Mitigation of Roadside Aerosols:

New data, new challenges, new opportunities

A presentation for Vegetation for Mitigation

June 2, 2015

Programs of the Breathe California/ Health Effects Task Force and UC Davis DELTA Group;

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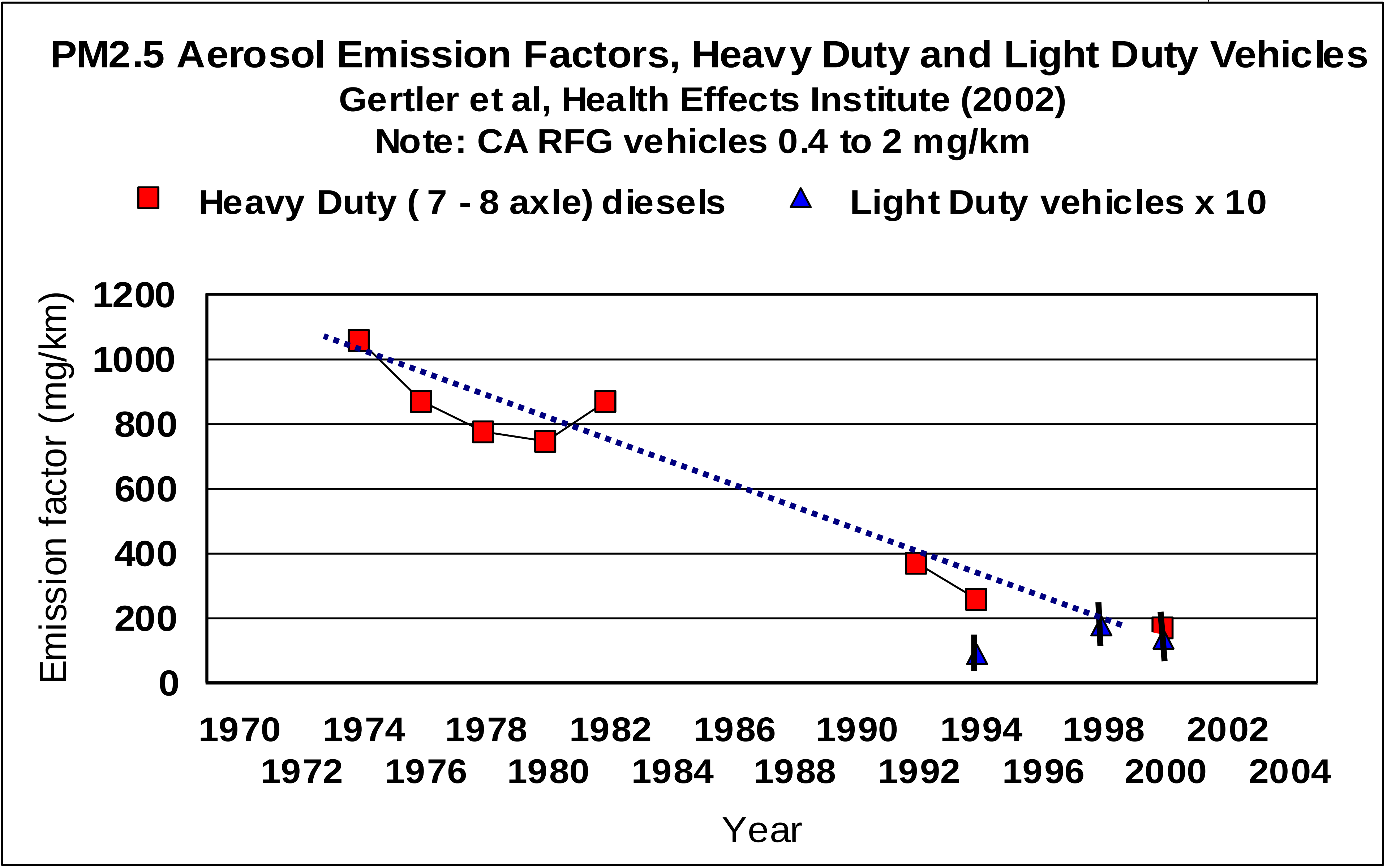
HETF assessment (circa 2005) of problems to be addressed for effective mitigation:

- Problem #1 What are we trying to mitigate, and why are we doing it?
- Problem # 2 Despite greatly reduced roadway emissions, health impacts continue to be observed.
- Problem #3 The health effects seen near roadways extend much farther out than models and data predict.
- Problem #4 The growing important of ultra fine metallic “wear” aerosols that lack data and are hard to model with vegetation.

Why do we still need to mitigate roadways?

We have achieved massive reductions in source emissions!



How are lower emission rates reflected in roadway aerosol measurements?

- **Assumptions**: Freeways, ≃ 5,000 v/hr, at grade, no obstructions, lateral winds 2 to 5 m/sec, freely moving vehicles circa 100 km/hr., 7% ± 3% heavy diesels.
- **Data** – $PM_{2.5}$ mass, size resolved and speciated aerosols, measured at downwind edge circa 10 m
  - 1973 Los Angeles 25 ± 3 μg/m^3 measured + modeled 1972 emission data

    (included 4.0 ± 0.3 μg/m^3 of ultra fine lead in the form PbBrCl) measured and modeled from emissions

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  - 1973 Los Angeles — 25 ± 3 μg/m^3 — measured + modeled 1972 emission data
  - 2008 Europe — 5.0 ± 1 μg/m^3 — measured
  - 2010 Michigan — 2.7 ± 0.5 μg/m^3 — modeled from 2002 emission data
  - 2010 Michigan — 2.0 ± 0.7 μg/m^3 — measured

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Despite lower emission rates, there are still well documented health impacts:

- For children,
  - Cancer (x6), leukemia (x8), asthma, and general respiratory distress, etc, etc. (Zhu et al 2009) including "Lung function in children living near freeways", Gauderman et al 2007 -

- For adults,
  - **Diesel exhaust and cancer**
    - Prop 65 Toxic Air Contaminant – ~ 2/3 of total cancer risk,
  - C**ardio-vascular disease**
    - HEI summary, 2009, HETF Central Valley Studies, (Cahill et al 2011), EPA ufp Meeting, ultra fine particles (Feb, 2015)
  - **Increased chance for strokes and decreased brain volume**

    Long-Term Exposure to Fine Particulate Matter, Residential Proximity to Major Roads and Measures of Brain Structure Wilke et al**, Stroke (2014)**

Despite lower emission rates, there are still well documented health impacts: possible causal agents?

- For children,
  - Cancer (x6), leukemia (x8), asthma, and general respiratory distress, etc, etc. (Zhu et al 2009) including "Lung function in children living near freeways", Gauderman et al 2007 -Very fine (< 0.25 µm) iron ?

- For adults,
  - **Diesel exhaust and cancer** (< 0.25 µm ultra fine PAHs)
    - Prop 65 Toxic Air Contaminant – ~ 2/3 of total cancer risk,
  - **Cardio-vascular disease** – (ultra fine metals)
    - HEI summary, 2009, HETF Central Valley Studies, (Cahill et al 2011), EPA ufp Meeting, ultra fine particles (Feb, 2015)
  - **Increased chance for strokes and decreased brain volume** (Only PM2.5 measured)
    - Long-Term Exposure to Fine Particulate Matter, Residential Proximity to Major Roads and Measures of Brain Structure Wilke et al**, Stroke (2014)**

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Problem # 3 Distances all wrong, and causal source(s) of the problem unknown.

