SAMPLING PROGRAM FOR RESIDENTIAL WOOD COMBUSTION

Winter of 1998-99 Study Report

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Executive summary

Sampling program for residential wood combustion, Winter of 1998-99

A study on the health and environmental impacts of air pollution in the Greater Montreal area undertaken by the *Regroupement montréalais pour la qualité de l'air* identified wood heating as one of the major sources of air pollution in the region (RMQA 1998). In response to these findings and information obtained from Montreal's ambient air quality monitoring network, the *Communauté ubaine de Montréa*l (CUM), Environment Canada (EC) and the Montreal Public Health Department (*Direction de la santé publique de Montréal-Centre—DSP Montréal-centre*), decided to conduct a sampling program during the winter of 1998-99 to assess the impact of residential wood burning. Rivière-des-Prairies was the neighbourhood selected for the project.

The primary objective of the winter sampling program was to assess the environmental impact of residential wood heating. This involved various subobjectives. Among them, those related to the environmental aspect of the program comprised: (a) determining concentrations of polycyclic aromatic hydrocarbons (PAH) and volatile organic compounds (VOC); (b) determining concentrations of inhalable and respirable particulate matter with an aerodynamic diameter of less than 10 and 2.5 micrometres respectively (PM_{10} and $PM_{2.5}$); (c) gaining a better understanding of the relations between weather conditions and PAH, VOC and fine particulate matter (PM_{10} and $PM_{2.5}$) concentrations; and, if possible, (d) quantifying the impact of residential wood burning on air quality in the neighbourhood studied (relative contributions of residential wood burning in relation to other potential sources). Subobjectives related to the health aspect comprised: (a) evaluating environmental exposure (outside air) to atmospheric emissions resulting from the residential use of wood stoves in the neighbourhood's population; (b) attempting to characterize behaviour related to wood stove use (e.g., more intensive use in the evening or during periods of high humidity); (c) acquiring data to develop a predictive tool for identifying situations in which poor air quality is likely to have an impact on the health of the population concerned; and (d) obtaining the data to be used to direct a study of the impact of residential wood heating on health.

PAH concentrations measured in Rivière-des-Prairies (RDP) over a 24-hour period (midnight to midnight) with a modified high-volume sampler were lower than concentrations obtained over an eight-hour period in the evening (4:00 pm to 12:00 midnight), with average levels of 76.8 ng/m^3 and 87.8 ng/m^3 respectively (Figure 1). Moreover, according to measurements made with the continuous PAH analyzer, PAH levels were twice as high during the evening as they were during the day (8:00 am to 4:00 pm). PAH concentrations at the RDP station were also twice as high as those measured at the Ontario Street station (40 ng/m^3). Another noteworthy finding was that, on Christmas Day, the total PAH concentrations measured during the evening were twice as high as those obtained throughout the day, findings which were confirmed by the continuous HAP analyzer.

PAH levels measured in 1998-99 in Rivière-des-Prairies were lower than those obtained in the early 1990s, but were similar to results obtained between 1989 and 1994 at the Ontario Street station. In the early 1990s, PAH levels were found to be 10 to 20 times higher in winter than they were in summer at another site in Rivière-des-Prairies (197 ng/m^3 and 21 ng/m^3 respectively) and in Sept-Îles (161 ng/m^3 and 11 ng/m^3), both of which are areas where wood burning is prevalent. In contrast, there was little seasonal variation in PAH levels at the Ontario Street station during the period 1989-94 (68 ng/m^3 vs. 57 ng/m^3). A slight increase in winter compared to summer was also observed at a station near the Metropolitan and Decarie expressways in Montreal (96 ng/m^3 vs. 66 ng/m^3), an environment strongly influenced by motor vehicle traffic.

Historical data show an increase in ambient air PAH concentrations at the Rivière-des-Prairies station from summer to winter. Assuming that PAH concentrations measured at the Ontario Street station are representative of PAH contributions from different urban sources on the Island of Montreal, the increase observed at the RDP station would be attributable to specific local emission sources. Using the 40 ng/m^3 measured at Ontario Street as a reference level, an estimated 45% of PAHs present in the ambient air in RDP probably come from point sources in the neighbourhood.

In terms of volatile organic compounds (VOCs), an analysis of polar VOCs (Table 1) shows that ambient air concentrations of certain aldehydes in RDP, including acrolein, are much higher than elsewhere in Montreal. Since wood combustion is a major source of polar VOCs, this strongly suggests that it is primarily responsible for the 200% increase in acrolein concentrations in RDP compared with the Ontario Street reference site.

With respect to fine particulate matter (Figure 2), in the winter of 1998-99, mean $PM_{2.5}$ concentrations (particles smaller than 2.5 µm) from continuous measurements at the RDP station were 12.9 µg/m^3. This contrasts with mean concentrations of 7.4 µg/m^3 and 10.4 µg/m^3 respectively at the Sainte-Anne-de-Bellevue and Drummond Street (downtown Montreal) stations during the same period. In general, in the Montreal area, particulate behaviour was similar from station to station. The one exception was the Rivière-des-Prairies station, which had several periods of high $PM_{2.5}$ concentrations during the winter that were not found elsewhere. This suggests a significant local influence on $PM_{2.5}$ levels at the RDP station.

An analysis of data gathered on weekdays as opposed to the weekend (including holidays) shows that concentrations of PAHs and fine particulate matter ($PM_{2.5}$) were generally higher during the weekend (Figures 2 and 3). $PM_{2.5}$ concentrations on weekend evenings were as much as 34% higher than during the week. For PAHs, the mean deviation for hourly values on weekdays and weekends was close to 30 ng/m^3 for the early afternoon (noon to 3:00 pm) and 45 ng/m^3 for the evening (5:00 pm to 10:00 pm). This represents differences of 92% and 39% respectively.

A comparison of data obtained at the Drummond Street station (where the main source of fine particulate matter is road transport) with the RDP data shows that $PM_{2.5}$ concentrations at RDP were roughly 25% greater. Moreover, RDP concentrations were 75% greater than at the Sainte-Anne-de-Bellevue station. A comparison of continuous readings of fine particulate matter obtained with a Tapered Element Oscillating Microbalance (TEOM) with those obtained with the dichotomous sampler shows that the TEOM consistently underestimated concentrations by 40%. A number of studies have suggested that such discrepancies are due to the volatilization of semivolatile particles, which are particularly abundant in environments rich in biomass combustion sources. When a correction factor was applied to take account of this phenomenon, levels of fine particulate matter at the RDP station were found to be roughly 100% higher than at the Sainte-Anne-de-Bellevue station and close to 40% higher than at the Drummond Street station.

The analysis of 47 trace metals found in fine particulate matter—including potassium and iron levels and particularly the potassium to iron ratio, which is a recognized tracer for wood combustion (Figure 4)—at the Rivière-des-Prairies station reveals that there is a local emission source with a significant output not found at the Anjou interchange or the downtown Montreal station. The roughly 40% increase in potassium concentrations in Rivière-des-Prairies over those at the Ontario Street reference site are probably due to a single significant source of emissions, most likely wood combustion.

The results obtained seem to indicate that wood combustion contributes to the poor ambient air quality found in the Rivière-des-Prairies neighbourhood. Additional studies are required, however, to confirm if the impact of wood combustion is as significant as some of the results of the sampling program seem to indicate. Therefore, additional sampling was carried out during the subsequent summers and winters to confirm the observations from the 1998-99 sampling program. These programs are still in progress and their results will be analysed when they have been completed.

This winter study raises a number of questions concerning public health and human exposure to contaminants from wood combustion. Consequently, the DSP Montréal-centre, in partnership with Environment Canada, the Quebec Environment Department and the *Communauté urbaine de Montréal*, is currently conducting a survey to study the distribution of wood combustion systems on the Island of Montreal, and to determine areas of heavy or light use of wood stoves. The DSP Montréal-centre has also initiated a pilot study to characterize and quantify individual exposure to wood smoke both inside and outside dwellings.

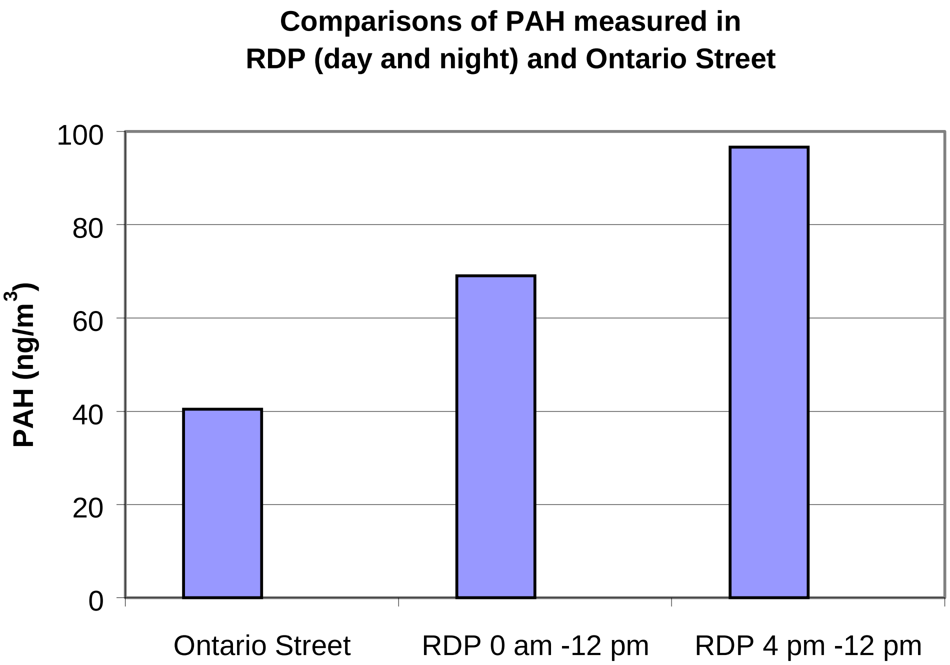

Figure 1: Comparisons of 24-hour and 8-hour PAH levels in RDP with those obtained at the Ontario Street station during the winter of 1998-99.

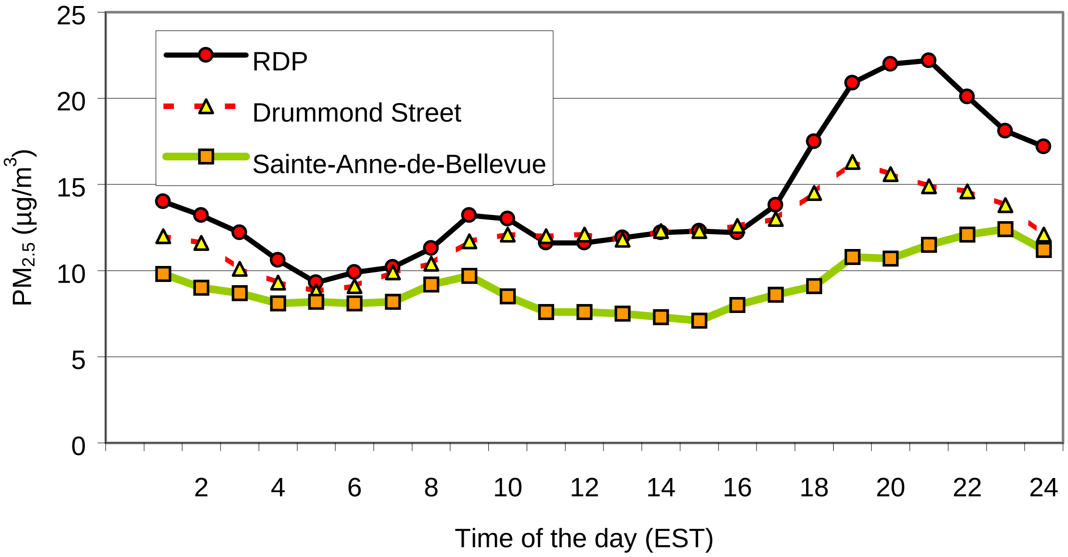

Figure 2: Hourly variations in $PM_{2.5}$ concentrations measured on weekends (including holidays) at different sites in the Montreal area during the winter of 1998-99

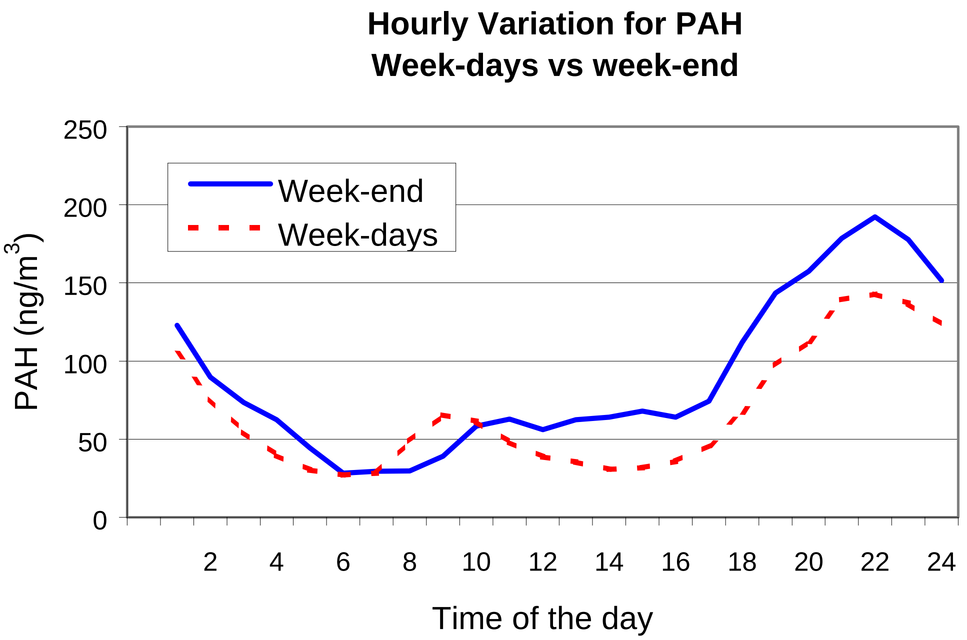

Figure 3: Hourly variations in PAH levels measured continuously on weekdays and weekends (including holidays) in RDP during the winter of 1998-99.

