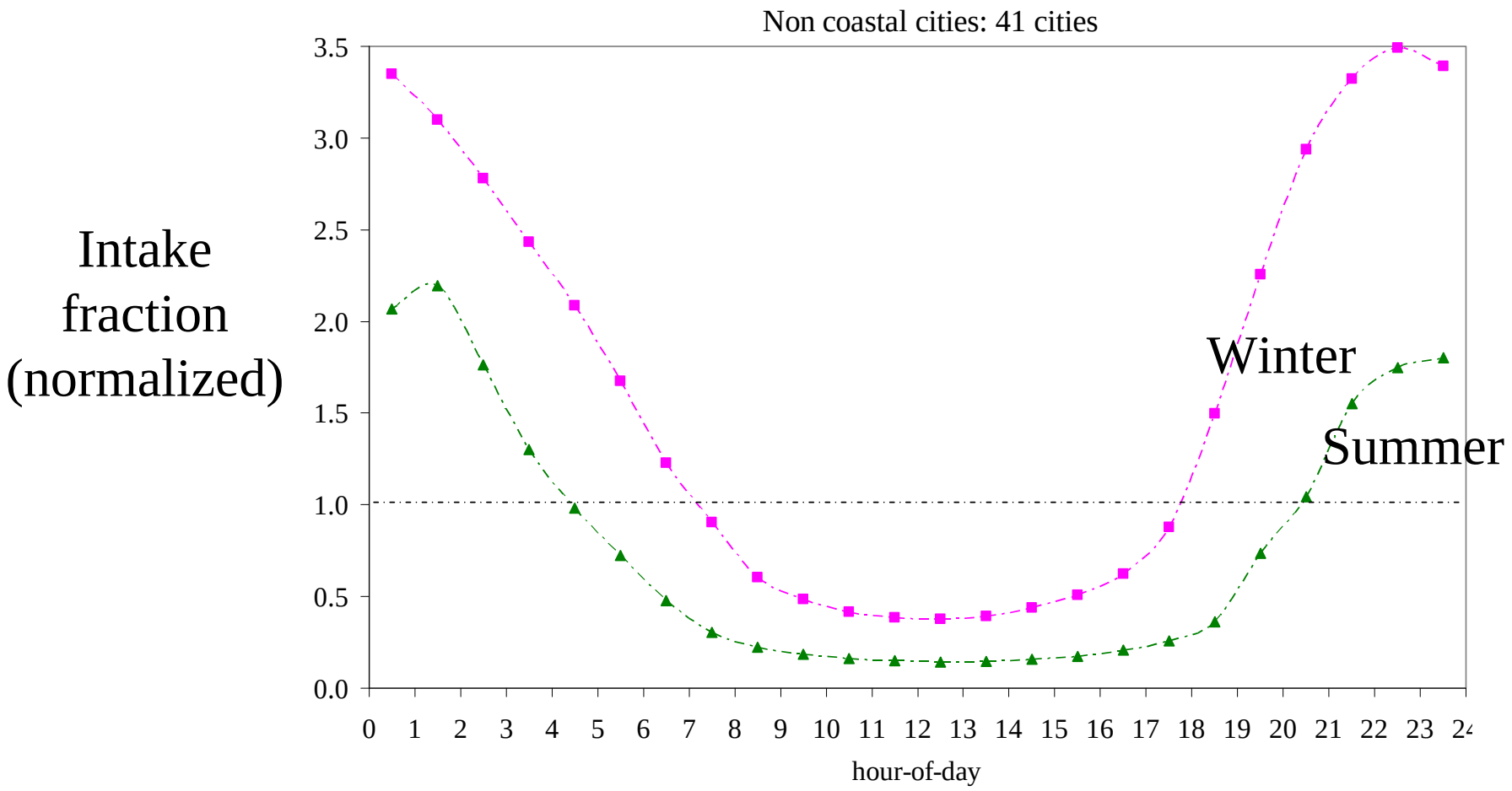


Comparison among diesel vehicles

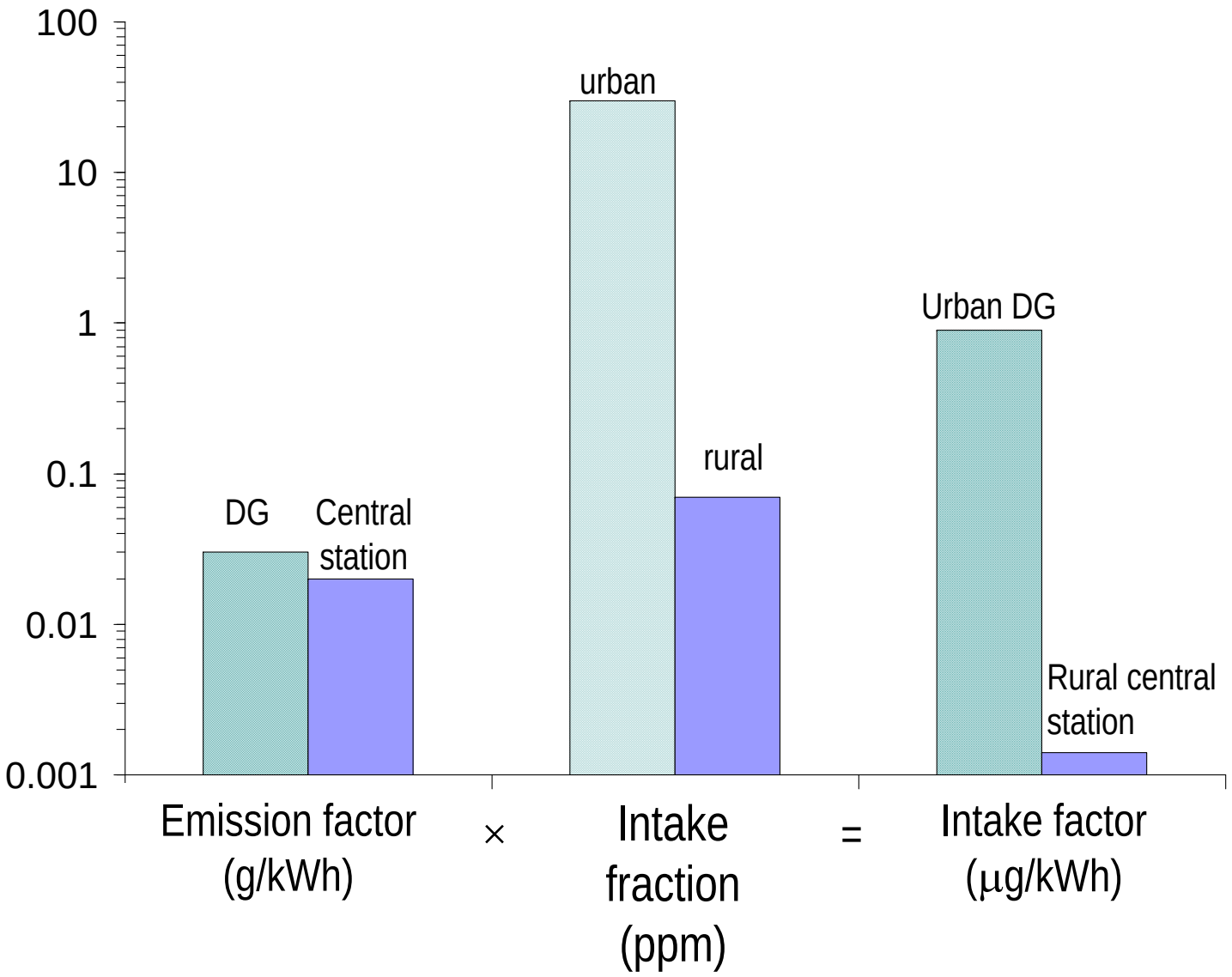
$PM_{2.5}$ inhaled per tonne emitted



Comparison by hour-of-day



Comparison: DG vs. central station

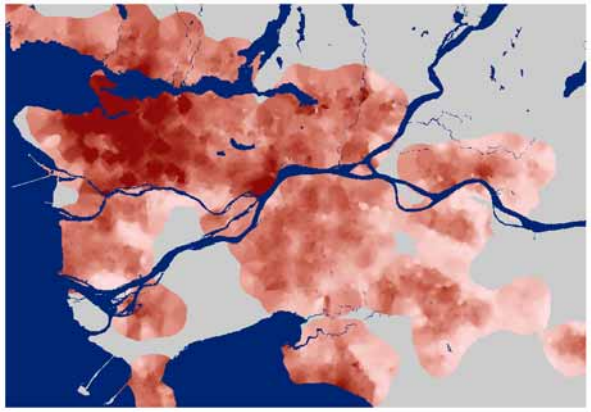


particulate matter ($PM_{2.5}$); urban (Los