Gauderman et al 2007

Distances for loss of lung function

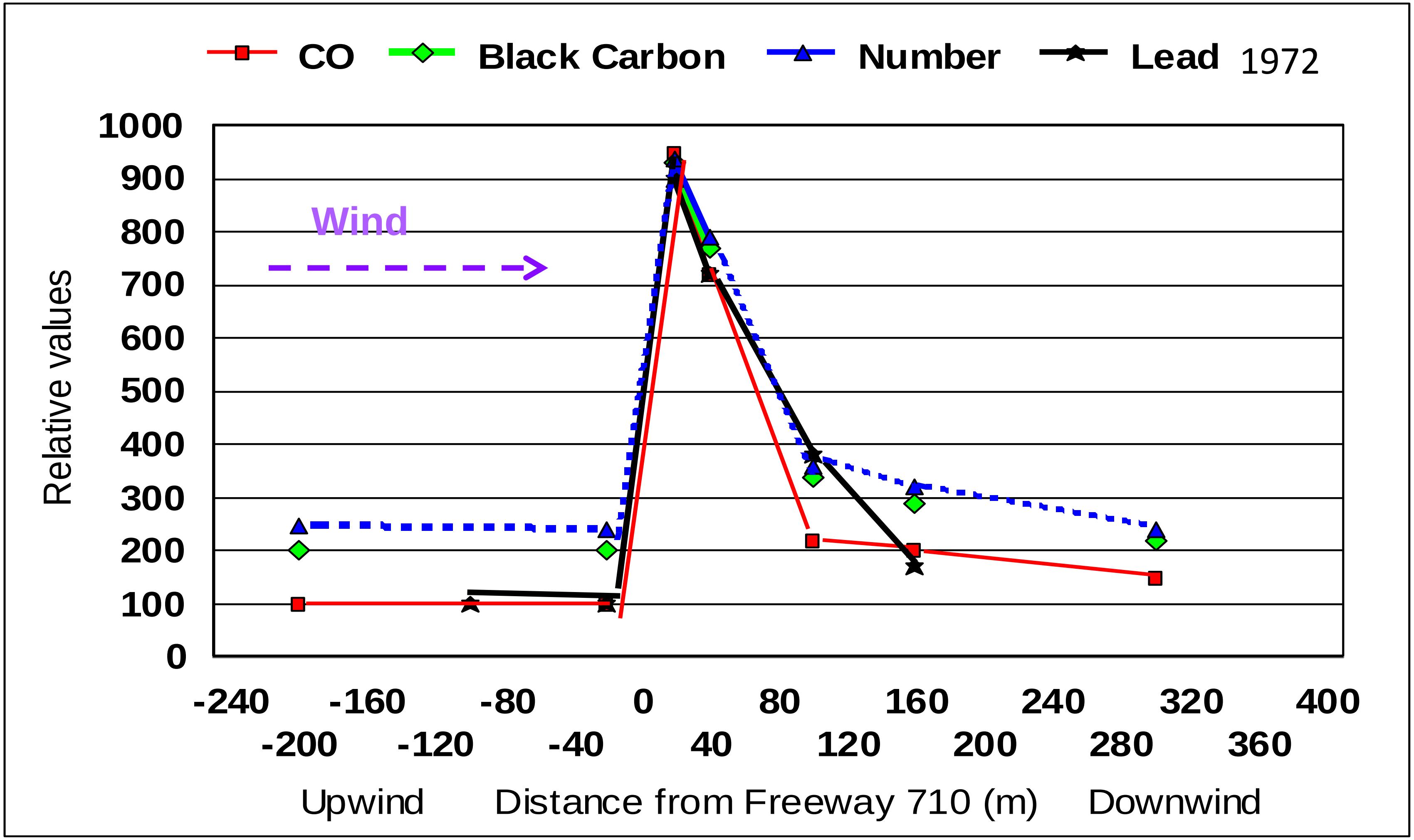
< 530 m,

<1060 m,

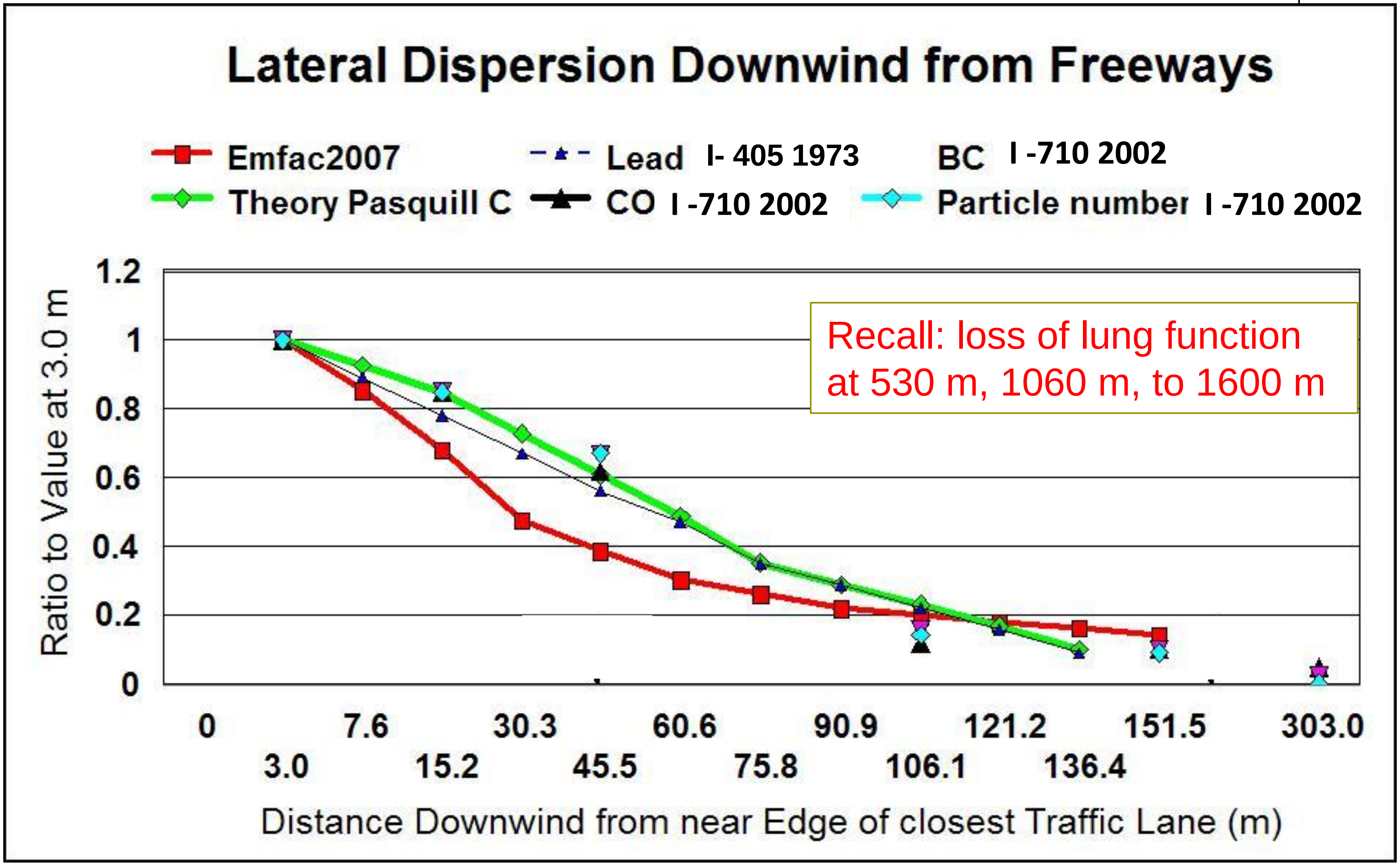
1060 m to 1600 m,

> 1600 m

Profile of gaseous and ultra fine pollutants near at-grade freeways (Zhu et al, 2002, I-710) and 1972 lead data (Cahill et al, 1973)



Comparison of line source diffusion models and pollutants downwind of an at-grade freeway



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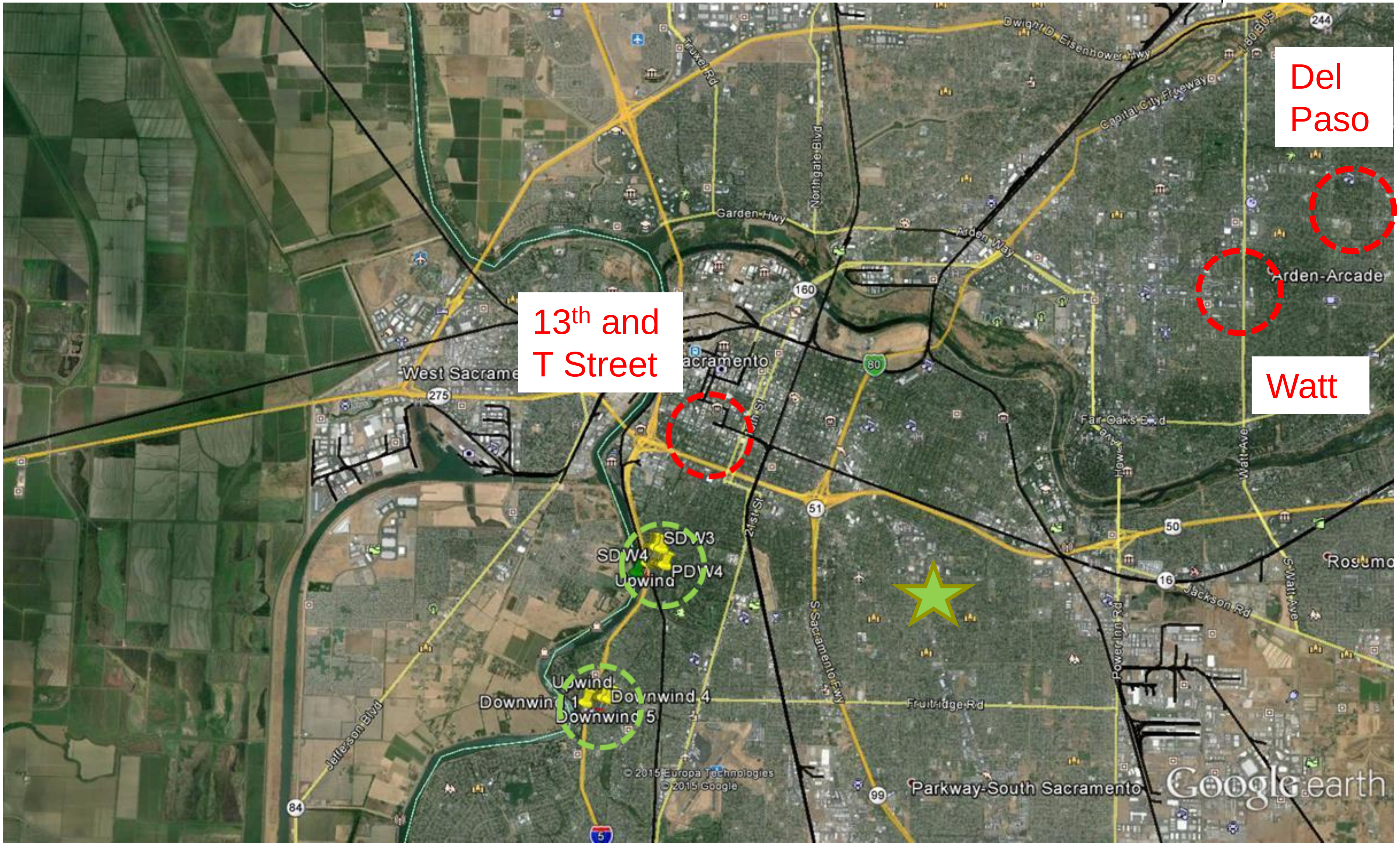
Problem #4: Europe – "wear" aerosols will soon equal tailpipe aerosols. What do we know?