Table 1: Mean concentrations (µg/m^3) of acrolein, benzaldehyde and m-tolualdehyde

Compound	Sampling Site				
	RDP	Ontario Street	PAT*	Ontario Street	ADM**
	12/01/98 - 03/31/99		**1998**		
Acrolein	0.77	0.26	0.14	0.17	0.11
Benzaldehyde	0.43	0.17	0.16	0.24	0.36
m-Tolualdehyde	0.53	0.02	0.03	0.13	0.12

*PAT : Pointe-aux-Trembles

**ADM : Montréal airport station

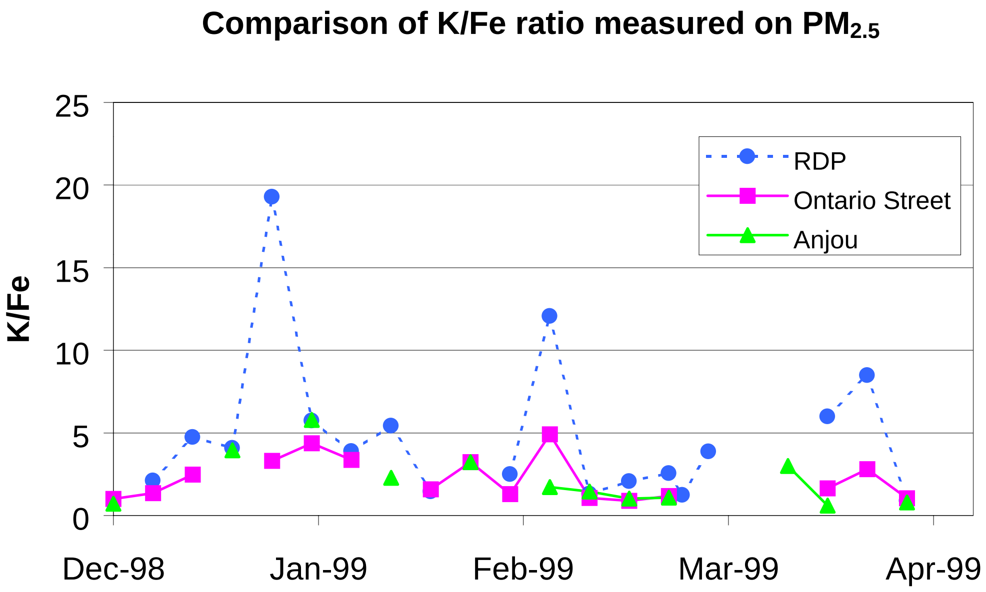

Figure 4: Daily variations in the $PM_{2.5}$ K/Fe ratio

Abbreviations and acronyms

ADM	Aéroport de Montréal (Montreal-Dorval airport)
AEP	Alberta Environmental Protection
B(a)P	Benzo(a)pyrene
CO	Carbon monoxide
CUM	*Communauté urbaine de Montréal*
DNPH	Dinitrophenylhydrazine
EC	Environment Canada
EST	Eastern Standard Time
Hivol	High-volume sampler
HPLC	High Pressure Liquid Chromatography
K/Fe	Potassium to iron ratio
NA	Information not available
NAPS	National Air Pollution Surveillance Network
NO	Nitric oxide
NO_2	Nitrogen dioxide
PAH	Polycyclic aromatic hydrocarbons
PAT	Pointe-aux-Trembles measuring station
PM_{10}	Particles with an aerodynamic diameter of less than 10 µm
$PM_{2.5}$	Particles with an aerodynamic diameter of less than 2.5 µm
RDP	Rivière-des-Prairies measuring station
RMQA	Regroupement montréalais pour la qualité de l'air
RRETC	River Road Environmental Technology Centre
SAB	Sainte-Anne-de-Bellevue measuring station
SO_2	Sulfur dioxide
TEOM	Tapered Element Oscillation Monitor (continuous sampler)
TSP	Total suspended particulates
USEPA	U.S. Environmental Protection Agency
VOC	Volatile organic compounds

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1. Introduction

1.1. Issues

According to data from a recent study carried out by Environment Canada (Environment Canada 1998), roughly a third of Quebec respondents use wood heating. Despite the lack of quantitative information available on the impact of the 1998 ice storm, there has probably been an increase in the use of residential wood combustion systems, with residents that were the most affected or disturbed by the storm seeking to protect themselves against a similar event in the future.

According to the 1995 National Pollutant Release Inventory Summary Report, residential wood heating represents the third greatest source of fine particulate matter emissions and, under some conditions in winter, the main source of these emissions (Environment Canada 1995). This occurs particularly during temperature inversions in winter.

Wood heating is also a significant source of polycyclic aromatic hydrocarbons (PAHs), and as a study on PAHs in Quebec from 1989 to 1994 shows, PAH levels vary significantly in residential areas where wood heating predominates (Germain 1997). In these areas, PAH concentrations can be 10 to 20 times greater in winter than in summer. This study also found that, except in rural areas, mean benzo[a]pyrene levels in Quebec do not meet Quebec interim standards or ambient air quality criteria in Ontario.

A recent study carried out by the *Regroupement montréalais pour la qualité de l'air* (RMQA 1998) on the health and environmental impacts of air pollution in the Greater Montreal area pointed to wood heating as one of the main sources of air pollution.

Table 1.1.1, based on data from the RMQA study, compares contributions from residential wood burning and industry (stationary emission sources) and from mobile sources for the various pollutants. The trade and services sector was not included, since there is a paucity of information on this sector in the *Communauté urbaine de Montréal* (CUM) and the areas north of the Island of Montreal (Laval, Lower Laurentians and Lanaudière regions).

As the table shows, among stationary emission sources, wood heating contributes around 59% of atmospheric emissions of volatile organic compounds (VOC), 78% of total suspended particulates (TSP) and 94% of carbon monoxide emissions (CO). Even when atmospheric emissions from mobile sources are included, wood heating is responsible for 53% of TSP emissions and 26% of VOC emissions.

Table 1.1.1: Atmospheric emissions (in metric tonnes) of different pollutants from wood combustion from the residential and industrial sectors in 1994 in the Greater Montreal area

Pollutants	Fixed Sources			Mobiles Sources [b]	%[c]
	Industrial	Residential sector Wood heating	% [a]		
CO	7 778	131,635	94	494,518	21
SO_2	21,115	244	1	N.A.	1
NO and NO_2	8,224	611	7	72,190	1
TSP	8,835	30,525	78	17,859	53
VOC	17,529	24,905	59	54,946	26

a : relative contribution from residential sector vs. Industrial sector
b : related to road transportation
c : relative contribution from residential sectour vs Industrial and mobile sources
CO : carbon monoxide, SO_2 : Sulfur dioxide, NO et NO_2 : Nitrogen monoxyde and dioxyde,
TSP : Total suspended particulates, VOC : Volatile organic compounds,
N.A. : information not available

Based on these data and other observations obtained from the CUM's air quality monitoring network in 1997, the *Communauté urbaine de Montréal* , Environment Canada and the *Direction de la santé publique de Montréal-centre* decided to jointly undertake a sampling program during the winter of 1998-99 to determine the impact of residential wood burning.

1.2. Objectives of winter 1998-99 sampling program

The primary objective of the sampling program was to assess the environmental impact of residential wood heating. Various subobjectives were also identified, depending on whether the main interest was the environment, public health, or population exposure.

1.2.1 Environmental subobjectives

- Determine concentrations of polycyclic aromatic hydrocarbons (PAHs) and polar volatile organic compounds (VOCs);
- Determine concentrations of fine particulate matter with an aerodynamic diameter of less than 10 and 2.5 micrometres (PM_{10} and $PM_{2.5}$) respectively;
- Determine links between meteorological conditions and measured concentrations of PAHs, VOCs and fine particulate matter (PM_{10} and $PM_{2.5}$);
- Quantify the impact of residential wood heating on air quality in the neighbourhood studied (relative contribution of residential wood heating in relation to other potential sources).

1.2.2 Public Health and population exposure subobjectives

- Assess the environmental exposure (exterior air) of the population living in the neighbourhood choosen to atmospheric emissions from the use of residential wood stoves;
- Try to characterize the use of wood stove in terms of population habits (e.g. more intensive use in evenings or in humid conditions;
- Acquire data in order to developp a previsional tool permitting the identification of periods of air quality deteriorations that could have an impact on the health of the population concerned;
- Have on-hand data permitting the orientation of study of public health impacts of residential wood heating (possibility of study of epidemiologic type for exposed zone vs. non-exposed zone or quantitative risk assessment)

2. Materials and methods

2.1 Sampling site

The residential area selected for the 1998-99 winter sampling program is a highly residential neighbourhood in Rivière-des-Prairies. Figure 2.2.1 shows the location of the site in relation to the entire Island of Montreal, while figures 2.2.2 and 2.2.3 provide a more precise view of the location of the sampling site and the residential area in question, including an overview of their immediate surroundings. The site was selected for a number of reasons.

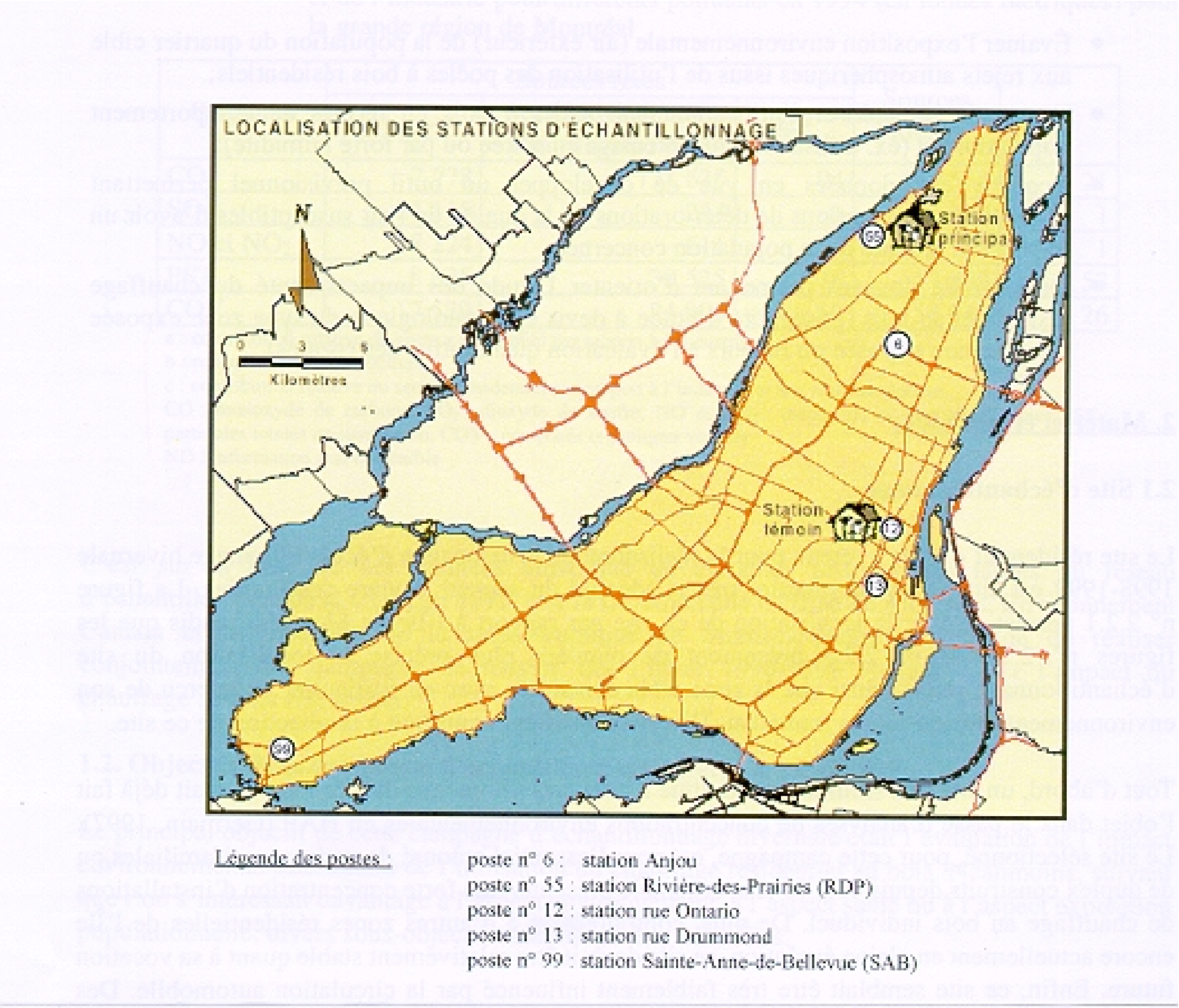

Figure 2.2.1: Location of main RDP station on the Island of Montreal (regional map)

First, a very similar site located a few kilometres away had been used in the past to analyze environmental PAH concentrations (Germain 1997). The site selected for the current study is surrounded mainly by single-family dwellings and duplexes, 10 to 15 years old, and appears to have a high concentration of individual wood combustion units. Furthermore, unlike other residential areas on the Island of Montreal that are still being developed, land use at this site should remain relatively stable in coming years. Lastly, the site appears to be affected very little by vehicle traffic. Photos shown in Appendix 1 give a fairly good idea of the type of dwellings present in the immediate environs of the site.

Figure 2.2.2: Location of main RDP station (semi-regional map)

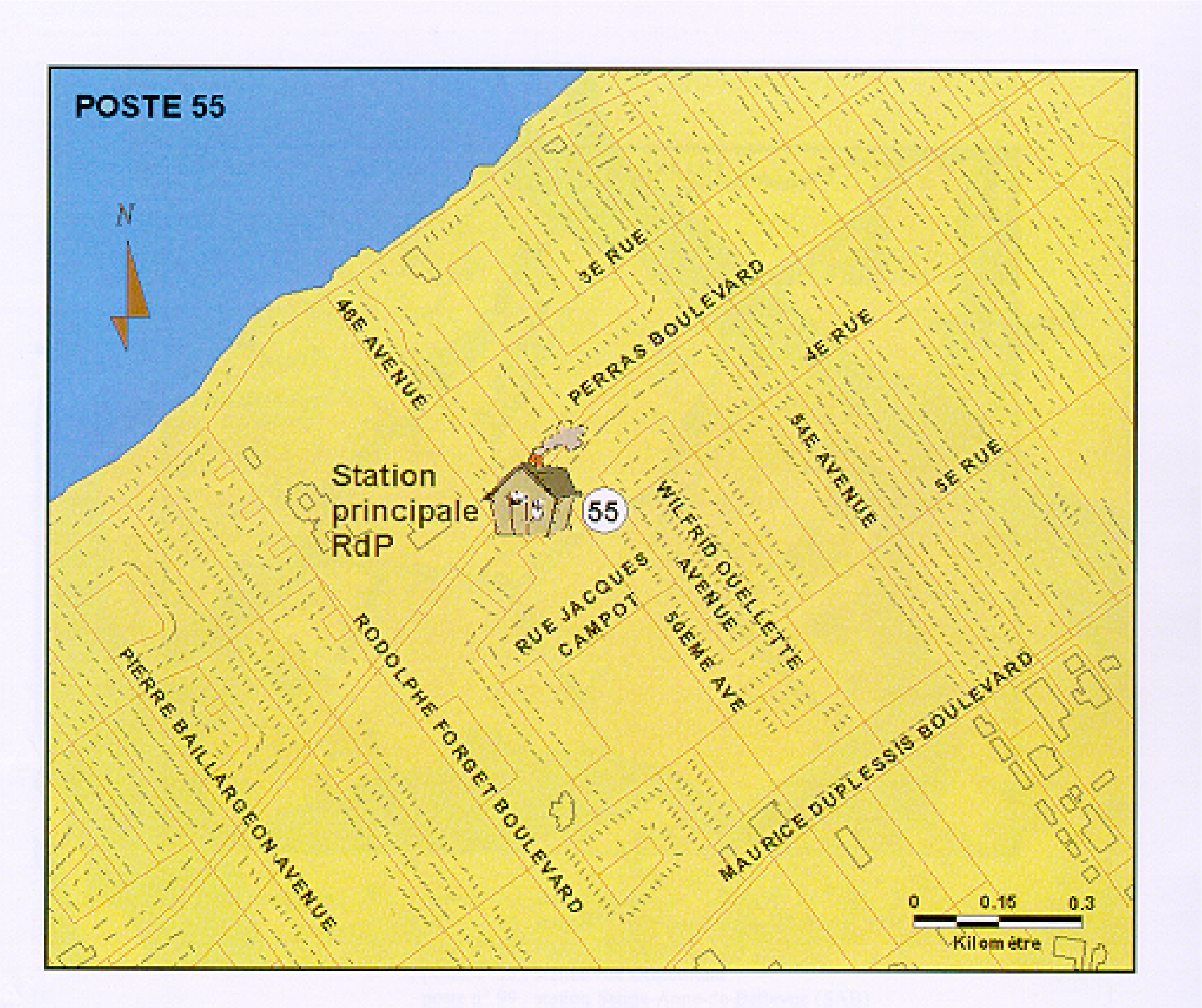

Figure 2.2.3: Location of main station (local map)

Furthermore, according to data from Environment Canada's Meteorological Service of Canada, the site has suitable prevailing winds at least during the period in winter when the sampling was to be carried out. Owing to the prevailing winds at the site, the neighbourhood in Rivière-des-Prairies should have fairly high concentrations of PAHs, VOCs and fine particulate matter, mostly due to contributions from the immediate neighbourhood. Figures 2.2.4 and 2.2.5 show the annual and seasonal wind roses (December to March) compiled for Montréal-Est (an area near Rivière-des-Prairies) during the period 1994-99. In winter, there are two prevailing wind directions, southwest and northeast, which together make up 60% of the wind directions recorded. Figure 2.2.6 shows the wind rose obtained during the sampling program, recorded at a local meteorological tower.

