How does Vegetation Affect Pollution Removal?

Thomas A. Cahill

DELTA Group, Univ. of California, Davis, and the Health Effects Task Force, Breathe California of Sacramento-Emigrant Trails

for

The Workshop on the Role of Vegetation in Mitigation Air Quality Impacts from Traffic Emissions

EPA RTP North Carolina

April 27, 28, 2010

Two key factors to consider – dilution and removal

1. **Roadways naturally disperse pollutants**
   a. The waste heat of vehicles plus
   b. Roadway heating by sunlight

   result in an unstable lapse rate and pollutant lofting above the roadway and thus dilution

   c. Anything that prevents lateral motion off the roadway enhances this chimney effect – tall vegetation is best

2. **The most dangerous aerosol pollutants from roadways are very fine to ultra fine**
   a. Diesel soot, metals, PAHs, .. are mostly << 0.25 μm
   b. These diffuse easily to surfaces when a nearby surface is provided
   c. Vegetation can provide such surfaces and thus removal

January 26, 2007

FOUNDED 1857

The Sacramento Bee

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Senator: Cheney interfered

'ew intelligence panel chief
·lls of efforts to stall Iraq probe.

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By Jonathan S. Landay
McCLATCHY WASHINGTON BUREAU

WASHINGTON – Vice President Dick Cheney exerted "constant" pressure on the Republican former chairman of the Senate Intelligence Committee to stall an investigation into the Bush administration's use of flawed intelligence on Iraq, the panel's Democratic chairman charged Thursday.

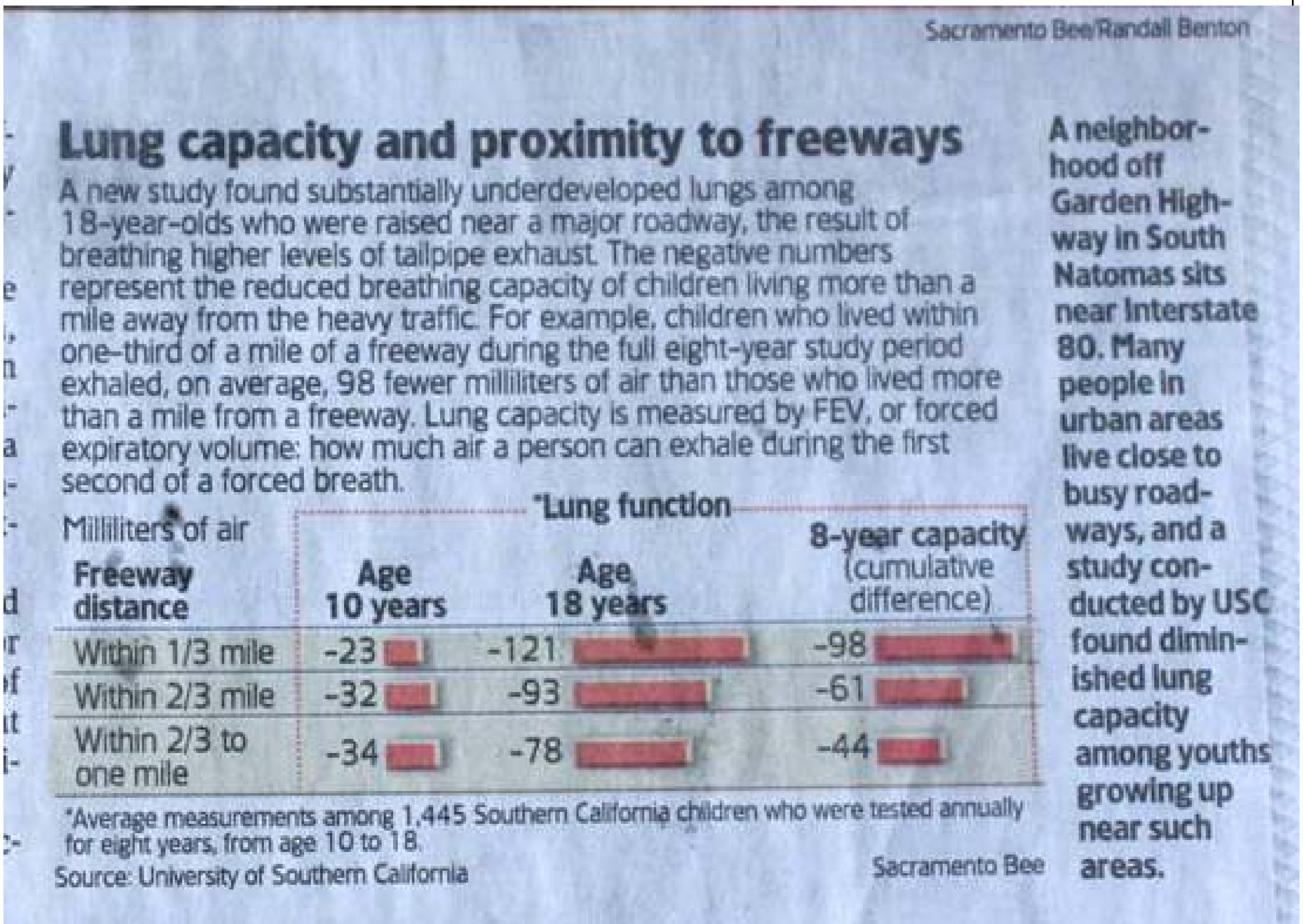
In an interview with McClatchy Newspapers, Sen. Jay Rockefeller of West Virginia also accused President Bush of running an illegal program by ordering eavesdropping on Americans' international e-mails and

Living near busy roads tied to kids' lung risk

Impact on breathing is long-term health threat, study says

And more ….

Check the distances: < 530 m, <1060 m, 1060 m to 1600 m, > 1600 m



Sacramento Bee/Randall Benton

Lung capacity and proximity to freeways

A new study found substantially underdeveloped lungs among 18-year-olds who were raised near a major roadway, the result of breathing higher levels of tailpipe exhaust. The negative numbers represent the reduced breathing capacity of children living more than a mile away from the heavy traffic. For example, children who lived within one-third of a mile of a freeway during the full eight-year study period exhaled, on average, 98 fewer milliliters of air than those who lived more than a mile from a freeway. Lung capacity is measured by FEV, or forced expiratory volume: how much air a person can exhale during the first second of a forced breath.

*Lung function

Milliliters of air

Freeway distance	Age 10 years	Age 18 years	8-year capacity (cumulative difference)
Within 1/3 mile	-23	-121	-98
Within 2/3 mile	-32	-93	-61
Within 2/3 to one mile	-34	-78	-44

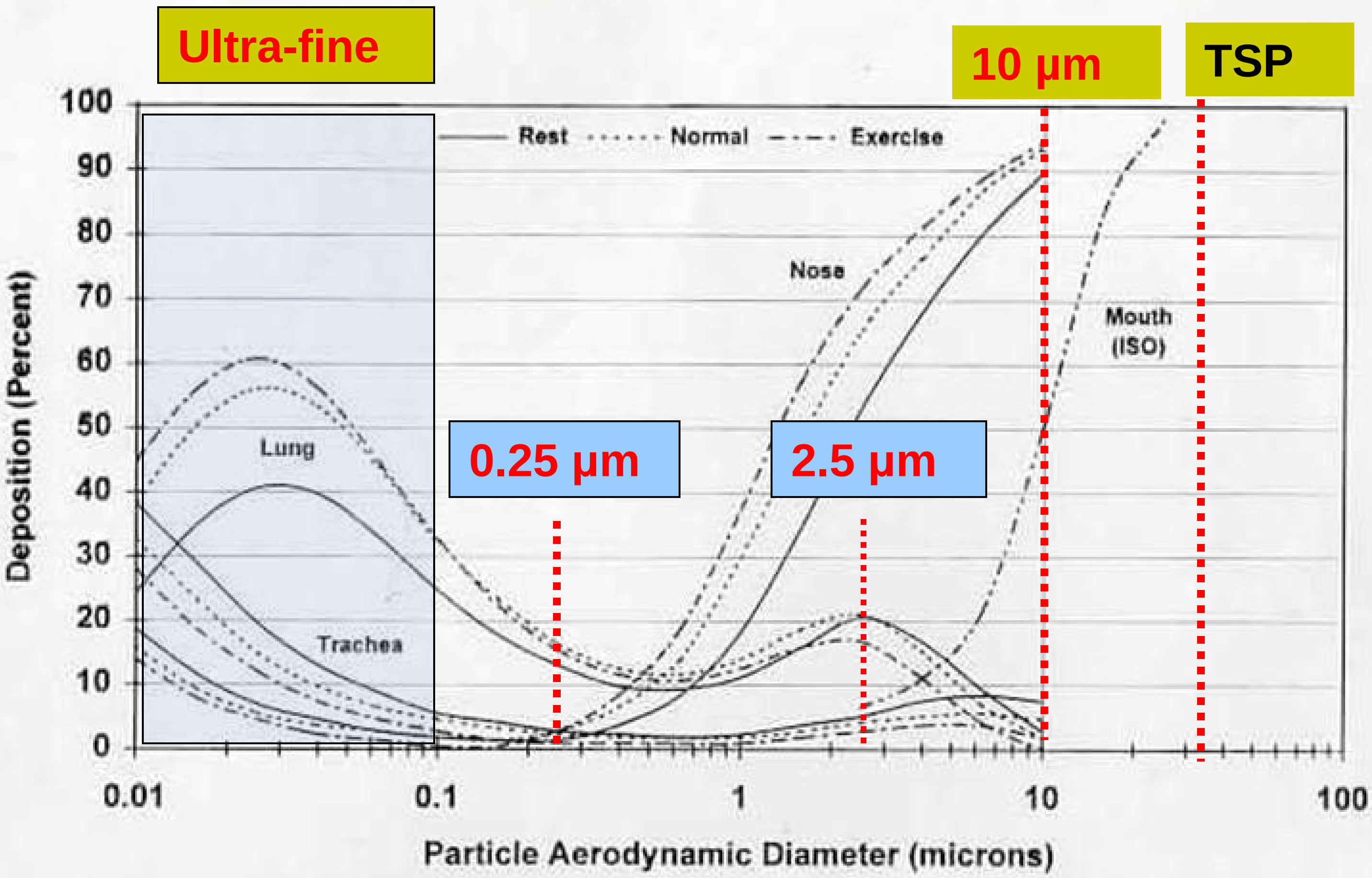
*Average measurements among 1,445 Southern California children who were tested annually for eight years, from age 10 to 18.

Source: University of Southern California

Sacramento Bee

A neighborhood off Garden Highway in South Natomas sits near Interstate 80. Many people in urban areas live close to busy roadways, and a study conducted by USC found diminished lung capacity among youths growing up near such areas.

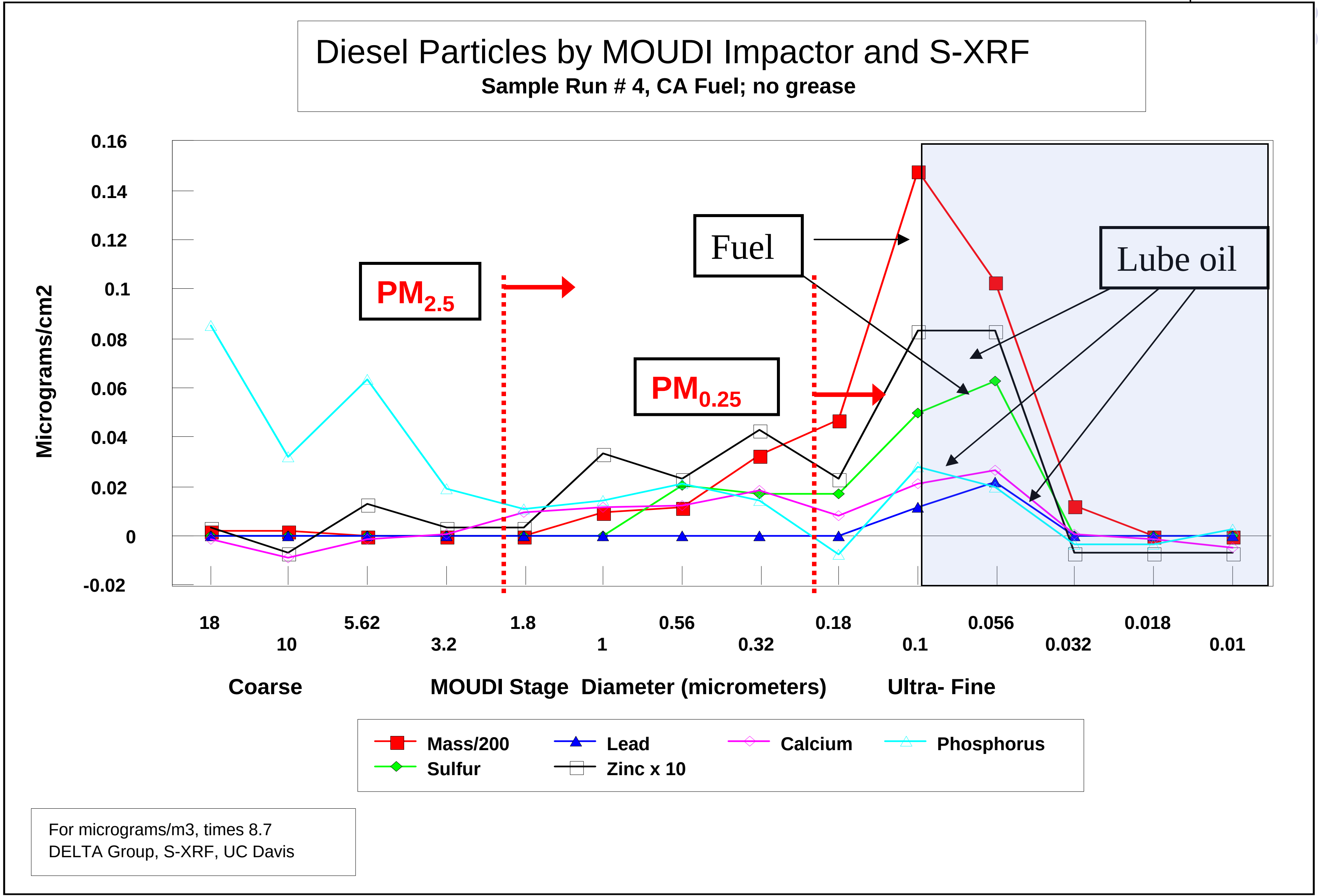
Particle Size versus fraction deposited – mouth, nose, trachea, and lung



