

# Determining Sources Contributing to PM<sub>2.5</sub> and PM<sub>10</sub> in Ambient Air

Peter L. Jackson\*

Environmental Science & Engineering Program  
Natural Resources and Environmental Studies Institute

University of Northern British Columbia

**\*with many graduate students, research assistants and  
postdoctoral fellows: Melanie Noullett, John Spagnol, Bruce  
Ainslie, Bryan McEwen, Melissa Darby, Vanessa Egginton,  
Brendan Murphy, Tracy McKay...**

# Air Quality Considerations

Sources → Atmosphere → Receptors

**All must be considered!**

**Most AQ issues are complex and solutions that work can be challenging**

# Sources

- No source = no pollution!
- Amount, configuration, characteristics all important

# Atmosphere

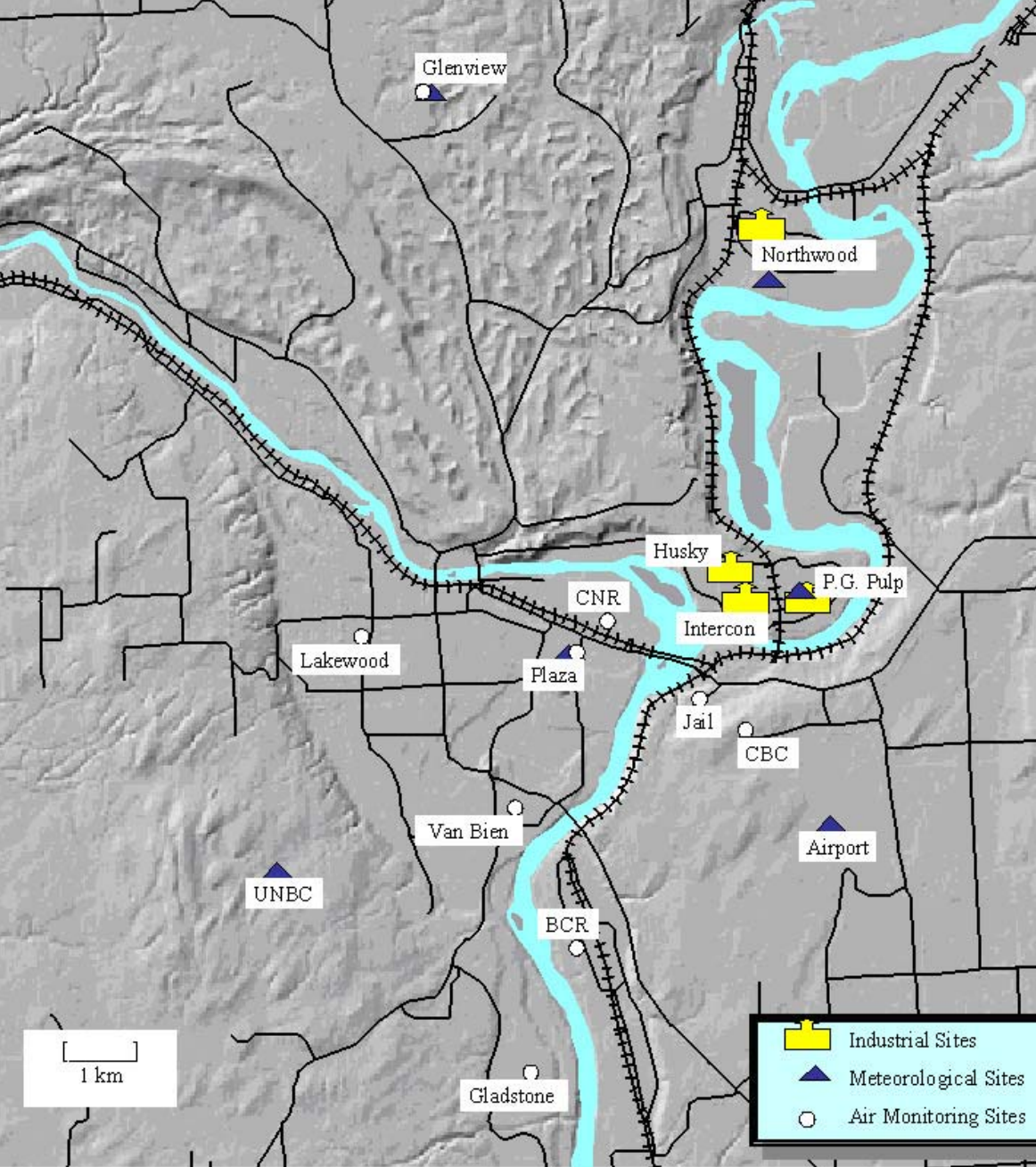
- Acts to **dilute, disperse, transform, remove** pollutants, as well as **transporting** them between source and receptor
- Most AQ episodes are due to atmospheric conditions, **not** emission changes
  - **Inversions and light winds associated with High Pressure systems cause episodes in PG**

# Receptors

- Where pollution is received and has impact (where people live and work)
- Health issues, environmental degradation, visibility, nuisance / odor, etc.

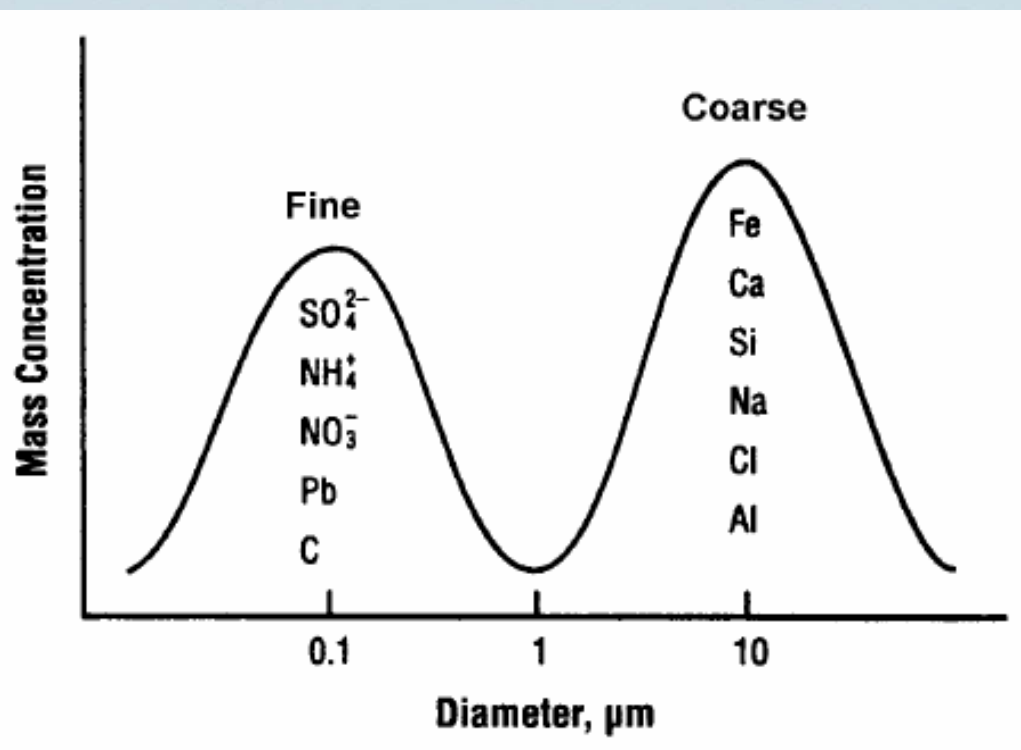
# PG Topography

- PG in a “bowl”
- “bowl” restricts free mixing of air and dilution of pollution
- especially under inversion conditions and light winds



# Particulate Matter – What is it?

- An airborne atmospheric particle
- PM10 - a particle of 10 microns, about 1/5th the width of a human hair.
- PM2.5 - a particle of 2.5 microns, about 1/20th the width of a human hair
- BC Ministry of Health has called PM **“single greatest air pollution problem in BC”**
- PM10 – travels into the lungs and cause a variety of respiratory problems
- PM2.5- penetrates the respiratory system deeper and is therefore more of a problem than the sizes  $> 2.5$  microns



- PM size distribution is bi-modal.

- coarse mode generally results from mechanical breakdown of larger particles

- fine mode generally results from combustion processes and secondary particulates

Source: Seinfeld (1986)

- $PM_{2.5}$  is about 15% dust and the rest from combustion – it can be used as a measure of ambient conditions due to combustion sources

- The coarse fraction ( $PM_{10} - PM_{2.5}$ ) comprises 85% of the dust

# Typical PM<sub>2.5</sub> Components

- **Geological Material** – suspended dust consists mainly of oxides of Al, Si, Ca, Ti, Fe, and other metal oxides.
- **NaCl** – salt is found in PM near sea coasts, and after de-icing materials are applied.
- **Sulfate** – secondary particulate resulting from conversion of SO<sub>2</sub> gas to sulfate-containing particles.
- **Nitrate** – secondary particulate resulting from a reversible gas/particle equilibrium between NH<sub>3</sub>, HNO<sub>3</sub>, and particulate ammonium nitrate.
- **Ammonium** – ammonium bisulfate, sulfate, and nitrate most common.
- **Water (liquid)** – soluble nitrates, sulfates, ammonium, sodium, other inorganic ions, and some organic material absorb water vapor from the atmosphere.
- **Organic Carbon (OC)** – consists of hundreds of separate compounds containing mainly carbon, hydrogen and oxygen.
- **Elemental Carbon (EC)** – composed of carbon without much hydrocarbon or oxygen. EC is black, often called soot.