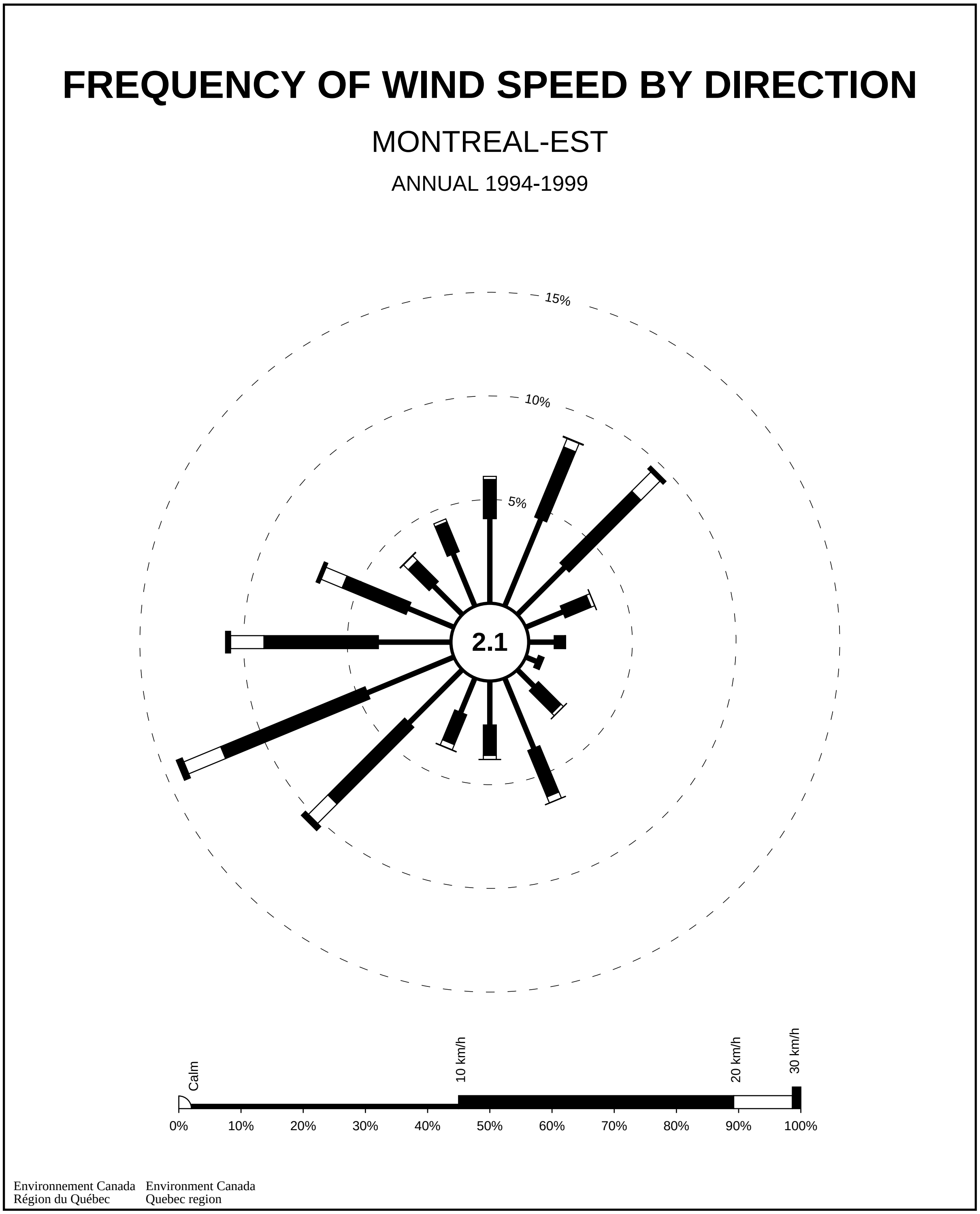

Figure 2.2.4: Wind rose for Montréal-Est (annual data for 1994-99)

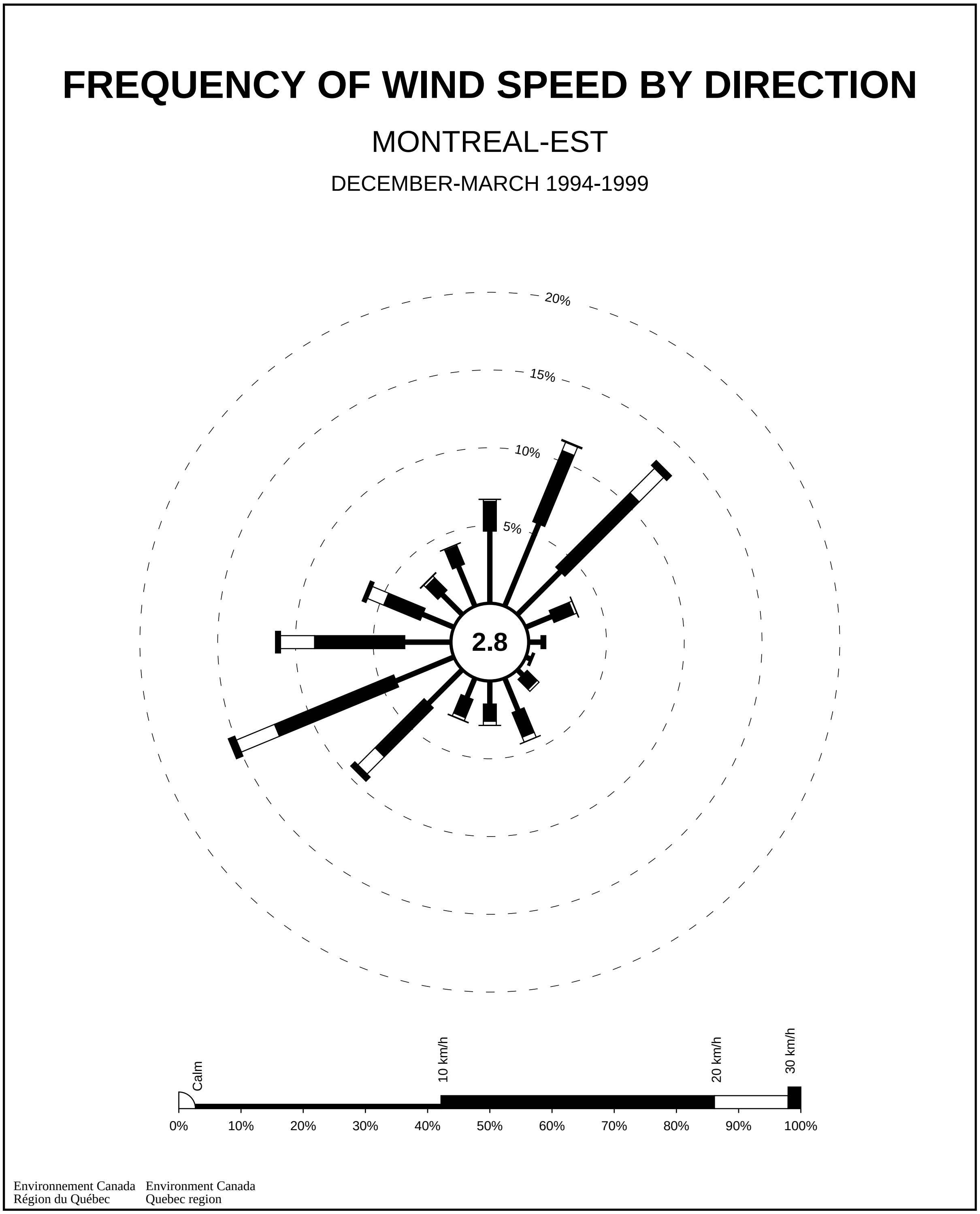

Figure 2.2.5: Wind rose for Montréal-Est (winter data for 1994-99)

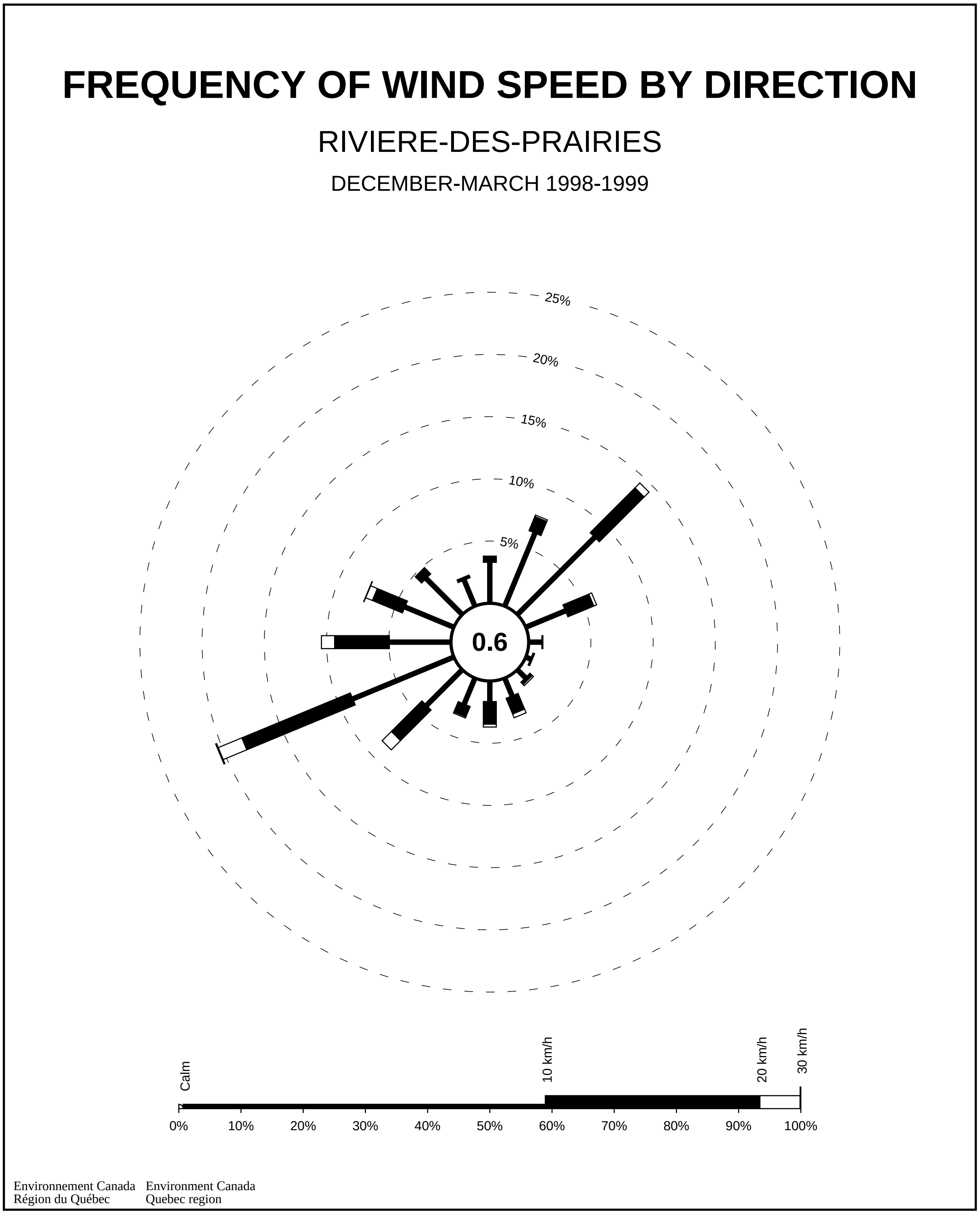

Figure 2.2.6: Wind rose for Rivière-des-Prairies (December 1998 - March 1999)

The wind directions recorded at the Rivière-des-Prairies site during the period December 1998 – March 1999 are fairly similar to those at Montréal-Est observed during the winters of 1994-99. Northeast winds over 20 km/h were less common at RDP than at Montréal-Est, however.

2.2. Pollutants and parameters studied

Pollutants included in the sampling program during the winter of 1998-99 are those typical of wood combustion emissions. They comprise polycyclic aromatic hydrocarbons (PAHs), polar volatile organic compounds (VOCs) such as aldehydes and ketones, and fine particulate matter (PM_{10} and $PM_{2.5}$). Nonpolar volatile organic compounds such as benzene and toluene tend to be associated with vehicular emissions.

2.2.1. Studied parameters, instruments and sampling frequency

The following table (Table 2.2.1) provides a list of the instruments used during the 1998-99 winter sampling program.

Table 2.2.1: List of instruments used during the winter of 1998-99

Parameters measured	Instruments used	Sampling Frequency	Remarks
Polycyclic Aromatic Hydrocarbons (PAH) in continuous mode	PAH analyzer CIE (4 L/min)	Mean of data collected over 1 hour.	Peak measurement. Analyze only the particulate PAH with a diameter less than 1 µm.
PAH	High volume sampler with polyurethane foam (700 L/min)	1-24 hour sample every 6 days (midnight to midnight). 1-8 hour sample every 6 days (4 pm to midnight)	Analyses done at RRETC laboratory in Ottawa. 28 PAH compounds can be analyzed.
Particles with a diameter smaller than 2,5 µm ($PM_{2,5}$) in continuous mode	TEOM (Tapered Element Oscillating Monitor) with a 2.5µm cyclonic head (16,7 L/min)	Mean of data collected over 1 hour.	Peak measurement. Analysis of total PM particulate with a diameter less than 2.5 µm.
$PM_{2.5}$ – PM_{10}	Dichotomous sampler (16.7 L/min for fine fraction and 1.67 L/min for coarse fraction)	1-24 hour sample every 6 days (midnight to midnight).	Analyses done at RRETC laboratory in Ottawa. Analysis of total particles collected on 2.5 µm and 10 µm and their constituants.
Volatile Organic Compounds (VOC)	Aldehydes sampler (1 L/min)	1-24 hour sample every 6 days (midnight to midnight).	Absorption on a DNPH tube. Analyses of 16 aldehydes and ketones done at the CUM laboratory.
Temperature and humidity	HMP-35 probe	Mean of data collected over 15 minutes.	Measured at two different heights : 2 and 10 metre above ground.
Winds	RM-Young anemometre	Mean of data collected over 15 minutes.	Measured 10 metres above ground.
Global solar radiation	LI-COR 200S pyronameter	Mean of data collected over 1 hour.	Direct and diffuse solar radiation received on a horinzontal surface.
Horizontal visibility	Belfort 6210	Mean of data collected over 1 hour.	Forward diffusion of the luminar pulse over a lenght of 1 metre

2.2.2. Polycyclic aromatic hydrocarbons (PAHs)

PAH sampling was done with the following two types of samplers:

- A high-volume sampler, modified according to Environment Canada specifications, which was used to analyze many PAHs;
- A continuous sampler used for the real-time monitoring of environmental data, which provided only one type of measurement: concentrations of total PAHs found on particles smaller than 1 µm (the particulate-bound fraction, also known as particulate PAH).

The use of a continuous analyzer to measure PAHs, though experimental, has a great advantage in that it allows fluctuations and peaks in particulate PAH concentrations to be monitored throughout the day. It also has major disadvantages, however, in that it does not sample volatile PAHs and does not allow the precise identification of the PAH species sampled.

The sampling mode adopted for the modified high-volume sampler allowed the detection of diurnal variations in PAH concentrations. Two samples were taken during the day, one from midnight to midnight (24 hours total) and one from 4:00 pm to midnight, Eastern Standard Time (8 hours total).

2.2.3. Fine particulate matter (PM_{10} and $PM_{2.5}$)

Respirable particulate matter ($PM_{2.5}$) was sampled continuously using a tapered element oscillating microbalance (TEOM). Inhalable particulate matter (PM_{10}) was sampled with a non-continuous dichotomous sampler. The dichotomous sampler was also used to sample the finer fraction ($PM_{2.5}$), allowing us to measure the $PM_{2.5}/PM_{10}$ ratio. In addition, the contents of the PM_{10} and $PM_{2.5}$ filters used with the dichotomous sample were analyzed for the presence of various metals, to attempt to identify tracers for wood combustion such as the potassium/iron (K/Fe) ratio.