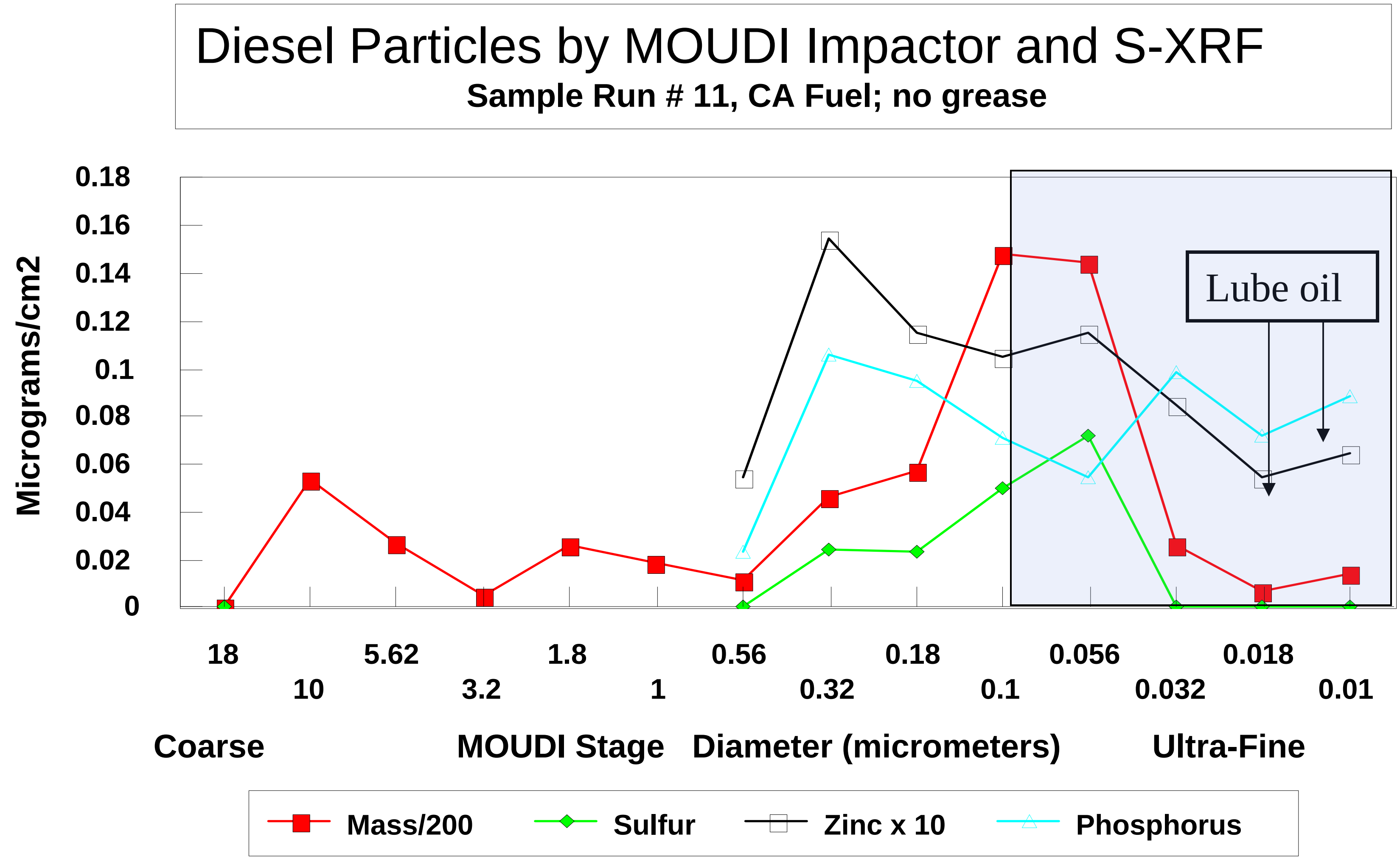
Journal of Inhalation Research (1995)

This figure shows the relationship between particle size and what percent is deposited in different parts of the respiratory tract.

U. Minn. Dynamometer Diesel tests; DRI mass and sulfates, DELTA Group S-XRF, S and elements



U. Minnesota Dynamometer Diesel Tests; same California fuel, different engine – no mention of smoke



For micrograms/m3, times 8.7
DELTA Group, S-XRF, UC Davis

Dilution

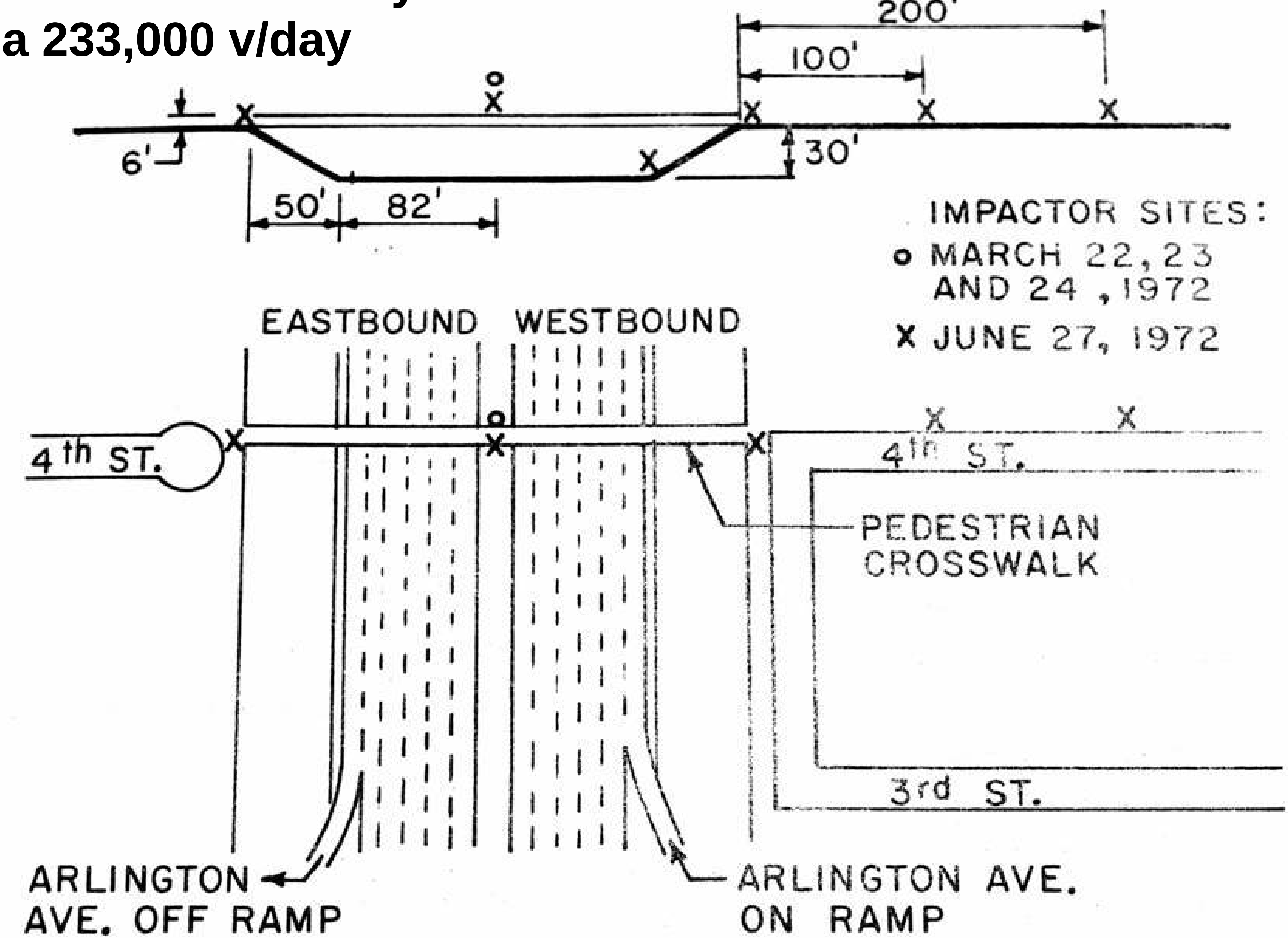
The infamous Los Angeles freeways –

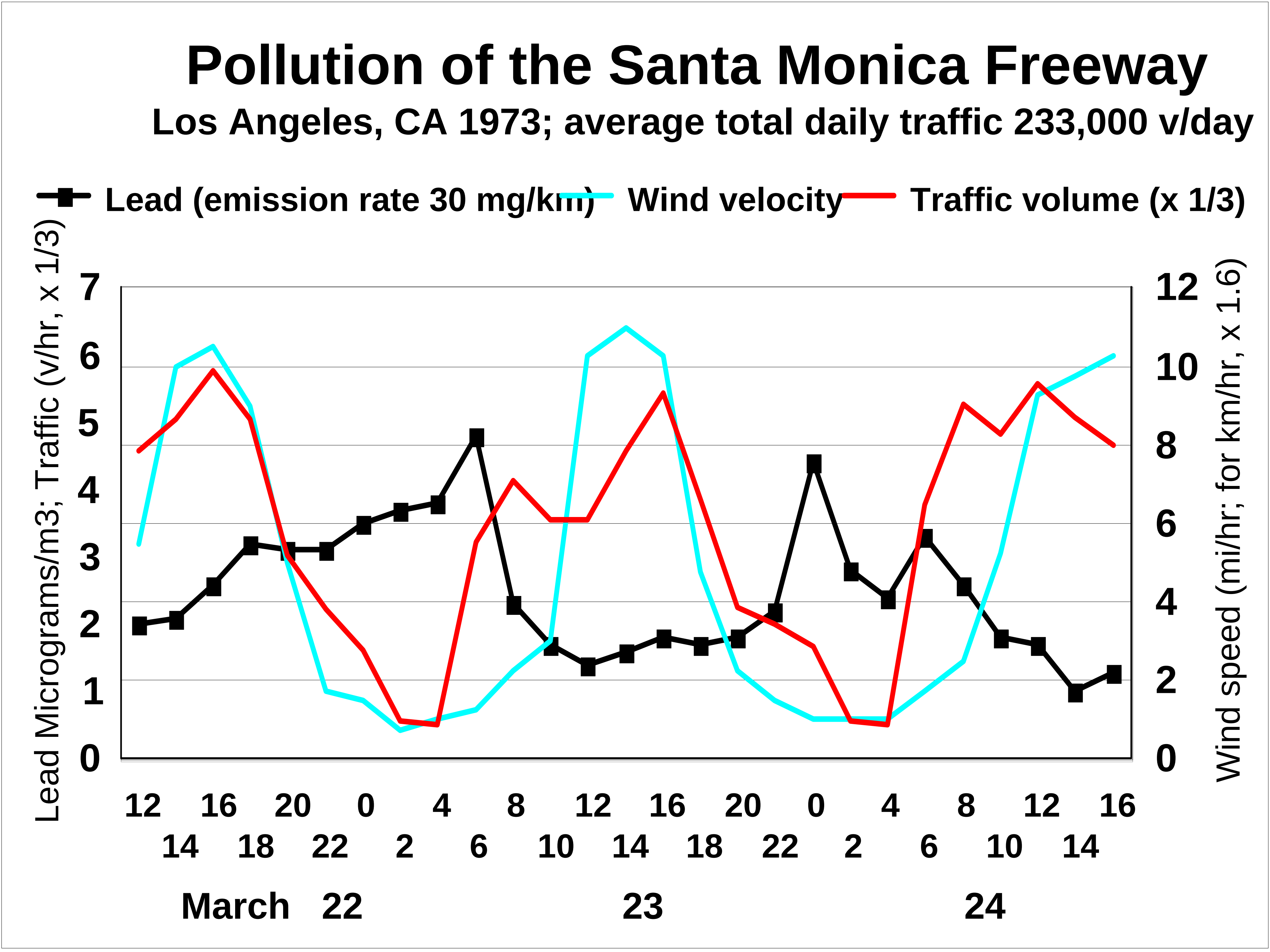
initial work focused on the dispersion of lead into neighborhoods and lack of dilution.