Chow and Watson, 1997

# Sources of PM

- Industrial processes
- Dust
- Locomotive engines
- Heating
- On-road mobile
- Burning
- Chemical transformations of gases (e.g.  $\text{SO}_2$ ) to sulfate (secondary particulates)
- **Many** others

**Diversity of Sources Makes PM difficult to manage!**

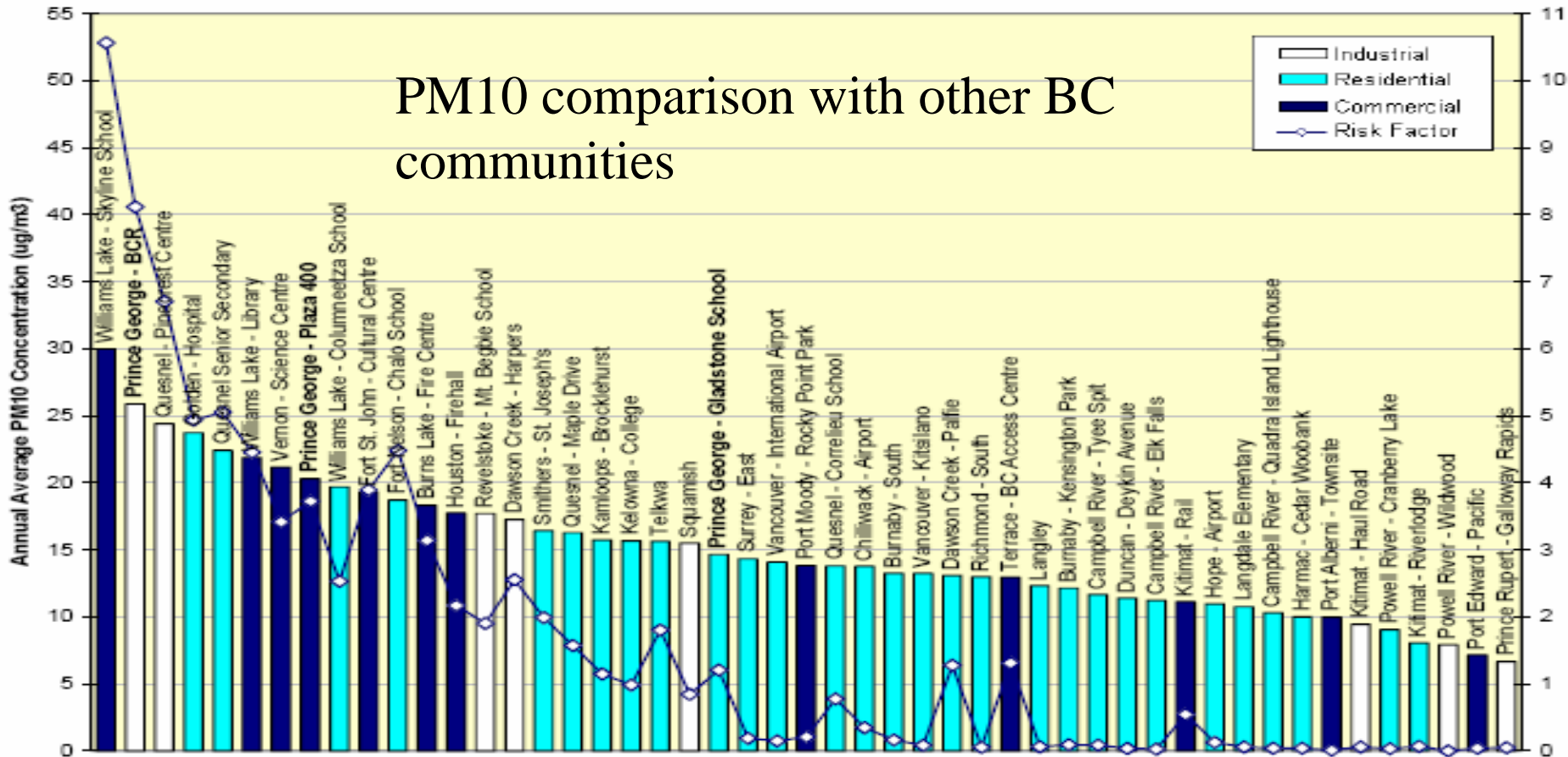
# Sources

**Table 7.11.1:** Summary of PM source emissions (g/sec).

| Sec No |                    | Maximum emission rates (g/sec) |       |       |       | Average emission rates (g/sec) |       |       |       |
|--------|--------------------|--------------------------------|-------|-------|-------|--------------------------------|-------|-------|-------|
|        |                    | NOx                            | SOx   | PM10  | PM2.5 | NOx.                           | SOx   | PM10  | PM2.5 |
|        | <b>PGAQ (2006)</b> |                                |       |       |       |                                |       |       |       |
| 2      | Permitted          | 60.0                           | 109.9 | 105.9 | 68.9  | 59.9                           | 109.9 | 105.1 | 68.5  |
| 3      | Road Dust          |                                |       | 101.7 | 17.6  |                                |       | 16.0  | 2.7   |
| 4      | Railway            | 864                            | 12    | 41    | 38    | 729.6                          | 10.4  | 34.3  | 32.3  |
| 5      | Mobile             | 77.0                           | 1.2   | 1.8   | 1.3   | 41.6                           | 0.65  | 0.97  | 0.7   |
| 6      | Heating            | 16.66                          | 2.67  | 10.16 | 10.14 | 5.95                           | 0.95  | 3.63  | 3.62  |
| 7      |                    |                                |       |       |       |                                |       |       |       |
| 8      |                    |                                |       |       |       |                                |       |       |       |

Permitted sources are a combination of stack testing and permit levels; road dust source estimates and locomotive estimates are uncertain.

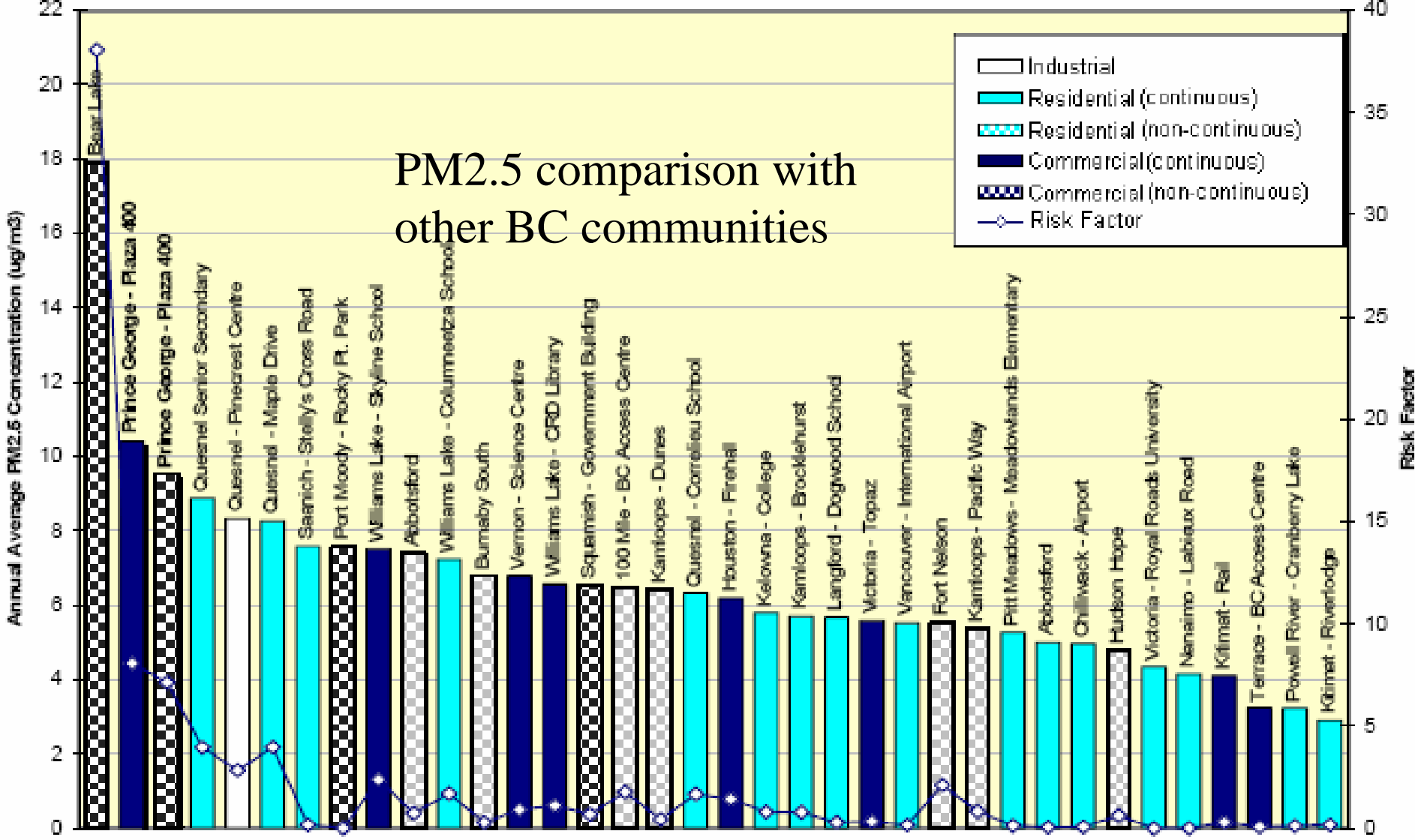
# PM10 comparison with other BC communities



Risk factor is a relative health index normalized to 2000 average values based on increments > 25 ug/m<sup>3</sup>

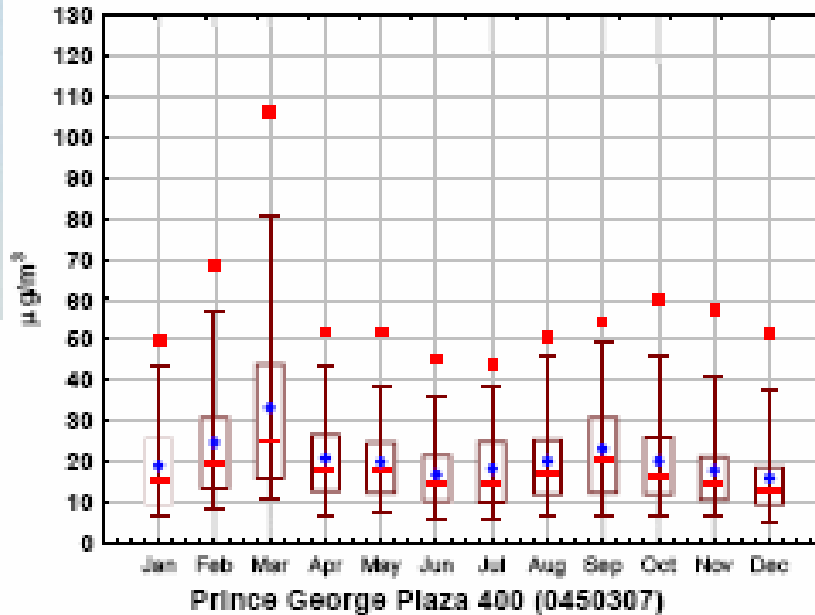
source: 2004 Annual Air Quality Report for Prince George, BCMOE