The continuous sampling of $PM_{2.5}$ allowed us to determine peak emission periods, to more accurately characterize daily fluctuations and to compare and analyze the behaviour of fluctuations. Indeed, this fraction of particulate matter ($PM_{2.5}$) is very typical of wood burning emissions. According to a 1984 study by Rau and Huntzicker (cited in the 1997 report by the Federal Provincial Working Group), roughly 95% of particulate matter emitted by wood stoves is of a diameter less than 0.4 µm.

2.2.4. Volatile organic compounds (VOCs)

A non-continuous sampler was employed to sample volatile organic compounds. The CUM uses the EPA's TO-11 sampling and analysis method for polar VOCs (USEPA 1999a) and the EPA's TO-17 method for nonpolar VOCs (USEPA 1999b). Sampling was carried out with absorbent DNPH tubes and, after 24 hours, the samples obtained were sent to the laboratory for HPLC analysis, to test for 16 aldehydes and ketones. Emissions of polar volatile organic compounds such as acrolein and formaldehyde are associated with wood heating (USEPA 1991), while nonpolar VOCs such as benzene and toluene are associated with mobile sources (such as gasoline combustion).

2.2.5. Meteorological parameters

A ten-metre-tall meteorological tower installed at the site was used to measure different meteorological parameters likely to affect the behaviour of locally emitted pollutants. The tower took readings at two heights, 2 m and 10 m. The following parameters were measured:

- Temperature
- Relative humidity
- Wind direction, speed and standard deviation (at 10 m only)
- Total solar radiation at 2 m

In addition, a parameter linked to horizontal visibility was measured to study the relation between particulate matter concentrations and visibility. Measurements were taken with a Belfort 6210 located on the roof of the trailer housing the equipment.

Acquiring these parameters was particularly important, not only to provide a basis for the development of a predictive model but also to better understand the factors influencing the dynamics of pollutants resulting from wood heating in a residential neighbourhood.

2.2.6. Identification of the relative contribution of wood stoves to air quality

To better identify the relative contribution of residential wood heating to local air quality, the potassium/iron ratio, derived from the analysis of metals in fine particulate matter, was analyzed. Of the analytical methods available to determine the wood heating contribution, which include the isotopic determination of the $^{12}C/^{14}C$ ratio (USEPA 1985), the K/Fe ratio method seems to be the least expensive and the easiest to carry out. In this method, the filters used for sampling particulate matter are analyzed for various metals, and these data are then used to calculate the potassium/iron ratio. Some authors have found K/Fe ratios ranging between 15 and 230 for smoke from wood stoves (with a high biomass component), while others have found values below 0.35 for other sources (Wolff et al. 1981; Watson 1979 in 1997 Federal Provincial Working Group). The results from the analyses of fine particulate matter were used to implement this method.

2.3. Sampling frequency

Table 2.3.1 below shows the sampling dates for the various pollutants measured at the RDP and Ontario Street stations.

<u>Table 2.3.1:</u> Sampling schedule for RDP and Ontario Street stations

Parameter	Site	December 1998						January 1999					February 1999					Mach 1999					
		1	7	13	19	25	31	6	12	18	24	30	5	11	17	23	**25**	1	7	13	19	25	31
PAH (24 h)	RDP		X	X	X	X	X	X	X	X	X	X	X	X	X	X	**X**	X	X	X	X	X	X
	Ontario[2]	X	X	X	O	X	X	O	O	O	X	X	O	O	X	O		X	X	X	X	X	X
PAH (8 h)	RDP		X	X	X	X	X	X	X	X	X	X	X	X	X	X	**X**	X	X	X	X	X	X
	Ontario																						
Polar VOC[1]	RDP				X	X	X	X	X	O	X	X	X	X	X	X	**X**	X	X	X	X	X	X
	Ontario	X	X	X	X	X	O	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Non-polar VOC	RDP				O	X	X	X	X	O	X	X	X	X	X	X	**X**	X	X	X	X	O	O
	Ontario	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
$PM_{2.5}$ and metals	RDP		X	X	X	X	X	X	X	X	X	X	X	X	X	X	**X**	X	X	X	X	X	X
	Ontario	X	X	X	O	X	X	X	O	X	X	X	X	X	X	X		O	O	X	X	X	X
PM_{10} and metals	RDP		X	X	X	X	X	X	X	X	X	X	X	X	X	X	**X**	X	X	X	X	X	X
	Ontario	X	X	X	O	X	X	X	O	X	X	X	X	X	X	X		O	O	X	X	X	X

[1] pol. = polar

[2] indicate Ontario street site

O : sample rejected

X : valid sample

Except for the February 25, 1999 sampling date, the dates coincided with those on the NAPS schedule, which covers a group of stations sampling on a 24-hour basis every six days (using a non-continuous sampler). This allowed comparisons to be made with other sites of the network located on the Montreal Island subject to other influences beside wood burning. This data could be particularly useful in identifying the most appropriate design for evaluating the potential health risks of exposure to wood smoke. On February 25, 1999, due to the specific weather conditions found (a temperature inversion), we decided to take additional samples at the RDP station, although the date was not on the NAPS schedule.

Readers should note that PM_{10} and $PM_{2.5}$ samples were also analyzed for the presence of various trace metals (47) (see Table 2.3.2 below for a list).

Based on the results of these analyses, the potassium/iron ratio was calculated, which was used to provide a more accurate understanding of the origin of contaminants and the relative contribution of residential wood heating to air quality in the study area.

Table 2.3.2: Metals analyzed from dichotomous sampler filters

Element	Symbol	Element	Symbol	Element	Symbol	Element	Symbol
Aluminum	Al	Antimony	Sb	arsenic	As	Baryum	Ba
Bromine	Br	Cadmium	Cd	Calcium	Ca	Cesium	Cs
Cerium	Ce	Chlorine	Cl	Chromium	Cr	Cobalt	Co
Copper	Cu	Gallium	Ga	Germanium	Ge	Iron	Fe
Iodine	I	Indium	In	lanthanum	La	Magnesium	Mg
Manganese	Mn	Mercury	Hg	Molybdenum	Mo	Neodymium	Nd
Nickel	Ni	Niobium	Nb	Palladium	Pd	Potassium	K
Phosphorus	P	Lead	Pb	Praseodymium	Pr	Rubidium	Rb
Scandium	Sc	Selenium	Se	Silicon	Si	Silver	Ag
Sodium	Na	sulfur	S	Strontium	Sr	Tellurium	Te
Tin	Sn	Titanium	Ti	vanadium	V	Yttrium	Y
Zinc	Zn	Zirconium	Zr				

2.4. Quality control

A number of quality control measures were employed during the PAH analyses. These consisted of spiking each sample with six deuterated PAHs, to measure the method's effectiveness in recovering the different products. An internal standard was also added for quantification purposes.

The laboratory also determined method blanks, by using the analytic method on the various solvents used and determining interferences that may occur during the process. In addition, the analysis of blanks spiked with a standard solution was used to determine average recovery rates using the method. These tests were carried out periodically or by batch of samples.

Field blanks were used to provide quality control in field operations. This method consists of installing a filter and polyurethane foam in the sampling apparatus and leaving them in place for the same period as an actual sample, but without pumping air through. The blank filters and foam therefore undergo the same handling for the same amount of time as actual samples, except that air is not drawn through them. This allowed the extent of contamination during sampling to be determined. This operation was carried out at the rate of one sample per station per sampling program. In the case of a large number of samples, one blank was used per 10 or 20 samples.

During field operations, the only calibration that could be done on the continuous PAH sampler was to adjust the "zero" setting. Actual calibration was done by verifying the accuracy of the conversion factor by comparing the results obtained with this sampler with those obtained with the modified high-volume sampler.

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3. Analysis of data and results

3.1. Polycyclic aromatic hydrocarbons (PAHs)

3.1.1. Levels measured

At Rivière-des-Prairies, 21 samples were taken between December 7, 1998 and March 31, 1999, all of which were analyzed and validated. Mean PAH levels were 76.8 ng/m^3 for samples taken over a 24-hour period (Table 3.1.1), compared with 87.8 ng/m^3 for an 8-hour period (between 4:00 pm and midnight) (Table 3.1.2). These values are roughly twice as high as those measured at the Ontario Street station in downtown Montreal, where mean PAH levels were 40.4 ng/m^3 (Table 3.1.3). Similarly, maximum levels measured at the RDP station were 2.5 times higher than at the Ontario Street station. When the PAH values used to calculate the mean are limited to those taken on the same sampling days, a mean level of 73 ng/m^3 is obtained at RDP, which is roughly two times higher than at the Ontario Street station (Table 3.1.4). Figure 3.1.1 provides a visual overview of the differences for each sampling day.

The values obtained during this project are lower, however, than those obtained at another site in Rivière-des-Prairies in 1989-90 (Germain 1997). The geometric mean of PAH concentrations was 61.6 ng/m^3 for samples taken during a 24-hour period in 1998-99, which is three times lower than the mean of 196.7 ng/m^3 calculated for the winter of 1989-90 (Table 3.1.5).

The difference could be explained by the number of dwellings located upwind of the two stations in the direction of the prevailing winds. More dwellings that could affect air quality were found at the site studied in the early 1990s than at the site chosen in 1998. It would have been preferable to reuse the same site, but this was not possible. During the period 1989-90, Germain (1997) reported PAH levels of 160.7 ng/m^3 at a station in Sept-Îles strongly influenced by residential wood heating , which are similar to those found in RDP.

For benzo(a)pyrene, one of the most studied compounds in the PAH family, 24-hour mean levels at the RDP station were 1.20 ng/m^3, with a maximum of 4.53 ng/m^3 (Table 3.1.1). Mean and maximum B(a)P concentrations measured in the evening were found to be practically identical to 24-hour values: 1.16 ng/m^3 and 4.10 ng/m^3 respectively (Table 3.1.2). In contrast, mean and maximum B(a)P levels measured at the Ontario Street station (Table 3.1.3) were roughly two times lower than at the RDP station (0.57 ng/m^3 and 1.89 ng/m^3 respectively). In contrast, Medicine Hat, Alberta, had lower mean (0.12 ng/m^3) and maximum (0.13 ng/m^3) B(a)P levels than the Island of Montreal (AEP 1999). Lastly, the geometric mean B(a)P value measured in 1998-99 (0.63 ng/m^3) was three times lower than the value obtained in 1989-90 (1.88 ng/m^3), as in the case of total PAHs.

Among the different PAHs measured, phenanthrene represented close to 30% of all PAHs, followed by fluoranthene and pyrene, each representing nearly 10% of total PAHs (Figure 3.1.2). Of these three products, the first two are generally associated with the gaseous fraction, while pyrene is associated with particulate matter (Germain 1997; Dann 1989). Benzo(b)fluoranthene was the most common heavy PAH found, representing roughly 5% of PAHs by mass.

Table 3.1.1: Synthesis of 24-hour PAH values obtained between December 7, 1998 and March 31, 1999 at the Rivière-des-Prairies station

Period 0 am -11:59 pm	# values	Detection frequency	Mean	Geometric mean	Median	Minimum	Maximum
Compounds		%	ng/m^3	ng/m^3	ng/m^3	ng/m^3	ng/m^3
Acenaphthylene	21	100	8.98	6.28	7.74	0.67	21.94
Acenaphthene	21	95	2.37	1.39	2.18	0.00	6.59
Fluorene	21	100	7.26	6.12	6.40	1.28	14.54
2-Me-Fluorene	21	90	1.49	0.72	1.49	0.00	4.04
Phenanthrene	21	100	21.96	18.56	20.95	4.02	42.69
Anthracene	21	100	2.50	1.99	1.95	0.31	4.97
Fluoranthene	21	100	8.31	6.69	8.10	1.20	21.96
Pyrene	21	100	6.23	4.95	5.52	0.77	15.80
Benzo(a)Fluorene	21	100	0.71	0.54	0.61	0.06	1.81
Benzo(b)Fluorene	21	95	0.38	0.28	0.33	0.03	0.86
1-Me-Pyrene	21	95	0.44	0.31	0.32	0.03	1.16
Benzo(g,h,i)Fluoranthene	21	100	1.19	0.90	0.97	0.11	2.94
Benzo(a)Anthracene	21	95	1.46	0.91	1.00	0.03	5.40
Chrysene	21	100	2.59	1.71	2.16	0.15	11.57
Triphenylene	21	86	0.42	0.18	0.41	0.00	1.56
7-Me-Benzo(a)Anthracene	21	24	0.01	0.00	0.00	0.00	0.07
Benzo(b)Fluoranthene	21	100	3.68	2.45	2.93	0.21	16.25
Benzo(k)Fluoranthene	21	100	0.91	0.65	0.82	0.05	4.05
Benzo(e)Pyrene	21	100	1.75	1.19	1.45	0.10	7.69
Benzo(a)Pyrene	21	95	1.20	0.63	0.94	0.00	4.53
Perylene	21	71	0.12	0.04	0.09	0.00	0.53
2-Me-Cholanthrene	21	0	0.00	0.00	0.00	0.00	0.00
Indeno(1,2,3-cd)Pyrene	21	100	1.21	0.88	1.11	0.08	4.44
Dibenzo(a,c)&(a,h)Anthracene	21	90	0.17	0.10	0.15	0.00	0.72
Benzo(b)Chrysene	21	90	0.08	0.05	0.06	0.00	0.29
Benzo(g,h,i)Perylene	21	100	1.25	0.94	1.14	0.08	4.29
Anthanthrene	21	95	0.16	0.10	0.11	0.00	0.58
Total PAH	21	100	76.83	61.63	71.50	10.01	184.08
Σ particulate PAH (Fluoranthene and heavier)	21	100	32.279	24.38	29.94	2.99	103.94
TSP (µg/m³)	21	100	58.06	50.63	53.93	21.47	132.47

In this project, samples were only taken in winter and the levels measured were lower than those obtained in the early 1990s in the same neighbourhood. PAH ambient air concentrations generally fluctuate according to location, source and season. Values obtained in this study were compared with seasonal values obtained by Dann (1989) in Toronto and Montreal and by Germain (1997) at several locations in Quebec. Table 3.1.5, which includes the values reported in the three studies, shows that geometric means vary much less in urban environments affected by vehicle traffic than in areas influenced by wood heating. In wood heating areas, PAH levels are 10 to 15 times higher in winter than in summer. In Montreal, stations affected mainly by automobile emissions have winter values 1.5 times higher than in summer. Significant seasonal variations can also be found near aluminium smelters.