The > 6,000 values from the UC Davis/ARB 1973 freeway study are still some of the most detailed freeway transport data available today

- Five Los Angeles freeways were tested via upwind (2 samplers) to downwind (4 samplers) comparisons in three configurations:
  - Fill section freeway – on an embankment (2)
  - At-grade freeway – flat land on both sides (1)
  - Cut section freeway – depressed below grade (2)
- Measurements were made around the clock every 2 hr, typically for 3 days, in 5 size modes (inlet to 15, 15 to 5, 5 to 2, 2 to 0.5, < 0.5 μm diameter)
- Elements from sodium to lead were measured in all samples by proton induced x-ray emission (PIXE)
- Quantitative analysis was made of freeway emission sources and compared to aerosol data

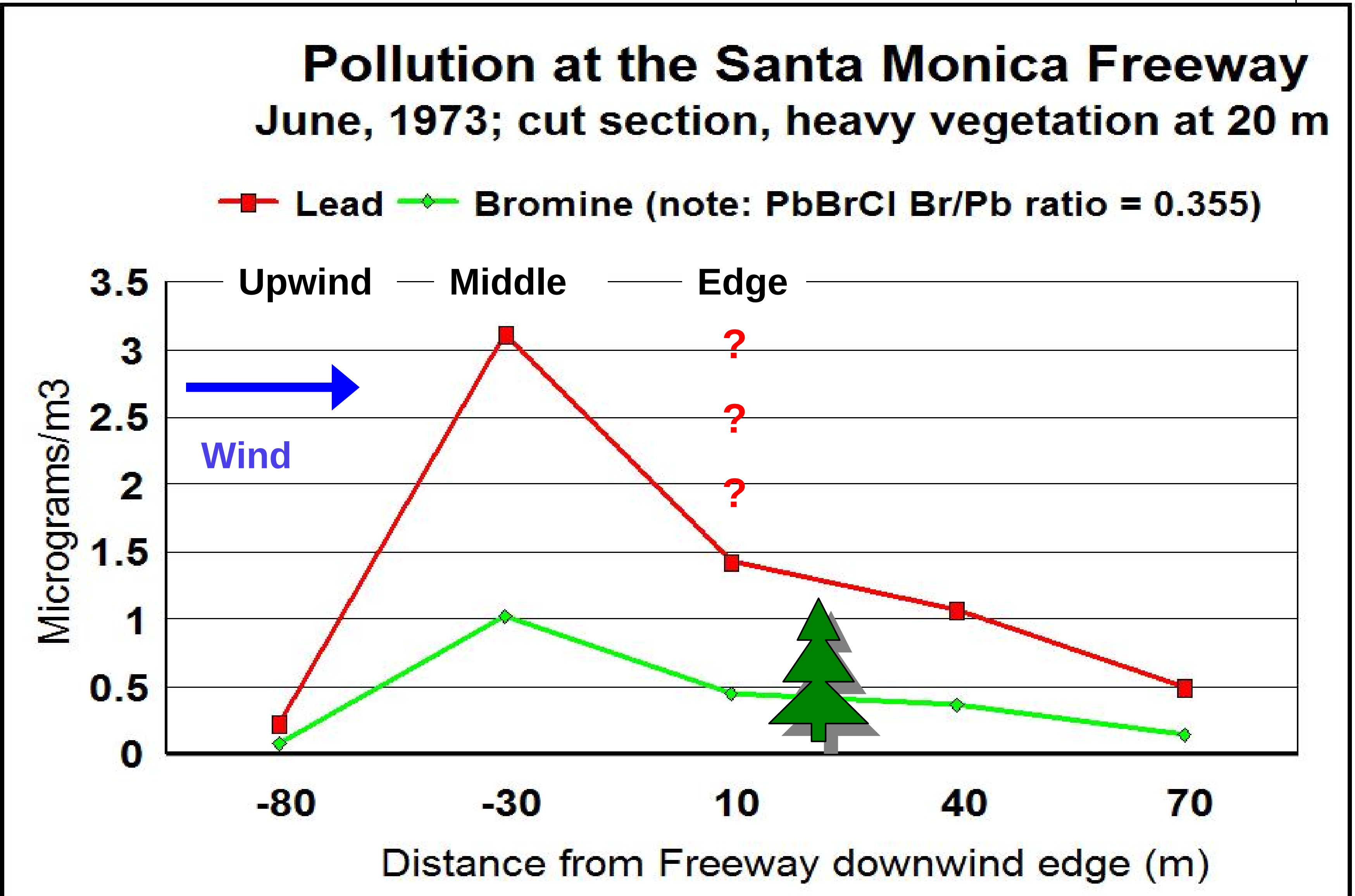
Santa Monica freeway
circa 233,000 v/day



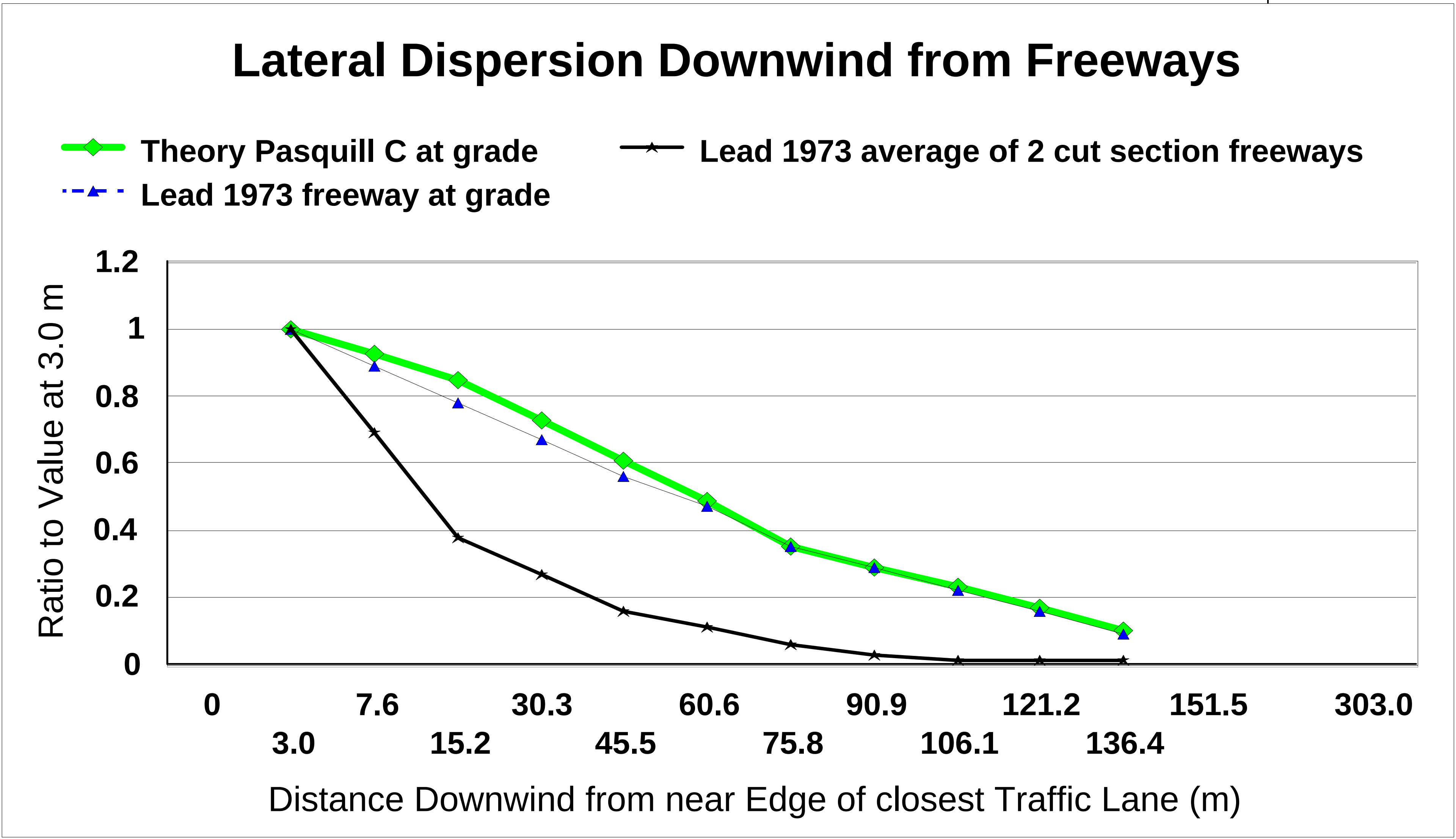


Pollution of the Santa Monica Freeway
Los Angeles, CA 1973; average total daily traffic 233,000 v/day
Lead (emission rate 30 mg/km)
Wind velocity
Traffic volume (x 1/3)
Lead Micrograms/m3; Traffic (v/hr, x 1/3)
Wind speed (mi/hr; for km/hr, x 1.6)
7
6
5
4
3
2
1
0
12
10
8
6
4
2
0
12 16 20 0 4 8 12 16 20 0 4 8 12 16
14 18 22 2 6 10 14 18 22 2 6 10 14
March 22
23
24

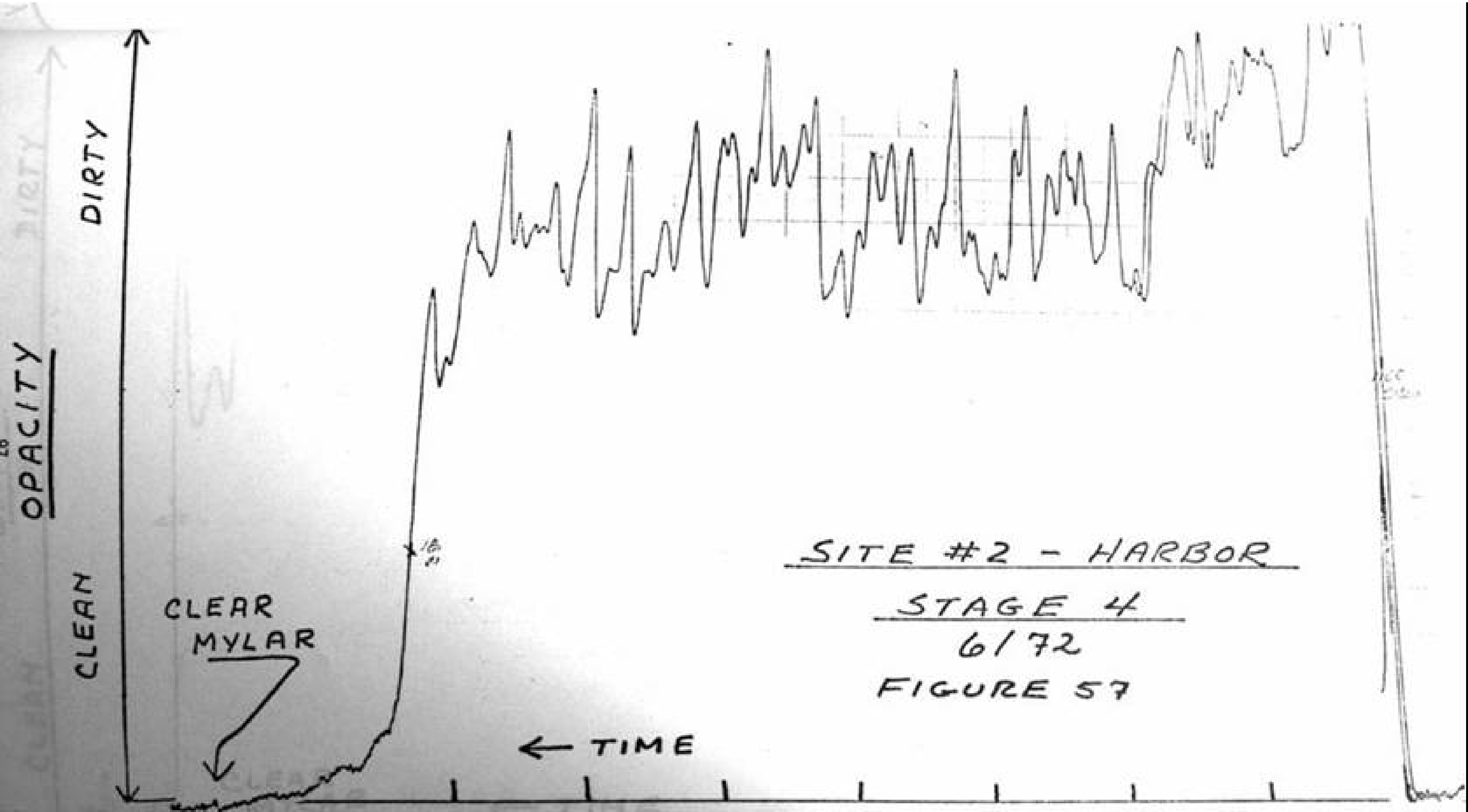
Results for the Santa Monica freeway – also used by US EPA for their model