Angeles, CA) microturbine DG versus rural (Morro Bay, CA) combined-cycle central station.

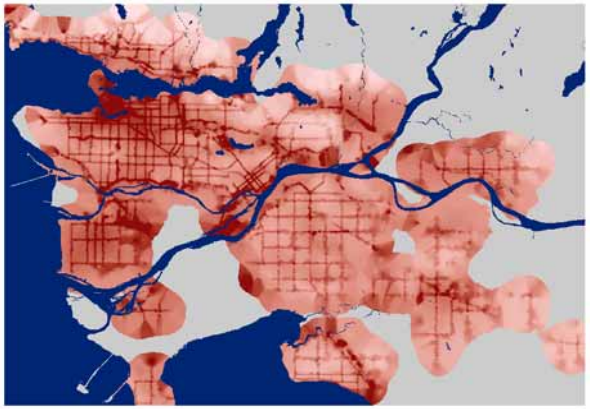
source: Heath et al., 2005.

2. Walkability & air pollution: Vancouver

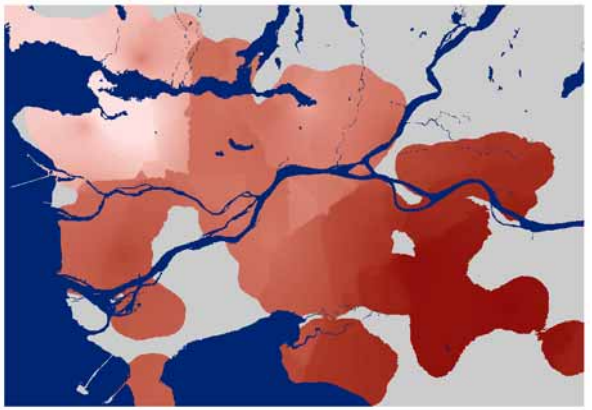
Walkability



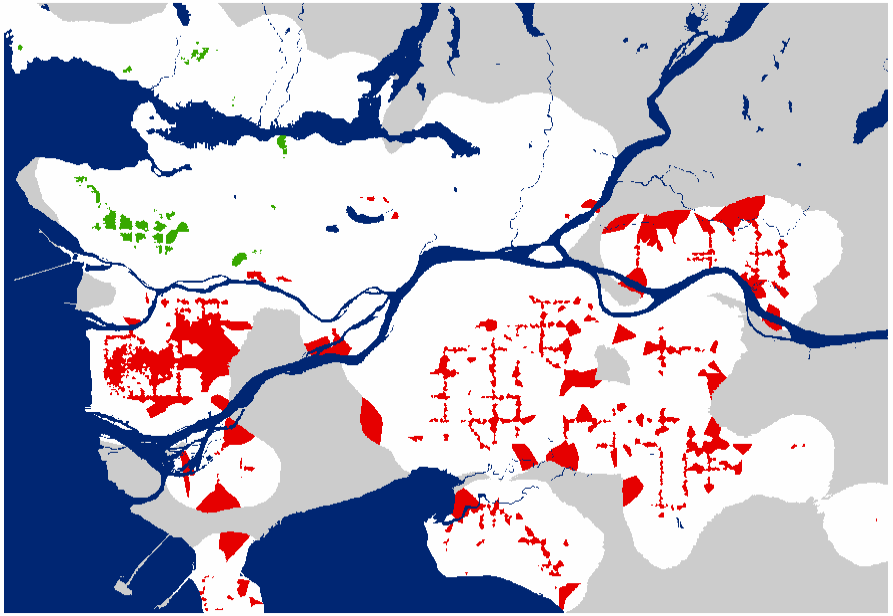
Nitrogen Oxide (NO)