Table 3.1.2: Synthesis of results obtained for PAH levels measured from 4:00 pm to midnight between December 7, 1998 and March 31, 1999 at the RDP station

Period 4 pm -11:59 pm	# values	Detection frequency	Mean	Geometric mean	Median	Minimum	Maximum
COMPOUNDS		%					
Acenaphthylene	21	100	15.38	10.62	11.58	2.01	58.89
Acenaphthene	21	100	3.67	2.96	3.25	0.78	8.52
Fluorene	21	100	7.77	6.27	7.27	1.76	18.07
2-Me-Fluorene	21	90	1.99	0.93	1.49	0.00	7.77
Phenanthrene	21	100	23.71	19.27	22.42	5.84	52.99
Anthracene	21	100	2.87	2.12	2.35	0.36	7.64
Fluoranthene	21	100	8.39	6.75	6.64	1.93	23.51
Pyrene	21	100	6.18	4.82	4.54	0.98	18.06
Benzo(a)Fluorene	21	100	0.79	0.58	0.60	0.06	2.41
Benzo(b)Fluorene	21	95	0.43	0.28	0.32	0.01	1.22
1-Me-Pyrene	21	95	0.48	0.31	0.34	0.01	1.63
Benzo(g,h,i)Fluoranthene	21	100	1.30	0.99	1.05	0.14	3.36
Benzo(a)Anthracene	21	95	1.43	0.83	1.03	0.01	4.98
Chrysene	21	100	2.36	1.66	1.58	0.21	6.88
Triphenylene	21	100	0.65	0.49	0.54	0.09	1.87
7-Me-Benzo(a)Anthracene	21	5	0.01	0.01	0.01	0.00	0.08
Benzo(b)Fluoranthene	21	100	3.44	2.47	2.54	0.35	10.21
Benzo(k)Fluoranthene	21	100	0.91	0.65	0.64	0.07	2.52
Benzo(e)Pyrene	21	100	1.67	1.18	1.28	0.16	5.27
Benzo(a)Pyrene	21	95	1.16	0.68	0.65	0.01	4.10
Perylene	21	62	0.21	0.07	0.11	0.00	1.03
2-Me-Cholanthrene	21	0	0.01	0.01	0.01	0.00	0.01
Indeno(1,2,3-cd)Pyrene	21	100	1.29	0.98	0.96	0.12	3.29
Dibenzo(a,c)&(a,h)Anthracene	21	81	0.17	0.10	0.13	0.01	0.50
Benzo(b)Chrysene	21	52	0.08	0.03	0.02	0.01	0.32
Benzo(g,h,i)Perylene	21	100	1.34	1.01	0.98	0.12	3.34
Anthanthrene	21	71	0.17	0.07	0.10	0.01	0.79
Σ PAH	21	100	87.84	69.49	69.99	15.85	197.24
Σ particulate PAH (Fluoranthene and heavier)	21	100	32.48	24.86	23.36	4.32	92.12
TSP (µg/m^3)	21	21	75.25	65.70	63.60	20.38	164.92

Table 3.1.3: Synthesis of results obtained for PAH levels over a 24-hour period between December 1, 1998 and March 31, 1999 at the Ontario Street station

	# values	Detection frequency	Mean	Geometric mean	Median	Minimum	Maximum
Composés		%	ng/m^3	ng/m^3	ng/m^3	ng/m^3	ng/m^3
Acenaphthylene	14	100	1,88	1,64	1,63	0,50	3,63
Acenaphthene	14	100	1,05	0,95	0,98	0,48	2,17
Fluorene	14	100	3,86	3,56	3,80	1,61	8,21
2-Me-Fluorene	14	100	0,95	0,87	0,97	0,42	2,03
Phenanthrene	14	100	11,69	10,73	10,69	5,23	18,31
Anthracene	14	100	0,78	0,68	0,75	0,30	1,71
Fluoranthene	14	100	4,97	4,21	4,45	1,50	10,22
Pyrene	14	100	3,63	3,15	3,53	1,10	7,12
Benzo(a)Fluorene	14	100	0,32	0,27	0,26	0,07	0,73
Benzo(b)Fluorene	14	100	0,17	0,13	0,14	0,03	0,61
1-Me-Pyrene	14	100	0,16	0,14	0,16	0,04	0,35
Benzo(g,h,i)Fluoranthene	14	100	0,52	0,44	0,48	0,13	1,23
Benzo(a)Anthracene	14	100	0,59	0,45	0,43	0,08	1,75
Chrysene	14	100	1,86	1,25	1,31	0,15	5,29
Triphenylene	14	100	0,44	0,30	0,36	0,04	1,24
7-Me-Benzo(a)Anthracene	14	0	0,00	0,00	0,00	0,00	0,01
Benzo(b)Fluoranthene	14	100	2,82	1,84	2,10	0,19	7,75
Benzo(k)Fluoranthene	14	100	0,64	0,44	0,49	0,05	1,56
Benzo(e)Pyrene	14	100	1,53	1,01	1,13	0,11	4,26
Benzo(a)Pyrene	14	100	0,57	0,41	0,39	0,07	1,89
Perylene	14	93	0,09	0,07	0,07	0,01	0,26
2-Me-Cholanthrene	13	0	0,00	0,00	0,00	0,00	0,01
Indeno(1,2,3-cd)Pyrene	14	100	0,72	0,55	0,57	0,09	1,84
Dibenzo(a,c)&(a,h)Anthracene	14	86	0,13	0,07	0,09	0,00	0,36
Benzo(b)Chrysene	14	79	0,04	0,02	0,03	0,00	0,10
Benzo(g,h,i)Perylene	14	100	0,97	0,77	0,82	0,14	2,24
Anthanthrene	14	86	0,05	0,03	0,04	0,00	0,14
∑ PAH	14	100	40,42	35,62	40,48	14,18	77,10
∑ particulate PAH (Fluoranthene and heavier)	14	100	20,23	16,10	16,08	3,85	48,22
TSP (µg/m^3)	14	100	48,89	44,73	44,50	20,40	79,90

Table 3.1.4: Synthesis of results obtained for PAH levels measured at the Rivière-des-Prairies and Ontario Street stations on the same sampling days (n = 13)

	Station		
	Ontario street	Rivière-des-Prairies	
Sampling period	24 hours (0 am – 11:59 pm)	24 hours (0 am – 11:59 pm)	8 hours (4 pm –11:59 pm)
	ng/m^3	ng/m^3	ng/m^3
Mean	40.2	69.0	96.7
Geometric mean	35.3	52.4	73.9
Median	40.7	65.8	76.5
Minimum	14.2	10.0	15.8
Maximum	77.1	184.1	197.2

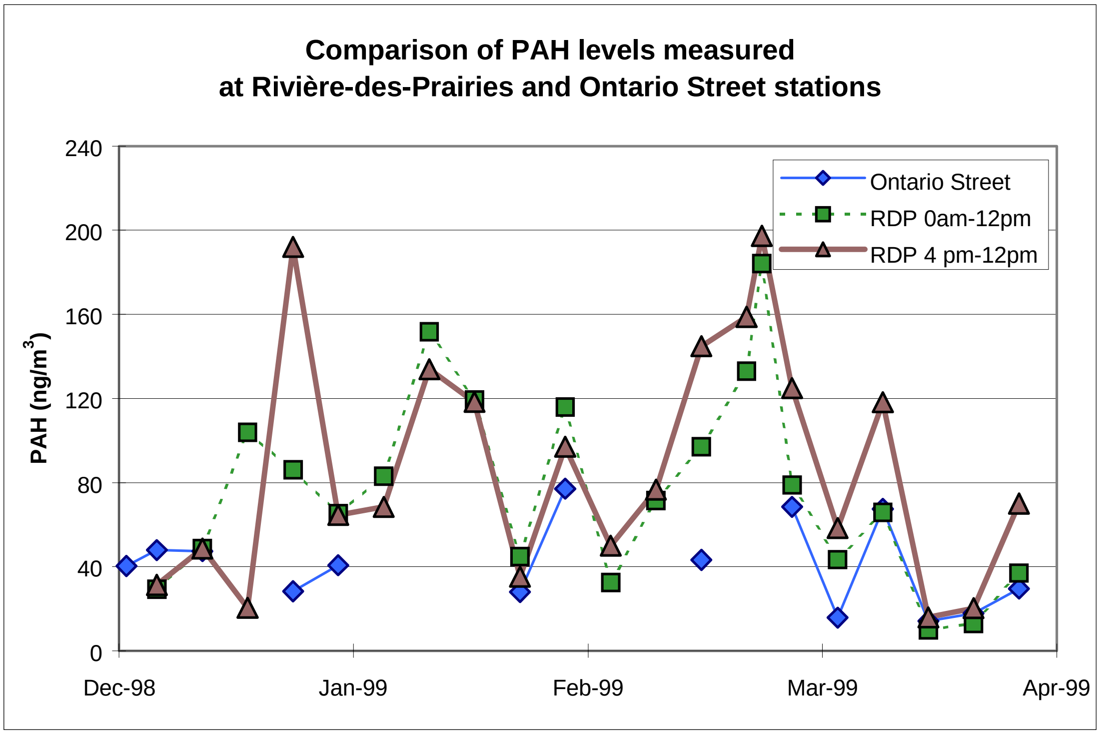


Figure 3.1.1: Comparison of PAH levels measured at the Rivière-des-Prairies and Ontario Street stations between December 1, 1998 and March 31, 1999 (modified high-volume sampler)

Table 3.1.5: Seasonal variations in total PAH levels and B(a)P measured mainly in Quebec

Compound	Total PAH (geometric mean in ng/m^3)				B(a)P (geometric mean in ng/m^3)			
Season	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
Sector and site								
WOOD HEATING								
Montréal (RDP) 98-99	-	-	-	61.6	-	-	-	0.63
Montréal (RDP)	-	21.2	104.9	196.7	-	0.08	0.68	1.88
Sept-Îles	-	10.7	-	160.7	-	0.05	-	1.50
TRANSPORTATION								
CUM(Duncan&Décarie)	-	66.3	-	95.6	-	0.26	-	0.66
Montréal (Ontario street) 98-99	-	-	-	36.6	-	-	-	0.41
Montréal (Ontario street)*	57.1	68.5	65.9	66.3	0.18	0.11	0.37	0.41
Toronto*	29.9	45.1	41.1	28.4	0.28	0.13	0.45	0.30
INDUSTRIAL								
Cap-de-la-Madeleine	-	-	199.5	129.3	-	-	0.27	0.59
INCINÉRATION								
Nouvelle	-	16.7	-	94.5	-	0.06	-	0.88
ALUMINUM SMELTERS								
Baie-Comeau	-	485.0	74.9	162.2	-	5.9	0.7	2.3
Beauharnois	-	145.8	54.9	113.6	-	0.22	0.64	1.44
Jonquière**	485.0	371.9	408.0	498.1	3.60	1.52	3.73	4.65
Laterrière	-	13.3	-	-	-	0.06***	-	-
Shawinigan	-	195.5	330.2	261.8	-	0.87	2.44	3.06

Reproduced from Germain (1997) and addition of results from this project and from Dann (1989)

- : not applicable, no samples

* : Data from RRETC

** : Including data from RRETC

*** : Arithmetic mean

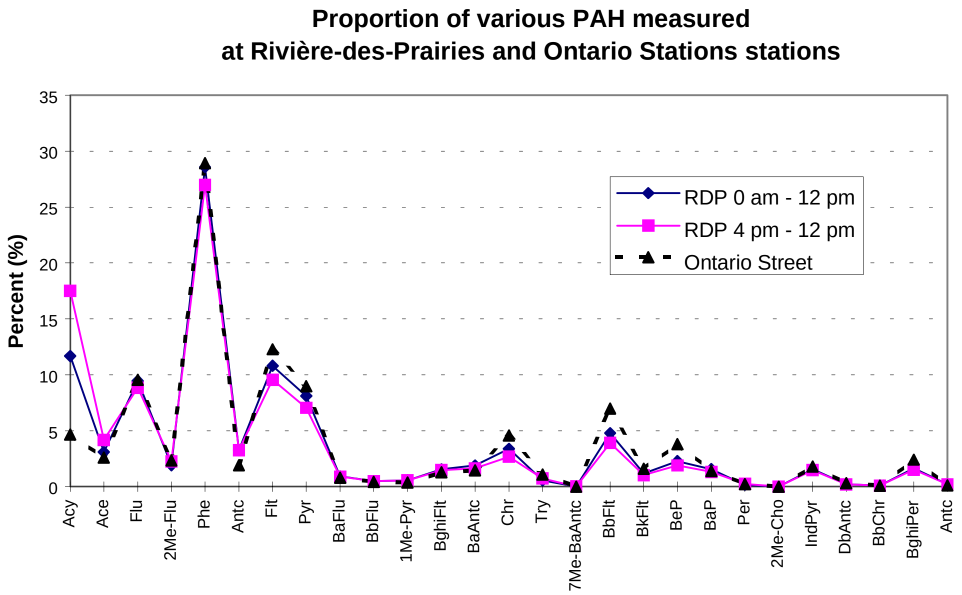


Figure 3.1.2: Proportion of different PAHs found in relation to total PAHs measured over a 24-hour period (midnight to midnight) and in the evening (4:00 pm to midnight) at the Rivière-des-Prairies station and over a 24-hour period at the Ontario Street station

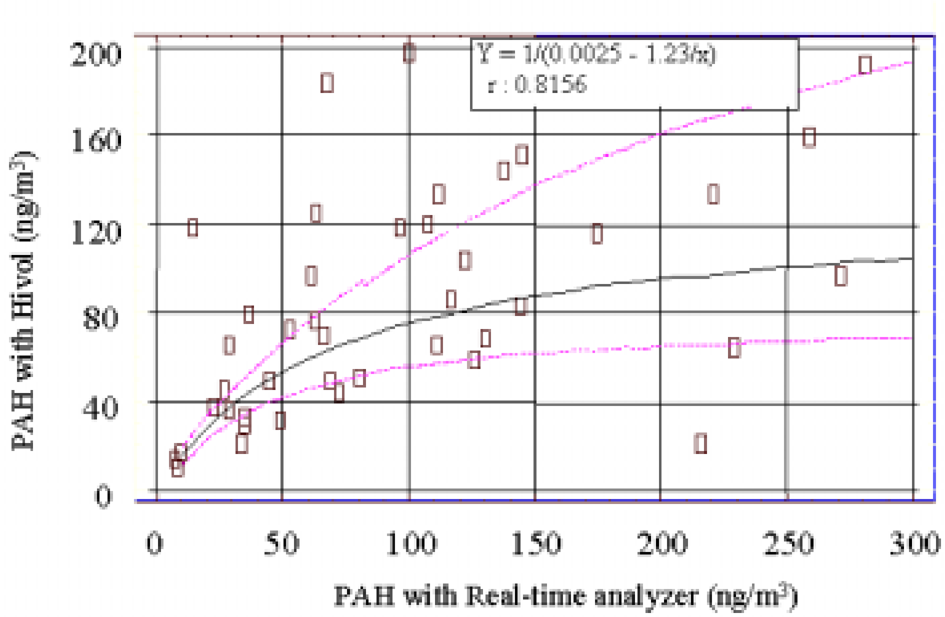
3.1.2. Continuous PAH analyzer

The project also allowed the performance of a continuous PAH analyzer to be tested over a fairly long period of time. The device is used to measure temporal variations in PAH values in the ambient air. However, the signal sent by the analyzer must be converted to express values in the form of concentrations. The manufacturer-recommended conversion factor was used initially, but since the values obtained with the real-time analyzer did not correspond to those obtained with the modified high-volume sampler, the results obtained with the modified high-volume sampler were used to determine the conversion factor. Figure 3.1.3 shows the correlation (at a 95% confidence interval) between the results obtained with the modified high-volume sampler and the continuous analyzer, after the conversion factor was applied. A significant correlation was found (r: 0.8156, $p < 0.01$), corresponding to a "double reciprocal " relation that can be expressed by the following equation:

$$y = 1/(a - b/x) \qquad \text{Equation (1)}$$

where
y = PAHs measured with modified high-volume sampler
x = PAHs measured with continuous sampler
a = value of intercept at origin: 0.00246
b = value of slope: 1.2341
red lines = curve for 95% confidence interval

Figures 3.1.4 and 3.1.5 show that, with the new conversion factor, the results obtained with the continuous analyzer are comparable to those obtained with the modified high-volume sampler, both for 24-hour and 8-hour samples, as shown by the very similar overall appearance of the curves.



Red dotted lines represent the 95 % confidence interval

<u>Figure 3.1.3:</u> Comparison of results obtained with continuous analyzer and modified high-volume sampler

Table 3.1.6 provides a summary of information obtained during the entire project. It shows the values of certain statistical parameters for the continuous analyzer, for periods of 24 and 8 hours, as well as statistical information on the corresponding non-continuous samples. In general, the statistical parameters obtained with the continuous PAH analyzer correspond to those obtained with the modified high-volume sampler. Values measured during the evening were 2.4 times (or 140%) greater than those measured during the day.