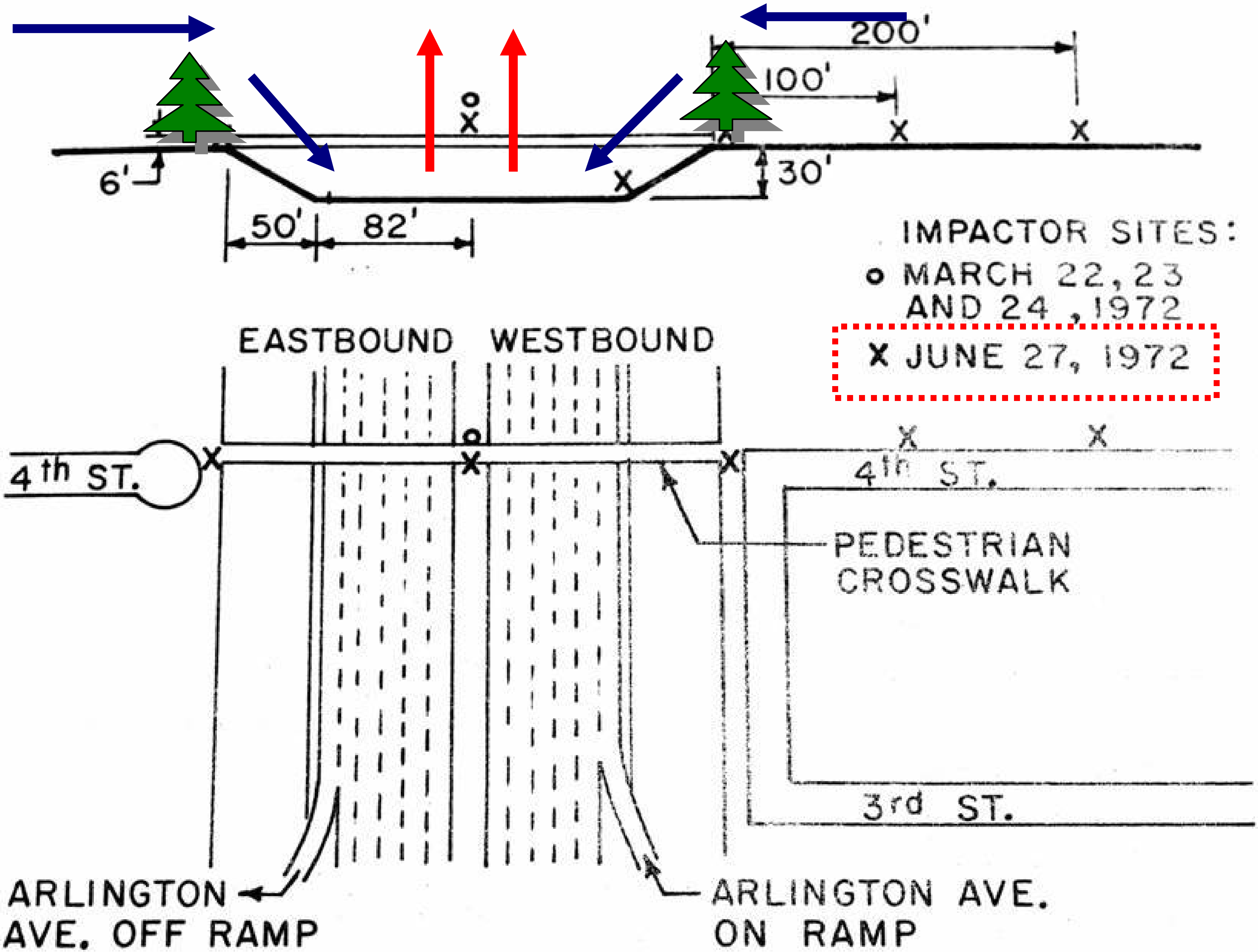


Lateral transport from freeways:
theory and data, lead from at grade; data from cut (depressed) freeway configuration



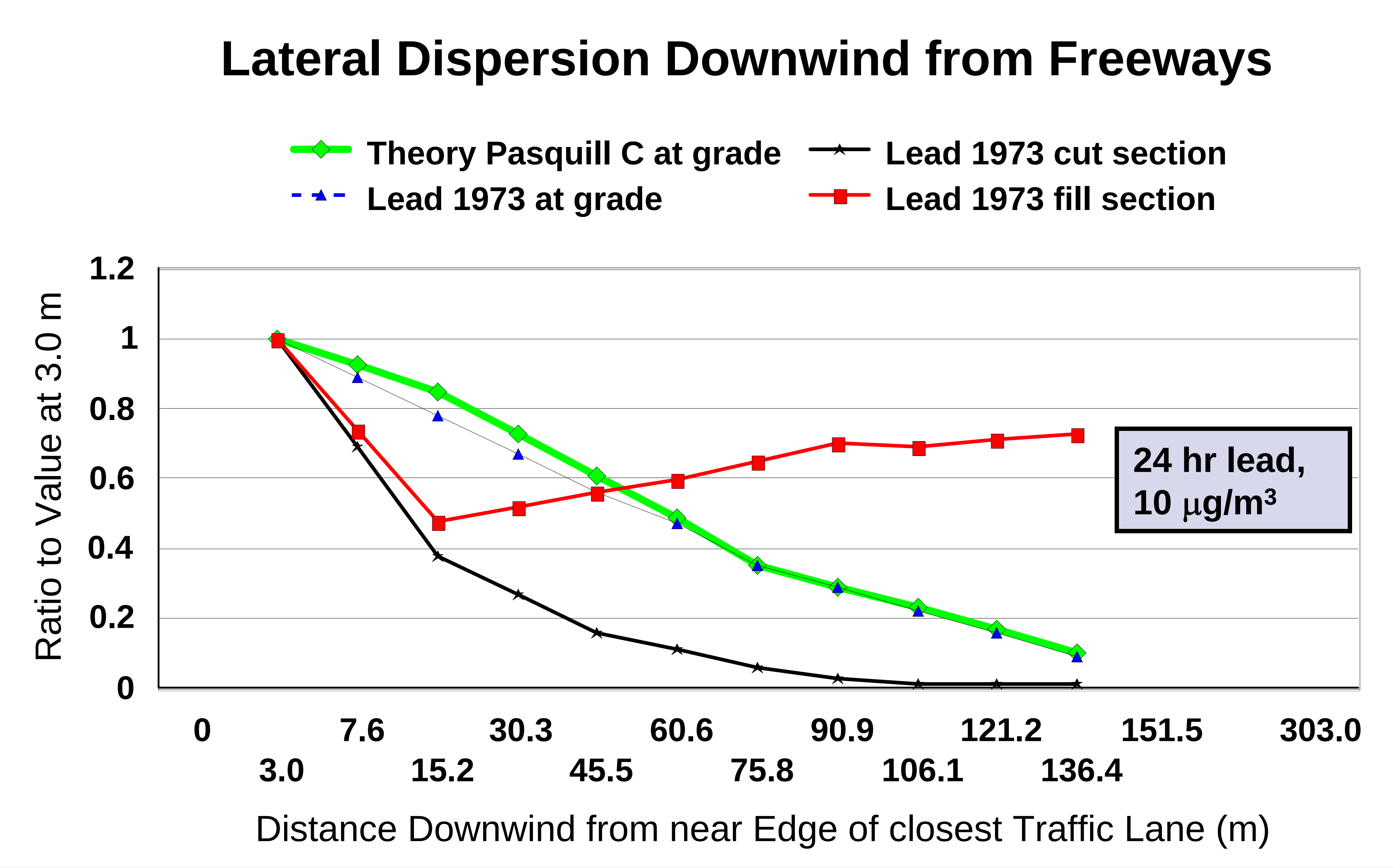
Cut section freeway - Opacity versus time – < 2.0 microns, high resolution; waste heat as a self-cleaning mechanism for freeways.





200'
100'
6'
30'
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

Lateral transport – at grade, cut and fill



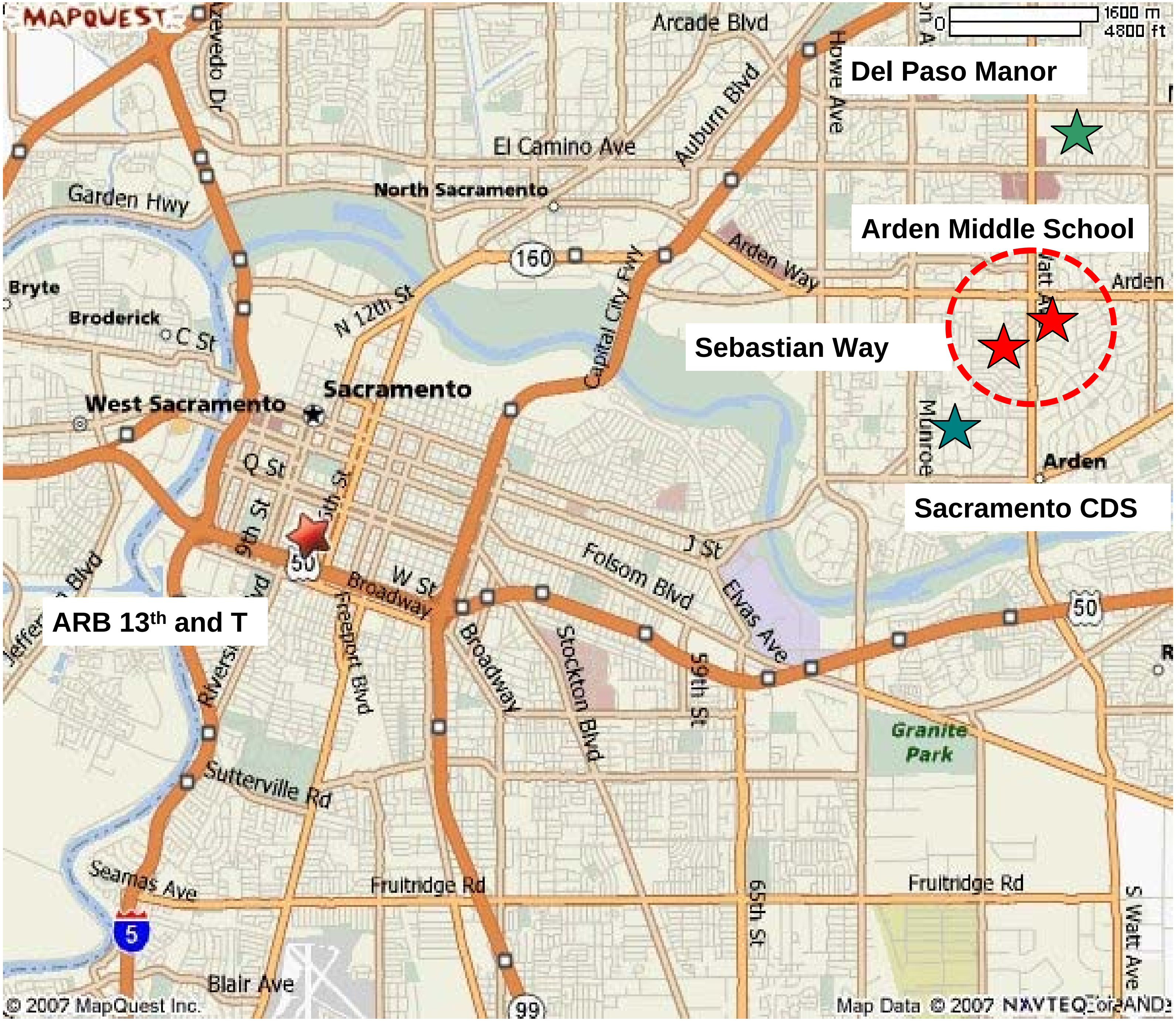
Dilution

The infamous Los Angeles freeways –

Bottom line:

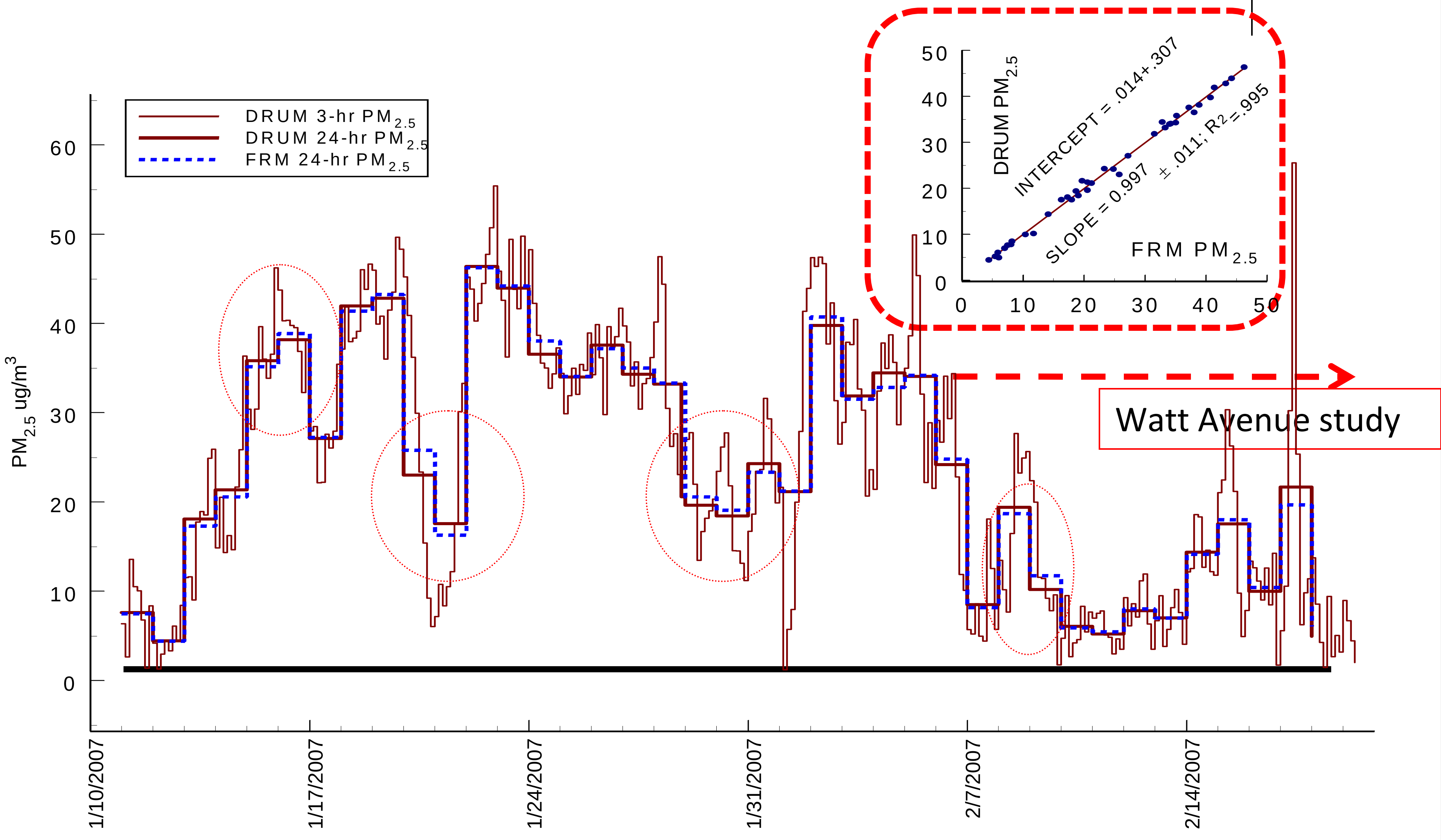
Never build an elevated freeway in a residential area;

Mitigate those that already exist.