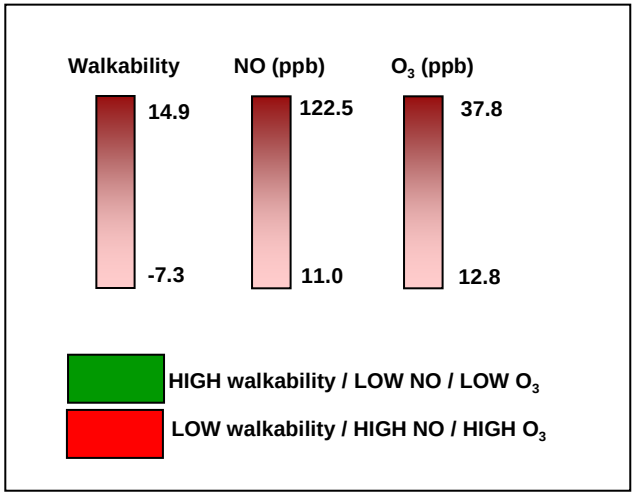


Ozone



“Sweet-spot” and “Sour-spot” Postal Codes





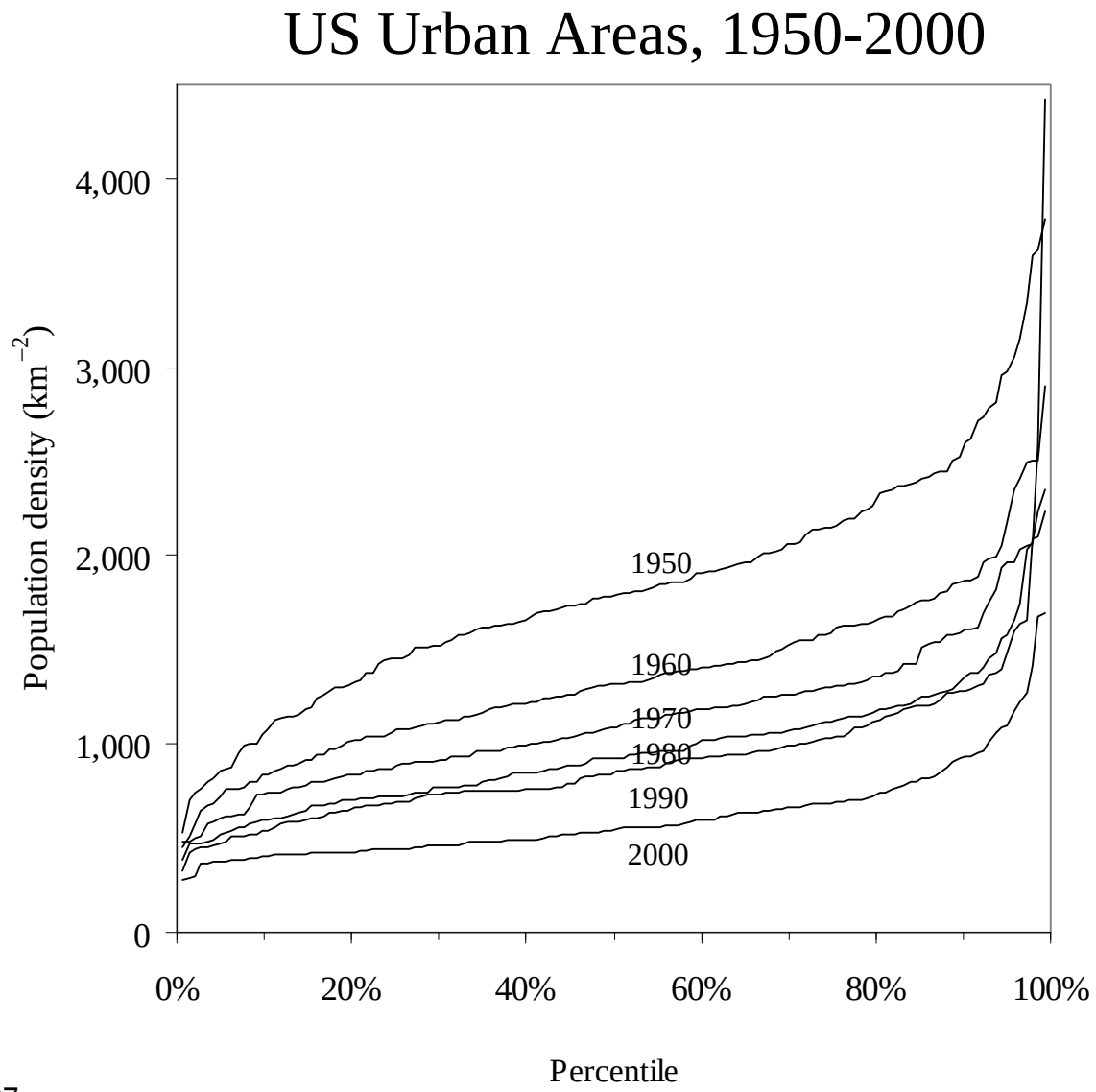
Walkability & AQ: main findings

- All three parameters (walkability, NO, O_3) exhibit an urban-rural gradient.
- NO and walkability are high for low-income; O_3 is high for middle-income.
- Sweet-spot neighborhoods (low pollution, high walkability) are rare and tend to be high-income and located near but not at the city-center.
- Sour-spot postal codes (high pollution, low walkability) are far from the city-center and are middle-income.

Future work:

- High-rises near rail stops?
- Changes over time: where is growth currently occurring?

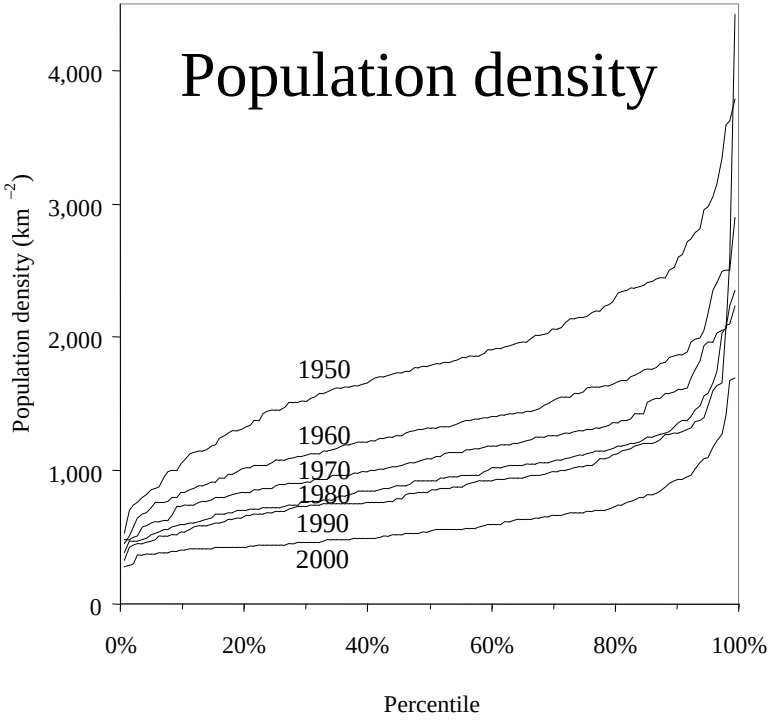
3. Urban growth: scaling rule

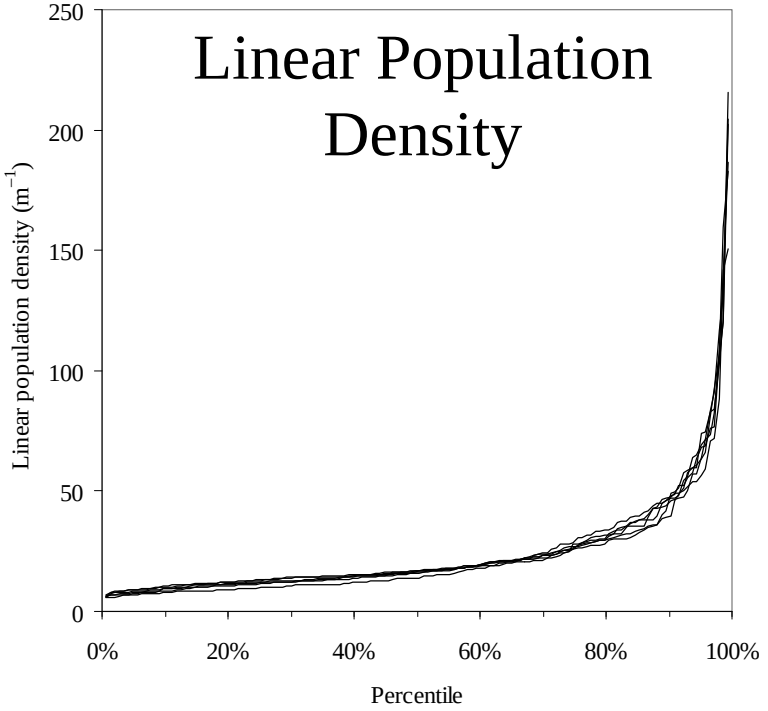


Source: Marshall, 2007

Measures of urban growth

Distributions by decade, US Urban Areas, 1950-2000





P / A
(people per sq km)

P / $A^{0.5}$
(people per m)

Source: Marshall, 2007

Urban scaling rule

The proposed equation is $A \propto P^n$.