Table 3.1.6: Synthesis of results obtained with continuous PAH analyzer and modified high-volume sampler (ng/m^3)

	Whole project	Real Time Analyzer NAPS sampling days		Modified Hi-vol samplers	
Sampling duration		0 am to 12 pm	4 pm to 12 pm	24 hours	8 hours
Number of values	Continuous	21	21	21	21
Mean (arithmetic)	74.3	75.7	125.9	76.8	87.8
Mean (geometric)	41.2	56.6	90.8	61.6	69.5
Median	41.2	64.8	98.4	71.5	70.0
Minimum	0.9	7.5	9.7	10.0	15.8
Maximum	845.0	175.0	281.6	184.1	197.2

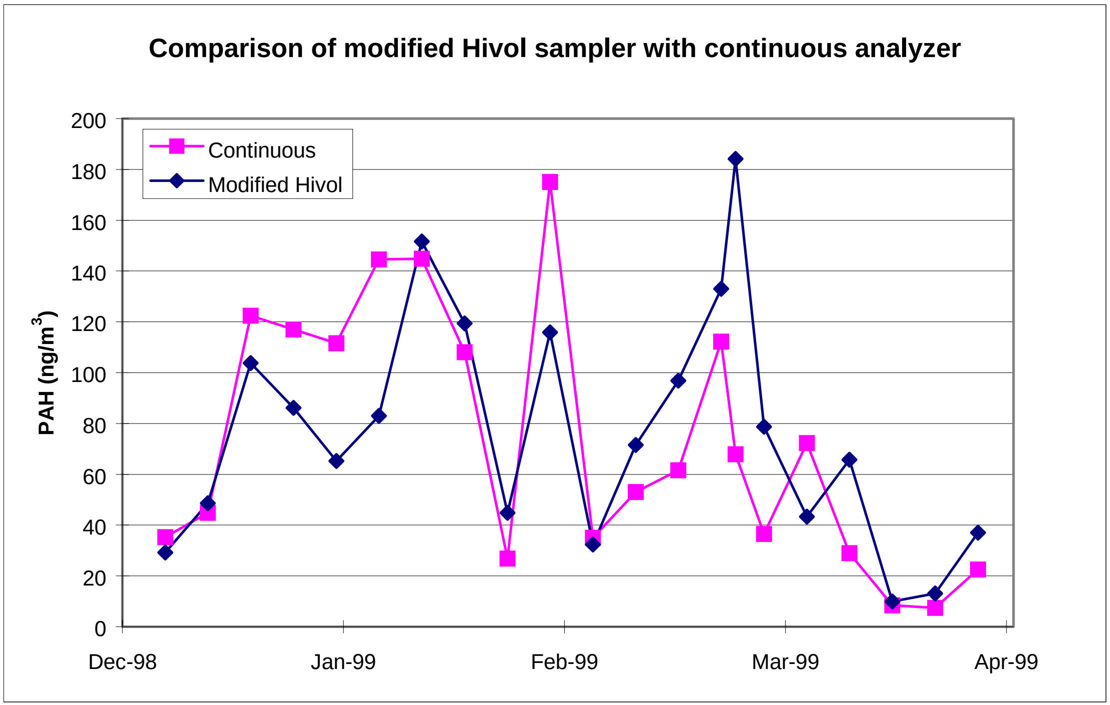


Figure 3.1.4: Comparison of 24-hour PAH concentrations obtained with continuous analyzer with those measured with modified high-volume sampler

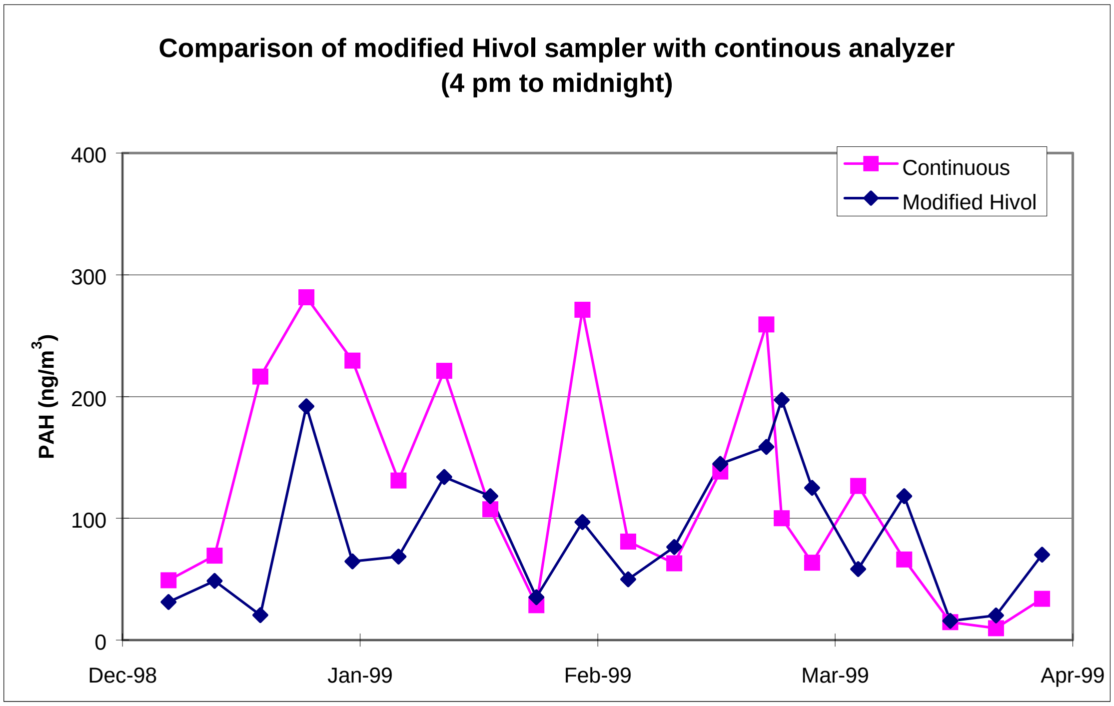


Figure 3.1.5: Comparison of 8-hour PAH concentrations (4:00 pm to midnight) obtained with continuous sampler with those measured with modified high-volume sampler

Some of the highest 24-hour PAH values were obtained on Christmas Day and New Year's Eve with the continuous analyzer, along with values measured between 4:00 pm and midnight. Mean values for Christmas Day were the highest and those for New Year's Eve were not far behind. Samples taken with the modified high-volume sampler, however, showed values in the middle range for 24-hour samples. The samples taken between 4:00 pm and midnight on Christmas night ranked highest among all the samples, while the sample taken on New Year's Eve was near the mean.

Figure 3.1.6 shows, based on an analysis of mean monthly values, that PAH weekday levels were generally lower than those measured on weekends. Figure 3.1.7 shows the hourly variations during weekdays. As can be seen in the figure, the lowest values were observed around 4:00 or 5:00 am in the morning; values then peaked around sunrise, decreased during the day and then increased again from 4:00-5:00 pm to midnight. Hourly values during the evening were higher on Monday than on other weekdays. Similarly, during weekends and holidays, the minimum values occurred in the early morning and values then rose at sunrise (Figure 3.1.8). Contrary to what was observed during the week, however, values on weekends did not drop during the day but remained stable until late afternoon, when they began to rise, reaching around 200 ng/m^3. Holidays were much like weekends except values were higher. This behaviour could be explained by the small number of holidays taken into account in the project. The different hourly variations in PAH levels on weekdays and weekends can be seen in Figure 3.1.9. As Figure 3.1.9 shows, the increase in PAH levels begins earlier on weekdays, but PAH levels are generally higher on weekends. The mean deviation between hourly values on weekdays and weekends is close to 30 ng/m^3 in the early afternoon (noon to 3:00 pm) and 45 ng/m^3 in the evening (5:00 pm to 10:00 pm), representing differences of 92% and 39% respectively.

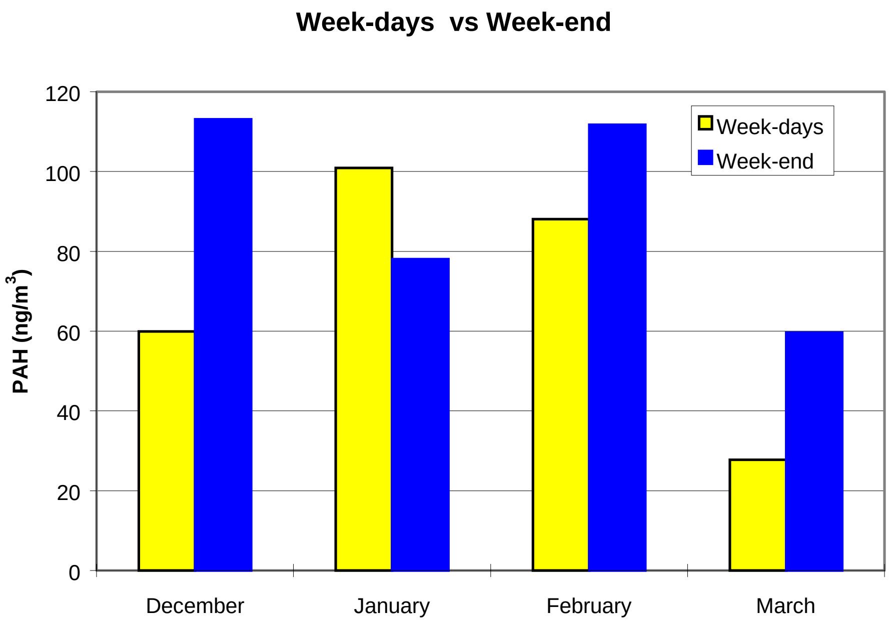


Figure 3.1.6: Comparison of monthly mean PAH values measured with the continuous analyzer on weekdays and weekends

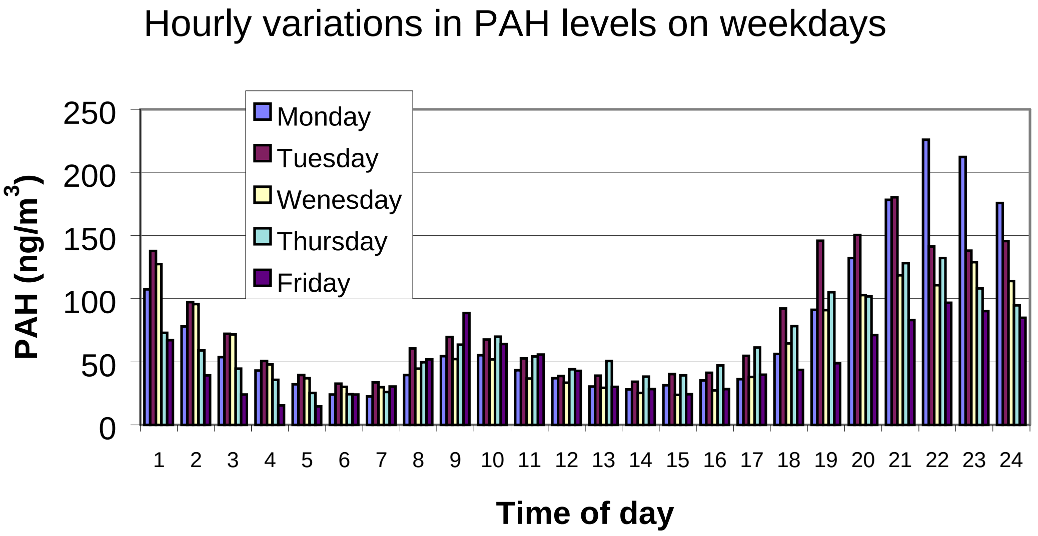


Figure 3.1.7: Hourly variations in PAH levels measured with the continuous analyzer on weekdays (except holidays) during the entire sampling program

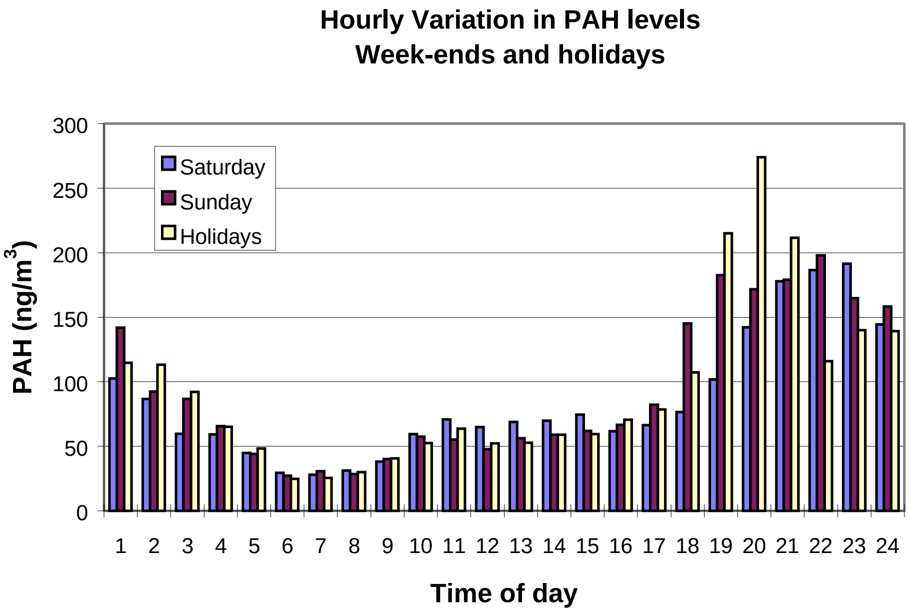


Figure 3.1.8: Hourly variations in PAH levels measured with the continuous analyzer on weekends and holidays during the entire sampling program

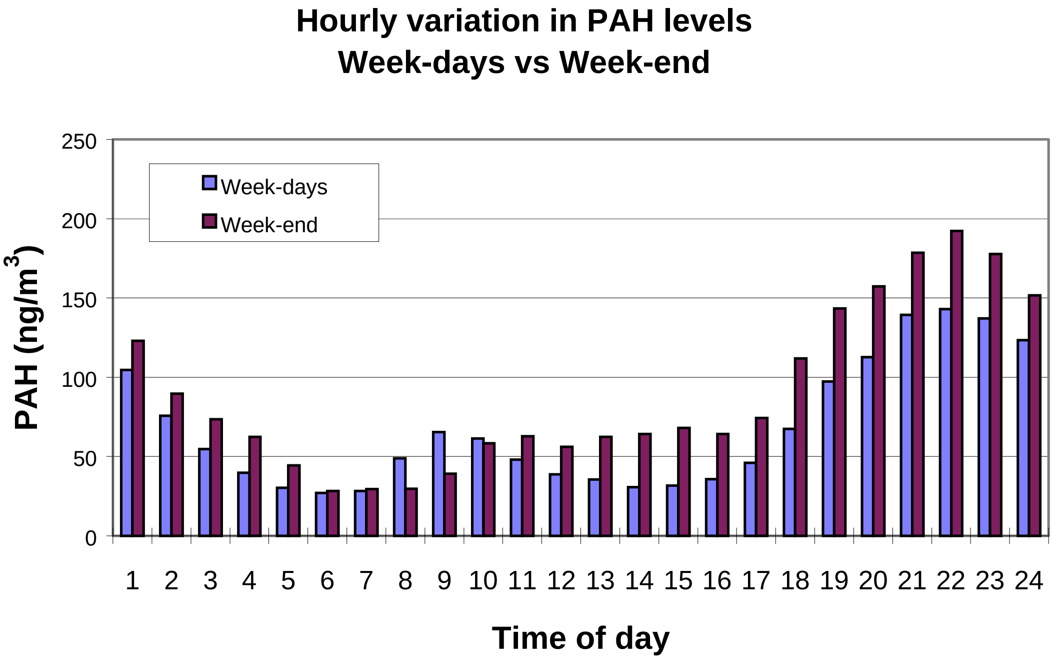


Figure 3.1.9: Hourly variations in PAH levels measured with the continuous analyzer on weekdays and weekends

3.1.3. Identification of PAH sources

According to Germain (1997), certain pairs of products can be used to help identify the origins of PAHs, particularly phenanthrene and benzo(e)pyrene [Phe/B(e)P], which can be used to distinguish aluminium smelter emissions from emissions from wood heating and motor vehicles (it does not distinguish between the last two sources, however). Phe/B(e)P ratios calculated from the results obtained at the RDP and Ontario Street stations were examined, along with three other ratios that appeared to be promising: chrysene/B(e)P [Chr/B(e)P], benzo(ghi)perylene/B(e)P [BghiPer/B(e)P] and fluorene/pyrene [Flu/Pyr]. The coronene/B(e)P ratio could also have been used, but coronene was not measured by the laboratory that performed the analyses in 1999. As Table 3.1.7 shows, although mean Phe/B(e)P values were slightly higher at the RDP station, they were not significantly different from those calculated at Ontario Street ($p < 0.05$) during the study period. Similarly, no significant differences were found for the pairs BghiPer/B(e)P and Flu/Pyr at the two stations. A significant difference was found between stations for the Chr/B(e)P ratio, however.