# PM2.5 comparison with other BC communities



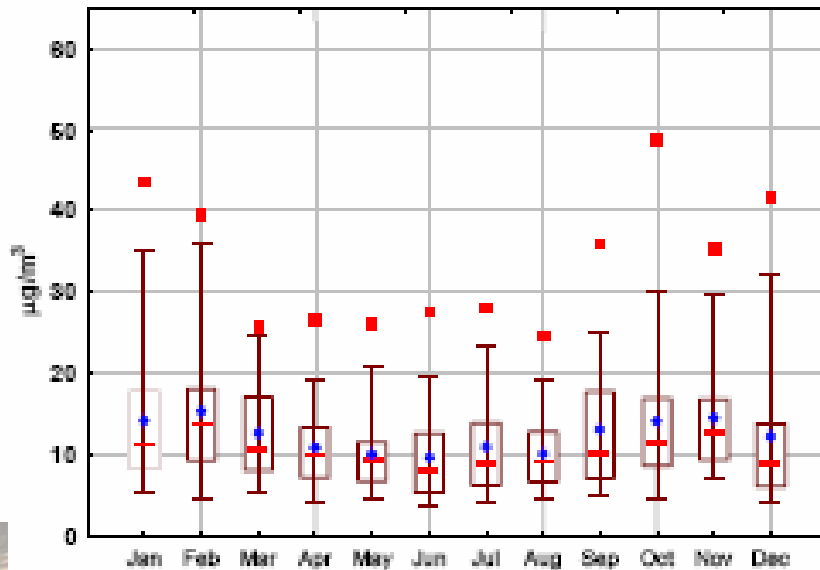
source: 2004 Annual Air Quality Report for Prince George, BCMOE

Prince George Plaza 400 (0450307)



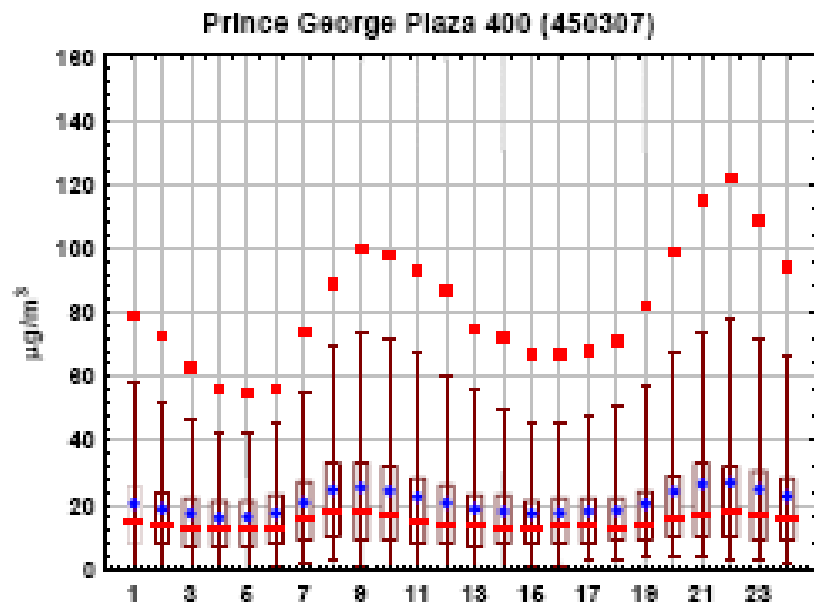
- annual variation in PM10 shows influence of dust episodes in late winter / early spring as roads dry out

Prince George Plaza 400 (0450307)

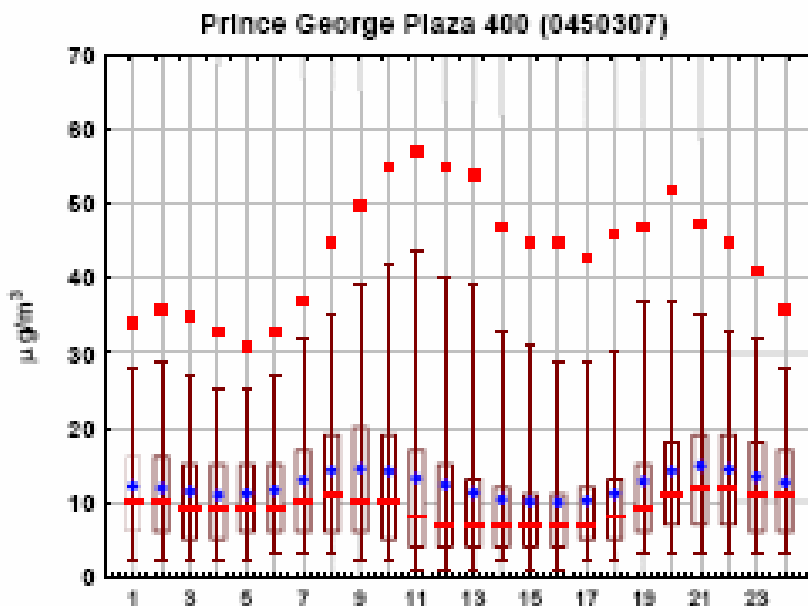


- PM2.5 levels are highest in fall and winter due to combustion combined with stagnation events

source: Suzuki and Taylor, 2003.



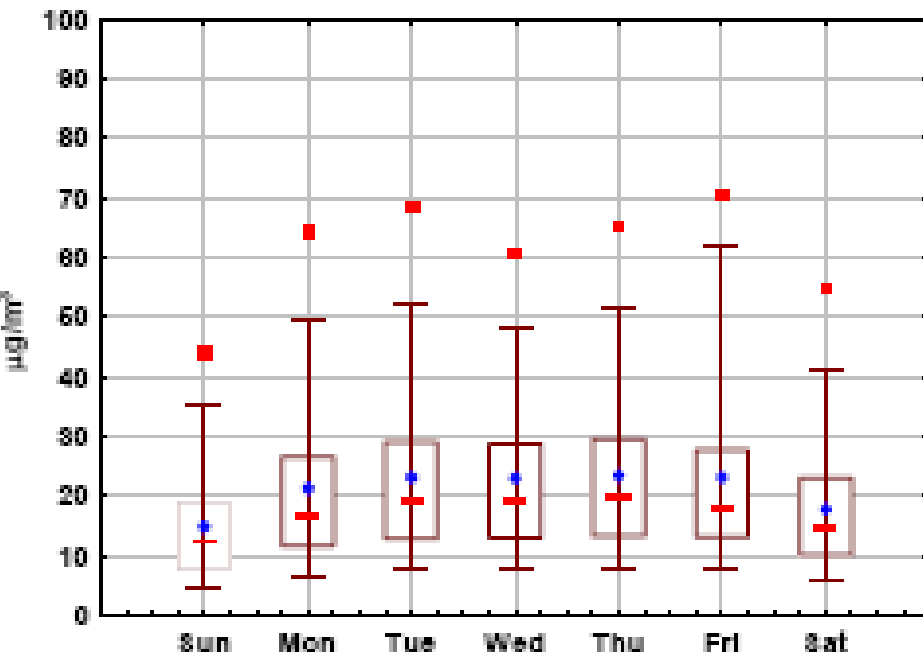
- PM10 – diurnal variation responds to traffic (dust)



- PM2.5 – can see the influence of fumigation events (late morning) on the 95<sup>th</sup> and 98<sup>th</sup> percentiles

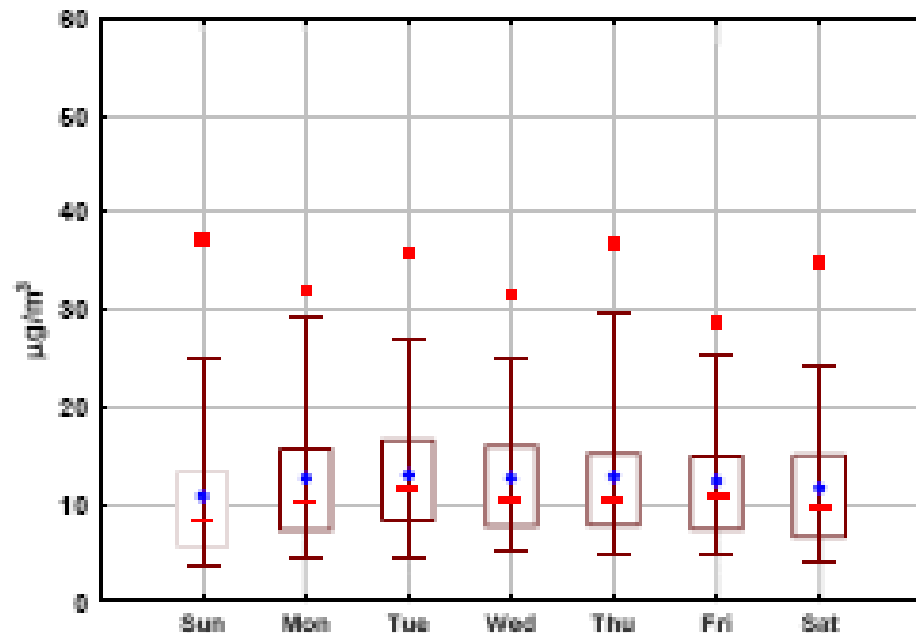
source: Suzuki and Taylor, 2003.

Prince George Plaza 400 (0450307)



- hebdomodal variability shows higher levels of  $PM_{10}$  during the week reflecting traffic and work patterns that generate dust (episodes caused by dust sources)

Prince George Plaza 400 (0450307)



- $PM_{2.5}$  have somewhat lower median and mean values during weekends, but 95 and 98<sup>th</sup> percentile values show no weekly trend (episodes caused by combustion sources which operate 24/7)

source: Suzuki and Taylor, 2003.