- It appears to hold well for urban growth.
- '*n*' varies, with ~2 as a central estimate.
- LPD distribution is nearly constant over a half-century.

Current research:

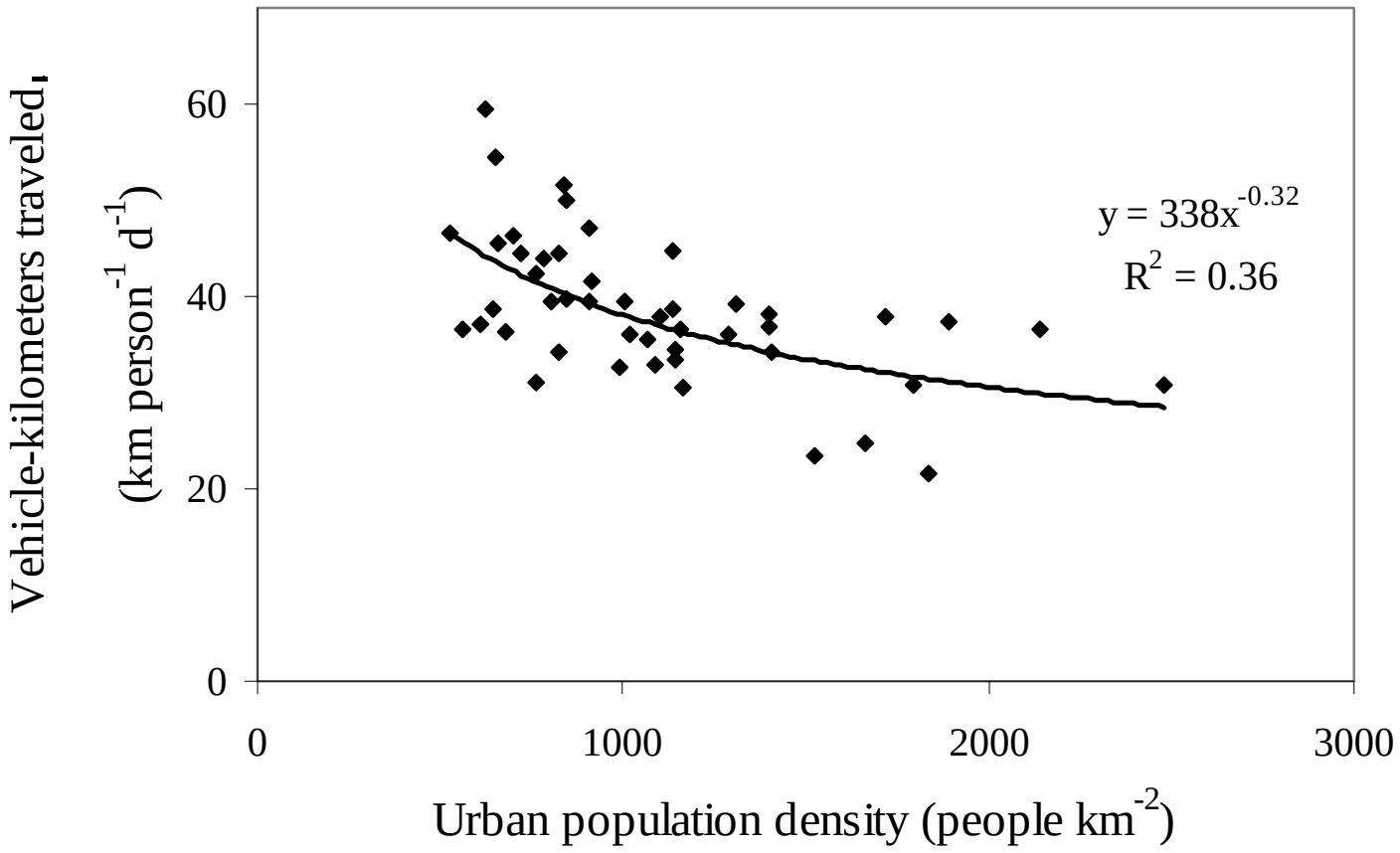
- Use the scaling rule to identify urban growth scenarios.
- Transportation-CO_2 emissions for scenarios.



4. Urban form & environment: satellite evidence

Can sprawl-reduction and other changes in urban form help address
- air quality,
- energy security, and
- climate security?