Ratios calculated at both stations were also compared with the values reported by Germain (1997). At Rivière-des-Prairies, Phe/B(e)P values in 1989-90 were significantly higher than in 1998-99, while values for the three other pairs were similar. Historical winter values at the Rivière-des-Prairies station were found to correspond to values calculated for the period 1989-90. The same procedure was used for samples taken between 1989 and 1994 at the Ontario Street station. Winter Phe/B(e)P values for the period 1989-94 were also higher than the values obtained in the most recent winter of sampling. For the other three pairs, recent values also differed from historical values but the differences were less than in the case of the Phe/BeP ratio. In 1989-94, the Phe/B(e)P ratio varied depending on whether samples were taken in areas affected by vehicle emissions or by wood heating while, in 1998-99, the Chr/B(e)P ratio was the one most affected by the origin of the sample.

In addition, local contributions to PAH ambient air concentrations at the RDP station were estimated by extrapolating from historical data. PAH ambient air concentrations in Rivière-des-Prairies probably increase from summer to winter. Assuming that PAH concentrations measured at the Ontario Street station are representative of contributions from different urban sources on the Island of Montreal, it can be inferred that the increase observed at RDP depends on contributions from RDP itself. Using the 40 ng/m^3 measured at the Ontario Street station as a reference level, it can be estimated that close to 45% of the PAHs present in the ambient air in RDP probably come from sources within the neighbourhood.

Table 3.1.7: Ratios between different PAHs measured at the Rivière-des-Prairies and Ontario Street stations

	n	Mean mean	Geometric mean	Median	Minimum	Maximum
Period : December 1998 – March 31, 1999						
Rivière-des-Prairies						
Samples taken over 24 hours						
Phe/BeP	21	17.38	15.55	18.52	5.41	40.68
Chr/BeP	21	1.46	1.44	1.48	1.12	2.17
BghiPer/BeP	21	0.80	0.78	0.78	0.52	1.14
Flu/Pyr	21	1.26	1.24	1.23	0.84	1.67
Samples taken over 8 hours (during evening)						
Phe/BeP	21	18.89	16.29	15.88	6.10	49.48
Chr/BeP	21	1.43	1.40	1.51	0.95	1.79
BghiPer/BeP	21	0.88	0.86	0.89	0.47	1.26
Flu/Pyr		1.37	1.30	1.33	0.66	2.38
Ontario street						
Phe/BeP	14	13.97	10.61	9.37	3.99	49.96
Chr/BeP	14	1.24	1.23	1.22	1.03	1.72
BghiPer/BeP	14	0.82	0.76	0.72	0.44	1.43
Flu/Pyr	14	1.23	1.13	1.18	0.67	2.24
Previous sampling period						
Rivière-des-Prairies						
Fall 1989 to Fall 1990						
Phe/BeP	31	28.65	21.24	22.08	2.37	161.42
Chr/BeP	31	1.81	1.72	1.78	0.68	2.92
BghiP/BeP	31	0.86	0.78	0.85	0.14	1.63
Flu/Pyr	31	1.44	1.30	1.46	0.53	3.18
Winter 1990						
Phe/BeP	12	29.32	18.19	18.42	2.37	161.42
Chr/BeP	12	1.98	1.95	1.82	1.52	2.60
BghiP/BeP	12	0.95	0.90	0.94	0.40	1.60
Flu/Pyr	12	1.69	1.60	1.55	0.98	3.18
Ontario street						
1989-1994, all data available						
Phe/BeP	134	62.16	34.49	34.22	0.16	482.50
Chr/BeP	134	2.05	1.90	1.95	0.12	7.49
BghiPer/BeP	134	1.09	0.95	1.03	0.28	2.60
Flu/Pyr	134	1.55	1.23	1.44	0.03	5.72
1989-1994, winter values only						
Phe/Bep	42	26.04	18.38	22.96	0.16	72.14
Chry/BeP	42	1.93	1.79	1.91	0.12	3.50
BghiPer	42	1.20	1.07	1.17	0.37	2.60
Flu/Pyr	42	1.79	1.48	1.69	.03	5.72

*: Phe: Phenanthrene; Chr: Chrysene; BghiPer: Benzo(ghi)perylene; Flu: Fluorene; Pyr: Pyrene; B(e)P: Benzo(e)pyrene

3.1.4. Relation with wind direction

Figure 3.1.10 shows the distribution of mean PAH values obtained with the continuous analyzer according to wind direction. The highest PAH concentrations at the RDP station were recorded under calm conditions (mean of 244.9 ng/m^3). Very high mean PAH concentrations were also recorded when the wind (measured at 10 m) was from the southeast. The immediate area to the southeast of the station comprises a residential neighbourhood where wood heating is very common. From a more regional perspective, the area is downwind from the eastern end of Montreal's South Shore. Heavily industrialized east Montreal, with its petrochemical industry, lies south-south-east of the station. However, winds from the south south-east are relatively infrequent (occurring 5.7% of the time in the winter of 1998-99). High PAH concentrations were also observed in Rivière-des-Prairies when winds were out of the south-south-west (3.1% of the time), coming from the direction of heavily residential neighbourhoods on the Island of Montreal. Concentrations were also high when winds were out of the east-north-east (2.7% of the time), coming from heavily residential neighbourhoods, beyond which lies the agricultural land of the Lanaudière region.

The lowest PAH concentrations were recorded when winds were out of the west to northwest (21.5% of the time). Few residences lie immediately upwind in this direction, and the area consists mainly of green spaces, beyond which lies the Laval region.

3.1.5. Adherence to standards

Quebec has established an annual standard of 0.9 ng/m^3 for B(a)P, which is used to assess the impact of new development projects on air quality. Mean values obtained at the RDP station during the program exceeded this standard, with 24-hour values of 1.20 ng/m^3 and 8-hour values of 1.16 ng/m^3. In contrast, mean B(a)P values at the Ontario Street station fell within Quebec's annual criteria. It should be noted, however, that the samples in question were taken in winter only and therefore the criterion in question (which is based on an annual mean) does not actually apply. Samples for the entire year would be required to compare the annual mean with the provincial criteria for B(a)P.

We also compared B(a)P levels measured at both stations to Ontario's 24-hour ambient air quality criterion, 1.1 ng/m^3. At the RDP station, 38% of samples exceeded this standard, compared with 14% at the Ontario Street station.

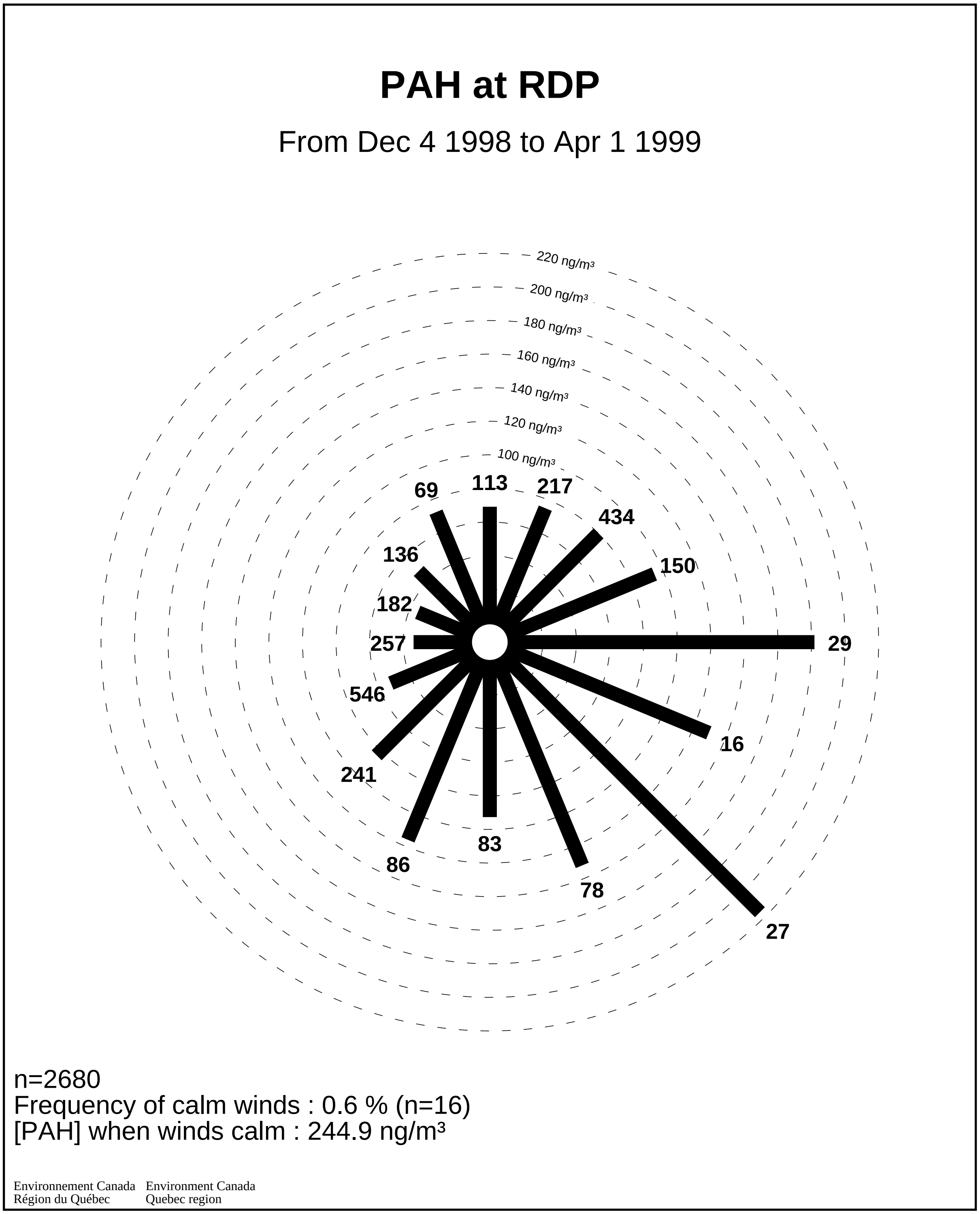


Figure 3.1.10: Mean PAH concentrations in Rivière-des-Prairies according to wind direction measured with continuous analyser

3.2. Fine particulate matter measured (24-hour samples) with the dichotomous sampler

Table 3.2.1 shows a summary of the results for the different particle size fractions measured at the RDP station. For the smallest fractions, only 24-hour concentrations were measured, with mean values of 16.7 µg/m^3 and 25.6 µg/m^3 obtained for $PM_{2.5}$ and PM_{10} respectively.

Table 3.2.1: Summary of results for fine particulate matter (measured with dichotomous sampler)

	Concentrations in µg/m^3								
	RDP station			Ontario street station			Anjou station		
	$PM_{2.5}$	$PM_{2.5-10}$	PM_{10}	$PM_{2.5}$	$PM_{2.5-10}$	PM_{10}	$PM_{2.5}$	$PM_{2.5-10}$	PM_{10}
# values	21	21	21	17	17	17	13	13	13
Mean	16.75	8.89	25.64	11.34	9.64	20.99	14.51	14.17	28.68
Geometric Mean	13.97	6.13	22.28	10.17	8.34	19.31	13.16	12.09	27.15
Minimum	1.87	1.13	7.49	3.32	3.09	8.44	5.37	3.93	13.75
Median	17.32	5.62	25.74	11.91	9.84	18.07	13.82	11.51	27.21
Maximum	30.74	25.33	50.99	21.29	17.01	38.29	26.16	35.92	52.66

The prevalence of very fine particles ($PM_{2.5}$) at the RDP station was echoed in the results obtained for the $PM_{2.5}/PM_{10}$ ratio: 66% at the RDP station compared with 54% at the two other stations, representing a relative increase of 22% (cf. Table 3.2.2).

Table 3.2.2: Summary of results for $PM_{2.5}/PM_{10}$ ratio

Descriptive parameters	Sampling Station		
	RDP	Ontario street	Anjou
# values	21	17	13
Arithmetic mean	66.2 %	54.8 %	53.2 %
Geometric mean	62.7 %	52.6 %	48.5 %
Minimum	25.0 %	23.9 %	20.3 %
Median	68.6 %	55.6 %	49.1 %
Maximum	95.9 %	77.9 %	81.3 %

Figure 3.2.1 illustrates daily variations in the fine fraction ($PM_{2.5}$) measured with the dichotomous sampler, while Figure 3.2.2 shows daily variations in the coarse fraction ($PM_{2.5-10}$) obtained with the same sampler.

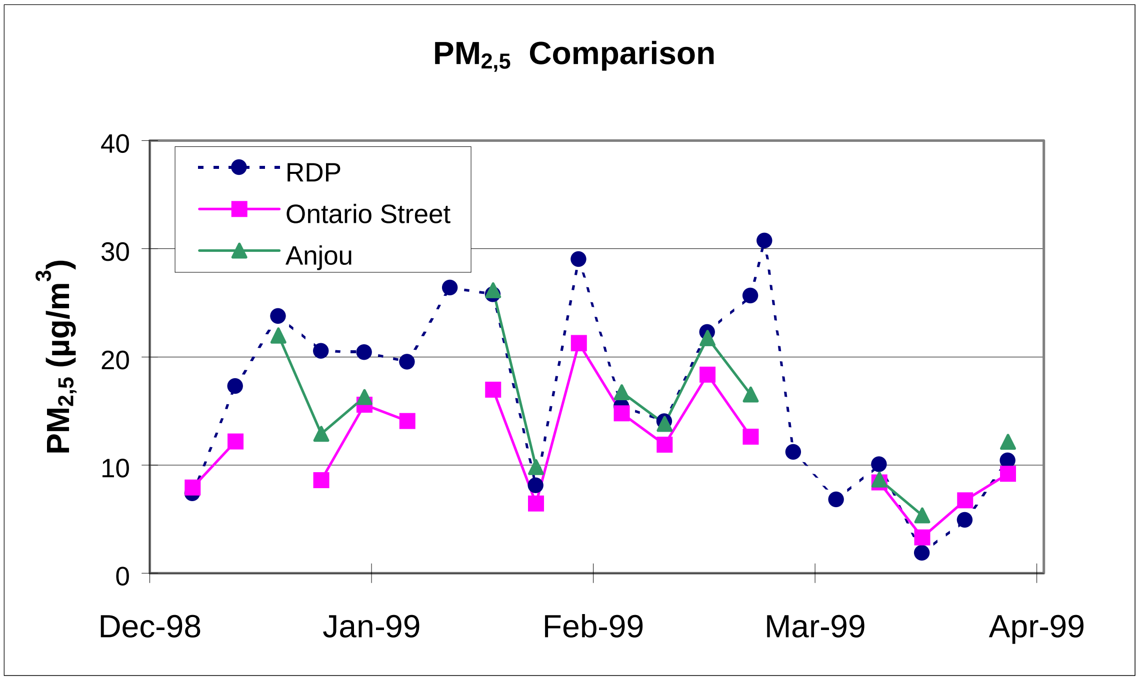


Figure 3.2.1: Daily variations in the fine particle fraction ($PM_{2.5}$) measured with a dichotomous sampler