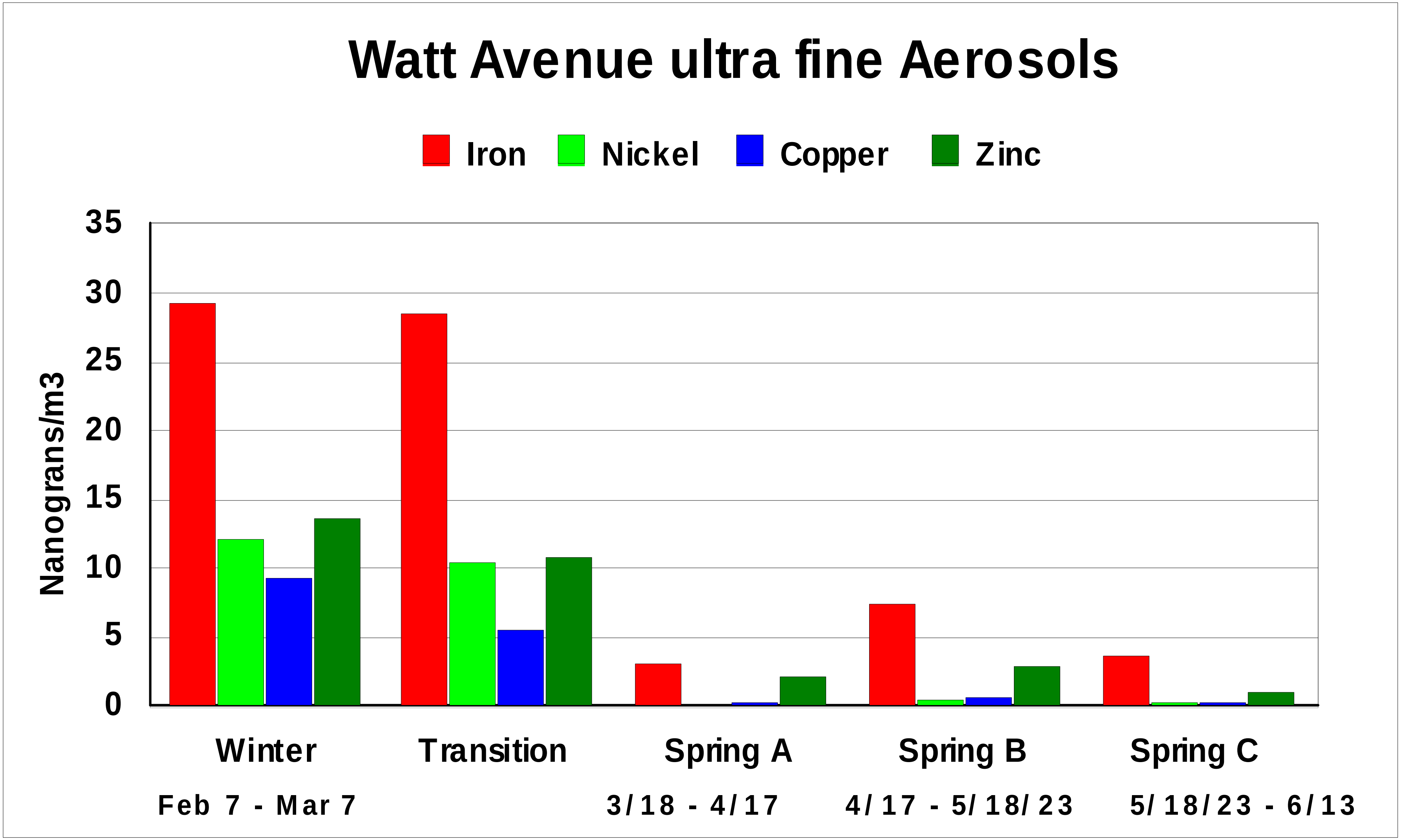
Health Effects Task Force, BC/SET, Sac Metro AQMD, and the DELTA Group, UC Davis

ARB staff analysis of intercomparison, DRUM vs ARB FRM data at 13th & T St.



View NE from Arden Middle School sampling site; 65,000 v/day, 1.5% diesel trucks (mostly 3 axle)

Decrease of Watt impacts – winter to summer

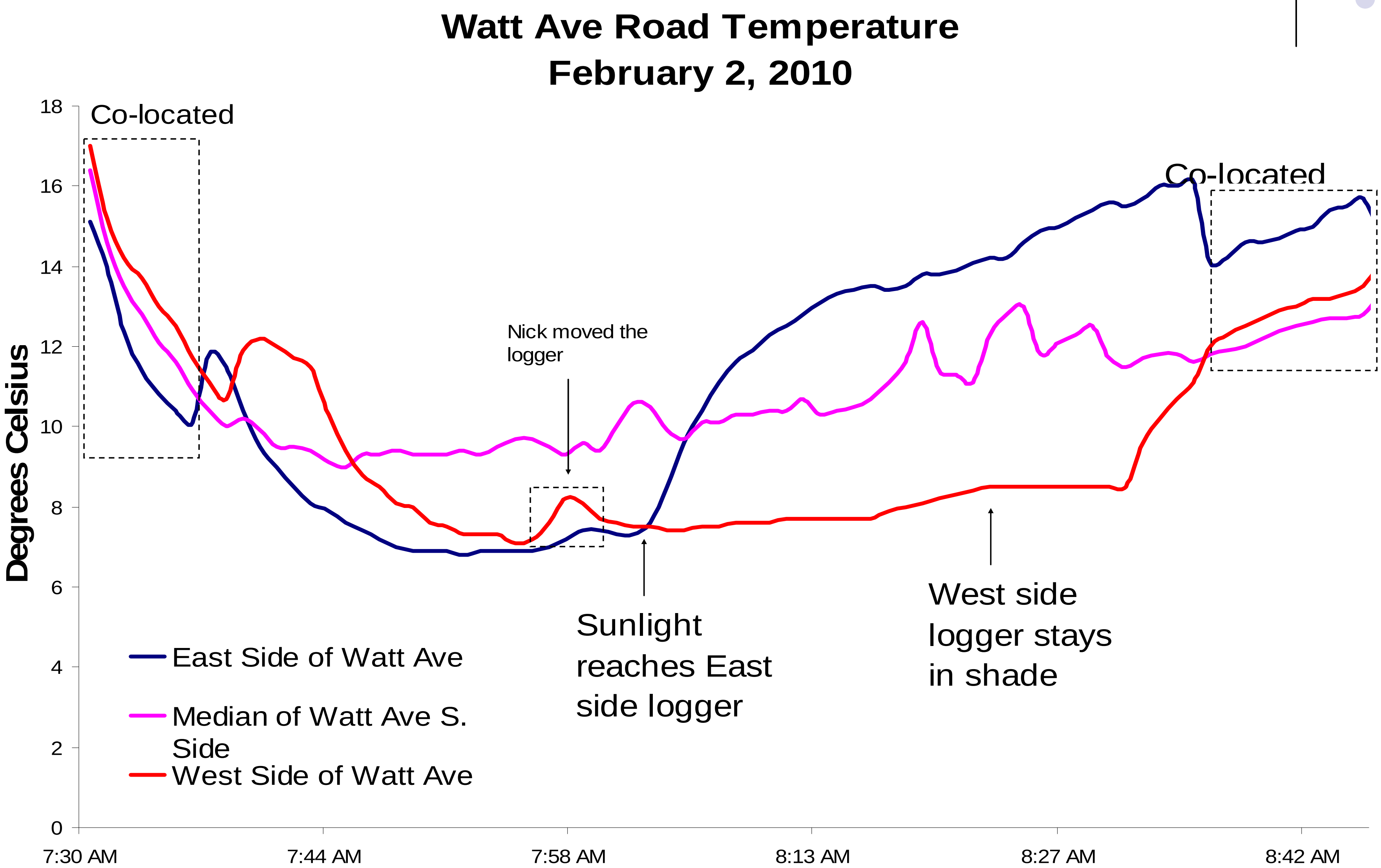


Ultra fine metals vanish in spring!
The upwind site had < 5% uf metals avg

Period	Silicon (ng/m^3)	Sulfur (ng/m^3)	Potassium (ng/m^3)	Chromium (ng/m^3)	Iron (ng/m^3)	Nickel (ng/m^3)
Winter	37.8	42.8	25.0	0.9	**29.3**	**12.1**
Transition (2 filters)	42.7	31.9	10.0	0.7	**28.6**	**10.4**
Spring (A, B, C)	59.2	128.7	11.6	0.05	**4.8**	**0.3**

Period	Copper (ng/m^3)	Zinc (ng/m^3)	Arsenic (ng/m^3)	Selenium (ng/m^3)	Bromine (ng/m^3)	Lead (ng/m^3)
Winter	**9.3**	**13.7**	0.45	0.14	1.3	1.57
Transition (2 filters)	**5.6**	**10.9**	0.33	0.14	0.9	1.75
Spring (A, B, C)	**0.4**	**2.00**	0.32	0.23	1.8	1.40

But despite the 2.5 C, the visible smoke did not rise above the road.



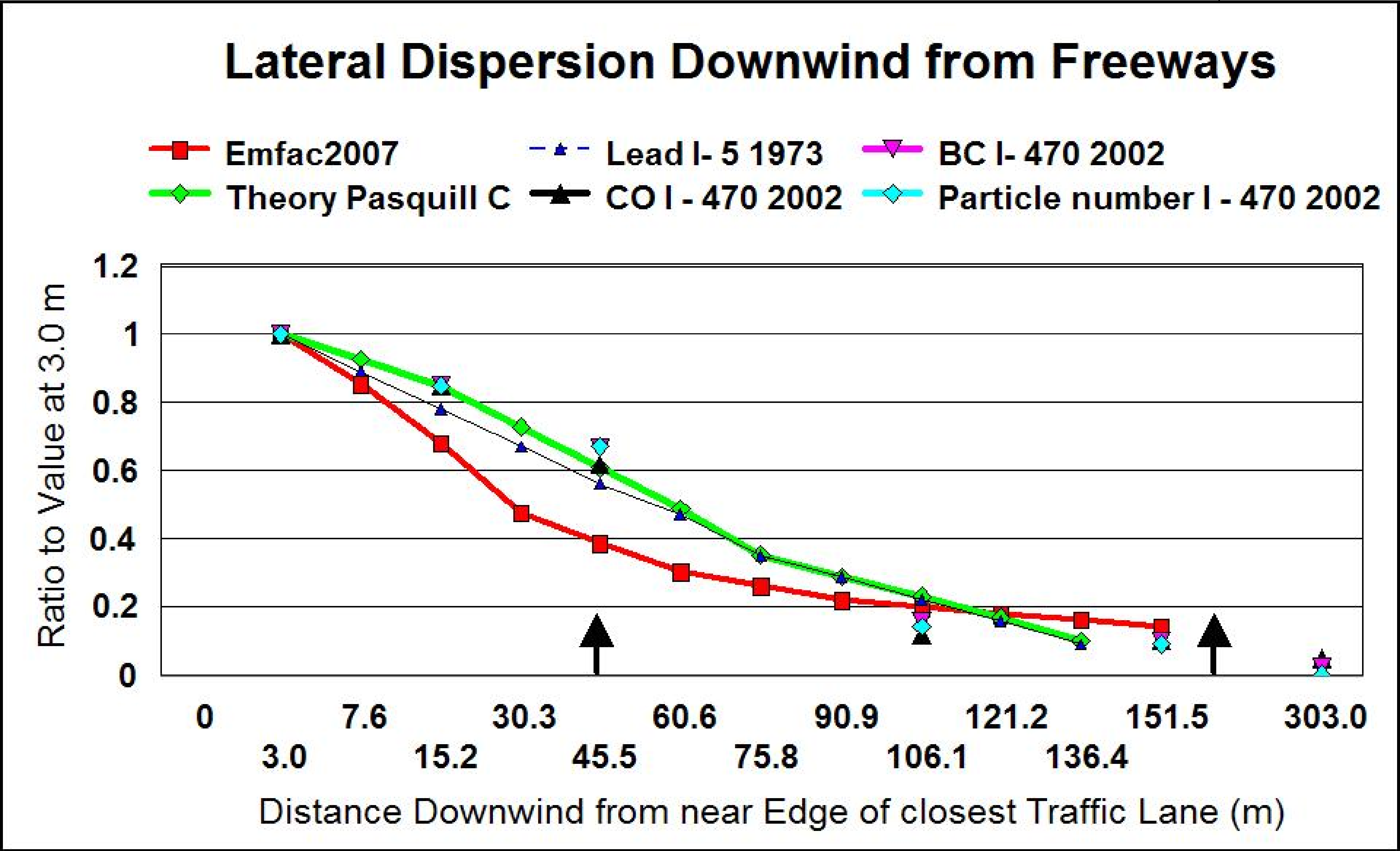
Bottom line: Dilution

- Meteorology rules!
  - Highest local pollution at low winds
- Geometry comes next
  - What volume of air is available for the pollutants to mix into
  - How much distance exists to receptors
  - Are there barriers to pollutant transport?
- Natural tendency for warm exhaust to rise if lateral transport off the roadway is hindered
- Caution: Much of the California data biased by persistent inversions – marine in LA, subsidence in the Central Valley