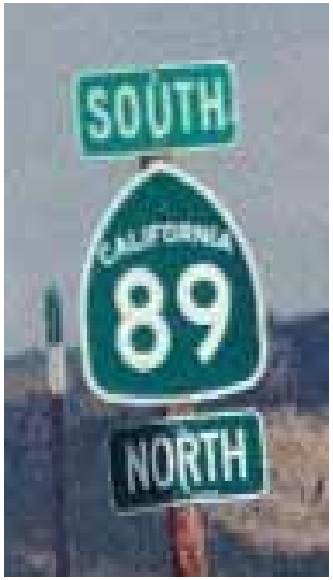
Urban form affects VKT



Source: US DOT; Marshall et al., 2006

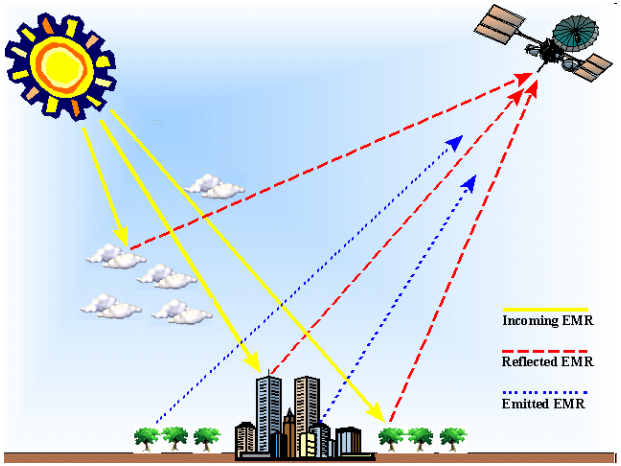
Urban form and air pollution

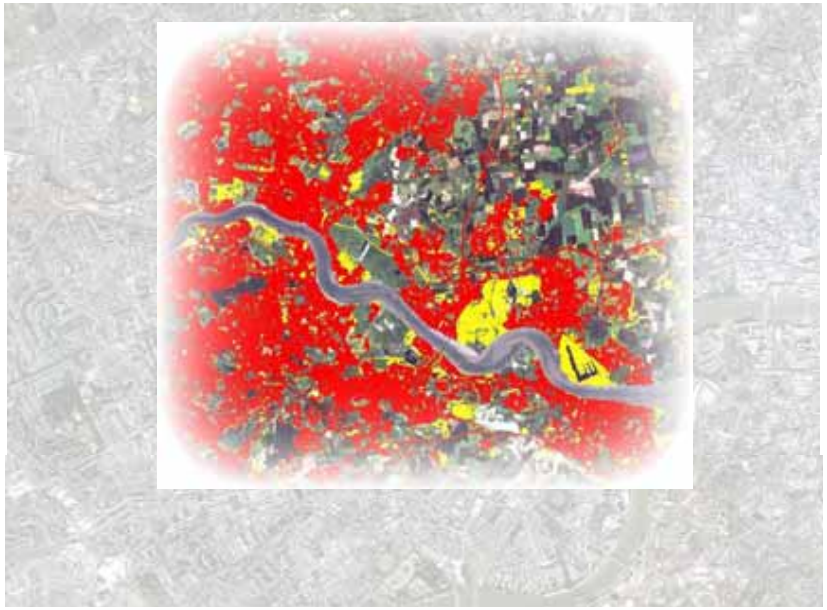
- Density affects transportation demand
- Density also affects proximity
- How does air pollution vary with density?