- **PM_{10} "wear" aerosols**
  - Good theoretical and experimental data on concrete roadbeds (Typically about 0.8 ± 0.4 $\mu g/m^3$ but no asphalt data) and non-soil iron (Typically 1.0 ± 0.5 $\mu g/m^3$, often > 10 x what is in soil).
  - Fair data on zinc (tire wear) (Widely varying from 0.02 $\mu g/m^3$ to 0.22 $\mu g/m^3$)
- **Ultra fine (uf) tailpipe aerosols < 0.25 µm**
  - Good experimental and theoretical data on zinc, sulfur, and phosphorus from diesels (Zielinska et al 2004)
  - Little if any data on metals in uf "wear" aerosols

While doing a Sacramento Valley transect of aerosols from I-5 and Hwy 99, the HETF/UCD developed ultra-fine "wear" data as an unexpected benefit of helping Arden Middle School, which was directly downwind of Watt Avenue

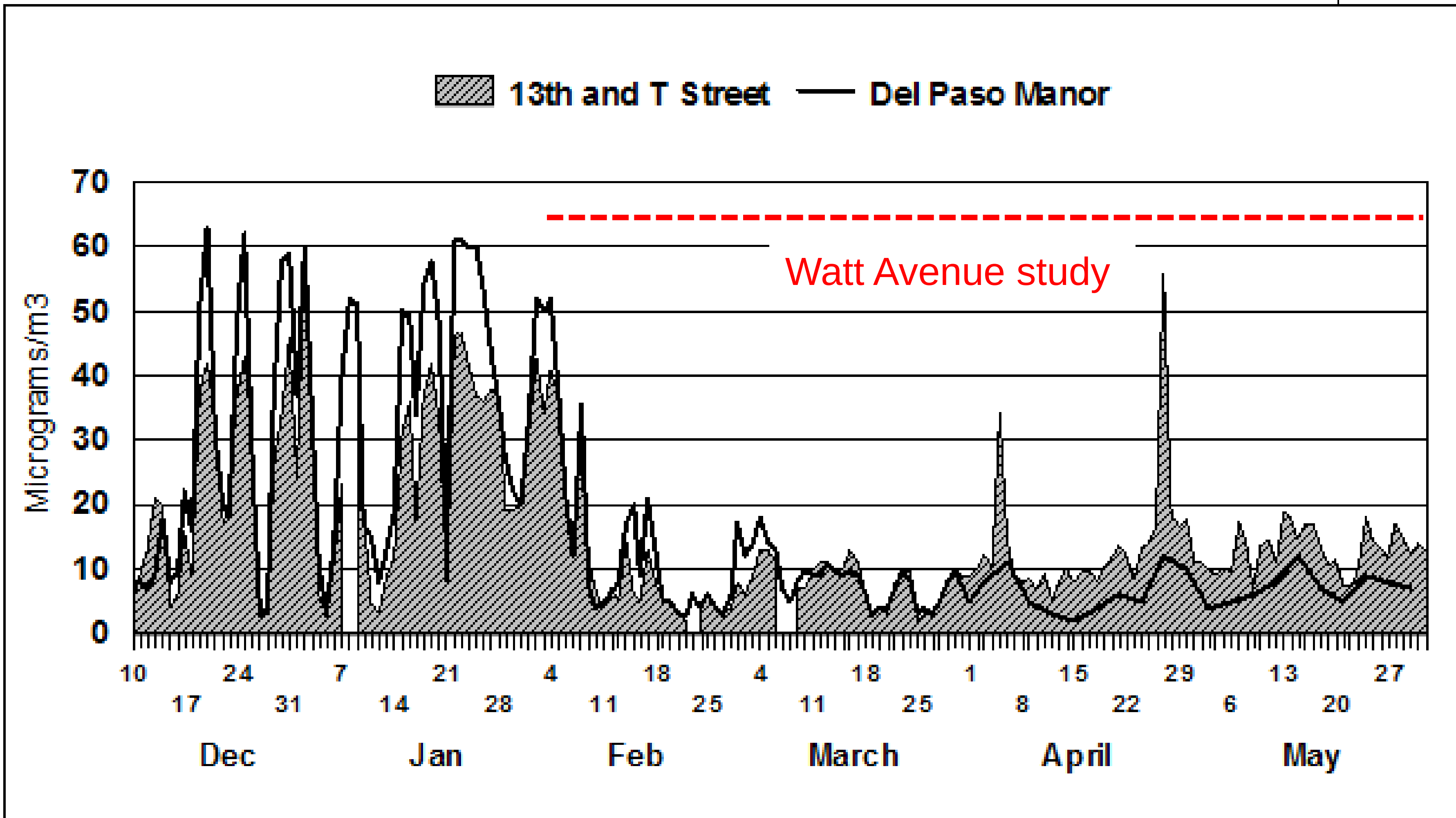
Sacramento; 13th and T St. , Watt and Arden, Del Paso Manor; I-5 Transects



Watt Ave Traffic – 15 m from school: 9 lanes of traffic, 65,000 v/day (1.5% diesels), and a stop light

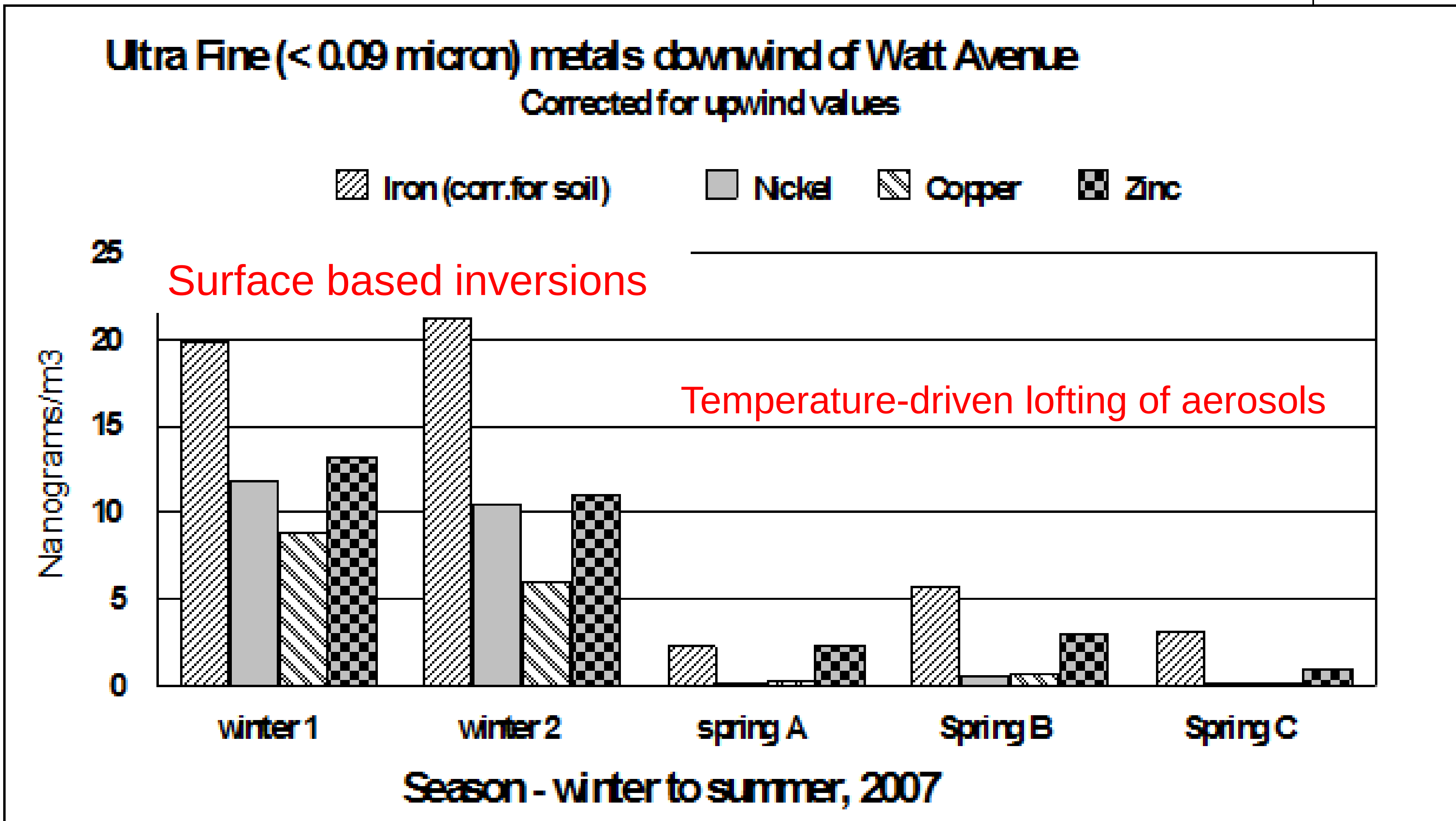
$\cong$ $PM_{2.5}$ mass as 165,000 v/day, (12% diesels) on I-5!

Pattern of $PM_{2.5}$ from winter (strong inversions) to spring and summer. The Del Paso Manor site is near Watt Avenue



Good news: The site 500 m upwind **had almost no ultrafine metals** (few % of the downwind values)

Bad news: Significant ultra fine (< 0.09 µm) transition metals downwind of Watt Avenue



Composition of brake pads. Brake drums also erode from a "grey iron" with a graphite admixture.

(Also must add uf zinc from zinc thio-phosphate in motor oil).

(Zielinska et al 2004)

Element (ppm)	10^{th} percentile	median	90^{th} percentile
Iron	**11,700**	**18,300**	**190,000**
Copper	**29**	**5,000**	**116,000**
Zinc	**127**	**1630**	**37,400**
Nickel	**44**	**342**	**652**
Manganese	**143**	**315**	**1088**
Lead	6	50	949
Barium	558	3195	6144

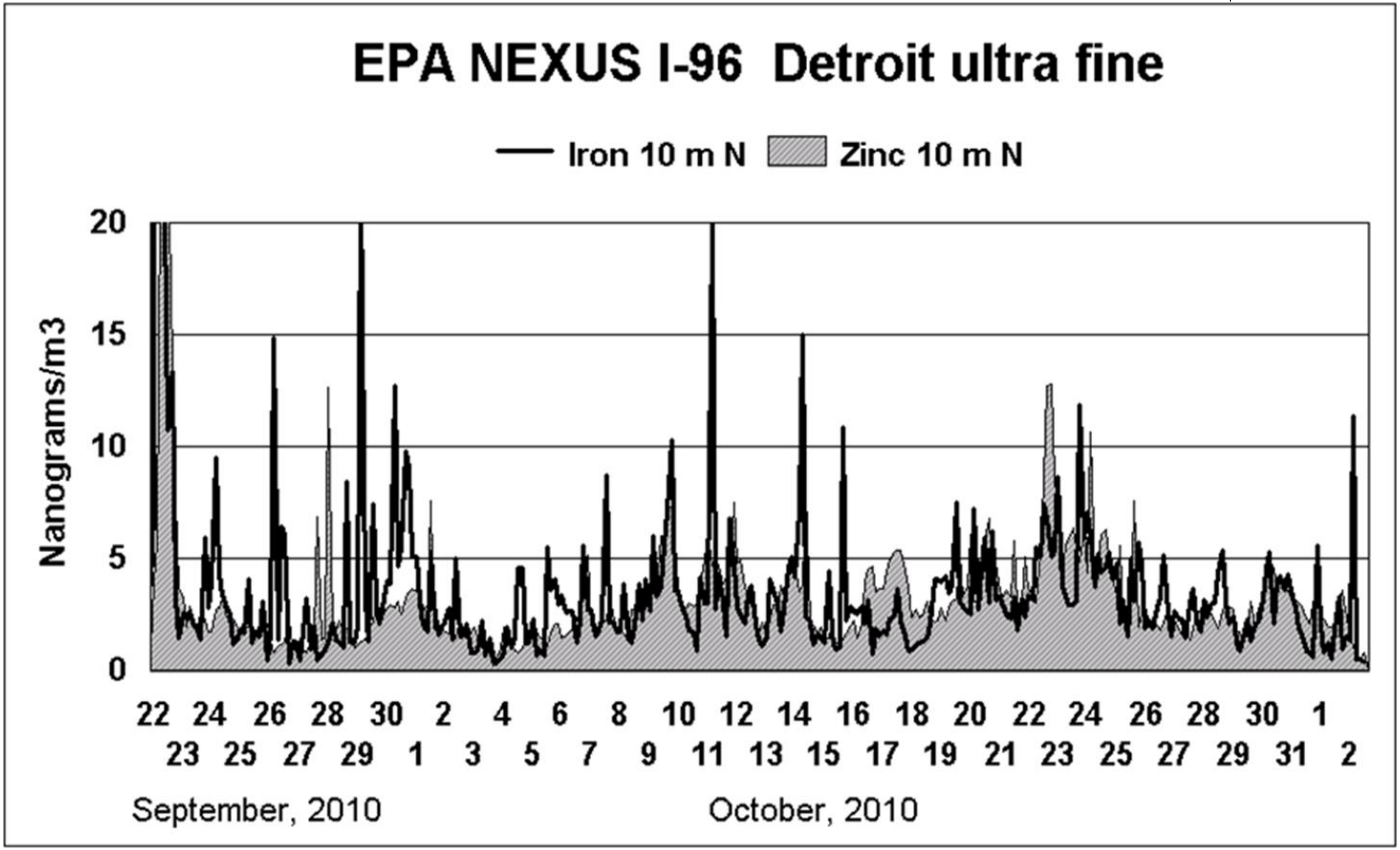
- Cahill, Thomas A., David E. Barnes, Nicholas J. Spada, **Seasonal variability of ultra-fine metals downwind of a heavily traveled secondary road**, Atmospheric Environment 94 173 - 179 (2014)