# Information / Research Needs for Management of PM

- Goal of PM management is to reduce both average and episodic PM levels in airshed
- This requires knowing which **sources** are contributing to average and episodic levels
- Characterization of PM sources from routine ambient data is useful but may not provide strong enough evidence
- Several methods for evaluating source contributions exist, each giving different sorts of answers: **none are perfect!**
- Methods can be highly complementary
- If results from different studies point to same results (triangulation), then they increase confidence and strengthen management actions that result

# Research Studies

- Past studies done by Industry, BCMOE, UNBC, etc.
- Some sources are very poorly characterized – especially non-industrial sources
- Current studies have the goal of improving understanding of contribution of all PM sources to ambient AQ and inform phase III AQ Mgmt plan

# Types of Source ID Studies

## 1. Receptor Modelling

- based on **ambient AQ data**
- wind sector analysis (Fudge et al, BCMOE)
- chemical mass balance (CMB) – associates source chemical source profiles to ambient data - not being attempted in PG
- PCA / PMF (EC/BCMOE/STI study, Allen) - lets the ambient data “speak for themselves” and infers source profile

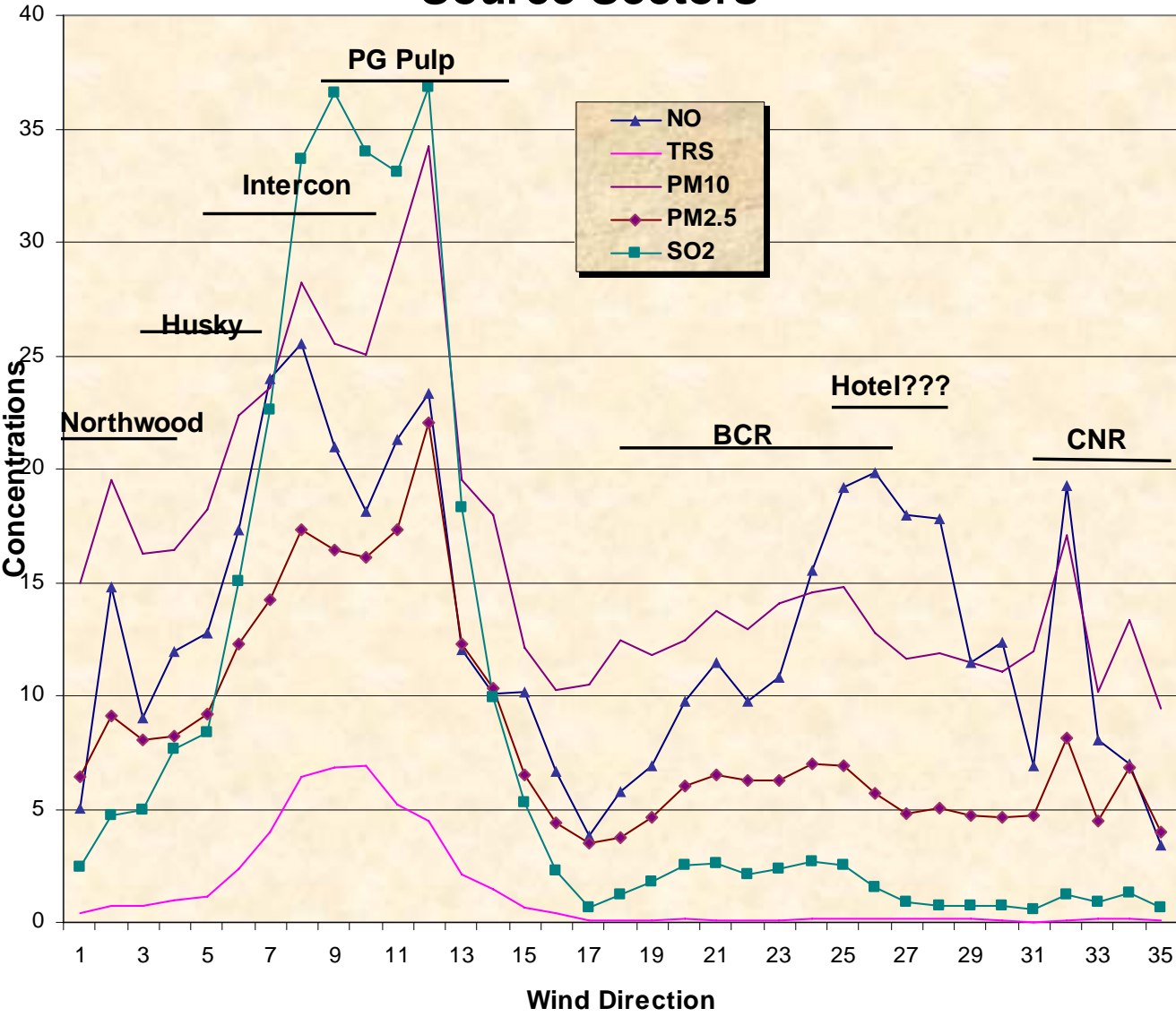
## 2. Dispersion Modelling

- based on **source emission inventory**, meteorological data
- validated by ambient data and can determine contributions of individual sources at any receptor in the airshed
- Many “levels” of modelling
- Several past studies by gov’t / industry, most were not
- Current comprehensive study using Calpuff (Spagnol et al, UNBC – PGAQIC – Research Working Group)

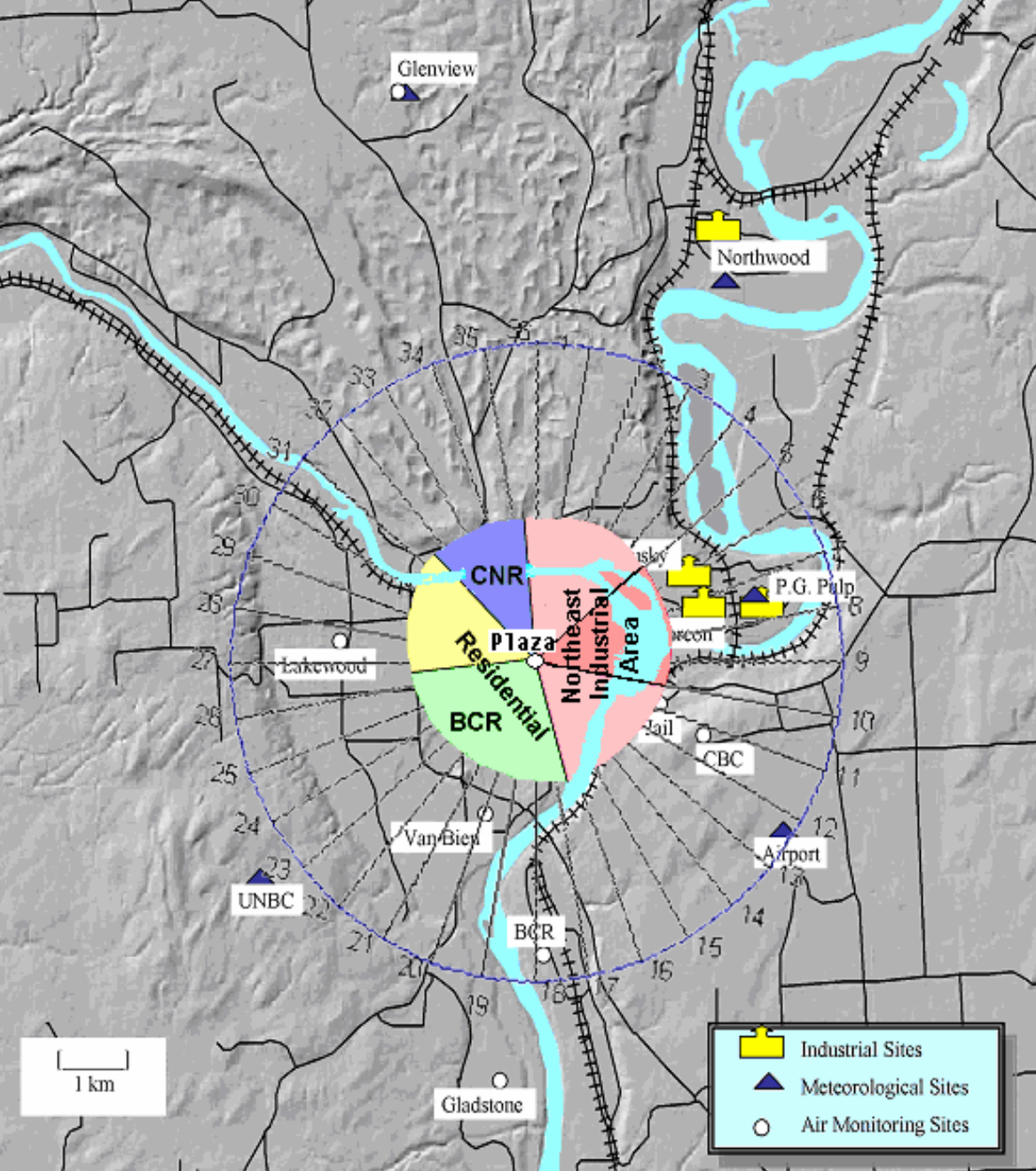
# Recent PM<sub>2.5</sub> Studies

- wind sector analysis by BCMOE used ambient AQ levels and winds at Plaza 400 to characterize direction of likely sources from Plaza 400 monitoring site
  - Take-home message from this study is that for PM<sub>2.5</sub>: probably about **40 % are from the direction of the heavy industrial area** NE of town, about **40% are public/commercial/industrial** from other directions, and about **20% are “background”**
  - Needs confirmation and refinement from other studies (not possible to identify or quantify specific sources)
- Another study of PM<sub>2.5</sub> monitored school children and neighborhoods in PG, by MSc student, Melanie Noullett