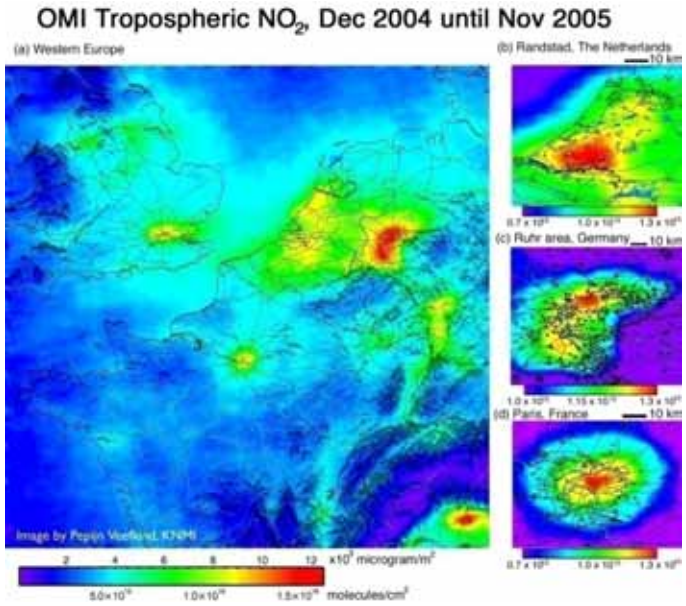
Reference: Marshall et al., 2005

Satellite evidence





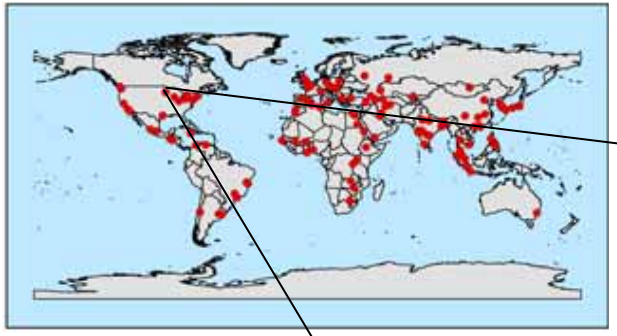
LandSat, 1972 – LandSat7, 1999



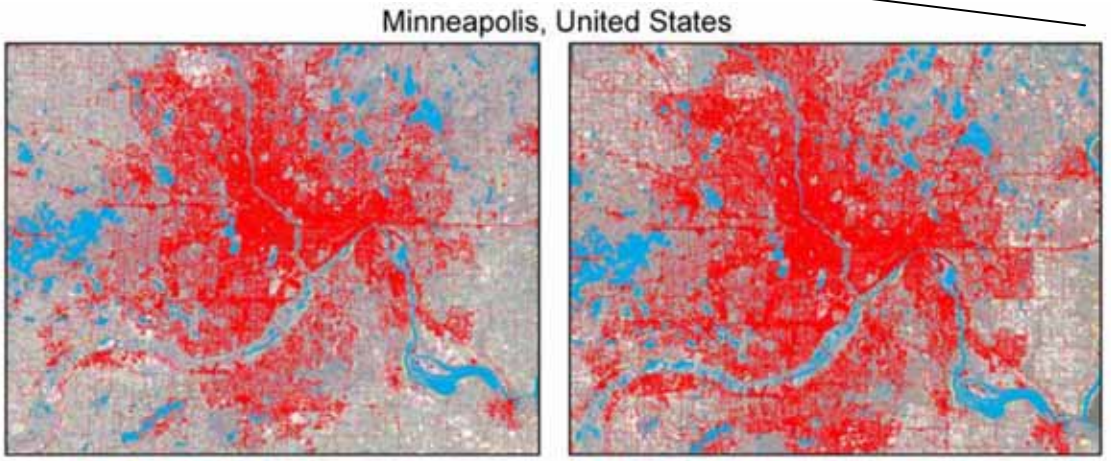
Aura/OMI, 2004

With D. Millet

Satellite evidence



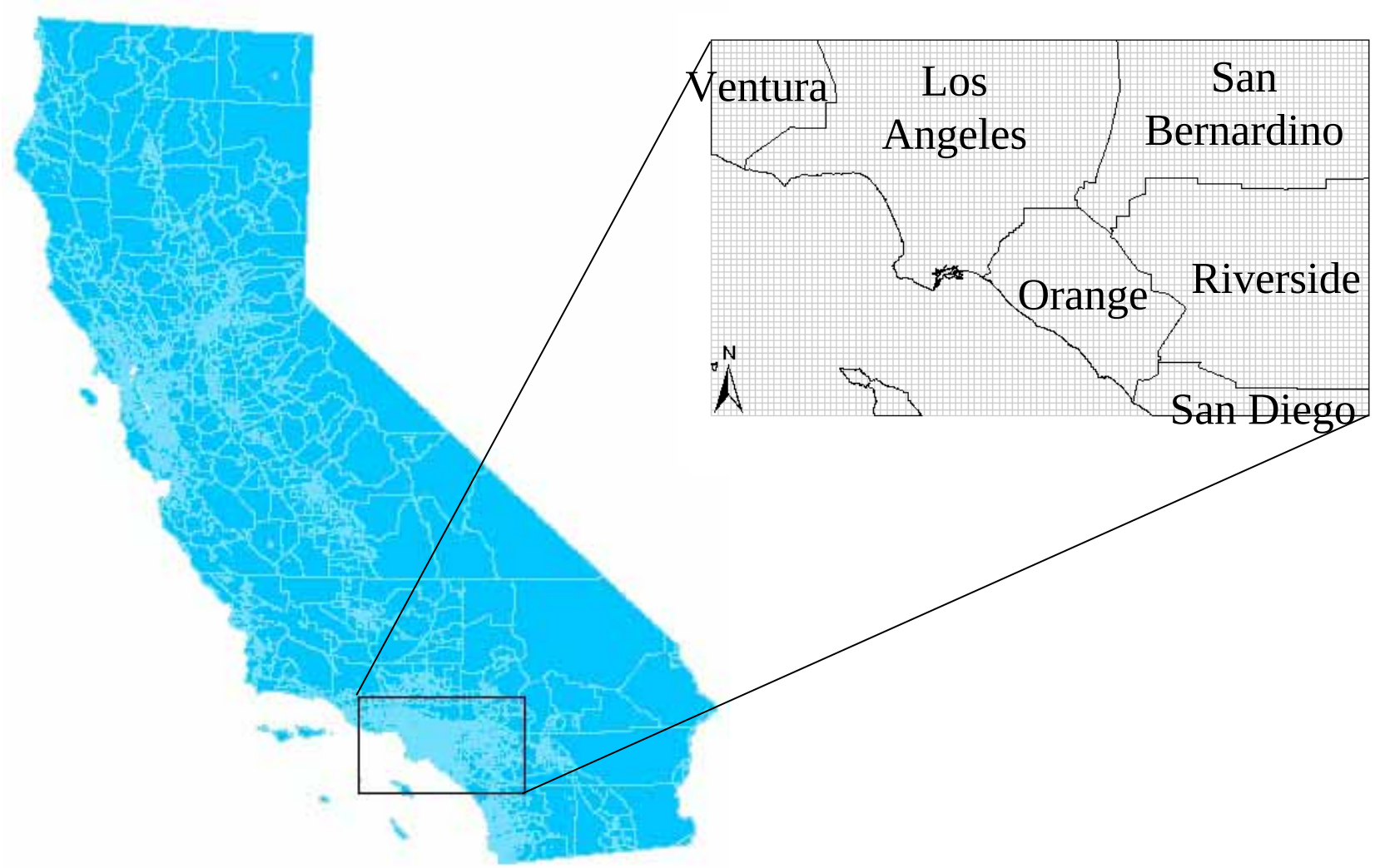
84 cities worldwide



Measure	T_1	T_2	Annual % Change
Population	2,166,839	2,483,341	1.56%
Built-Up Area (sq km)	1,079.31	1,427.62	3.24%
Average Density (persons / sq km)	1,917.39	1,609.17	-1.98%
Built-Up Area per Person (sq m)	521.54	621.44	2.02%
Average Slope of Built-Up Area (%)	2.72	2.86	0.56%
Maximum Slope of Built-Up Area (%)	15.79	16.28	0.35%
The Buildable Perimeter (%)	0.90	0.87	-0.30%
The Contiguity Index	0.66	0.90	3.53%
The Compactness Index	0.36	0.36	-0.01%
Per Capita Gross Domestic Product	$27,328.93	$31,958.98	1.80%