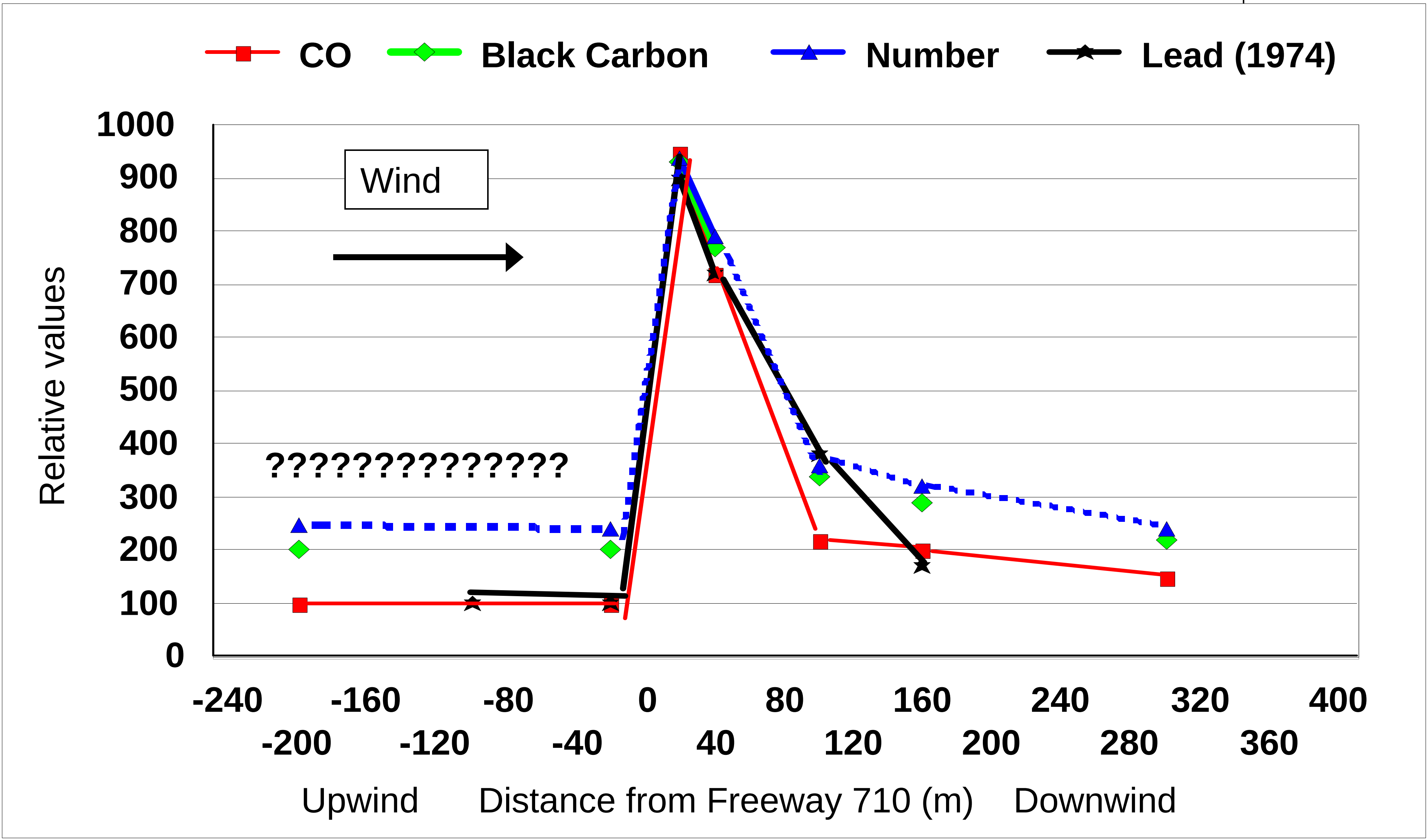
Removal

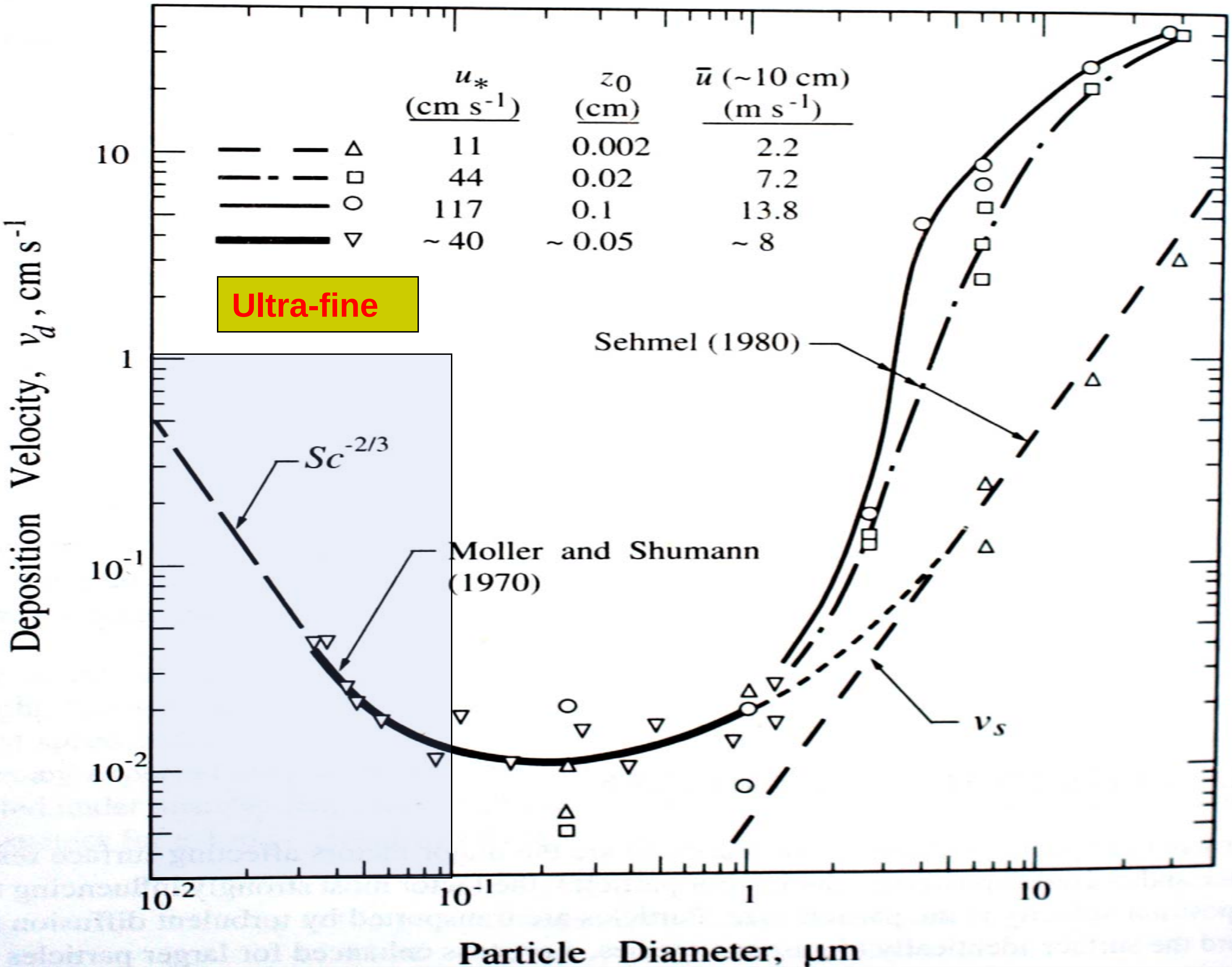
- The most toxic freeway aerosols are too small to ever settle
- It appears that with the sulfur removed from diesel, the remainder are too oily to pick up water and grow in size
- Hence they persist in very fine and ultra fine modes and fill the LA basin
- Removal at of near the source is one way to mitigate their impact
- Diffusion to a surface is one way to accomplish this, and vegetation is an attractive surface to employ

Lateral transport at grade: Cahill et al 1973: Zhu et al 2002



Lateral transport of ultra fine particles – efficient transport, no coagulation!





u_* (cm s^{-1})
z_0 (cm)
$\bar{u}$ (~10 cm) (m s^{-1})
11 0.002 2.2
44 0.02 7.2
117 0.1 13.8
~ 40 ~ 0.05 ~ 8
Ultra-fine
Sehmel (1980)
$Sc^{-2/3}$
Moller and Shumann (1970)
v_s
10
1
10^{-1}
10^{-2}
10^{-2}
10^{-1}
1
10
Deposition Velocity, v_d, cm s^{-1}
Particle Diameter, μm

UC Davis Mechanical Engineering 20 m wind tunnel

Measurement of needle area and spacing - deodar

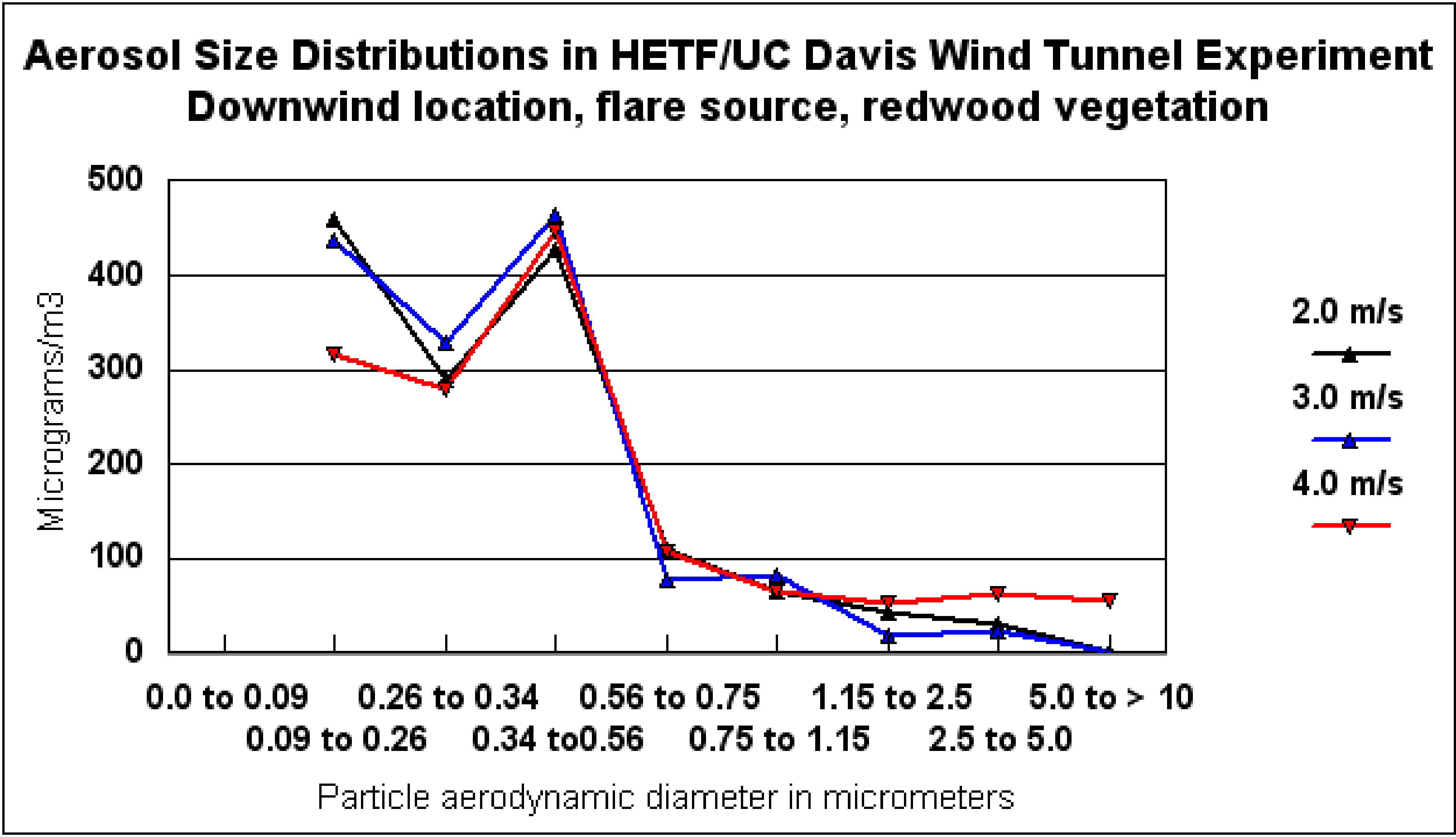
Aerosol diagnostics: upwind and downwind 8 stage DRUM samplers, Dustrak nephelometer