Table 4. Summary of concentrations of elements in New Zealand brake pads (Kennedy et al (2002), from largest to smallest concentrations of transition metals plus heavier elements

EPA/U. Michigan/UC Davis NEXUS study 9 miles west of Detroit

Figure 2. NEXUS transect array across I-96 west of Detroit.

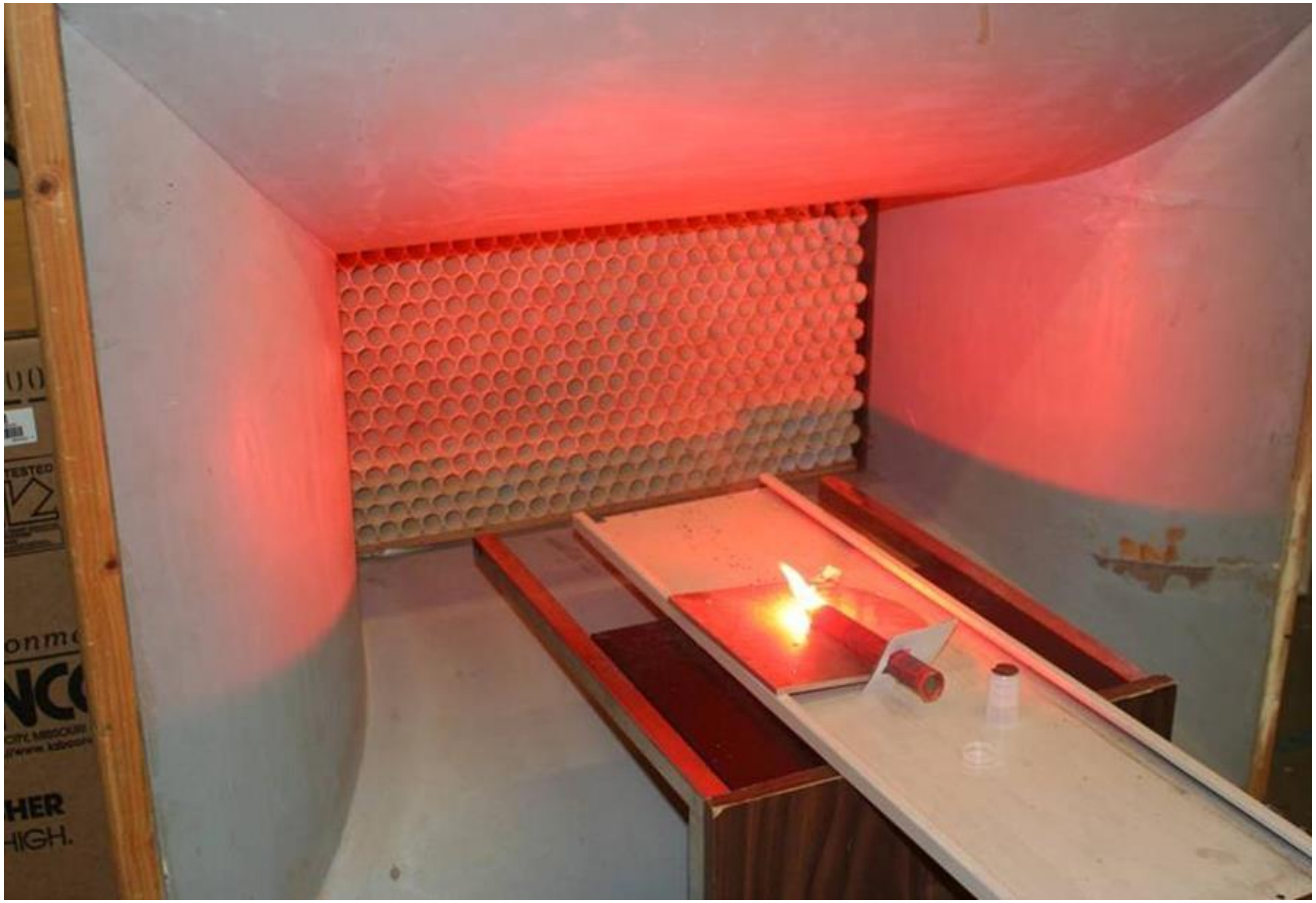
Ultra-fine (< 0.09 µm) iron and zinc, the two largest elements see heavier than calcium



Comparison – Ultra fine metals , Watt Avenue to NEXUS Detroit

The four largest ultra-fine elements heavier than calcium		HETF/UCD Watt Avenue (Spring, 2007) 15 m east		EPA/U. Mich./UCD NEXUS I-96 (October 2010) 10 m north	
		ng/m^3		ng/m^3	
Iron (small correction for soil)		3.7		3.3	
Nickel		0.43		0.40	
Copper		0.5		1.9	
Zinc		2.2		3.2	

To measure the impact of vegetation, we need transects. Since we no longer have lead as a tracer, highway flares can serve as a unique very fine/ultra fine (< 0.25 µm) aerosol source

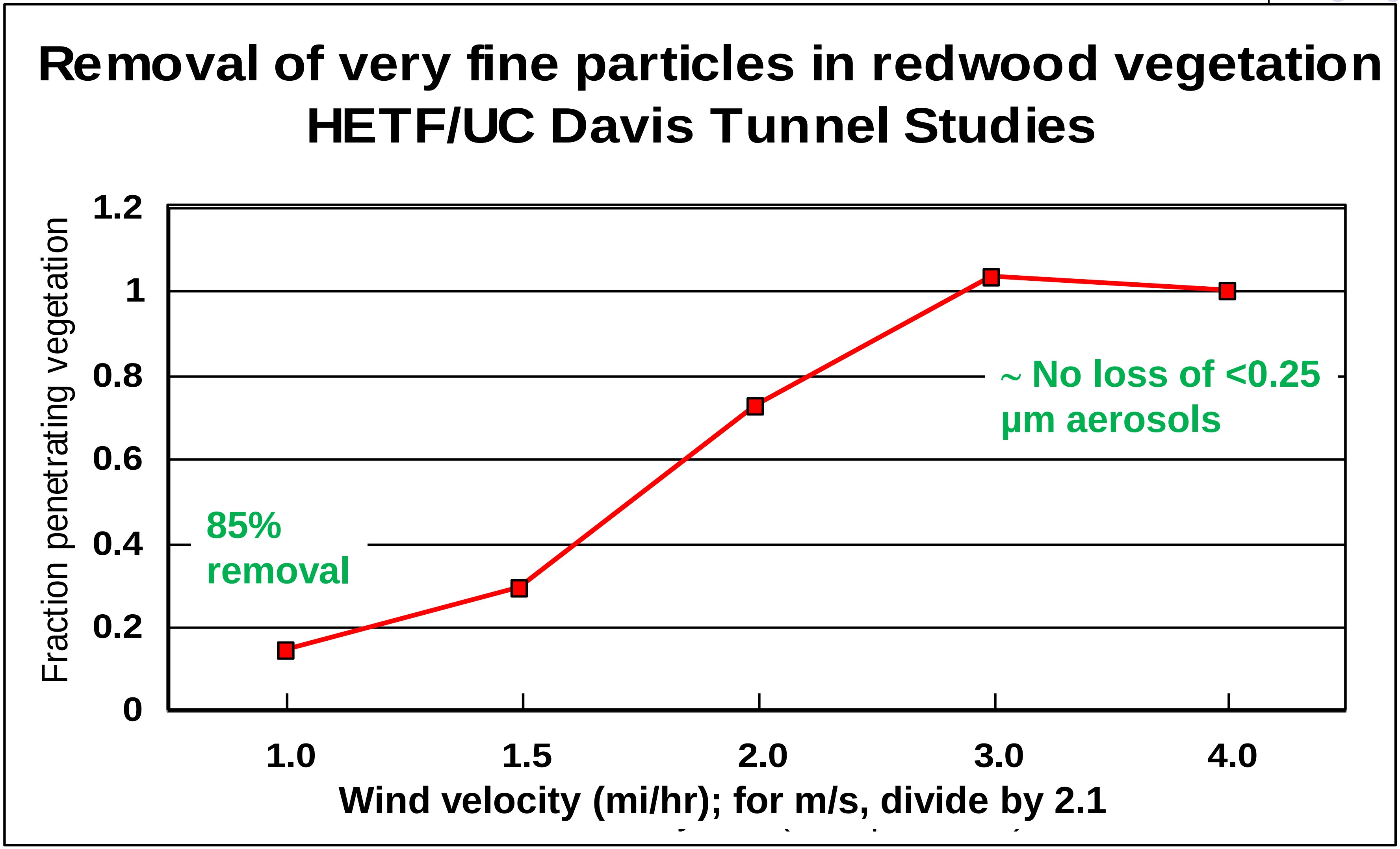


Typically strontium and potassium nitrate, potassium perchlorate, sulfur, aluminum, magnesium charcoal, sawdust