# Pollutant Levels Relative to Potential Source Sectors



Fudge and Sutherland, 2002



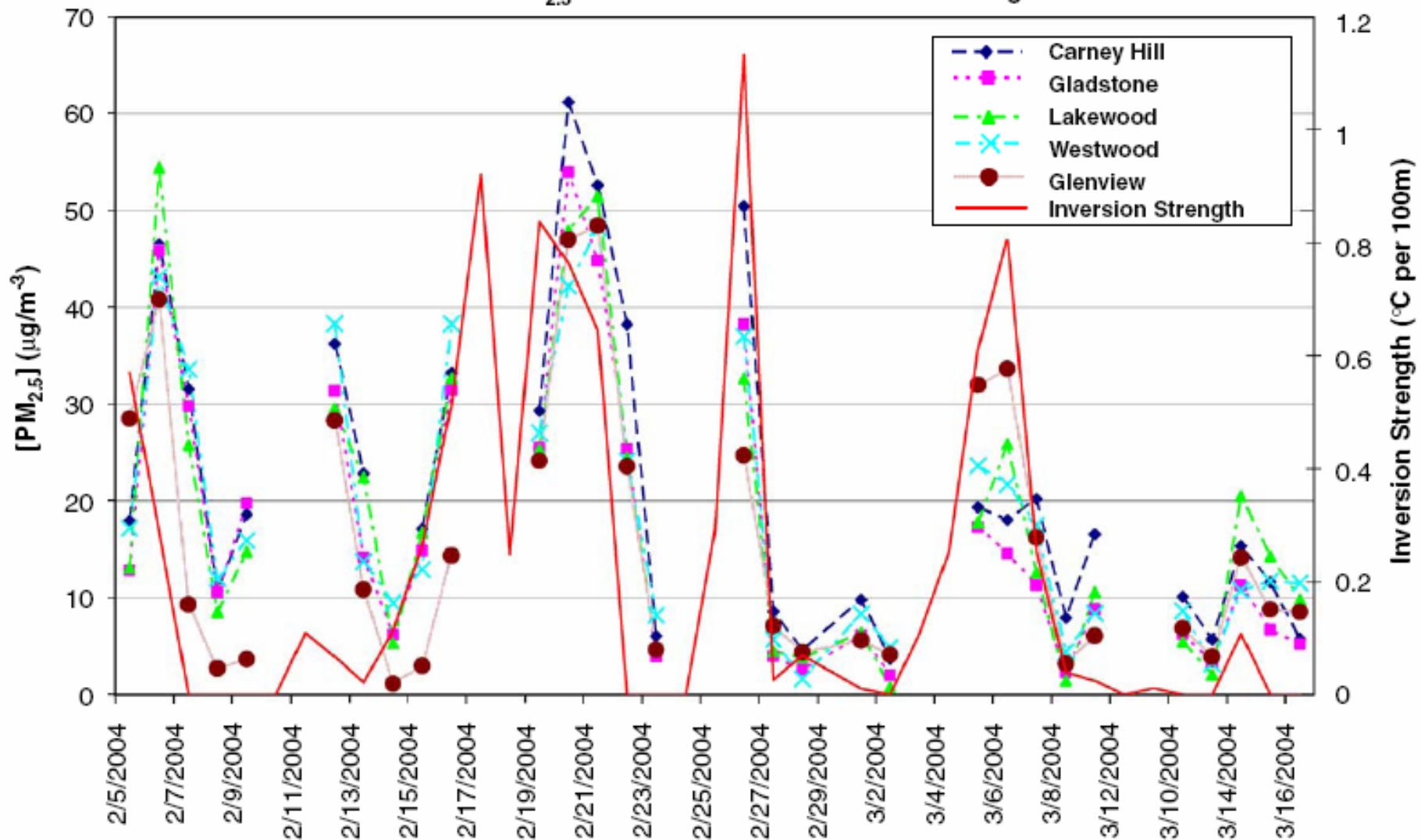
Fudge and Sutherland, 2002

# Average Percent Contributions to the Plaza Site (2000 - 2002)

| Sector                            | SO <sub>2</sub> | PM <sub>2.5</sub> | PM <sub>10</sub> | TRS   | NO    | NO <sub>2</sub> |
|-----------------------------------|-----------------|-------------------|------------------|-------|-------|-----------------|
| <b>Northeast Industrial Areas</b> | 77.2%           | 43.6%             | 31.9%            | 82.9% | 39.8% | 31.8%           |
| <b>Residential Area</b>           | 8.3%            | 16.5%             | 14.0%            | 4.0%  | 24.9% | 24.7%           |
| <b>BCR Industrial Area</b>        | 5.2%            | 6.3%              | 4.6%             | 0.7%  | 6.3%  | 7.1%            |
| <b>CNR/Commercial Area</b>        | 0.6%            | 1.6%              | 1.2%             | 0.3%  | 1.7%  | 1.8%            |
| <b>Unknown</b>                    | 8.7%            | 12.0%             | 9.7%             | 11.3% | 19.0% | 10.2%           |
| <b>Background</b>                 | 0.0%            | 19.9%             | 38.7%            | 0.8%  | 8.3%  | 24.4%           |

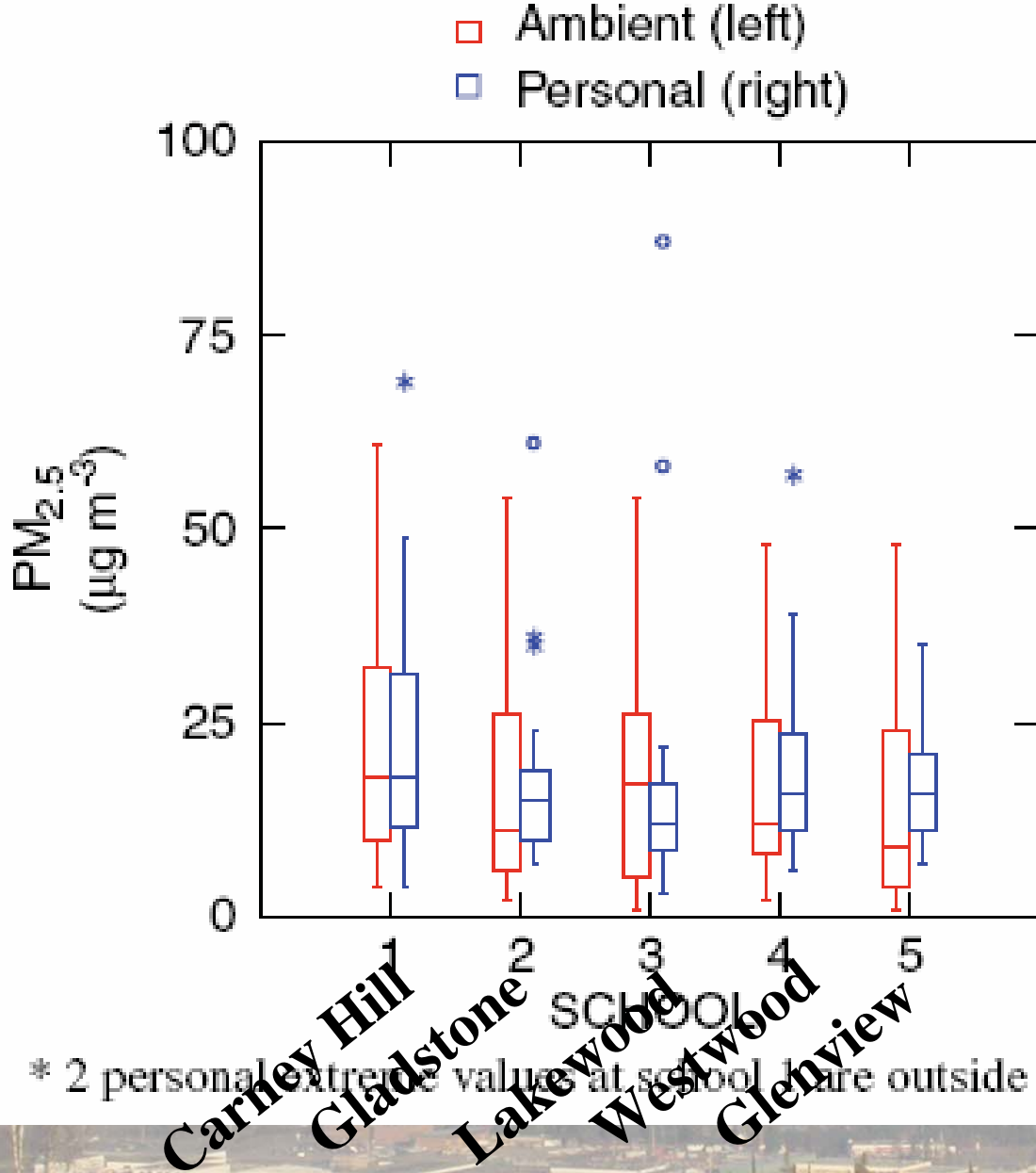
Fudge and Sutherland, 2004

# Ambient PM<sub>2.5</sub> Concentration and Inversion Strength



Source: Noullett, Jackson and Brauer, 2006 (note dates are actually in 2001)

See poster ...



Source: Noullett, Jackson and Brauer, 2006

\* 2 personal extreme values at school 1 are outside of the scale.

Table 5

Comparison of children's personal exposure, ambient concentration and the personal–ambient correlation from various locations where multiple samples were collected

| Location   | Subject health and age | Study period (season)     | # of subjects | # of samples personal (ambient) | Personal exposures              |                       |                               |                            | Ambient concentrations |        |          |        |
|--|------------------------|---------------------------|---------------|---------------------------------|---------------------------------|-----------------------|-------------------------------|----------------------------|------------------------|--------|----------|--------|
|  |                        |                           |               |                                 | Avg (SD)                        | Median                | GM (GSD)                      | Range                      | Avg (SD)               | Median | GM (GSD) | Range  |
| Prince George, BC CAN                                  | Healthy 10–12 years    | 2001 (Winter)             | 15            | 142 (149)<br>140 <sup>a</sup>   | 21 (22)<br>18 (13) <sup>a</sup> | 16<br>16 <sup>a</sup> | 16 (2)<br>16 (2) <sup>a</sup> | 3–179<br>3–87 <sup>a</sup> | 18 (15)                | 14     | 13 (3)   | 1–61   |
| Wageningen, Netherlands (Janssen et al., 1999)         | Healthy 10–12 years    | 1995 (Spring)             | 9             | 55                              | 24 (5)                          | —                     | —                             | 19–33                      | 17 (3)                 | —      | —        | 15–22  |
| Santiago, Chili (Rojas-Bracho et al., 2002)            | Healthy 10–12 years    | 1998/99 (Winter)          | 18            | 87                              | 70 (25)                         | 58                    | —                             | 20–202                     | 68 (28)                | 61     | —        | 17–190 |
| Seattle, WA USA (Liu et al., 2003)                     | Asthmatic 6–13 years   | 1999/01 (All)             | 19            | 263 (272)                       | 13 (8)                          | —                     | 11 (2)                        | 1–49                       | 11 (6)                 | —      | 10 (2)   | 3–40   |
| Alpine, CA USA (Wu et al., 2005; Delfino et al., 2004) | Asthmatic 9–17 years   | 1999/00 (Fall and spring) | 20            | 202 (170)                       | 24                              | —                     | 20 (2)                        | 2–72                       | 13                     | —      | 12 (2)   | 4–32   |

All units are  $\mu\text{g m}^{-3}$ .<sup>a</sup>Results are reported with two extreme outliers (149 and 179  $\mu\text{g m}^{-3}$ ) removed from the analysis.<sup>b</sup>Article does not report whether this longitudinal correlation is a median or mean value.