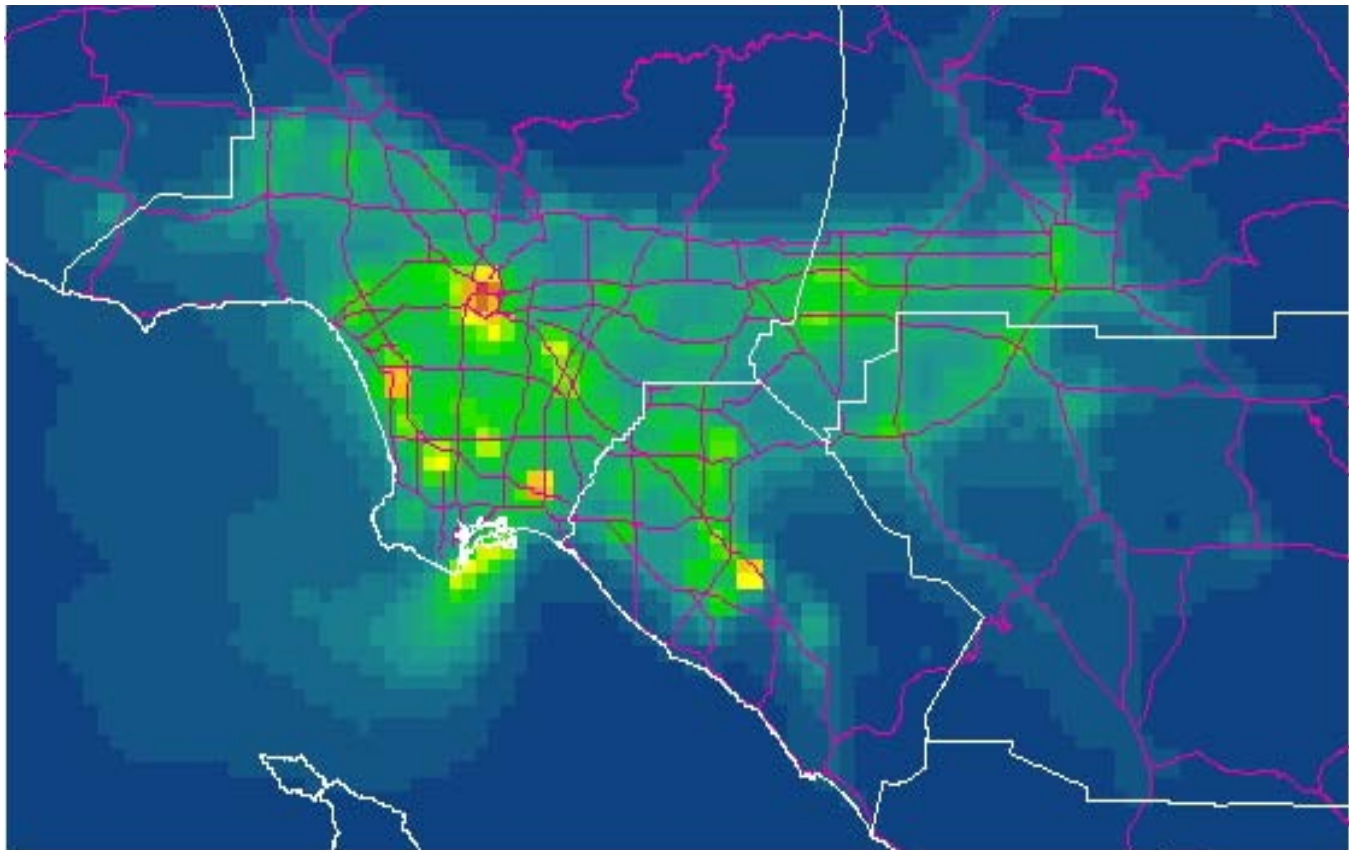
Source: Angel et al., 2005

5. Exposure simulation for California's South Coast

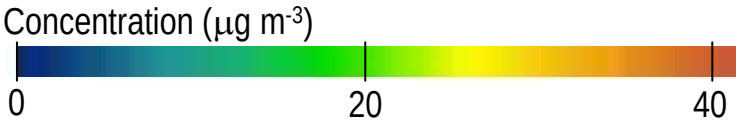


South Coast: Concentrations

Diesel $PM_{2.5}$



8:00 am, Nov 3, 1998

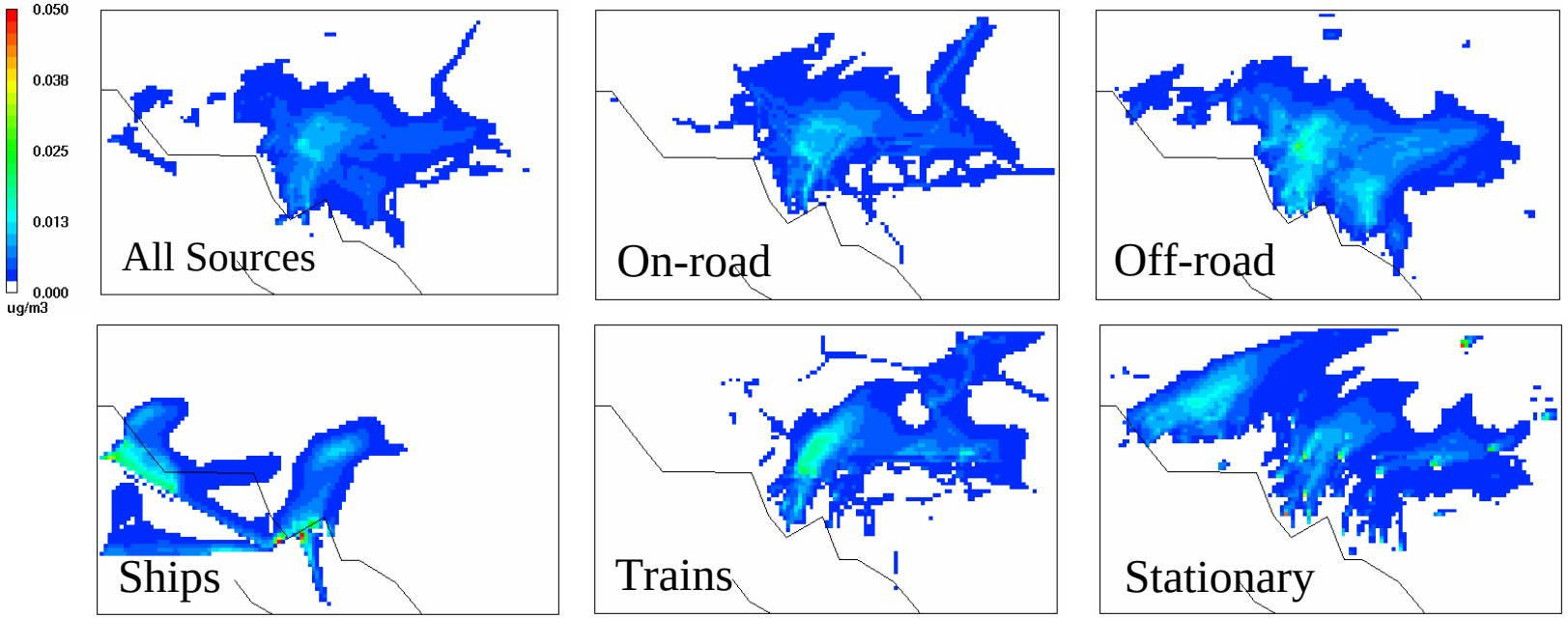


South Coast: Concentrations

Movie

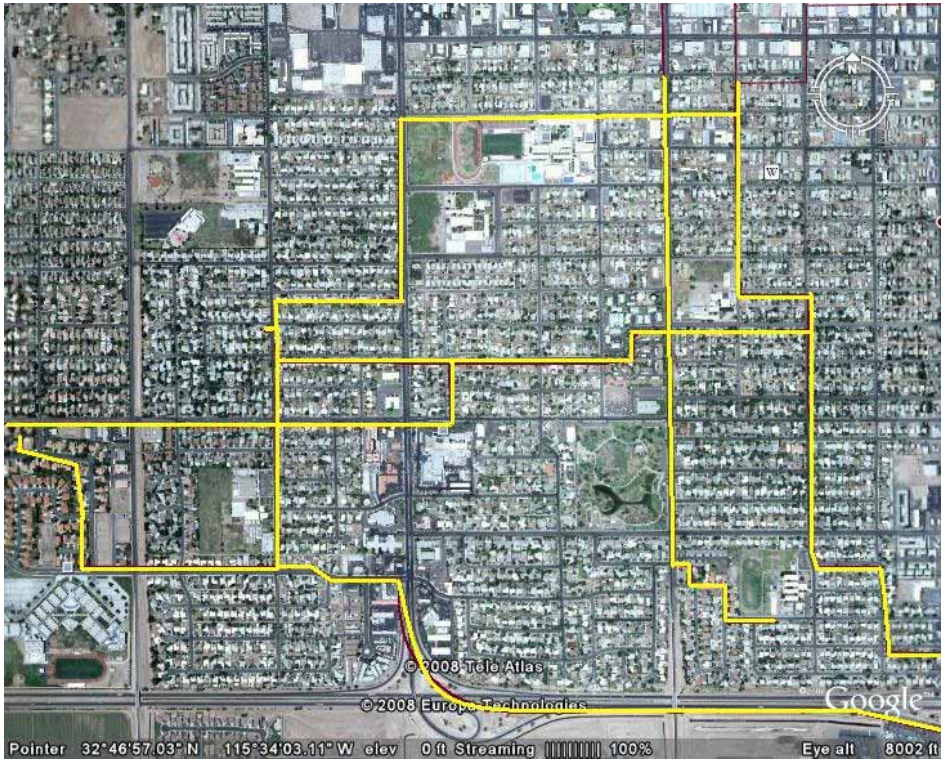
Spatial impacts vary per source: diesel particles

Concentrations change from an emission reduction (1 ton per week)



South Coast: Mobility

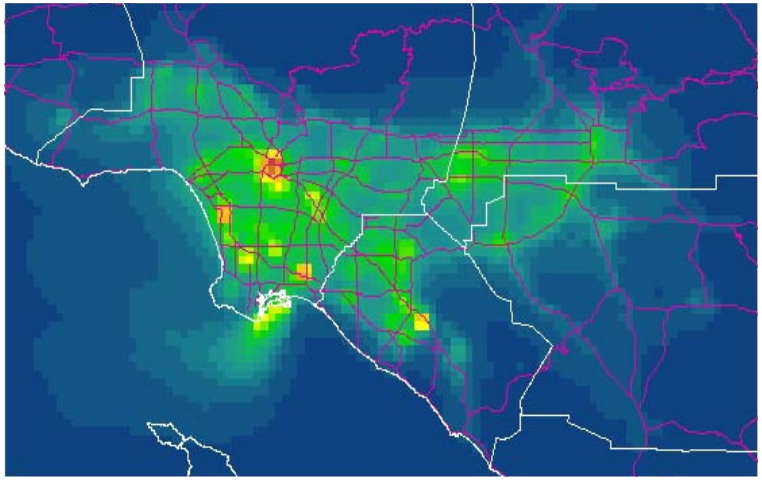
TRAVEL DIARY ROUTE



South Coast: Results

Output:

- Inhalation rate (g d^{-1}) for each pollutant for each individual

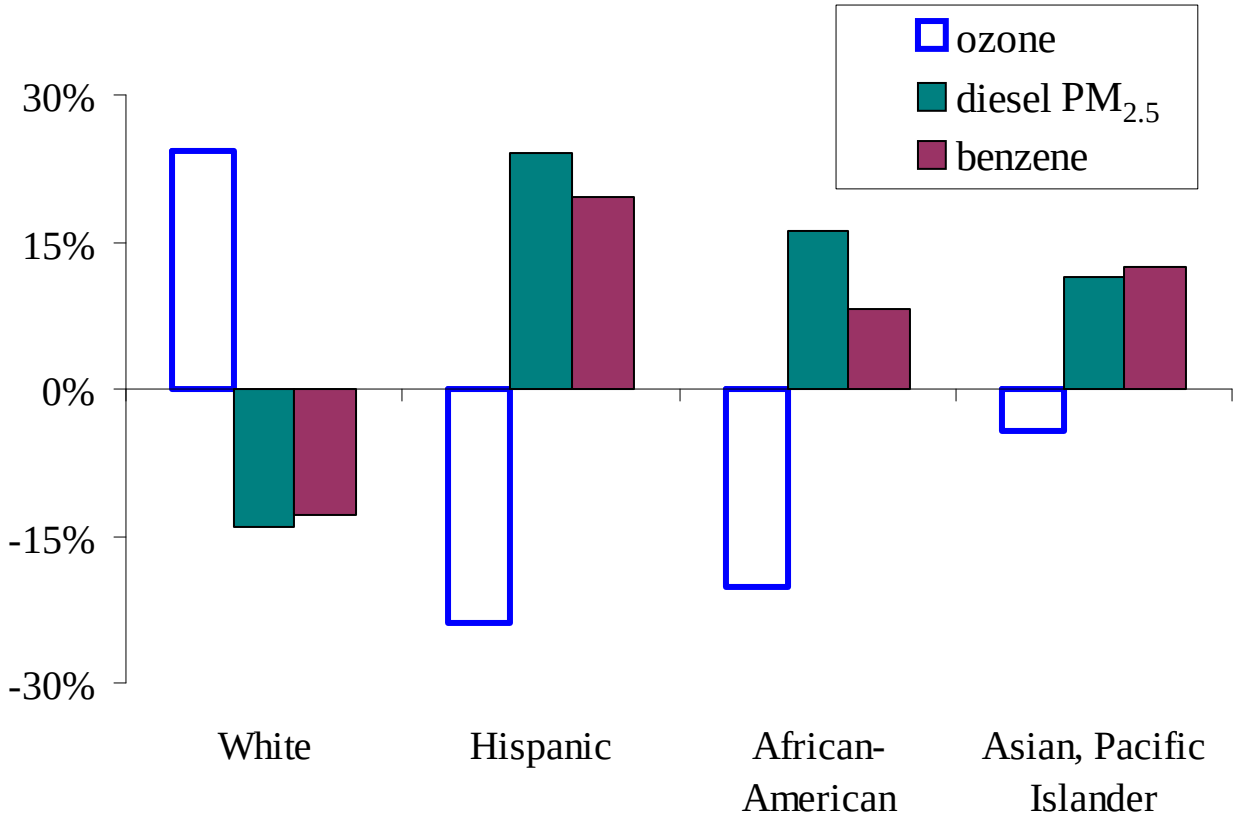


Analyses:

- Environmental justice
- Strategies for improvement

Intakes and ethnicity

Median intake, relative to population median

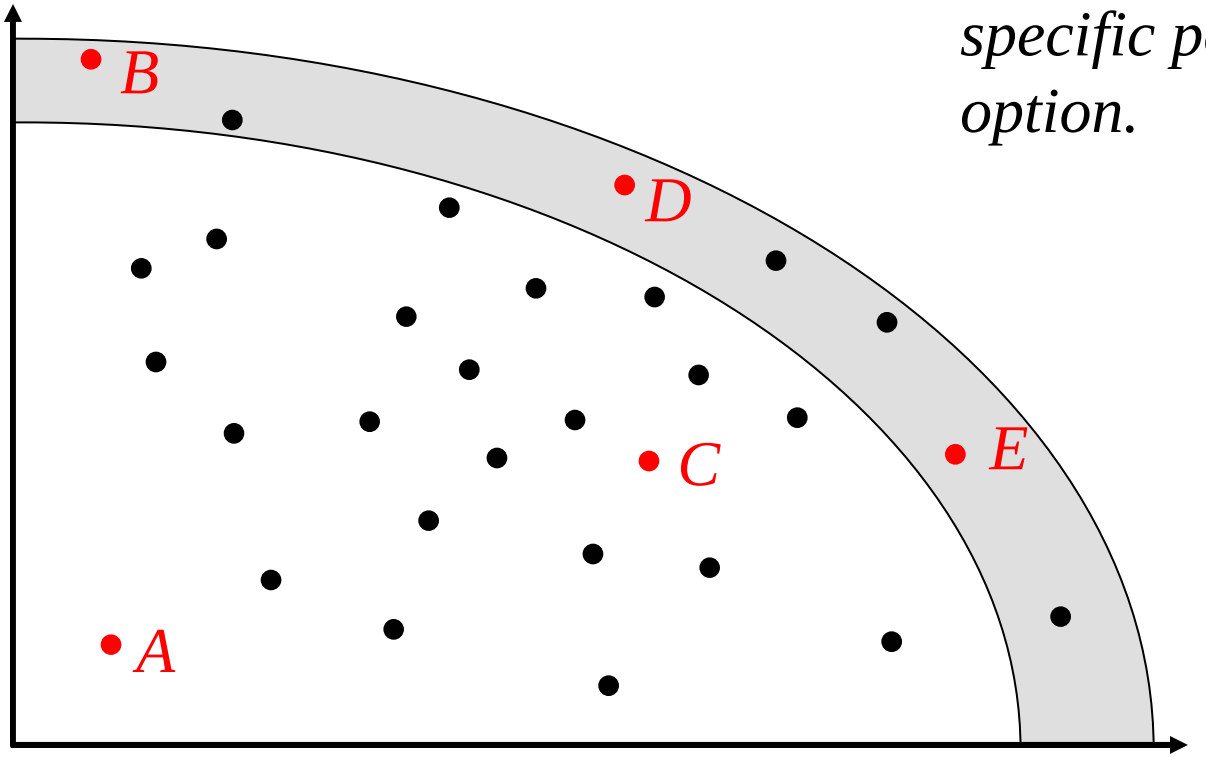


Source: Marshall et al., 2006, Marshall, 2008

Pareto-optimal improvements: theory

Each dot is a specific policy option.

Reduction in exposure inequity



Reduction in average exposure

Goal: Healthy cities, blue skies

The garden city is a will-o'-the-wisp. Nature melts under the invasion of roads and houses and the promised seclusion becomes crowded settlement — but the solution will be found in the vertical garden city, the fruit of modern technology adapted to the conditions of modern life.

– Le Corbusier

Acknowledgements

Faculty collaborators

- E Wilson (Public Policy), D Kittelson (Mechanical Engineering), D Millet (Soil, Water, & Climate), G Ramachandran (Public Health)
- M Brauer (Public Health, UBC), L Frank (Urban Planning, UBC)

Students

- K Lundquist, M Bechle, S Hankey

Thank you.