K 187,
Sr 131,
Cl 90,
S 68,
Si 38,
Mg 22,
P 5,
rest < 0.1

UC Davis Mechanical Engineering 20 m wind tunnel – redwood branches in place

Removal of very fine (< 0.25 μm) and ultra fine (< 0.1 μm) particles in vegetation as a function of wind velocity



Applying flare tracer to ambient conditions: Transects of I-5 at 10th and 13th Avenues

UC Davis DELTA Group/HETF/USEPA highway transect studies

Purple indicates data from artificial tracers

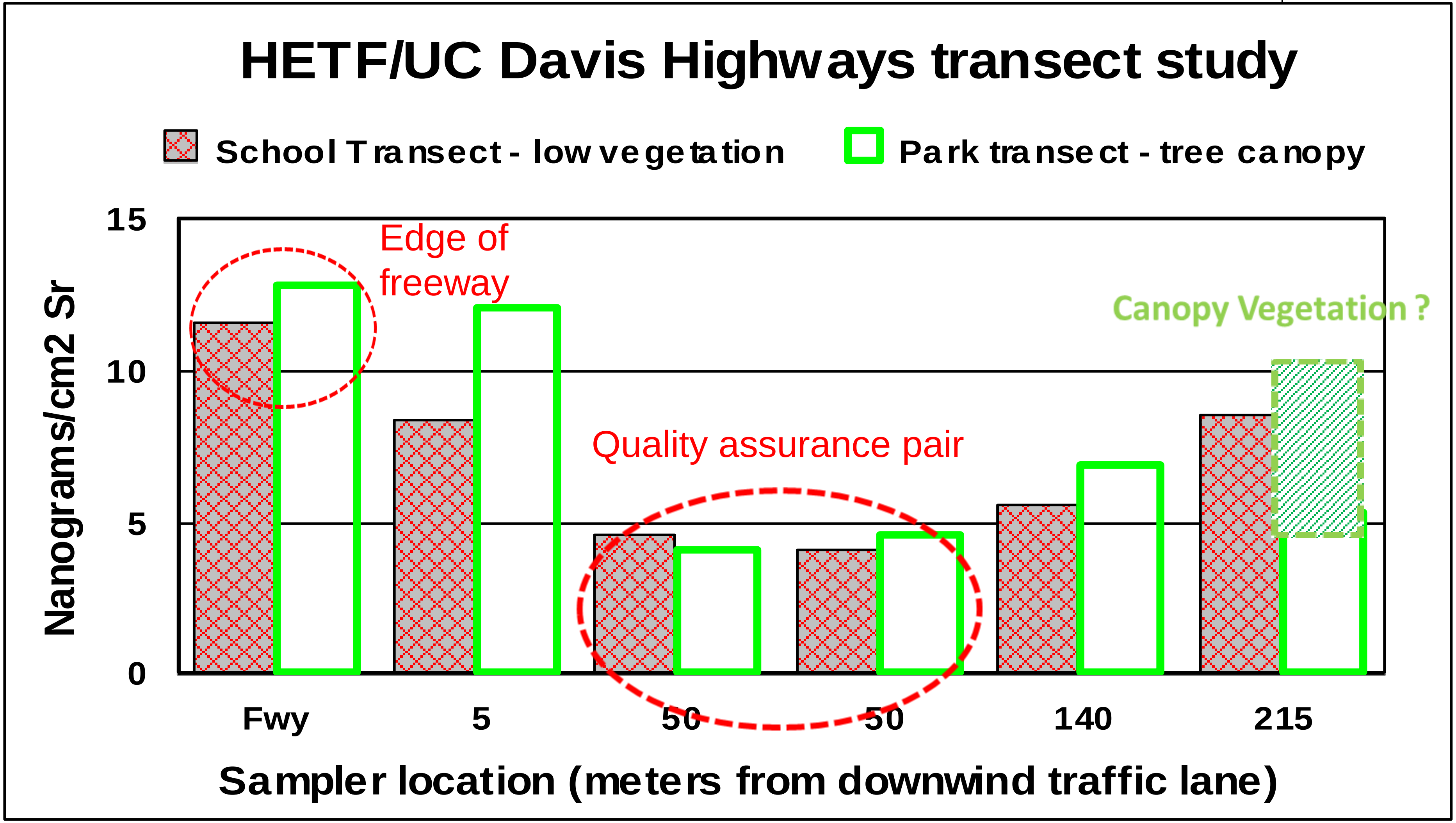
Freeway configuration			Vegetation	Vegetation	Season			Transect site
	Traffic braking?	Sound wall?	Barrier + sound wall	Downwind canopy	Summer	Spring, Fall	Winter	
Raised 5 ft	**No**	**Yes**	**~ 0.3**	**~ 0.2**	**Yes**	**Yes**	**Yes**	**10th Ave**
At Grade	**No**	**Yes**	**~ 0.5**	**~ 0.8**	**Yes**	**Yes**		**13 th Ave**
Raised 30 ft	**No**	**Yes**	**~ 1.0**	**~ 0.3**	**Yes**		**Yes**	**35th Ave**
At Grade	Yes	No	No	No	Yes	Yes	Yes	Watt Ave
At Grade	**No**	**No**	**No**	**No**		**Yes**		**Detroit* 2010**

Rolling cart with flares on the upwind bike path, used for 10th Ave and 13th Ave studies

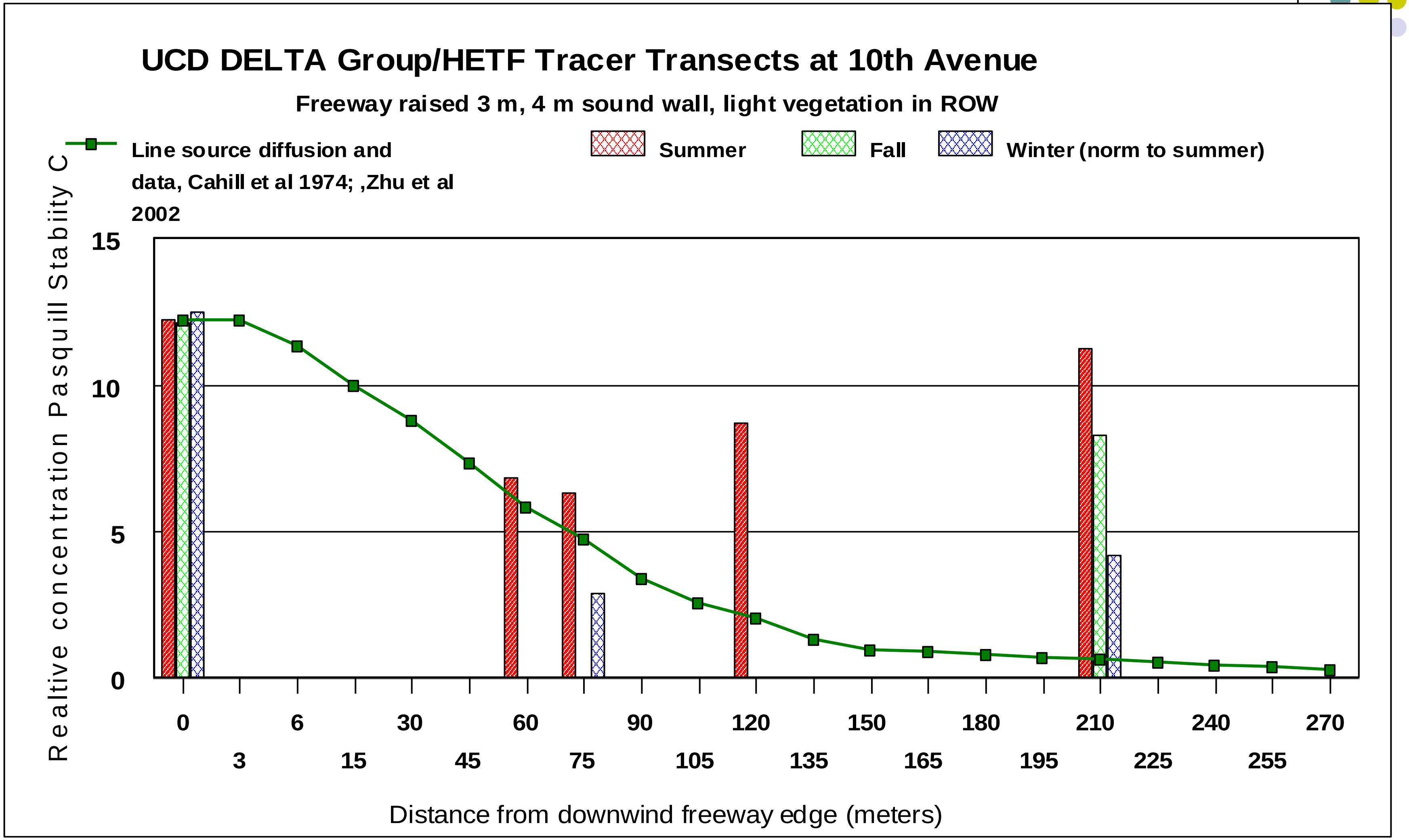
10th Avenue transect, SDW1 at top of ROW wall

At 50 m downwind, paired samplers for quality assurance checks; Camille guarding her QA site

Transect sites #2 10th Avenue (little vegetation), and #3 13th Avenue, (freeway screen, and tree canopy downwind); Vw = 5 mph