Source: Noullett, Jackson and Brauer, 2006

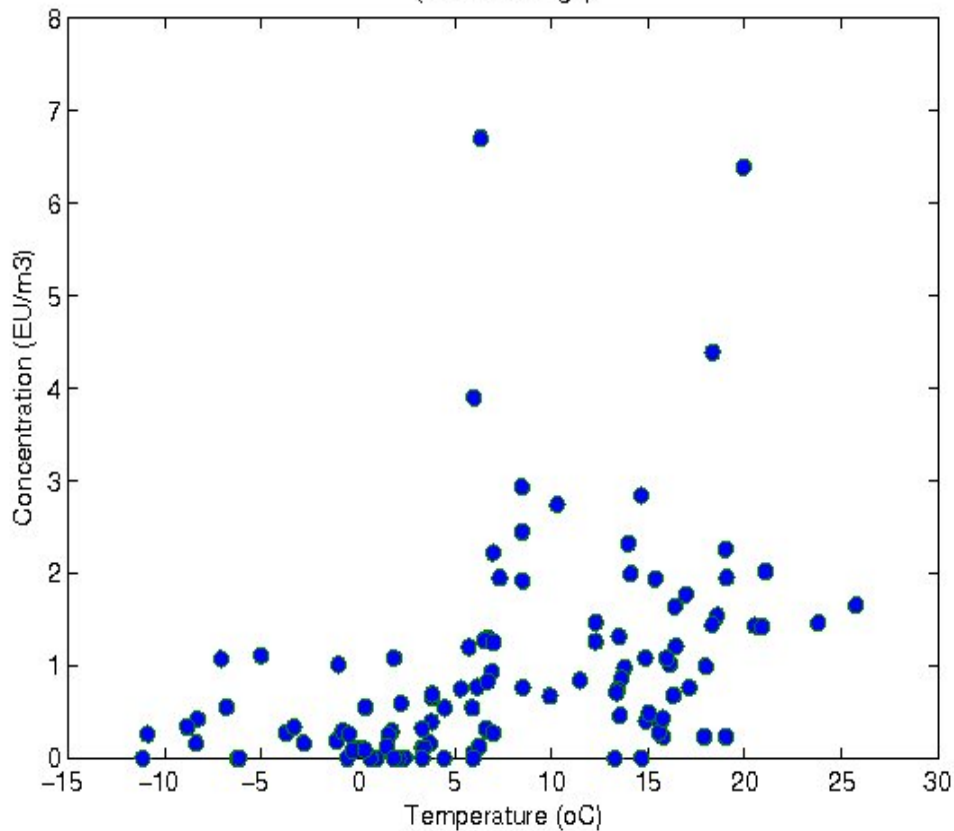
# Current PM2.5 Studies

Need more info on PM2.5 sources affecting ambient AQ before phase III of AQ Mgmt plan can be made. Current studies will provide this info:

1. BC MOE / EC PM2.5 receptor modelling / speciation study. Data collection complete, reports due summer 2007
2. **UNBC / EC / BC MOE PM speciation study (PM10 and PM2.5) being done by MSc student Janice Allen. Data collection in PG and Kelowna complete, thesis due September 2007 (probably! – see poster)**
3. UNBC / City of PG modelling study – areas for burning of MPB wood around the city to minimize AQ impact on built-up areas. AERMOD and CALPUFF used to estimate impacts of wood burning. Started September 2006, completion April 2007
4. **UNBC / City of PG / BCMOE / EC/ Northern Health / Canfor modelling study (PGAQIC – Research Working Group). Comprehensive study started February 2006, completion March 2008**

- First two speciation / receptor modelling studies use chemical info on PM filters to infer sources – data-based approach
- Idea is to use PCA / PMF to look for associations amongst metals and ions and relate these to sources
- Results so far for “endotoxin”...

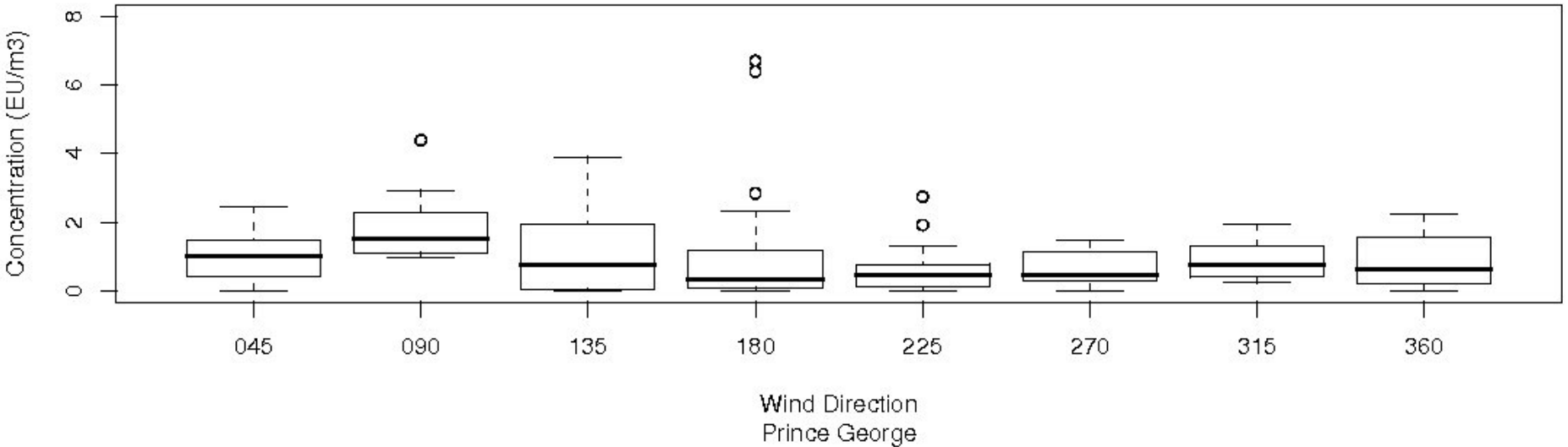
PM10 Endotoxin Concentration as a Function of Temperature  
(Prince George)



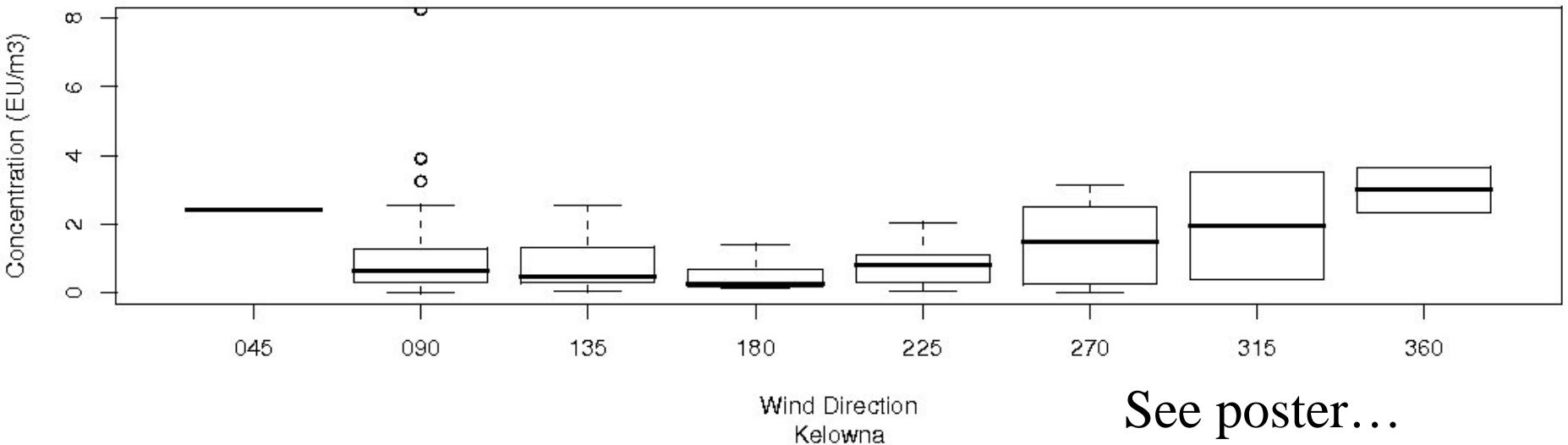
- Endotoxin is part of the outer membrane of cell wall of Gram-negative bacteria
- Inhalation of endotoxin causes symptoms of respiratory distress

- higher levels only occur with  $T > 5 \text{ }^{\circ}\text{C}$

## Variation in PM10 Endotoxin Concentration with Wind Direction



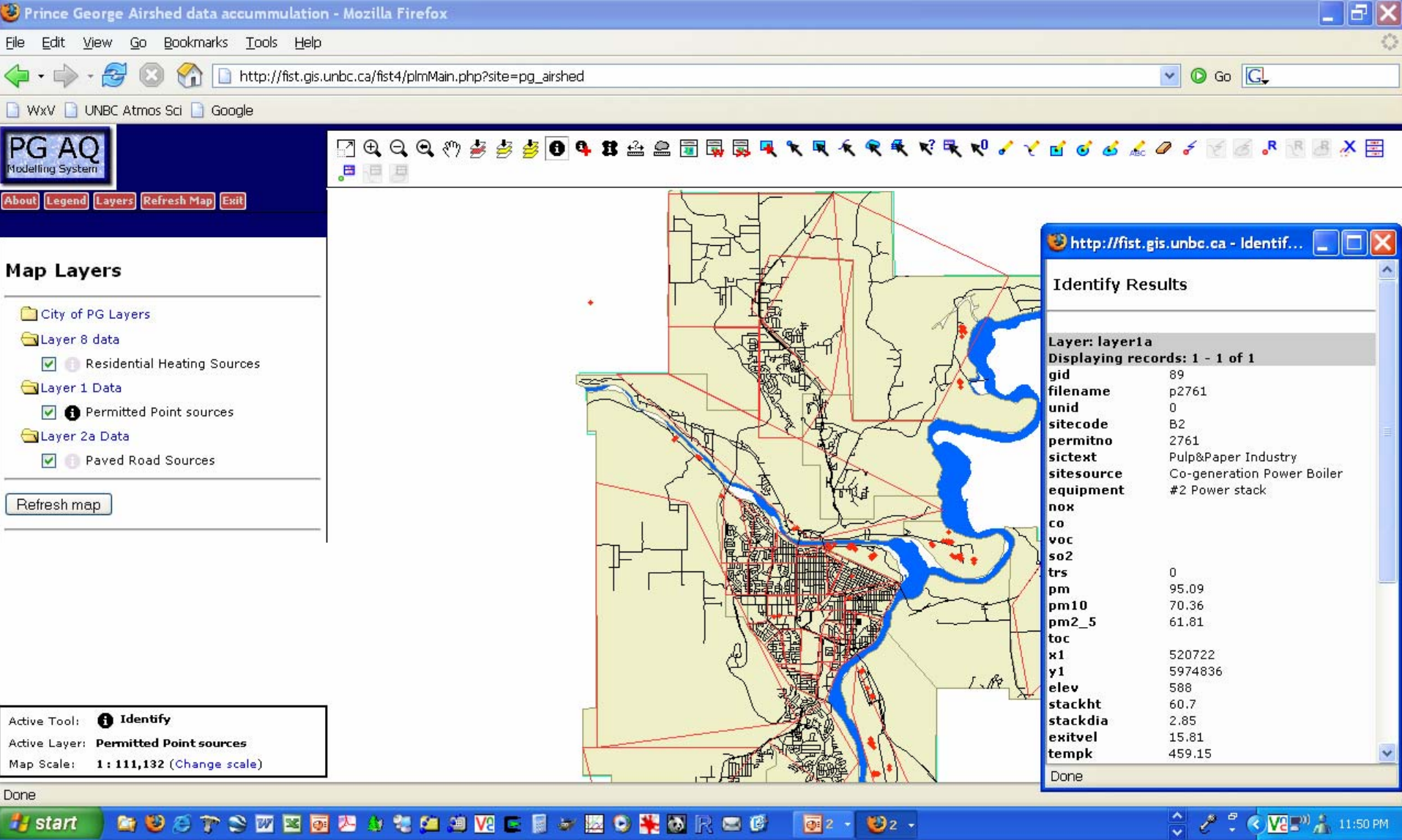
- not clear whether there are preferred source directions



See poster...