Highway flares as a convenient very fine/ultra fine aerosol source

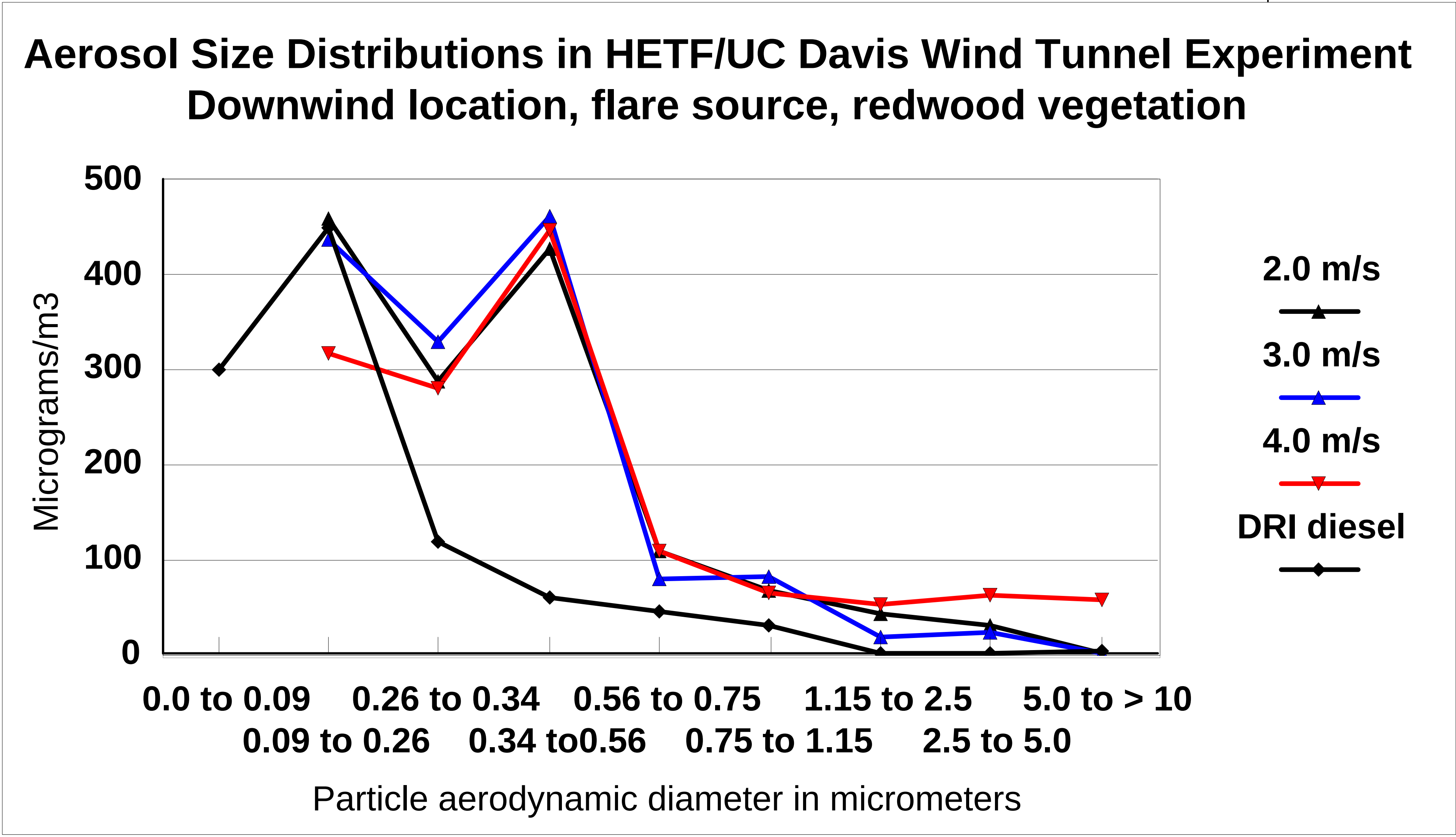
Typically strontium and potassium nitrate, potassium perchlorate, sulfur, aluminum, magnesium charcoal, sawdust

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

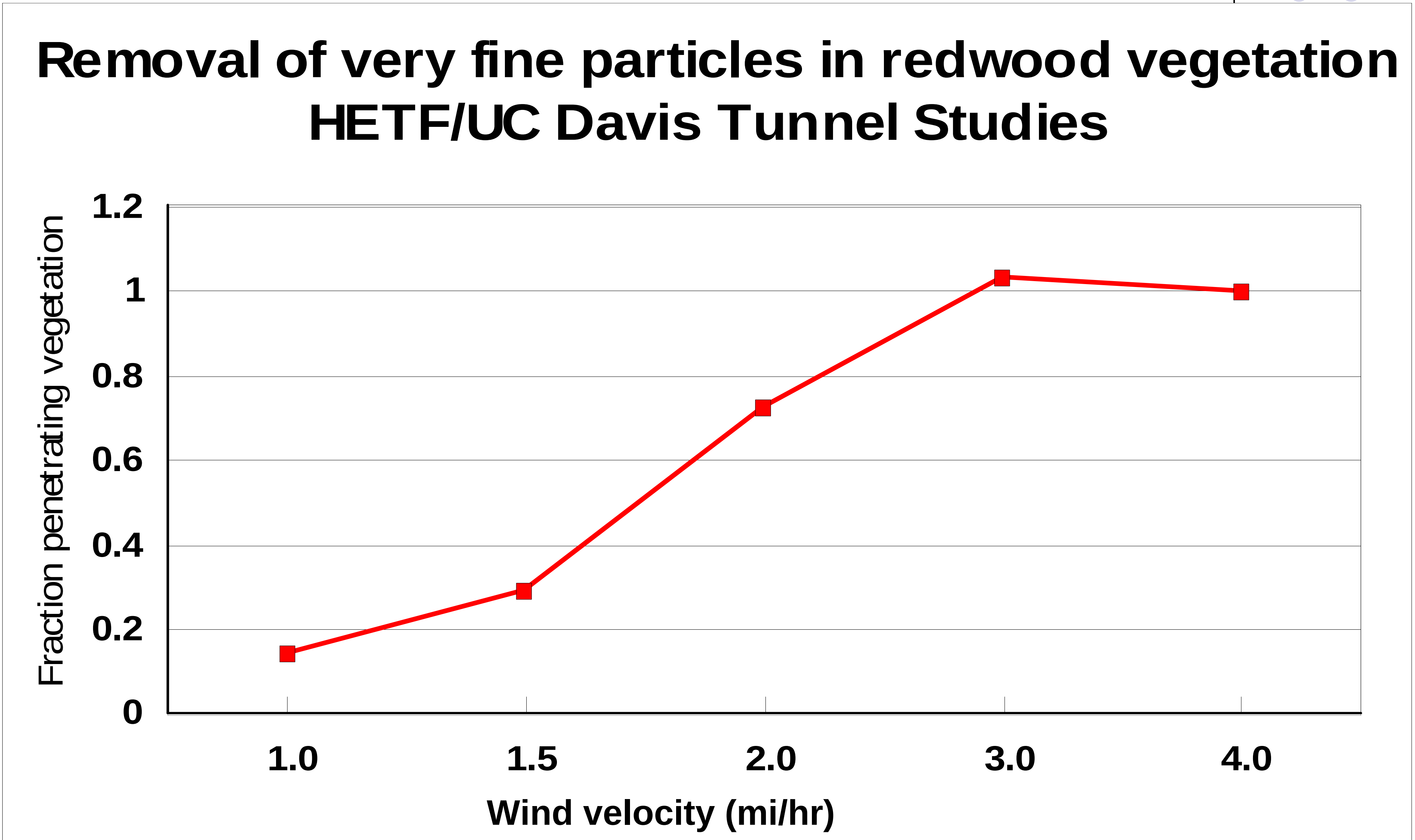
Size distribution of flare aerosols – scaled to tunnel wind velocity



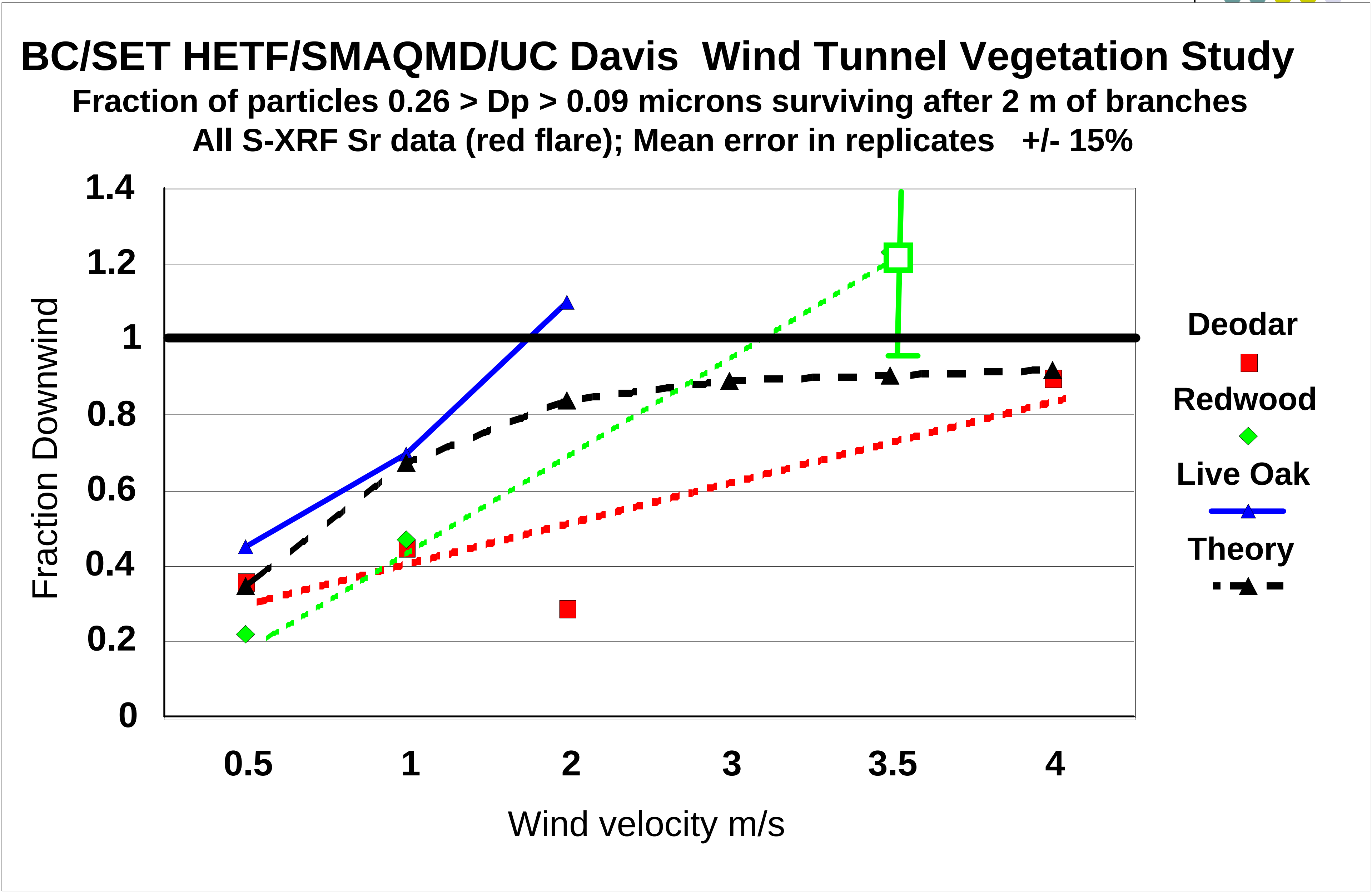
Comparison of road flare to diesel exhaust;