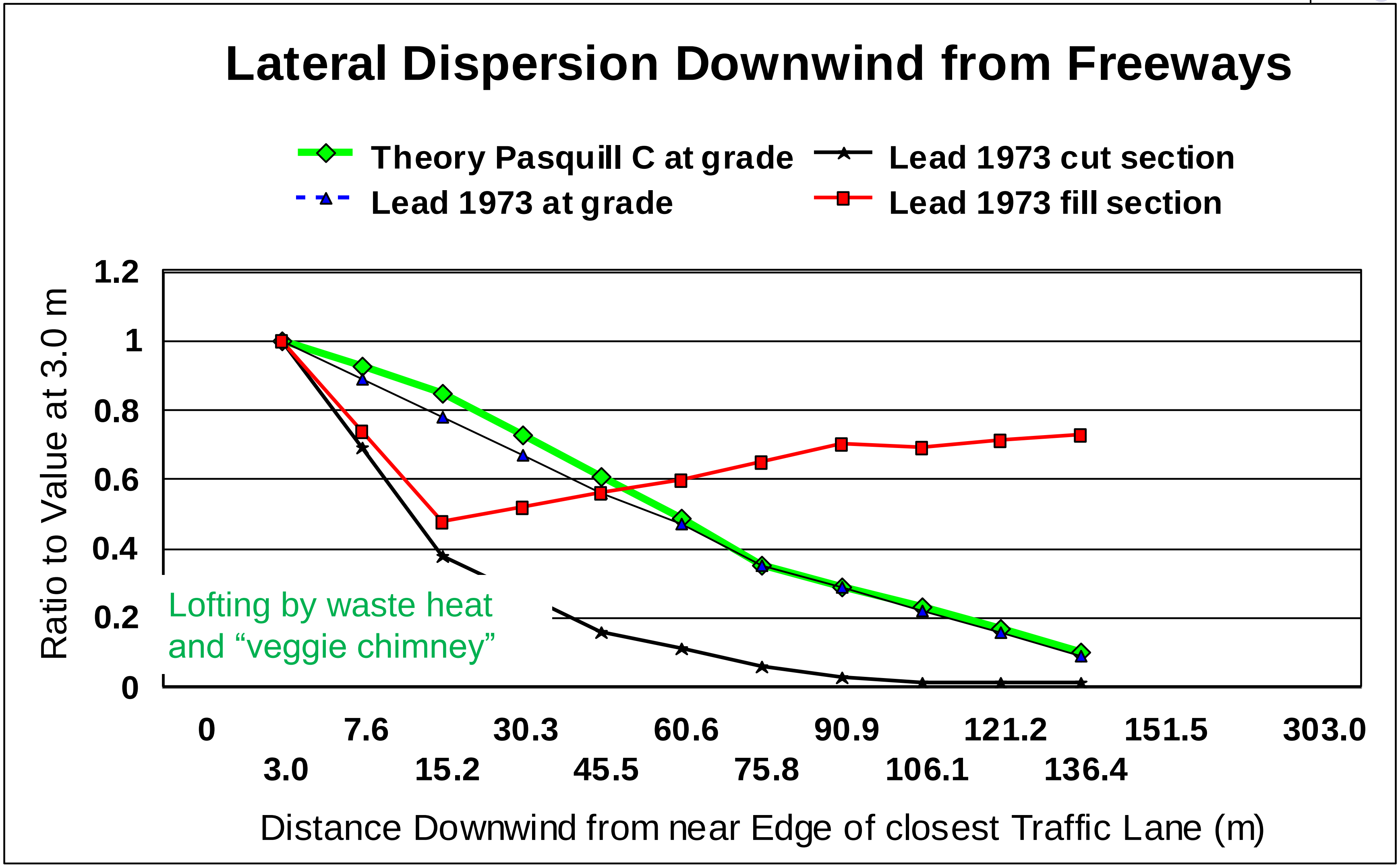


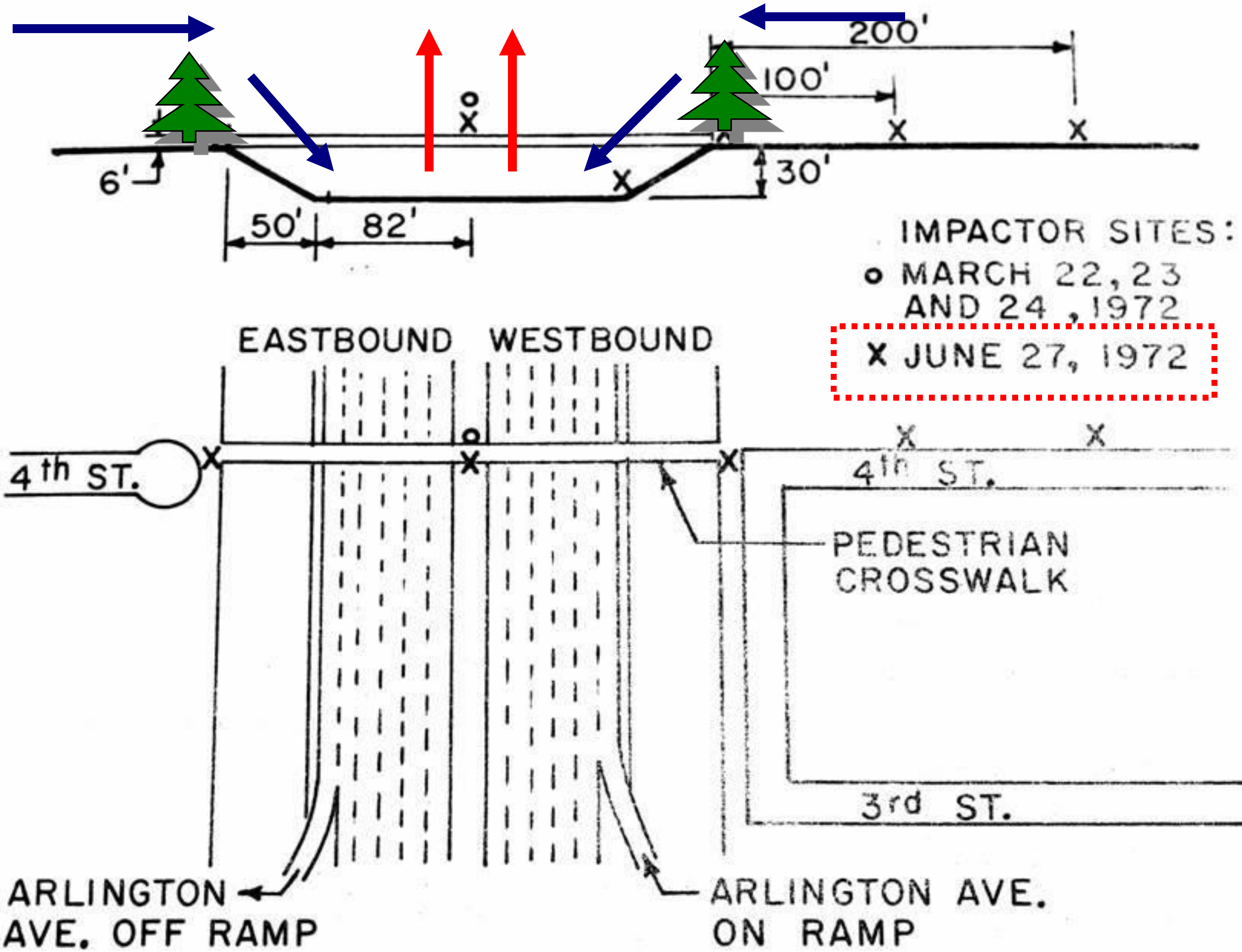
Applying flare tracer to ambient conditions: Transect of I-5 at 10th Avenue



At-grade freeway with 4 meter sound wall

Results for 5 transects (2 cut, 2 fill) downwind with ultra fine lead (Cahill et al 1973; Feeney et al, 1975.)





200'
100'
30'
6'
50'
82'
IMPACTOR SITES:
o MARCH 22, 23 AND 24, 1972
X JUNE 27, 1972
EASTBOUND
WESTBOUND
4th ST.
4th ST.
PEDESTRIAN CROSSWALK
3rd ST.
ARLINGTON AVE. OFF RAMP
ARLINGTON AVE. ON RAMP