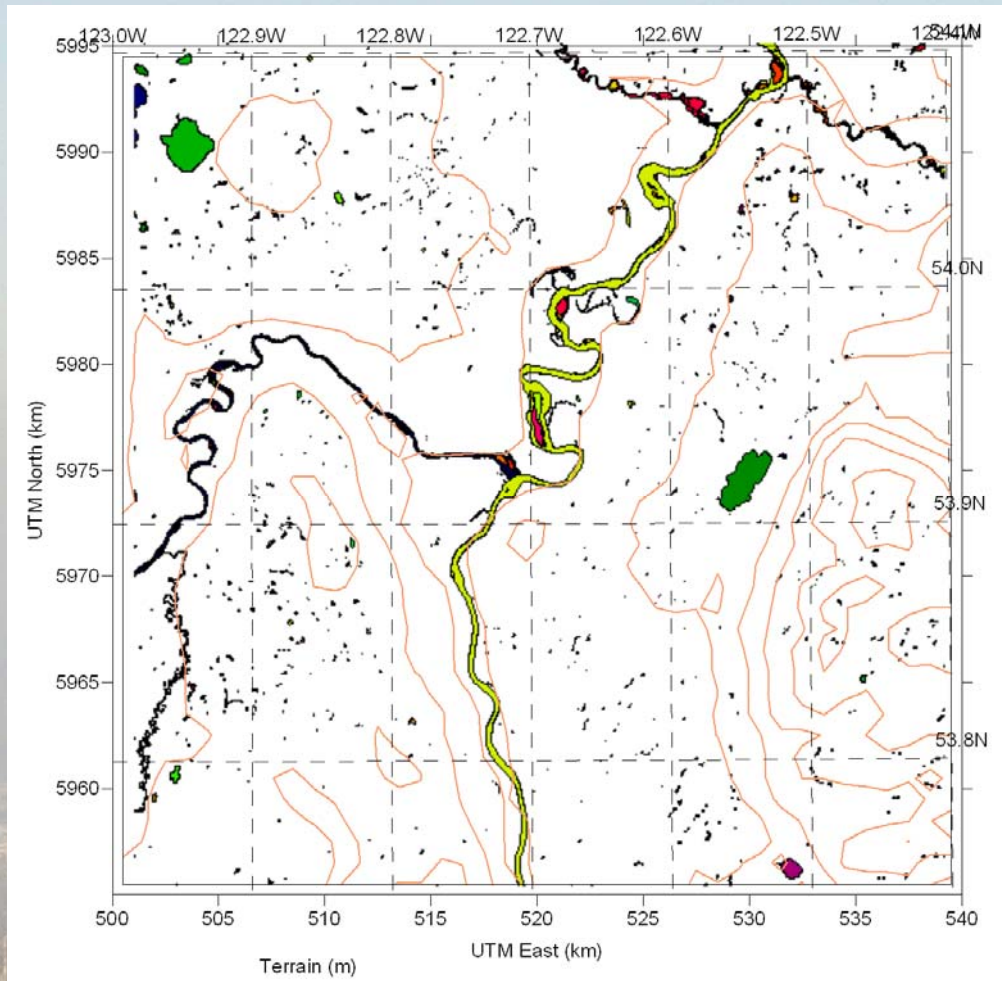
# PG AQ Modelling Study

- Comprehensive AQ study **models** all sources in the airshed to find ambient AQ levels. By John Spagnol, postdoctoral fellow at UNBC.
  - First step is to specify the emissions (this could take as much time as we have, first estimates mostly done)
  - Next step is to model the AQ (started already)
  - Plan to model 2000 – 2005 – validate by comparing model with observed ambient levels
  - Will be able to see the relative contributions of all sources modelled and therefore inform Phase III



- Micro-emission inventory with a web based tool

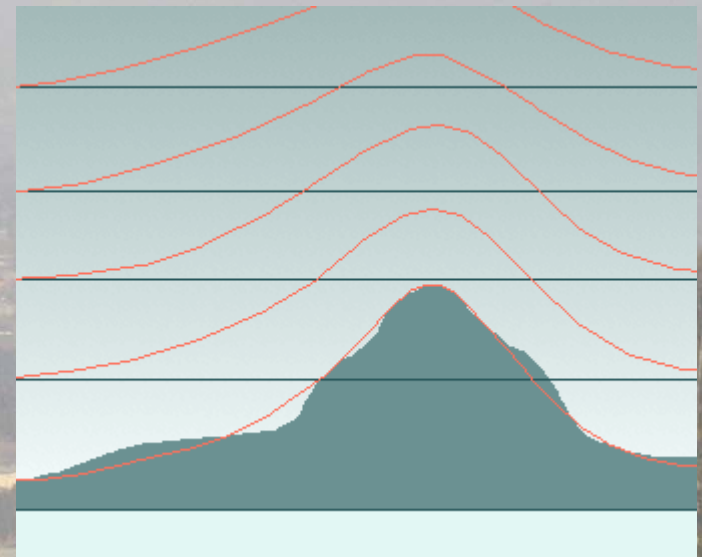
# Modeling Domain



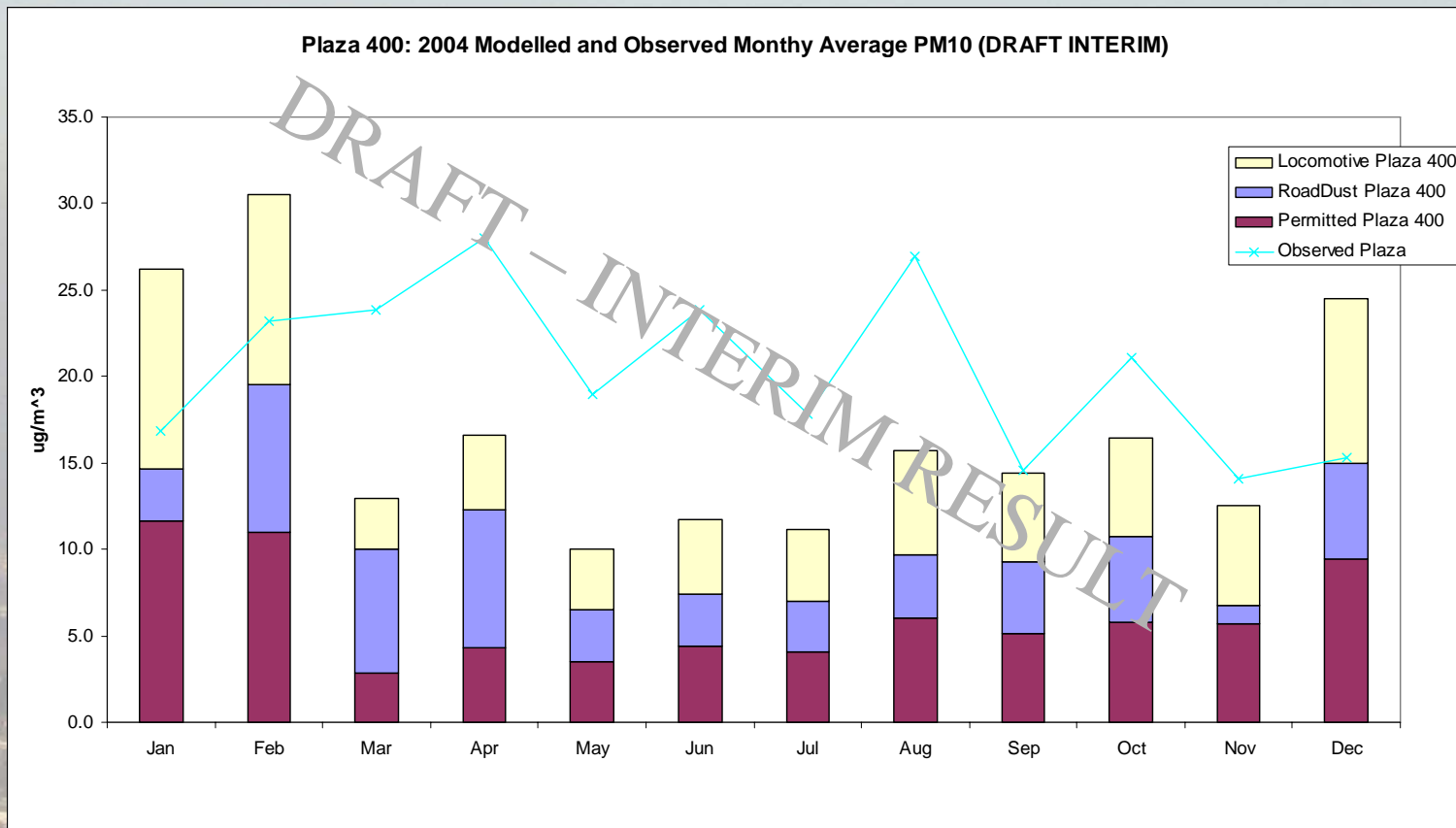
40 km x 40 km @ 1 km resolution

11 levels (10 layers)  
(metres)