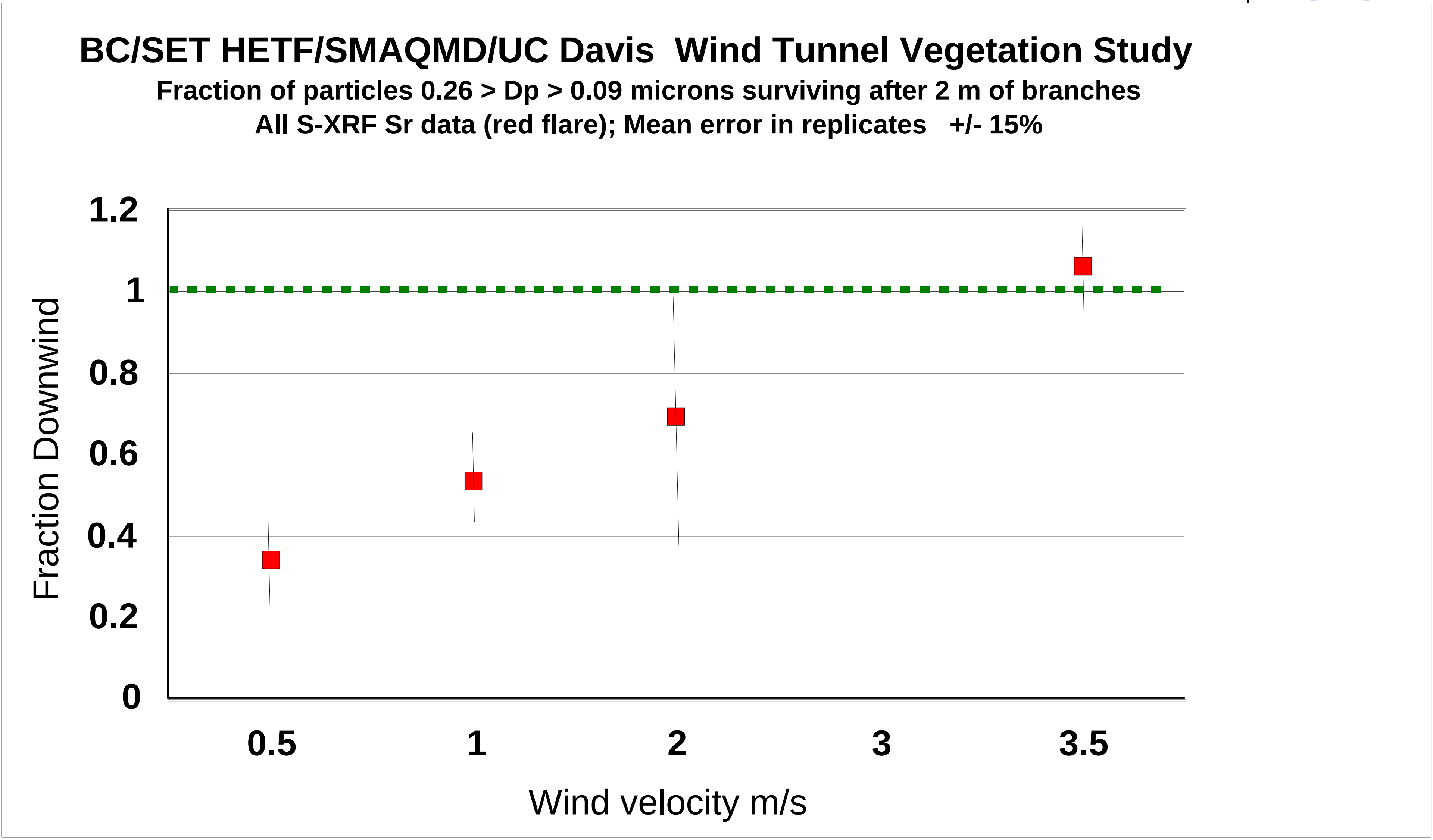
Mitigation of very fine and ultra fine particles by vegetation



Removal of very fine particles



Summary of all S-XRF analyses, all vegetation types



Conclusions – wind tunnel vegetative capture studies

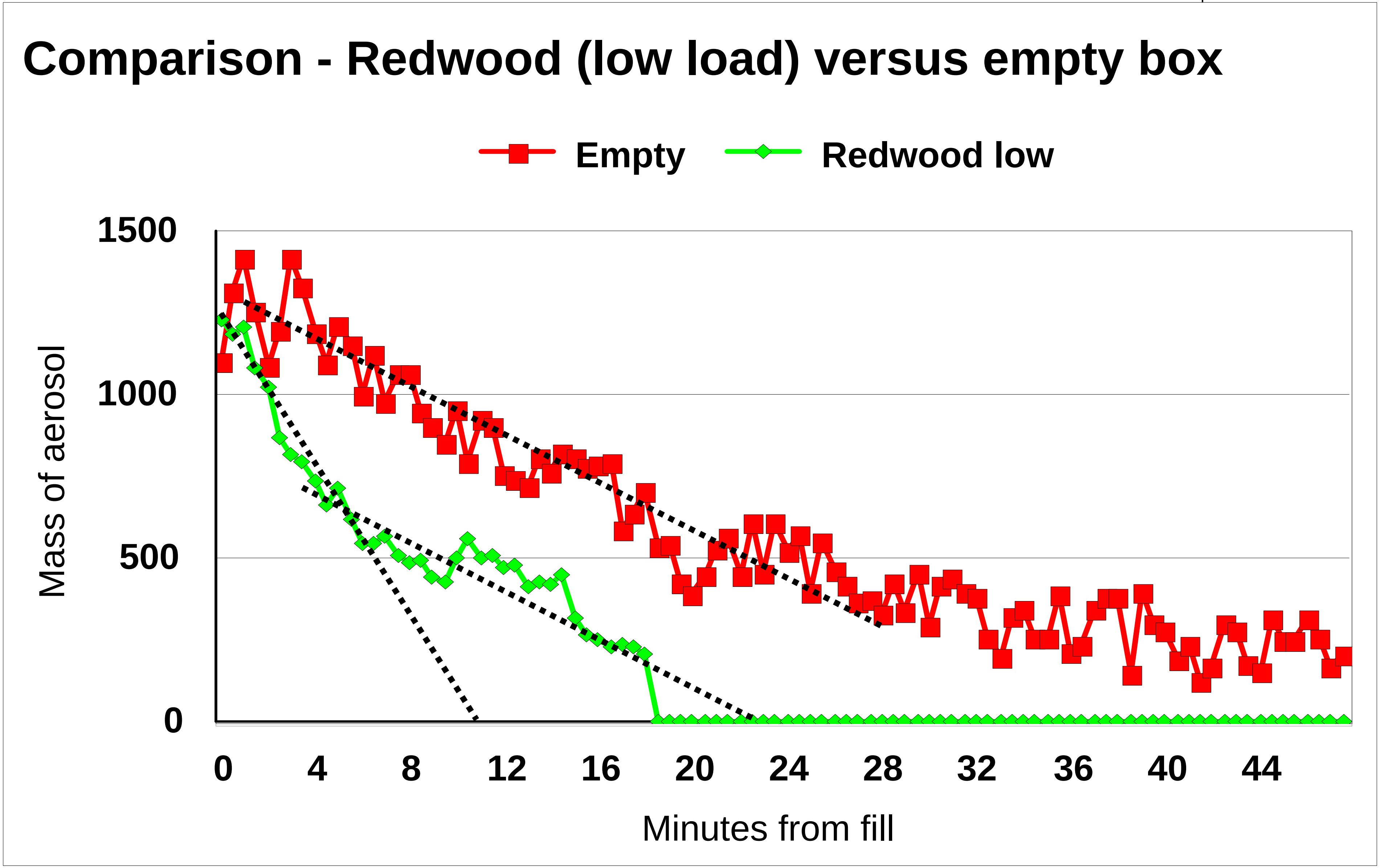
- Typically 75% of very fine particles 0.26 to 0.09 μm are removed by 2 m of vegetation at 1 mi/hr wind velocity.
- Calculations indicate 95% removal of ultra fine particles in the same situation.
- This process becomes inefficient with wind velocities above 3 mi/hr
- Redwood and deodar are better than live oak.

Measured removal rate of very fine particles in 2 m of vegetation at 1 mi/hr winds

Particle diameter µm	Deposition velocity cm/s	Redwood % removed	Deodar % removed	Live Oak % removed	Comment
0.17	**0.010**	**79%**	**65%**	**55%**	**Measured**
0.10	0.0125	83%	72%	64%	Estimated
0.075	0.015	86%	77%	70%	Estimated
0.050	0.02	90%	83%	78%	Estimated
0.035	0.045	95%	92%	90%	Estimated
0.010	0.25	99%	99%	90%	Extrapol-ated

Chui adding oleander branches

Branches versus empty box



Summary: With vegetative barriers on both sides (and ideally the median) of roadways, one benefits by -

- At high and medium wind velocities, turbulence mixes and lofts roadway pollutants
- At medium and low wind velocities, the barriers slow lateral transport and allow vehicular and roadway waste heat to loft pollutants
- At low wind velocities, very fine and ultra fine particles will be captured as they migrate through the semi-transparent vegetation barriers.

Mitigation options – we must move in parallel on all of them!

- Roadway source improvements, including
  - Cleaner engines, fuel, and new artificial lubricating oils
  - Removal of gross emitting vehicles (~ 3%) from roadways (worst 1% vehicles = ~ 30% of vf/uf mass)
  - Reduced traffic via transportation alternatives
- Roadway design options – “Complete Streets”
  - Highway design; cut section good, raised very bad
  - Pollution barriers – use waste heat and vegetation to loft and trap uf particles (walls alone don’t work very well)
- Reduced Transport efficiency to residences
  - Distance! This should be a key factor in new roads.
  - Pollution barriers, especially vegetation
- Residential indoor air quality improvement
  - Positively pressurized filtered receptors

I 5 south of Sac – good barrier

Roseville railyard – no barrier

Where are the gaps in meeting research and policy needs? Dilution

- Inadequate near roadway models (Calline 4, Emfac 2007)
  - Roadway configuration not well handled
  - Complex meteorology in vegetation barriers
  - Match of vegetation type to realistic freeway configurations
  - Impact of local meteorological inversions
  - No consideration of temperature impacts
- Few near roadway studies with vegetation
  - Very few studies of heavily traveled secondary streets
  - Weak highway signature via mass
  - Lack of “smoking gun” highway tracers
    - **We can add one!**
  - Lack of interest by agencies (until now?)

Where are the gaps in meeting research and policy needs? Removal

- Good deposition models but
  - lack ultrafine validation
  - Lack of detailed vegetation needle/leaf structure
  - No real studies on aerosol retention/re-emission
- Few removal studies with vegetation
  - Limited species studies
    - Need regionally appropriate trees,
    - Match vegetation to realistic freeway conditions
  - No direct measurement of ultra fines
  - Lack of interest by agencies (until now?)

Result: Quantitative estimates on the value of near roadway vegetation unavailable to planners

A proposal

- One of the major handicaps of near roadway studies is lack of a definitive conserved roadway tracer with sizes close to highway emissions, including ultra fines
- I propose we provide one using
  - highway flares in a steel pipe in the back of
  - a pickup truck that shuttles between two off ramps circa 1000 m apart for
  - 2 hrs as 8 sequential 15 minute flares burn
- The concentrations are
  - high enough to be easy to measure in 2 hr samples and
  - unique enough not to require upwind samples
- Numerous simple battery powered filter samplers can be used since no particle sizing is required
  - Indoor - outdoor ratios can be done

Ca;lifornia Freeways versus Arden at Watt

Comparison	Parameters	Units	Freeway	I-5 Sacr flare	I-5 Sacr cars	I-5 Sacr. trucks	Watt Ave cars	Watt Ave trucks
			1974		2003	2003	2003	2003
			Lead		PM2.5	PM2.5	PM2.5	PM2.5
		mg/mi	48		22.4	216	22.4	216
Source	Lead	mg/km	**30**		**14**	**135**	14	135
	< 5 um							
Box volume	Height	m	3.5	3.5	3.5	3.5	2.5	2.5
	Width	m	60	60	60	60	40	40
	Length	m	1600	1000	1600	1600	1600	1600
	Volume	m3	336000	210000	336000	336000	160000	160000
# vehicles in box	Traffic	vehicles/hr	5000		7900	325	3800	53
(daytime 12 hr)		(averaging)	(normalized)		(AADT/18)	(AADtr/24)	(AADT/18)	(AADTr/12)
	Speed	mi/hr	60		45	45	20	20
		km/hr	96		72	72	32	32
	# vehicles/box	vehicles	83		176	7	190	3
	Emission	mg	4000	10667	3932	1560	4256	572
	per minute							
	Concentration	ug/m3	11.9	50.8	11.7	4.6	26.6	3.6
	in box/min							
Wind velocity	lateral	m/s	3	2	2	2	2	2
Sliding box	translation	s	20.00	30.00	30.00	30.00	20.00	20.00
	fraction of min		0.33	0.50	0.50	0.50	0.33	0.33
Predicted	Avg concentration	ug/m3	3.97	25.40	5.85	2.32	8.87	1.19
	in mixed zone	PM2.5	(lead)					
Predicted in mixed zone					8.2		10.1	
Actual at site					10		7	

Could this work?

- We did something very much like this in 1978 for General Motors looking at sulfur in catalytic equipped cars
  - Courtney, W.J., S. Rheingrover, J. Pilotte, H.C. Kaufmann, T.A. Cahill, J.W. Nelson. **Continuous observation of particulates during the general motors sulfate dispersion experiment**. *Journal of the Air Pollution Control Association.* 28:225-228 (1978).
- The pollution levels even on the highway do not violate $PM_{2.5}$ mass standards for the 2 hr test
- The costs are very low and this allows numerous sampling sites needed for complex vegetation