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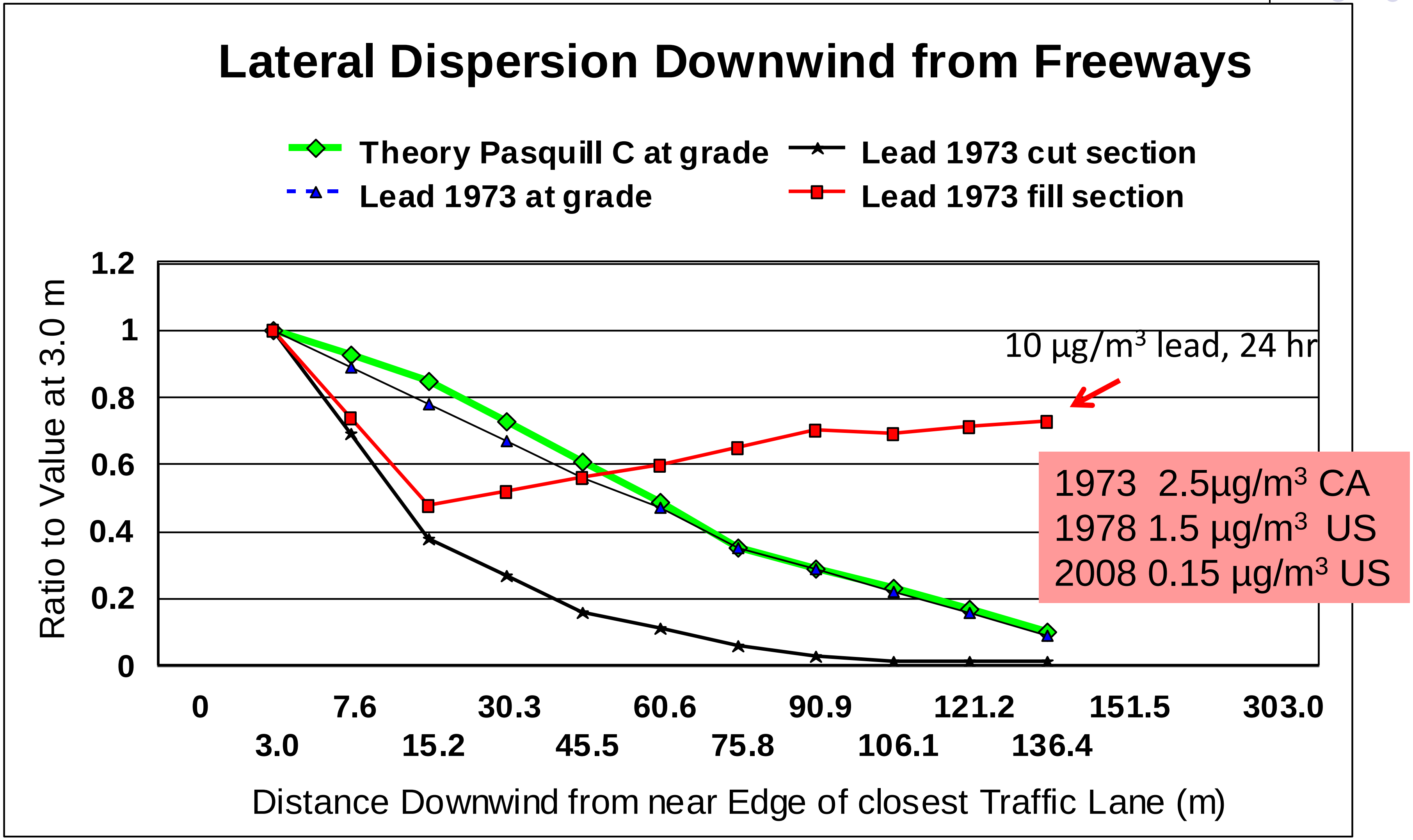
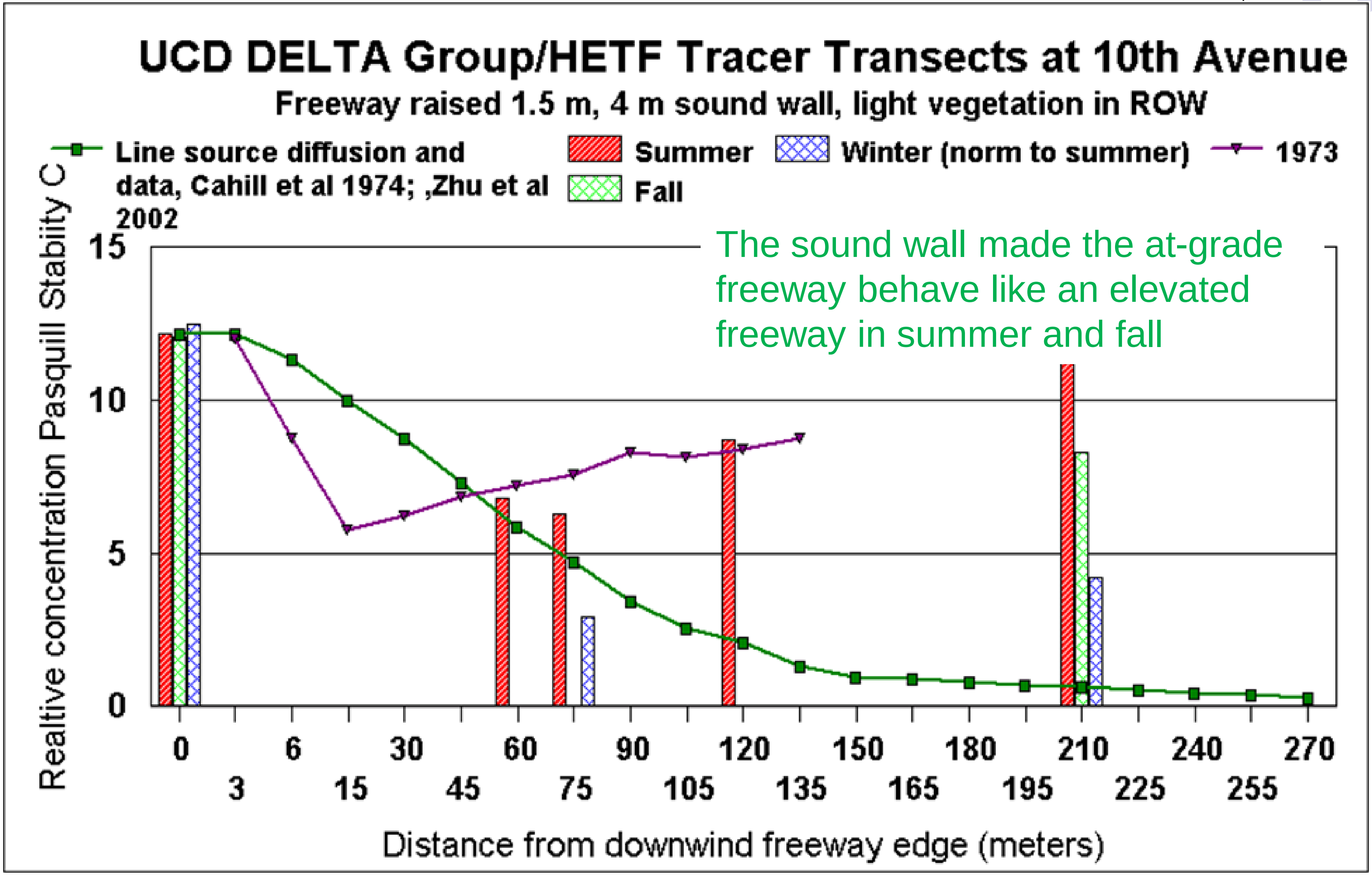
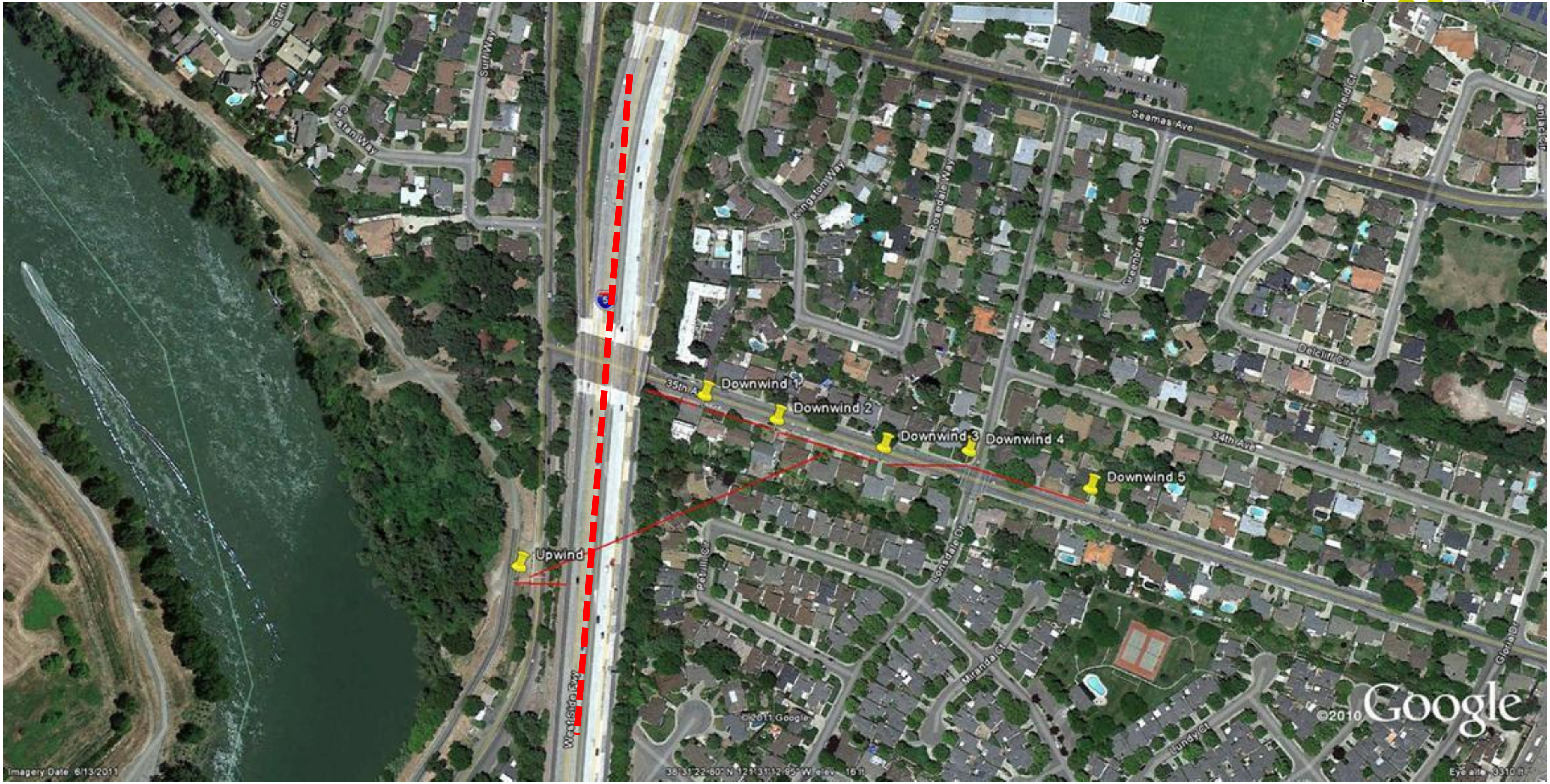


Adding 1972 lead data from 2 raised section Los Angeles freeways (Cahill et al, 1973), 10th Avenue