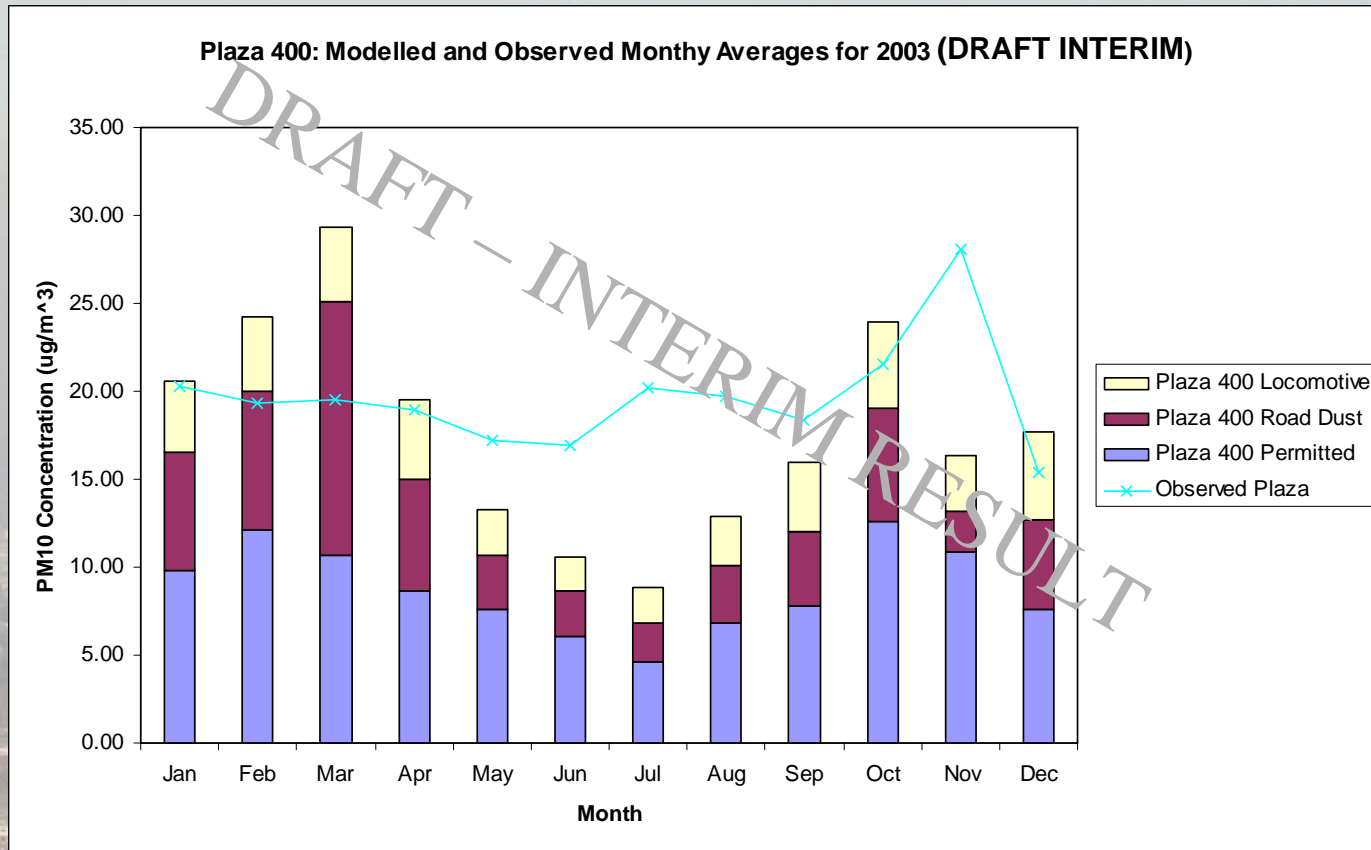
0, 20, 50, 80, 100,  
200, 400, 800, 1400,  
2000, 3000



# Interim / Draft results for 2004 PM10

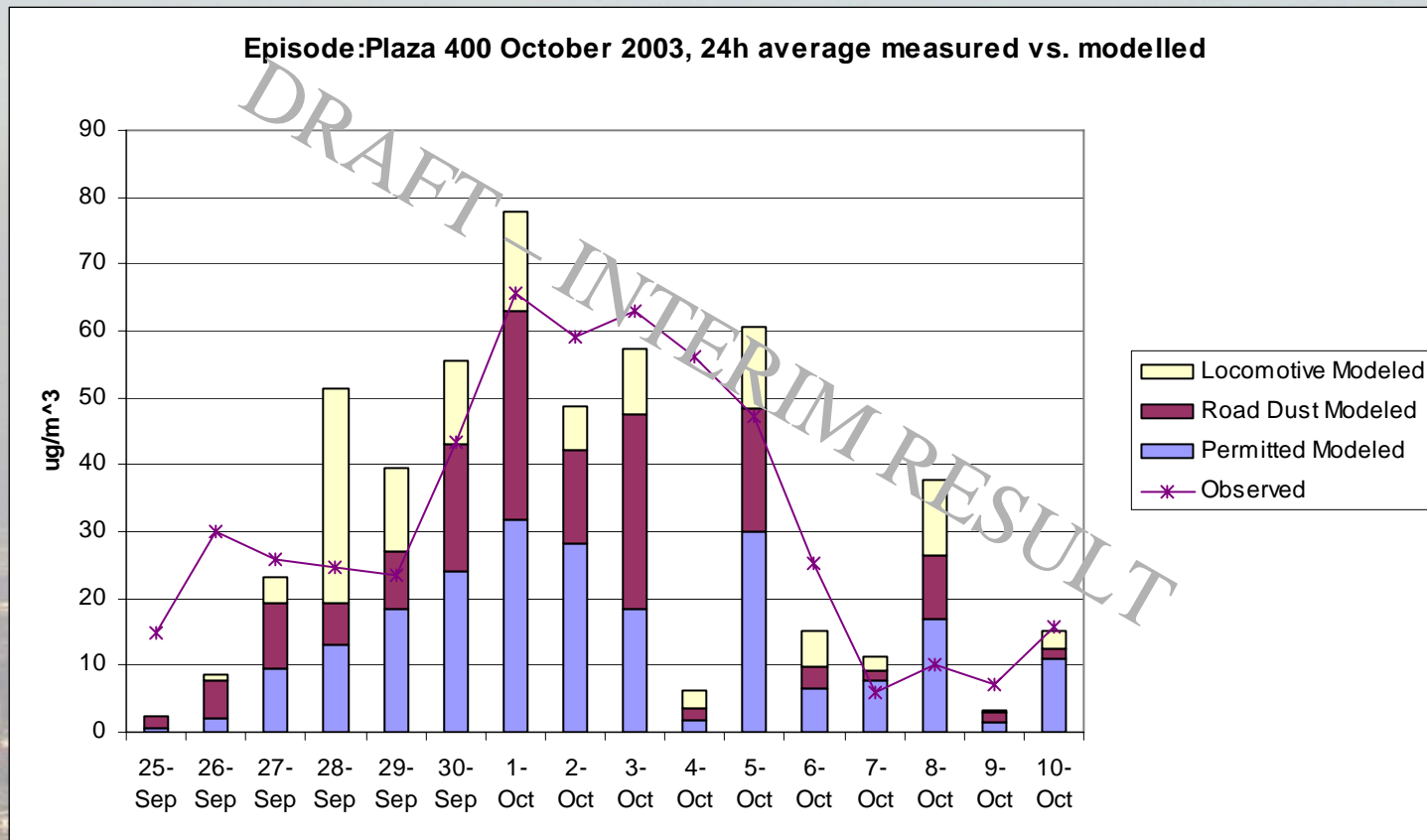


# Interim / Draft results for 2003 PM10



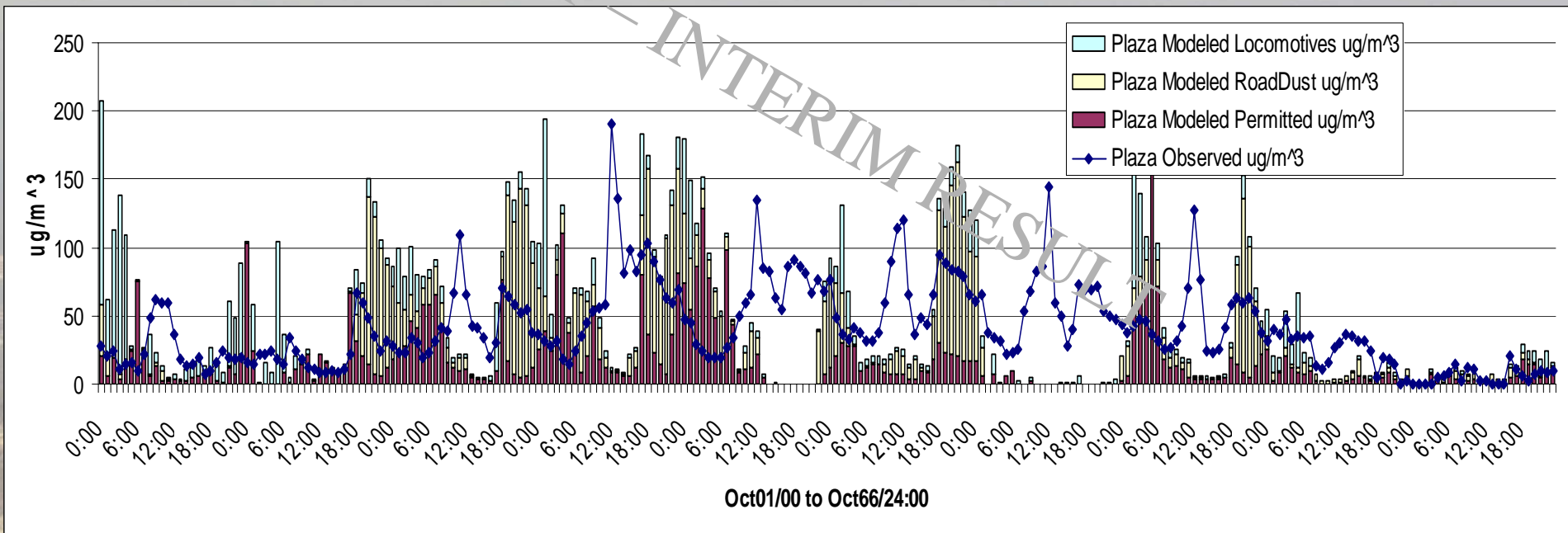
# PM10/2.5 Episode in October 2003

## 24h average PM10 levels – INTERIM!!



# October 2003 – hourly values

- problems with handling fumigation, even though 24 h values not too bad (INTERIM!)



# The End!