Applying flare tracer to ambient conditions: Transects of I-5 at 35th Avenue

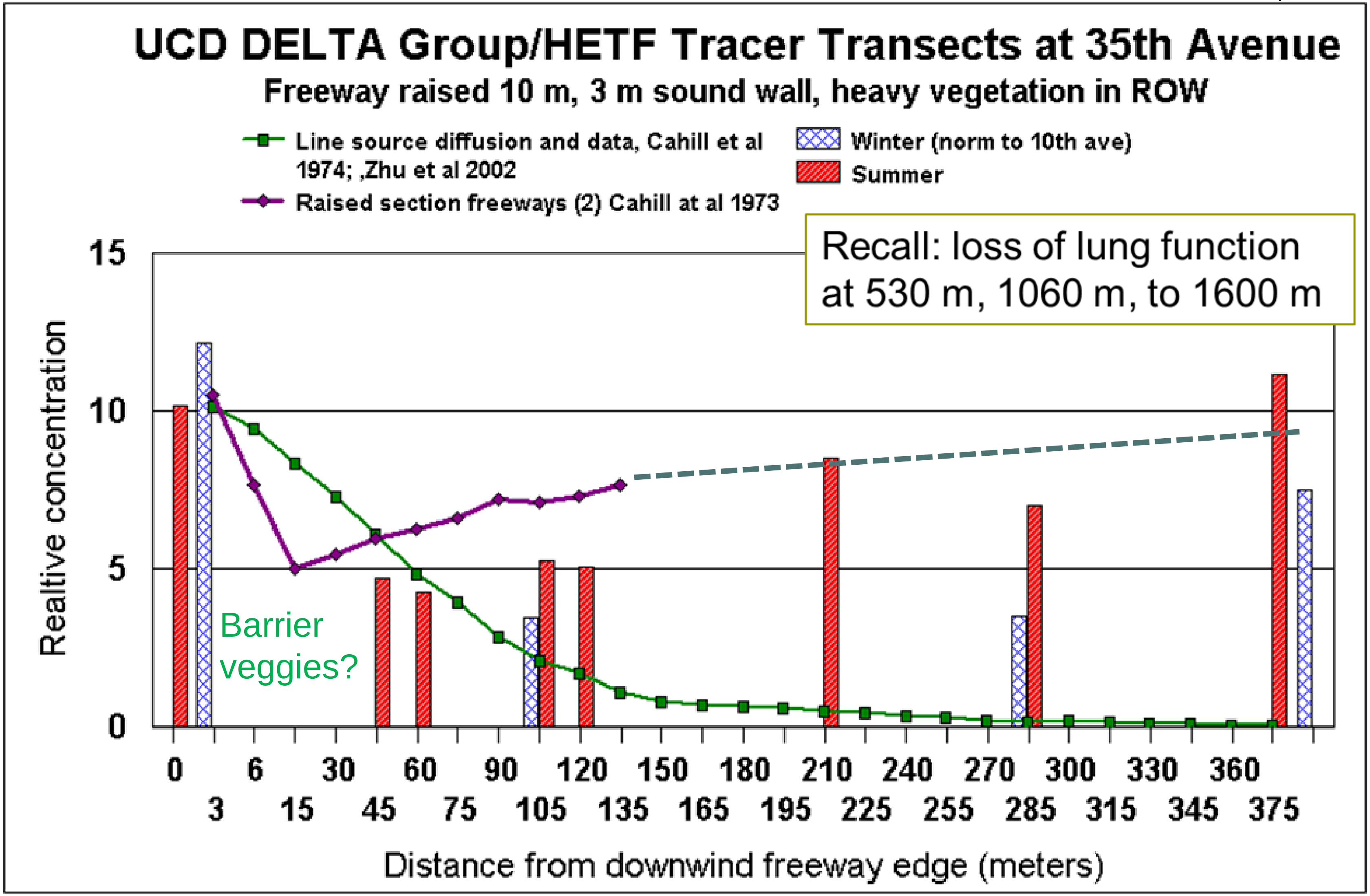


The winds in this transect were from the southwest

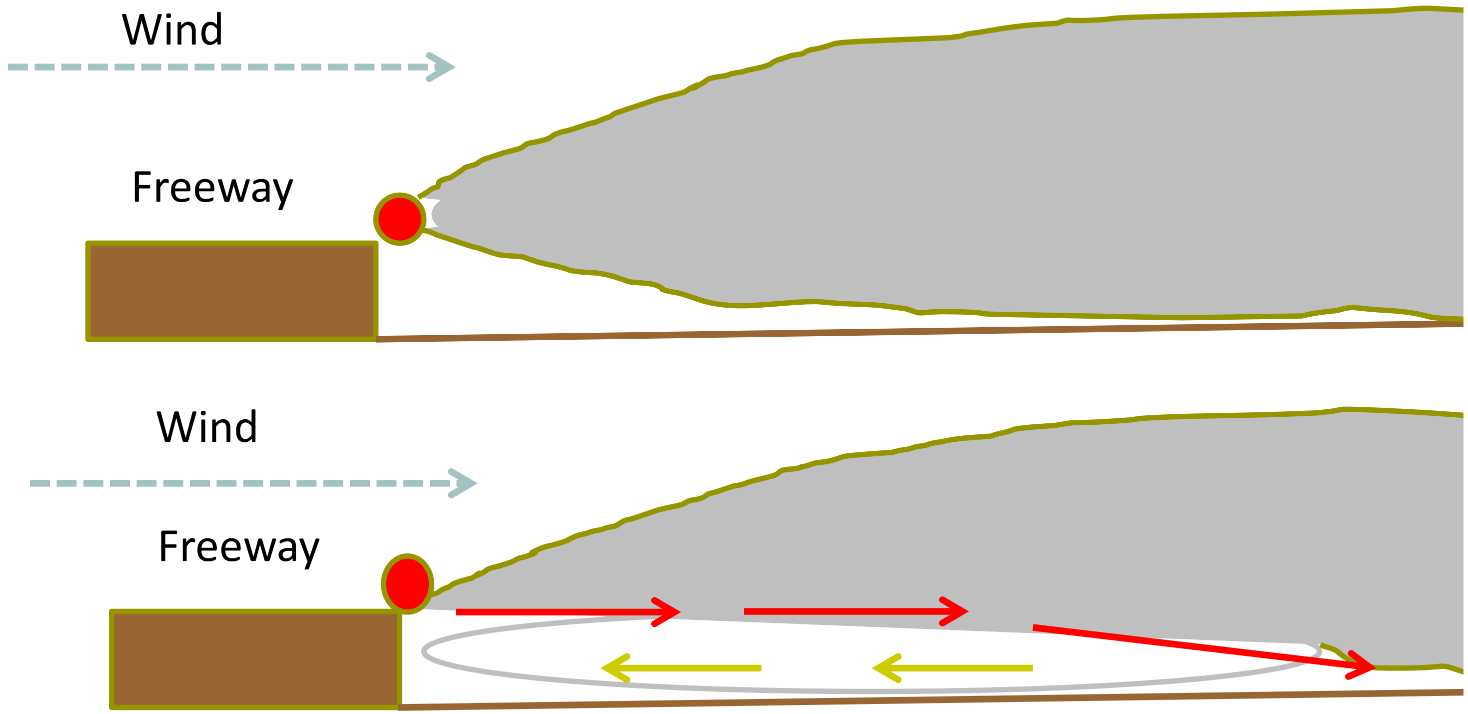
Redwood barrier on Interstate 5 near 35th Avenue

Downwind distribution of very fine and ultra fine aerosols – 1973 and 2010.

- The raised freeway trumped the vegetation!



Line source dispersion modeling - elevated source



Top – model used in Cahill, Myrup, and Dunn in 1973 Final Report, ARB
Bottom – model used be Baldauf et al US EPA, current

Mitigation must occur at all levels
(vegetation options in green)

- Source mitigation - federal and state responsibilities
  - Tailpipe - Fuels, engines; but also lubricating oil
  - “Wear” aerosols - Brake pads, brake drums, disks, roads (~ ½ of total)
- Roadway to right-of-way fence – transportation agencies
  - Roadway design (Complete streets; avoid elevated freeways)
  - Distance
  - Traffic volume and type mitigation
  - Barrier vegetation
- Right-of-Way fence to receptors – regional and local planners
  - Distance (but this conflicts with in-fill emphasis)
  - Traffic volume and type mitigation
  - Barrier vegetation
- Receptors – local planners, receptor responsibility
  - Canopy vegetation
  - Indoor mitigation – indoor vegetation, ultra filtration

…..and acknowledgements

- To Sac Met AQMD, long time supporter of BC/SET
- To the HTEF and BC/SET, for encouraging and guiding these studies
- To the Arden Middle School principal and staff
- To the crew of the UC Davis DELTA Group, Dr. David Barnes and many students, and Camille, our French intern,
- To EPA Region IX and the Resource Legacy for funding
- To the US EPA, who helped develop these technique and are using them in Detroit
- To Dr. Steve Cliff, Dr. Yongjing Zhao, and Prof. Kevin Perry, who achieved amazing Synchrotron induced –X-ray Fluorescence Analysis (S-XRF) analytical sensitivity of these very clean filters
- The Sacramento Police, who didn't arrest us even after a bomb threat was phoned in. After that, we always had people at sites.

Recent relevant HETF/UC Davis publications….

- Cahill, Thomas A., David E. Barnes, Nicholas J. Spada, **Seasonal variability of ultra-fine metals downwind of a heavily traveled secondary road**, Atmospheric Environment 94 173 - 179 (2014)
- Baldauf, Richard, Greg McPherson, Linda Wheaton, Max Zhang, Tom Cahill, Chad Bailey, Christina Hemphill-Fuller, Earl Withycombe, and Kori Titus, **Integrating Vegetation and Green Infrastructure into Sustainable Transportation Planning,** Transportation Research Bulletin, National Academy of Sciences (2013)
- Cahill, Thomas M, and Thomas A. Cahill, **Seasonal variability of particle-associated organic compounds near a heavily traveled secondary road**. *Aerosol Science and Technology*, (2013) doi: 10.1080/02786826.2013.857757
- Thomas A. Cahill, David E. Barnes, Earl Withycombe, and Mitchell Watnik. **Very fine and ultra-fine metals and ischemic heart disease in the California Central Valley 2: 1974 – 1991**. *Aerosol Science and Technology* 45:1135-1142 (2011) doi:10.1080/02786826.2011.582196
- Thomas A. Cahill, David E. Barnes, Nicholas J. Spada, Jonathan A. Lawton and Thomas M. Cahill. **Very fine and ultra-fine metals and ischemic heart disease in the California Central Valley 1: 2003 – 2007**. *Aerosol Science and Technology* 45:1125-1134 (2011) doi:10.1080/02786826.2011.582194
- Cahill, TM, Size-Resolved **Size-resolved organic speciation of wintertime aerosols in California's Central Valley**. *Environmental Science and Technology* 44:2315 - 2321 (2010) doi 10.1021/es902936v

- Thomas A. Cahill, Thomas M. Cahill, David E. Barnes, Nicholas J. Spada and Roger Miller. **Inorganic and organic aerosols downwind of California's Roseville Railyard.** Aerosol Science and Technology 45:1049-1059 (2011) doi:10.1080/02786826.2011.580796

- Plus 2 from EPA NEXUS….
- Robert Willis[1], Thomas A. Cahill[2], David E. Barnes[2], Jonathan A Lawton[2], Roger S. Miller[2], and Nicholas J. Spada[3] **Relationships between Indoor and Outdoor PM in a downtown Detroit school by size, time, and compositionally resolved aerosols** (under EPA review)
- Thomas A. Cahill[1], David E. Barnes[1], Jonathan A Lawton[1], Roger Miller[1], Nicholas Spada[2], and Robert D. Willis[3], **Coarse, fine, very fine, and ultra-fine transition metals from the NEXUS I-96 Transect near Detroit** (under EPA Review)