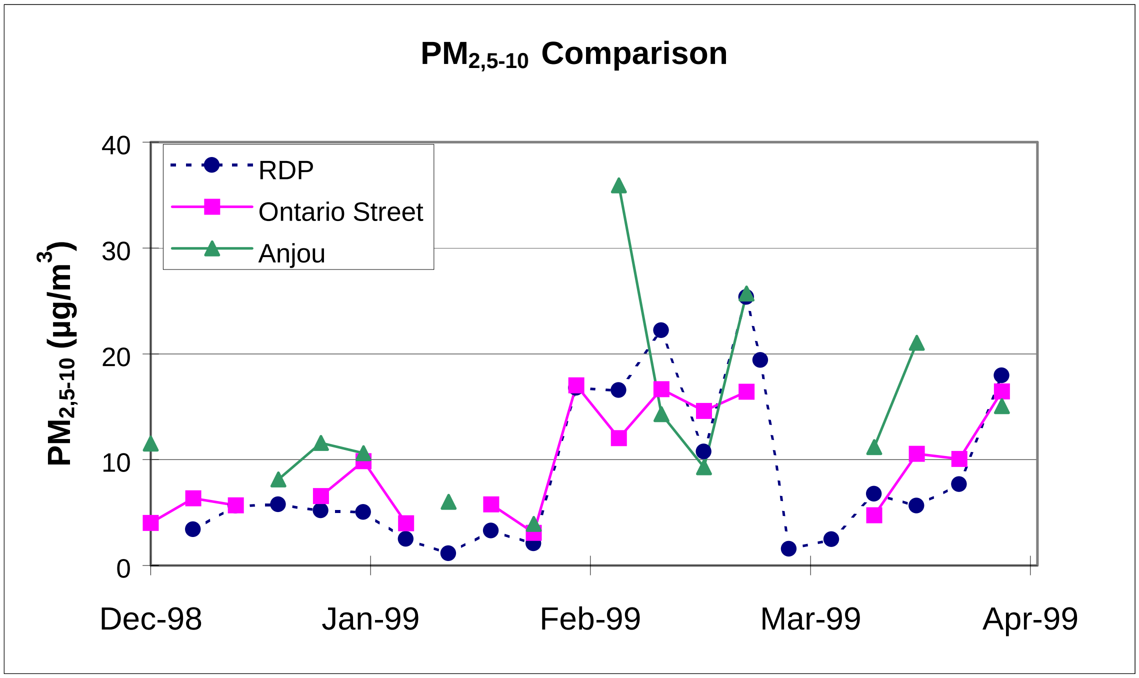


Figure 3.2.2: Daily variations in the coarse particle fraction ($PM_{2.5-10}$) measured with a dichotomous sampler

3.3 Continuous measurements of fine particulate matter

3.3.1 Levels measured

During the winter of 1998-99 at the RDP station, mean $PM_{2.5}$ levels were 12.9 µg/m^3, as measured with the Tapered Element Oscillation Monitor or TEOM. ($PM_{2.5}$ can be defined as particles with an aerodynamic diameter of less than 2.5 µm). Table 3.3.1 shows the monthly variations in fine particulate matter concentrations measured at the station. February was the month with the highest monthly mean, 17.2 µg/m^3, while December and March had similar means (10.6 µg/m^3).

Values at RDP were higher than at the other sites in the CUM network, including downtown Montreal (Drummond Street station) and the West Island (the Sainte-Anne-de-Bellevue or SAB station). Table 3.3.2 shows variations in $PM_{2.5}$ concentrations during this period on the Island of Montreal. At all stations, $PM_{2.5}$ concentrations were higher in February than during the other winter months. On average, values for fine particulate matter at the RDP station were 1.7 times higher than at the SAB station and 1.2 times higher than at the downtown Montreal station.

Table 3.3.1: $PM_{2.5}$ statistical values (µg/m^3) measured with the TEOM during the winter of 1998-99 at the Rivière-des-Prairies station

	Winter	December	January	February	March
Arithmetic mean	12.9	10.6	13.4	17.2	10.6
Standard deviation	10.1	7.5	10.4	12.3	8.2
Minimum value	0.4	0.4	0.6	0.7	1.0
Maximum value	99.2	78.2	99.2	75.9	78.6
% of valid data	98.6	98.9	96.3	99.4	99.7

Table 3.3.2: Mean $PM_{2.5}$ concentrations (µg/m^3) measured with the TEOM during the winter of 1998-99 at various sites on the Island of Montreal.

	Dec. To March	December	January	February	March
Sainte-Anne-de-Bellevue	7,4	6,1	7,6	9,9	6,1
Drummond	10,4	8,9	10,3	13,0	9,5
Rivière-des-Prairies	12,9	10,6	13,4	17,2	10,6

Setting aside monthly means, which were higher at the Rivière-des-Prairies station, hourly means were much more variable at this station than at the other MUC stations. Figure 3.3.1 shows hourly concentrations in January 1999 at the three stations. In general, the stations on the West Island and downtown had similar temporal behaviour, while behaviour at RDP differed. Although several periods of high particulate concentrations were recorded concurrently at the three stations, other periods of high values occurred exclusively at the RDP station, indicating the influence of a very significant local source. Furthermore, during most of the region-wide periods of high $PM_{2.5}$ concentrations, values at the RDP station were the highest. These increased concentrations seem to have resulted from a significant local contribution.

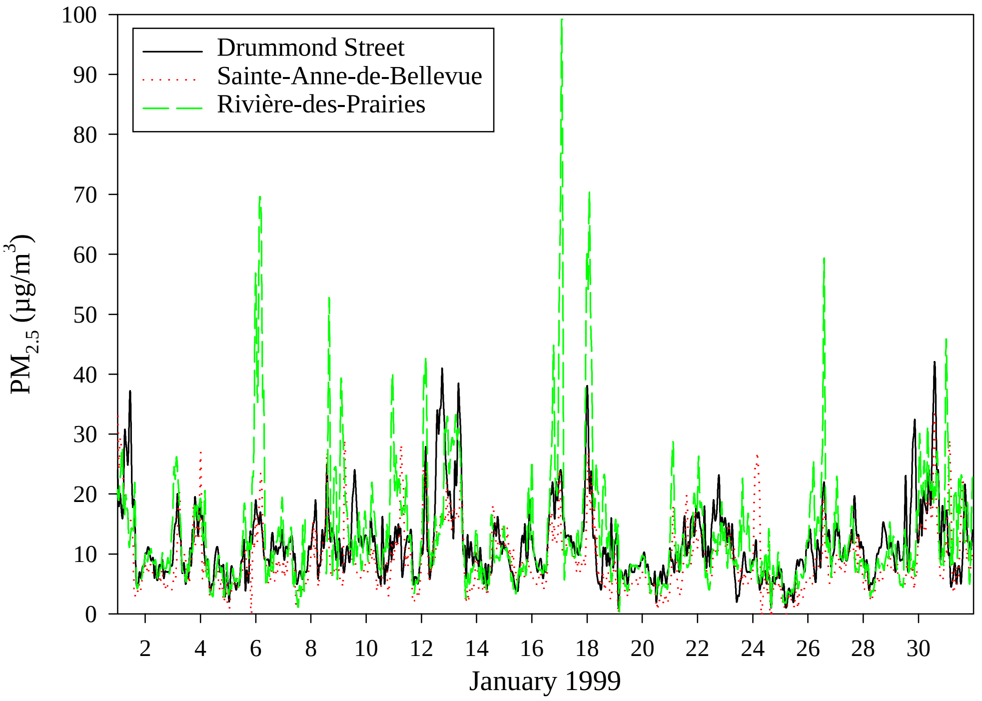


Figure 3.3.1: Hourly variations in $PM_{2.5}$ recorded at several sites in the Montreal area in January 1999

3.3.2 Hourly variations

An analysis of hourly variations was performed at each of the $PM_{2.5}$ measuring stations in Montreal by calculating the hourly mean over the entire winter period. As Figure 3.3.2 shows, fairly similar patterns of diurnal and nocturnal behaviour were observed at the stations. Significant differences did occur, however. The SAB station had a fairly even nocturnal-diurnal cycle with two maxima during the day, a sharper one around 9:00 am and another less well-defined one around 11:00 pm. Minimum values occurred during the afternoon, when the mixing layer was at its highest. Hourly variations at the Drummond Street station showed a very different pattern in the afternoon. In the morning, concentrations increased sharply and then reached a plateau of around 13 µg/m^3 until 2:00 pm; then, concentrations decreased slowly before rising again in the early evening, reaching a maximum at around 7:00 pm. At the RDP station, concentrations increased very rapidly in the morning but then decreased, reaching their lowest point in the early afternoon (10 µg/m^3 around 1:00 pm), in contrast with the afternoon plateau at the Drummond Street station. Concentrations increased sharply again in the late afternoon, reaching a maximum of close to 19 µg/m^3 around 8:00 pm. The maximum value recorded at the RDP station (at 8:00 pm) was 1.4 times greater than the maximum value at the Drummond Street station and 2.1 times greater than at the SAB station.

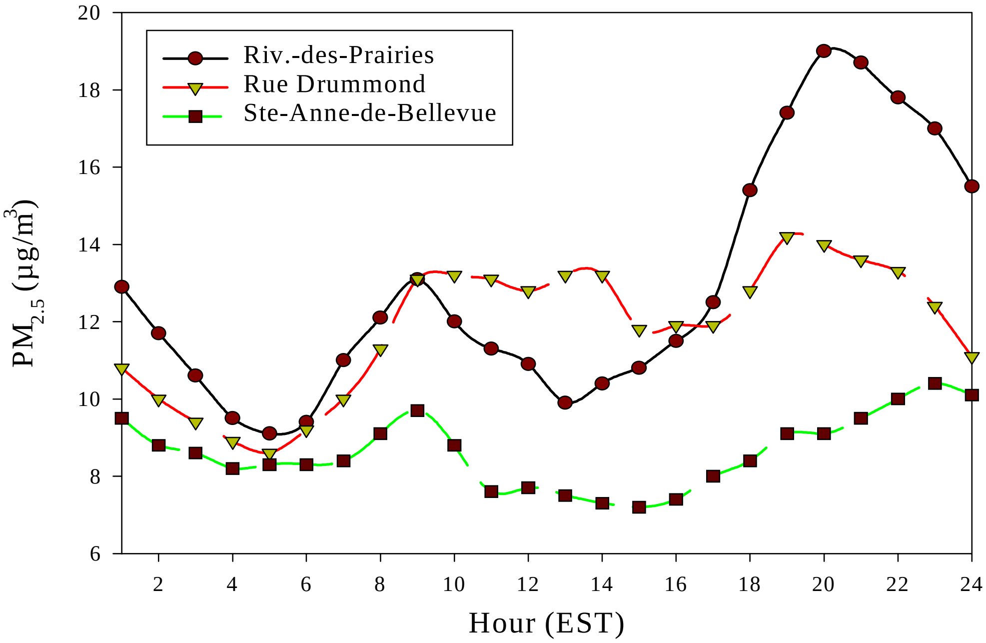


Figure 3.3.2: Mean hourly $PM_{2.5}$ concentrations measured at different stations in the Montreal area during the winter of 1998-99.

3.3.3 Differences between weekdays and weekends

To determine the cause of the striking rise in $PM_{2.5}$ concentrations in the afternoon and early evening at the RDP station, a distinction was made between weekdays, and weekends and holidays. Figure 3.3.3 shows hourly $PM_{2.5}$ behaviour at the three MUC stations during the week. The pattern at SAB is very similar to the one in Figure 3.3.2. Concentrations measured at the Drummond Street station, however, were slightly greater on weekday afternoons (by about 1 µg/m^3). However, there were few differences in the two curves for the RDP station, except that concentrations were lower on weekday evenings.

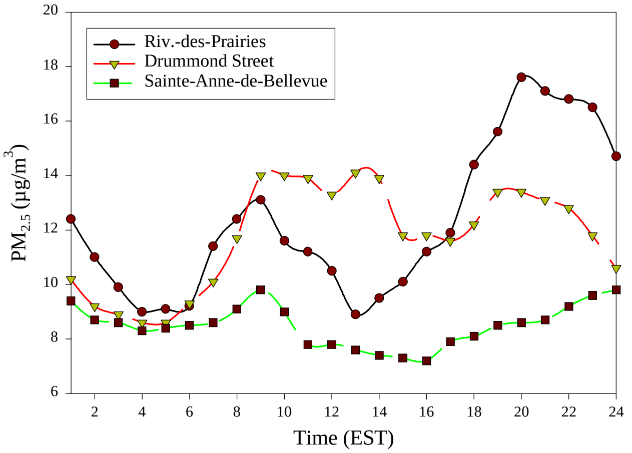


Figure 3.3.3: Mean hourly $PM_{2.5}$ concentrations on weekdays (excluding holidays) at different sites in the Montreal area during the winter of 1998-99

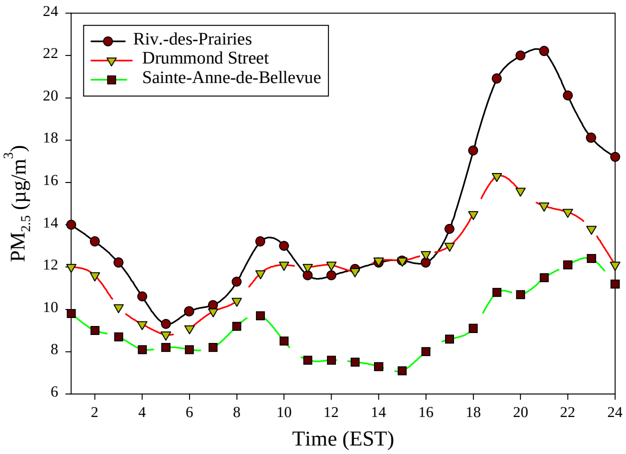


Figure 3.3.4: Mean hourly $PM_{2.5}$ concentrations on weekends and holidays at different sites in the Montreal area during the winter of 1998-99

A comparison of figures 3.3.3 and 3.3.4 shows that there is a difference in hourly behaviour at the stations. At SAB, values were relatively stable during the day but, during the evening, concentrations were higher on weekends by 2-3 µg/m^3. At the Drummond Street station, a significant difference in behaviour occurred in the morning and afternoon. In the early morning, fine particulate matter concentrations were significantly lower on weekends (2 µg/m^3 less during weekends). The same difference was observed throughout the afternoon. In the late afternoon and early evening, values increased at the Drummond Street station, but the increase was much more significant on weekends than during weekdays, and higher values were found on weekends. Similarly, at the RDP station, hourly behaviour differed during the week and on weekends. The most significant differences occurred in late morning and in the afternoon: during the weekend, particulate matter concentrations remained stable at close to 12 µg/m^3 instead of decreasing as they did during the week. Therefore, despite the increase in the mixing capacity of the lower atmosphere in the afternoon, concentrations remained fairly stable, indicating an increase in emission levels at the RDP station during the weekend. This increase was not recorded at the other stations, which leads one to suspect that local emission sources were responsible. With sunset and dropping temperatures, the height of the mixing layer also decreases, leading to a rapid increase in concentrations in the late afternoon and early evening. Values of 22.2 µg/m^3 occurred around 9:00 pm during the weekend, which was 5.1 µg/m^3 higher than on weekdays, representing a 34% increase over concentrations measured at the same time on weekdays.

3.3.4 Relation with wind speed and direction

Figure 3.3.5 shows the distribution of the frequency of occurrence of certain levels of particulate matter concentrations according to wind direction. Levels were chosen by selecting the closest integers to the following percentiles: 50%, 75%, 85%, 90% and 98%, which correspond to the following concentrations: 10, 15, 20, 25 and 50 µg/m^3. The length of the segment determined the probability of occurrence of the level for a given wind direction. According to the figure, the frequency of occurrence of west-south-west winds was 20.2% at the RDP station. Out of this percentage (corresponding to the total length of the segment), 10.2% of concentrations were below 10 µg/m^3, 5.2% were between 10 and 15 µg/m^3, 2.6% between 15 and 20 µg/m^3, 1.0% between 20 and 25 µg/m^3, 1.3% between 25 and 50 µg/m^3 and 0% over 50 µg/m^3. Table 3.3.3 summarizes the distribution of frequency of occurrence by wind direction. Note that during the winter of 1998-99, 9.5% of hourly values were greater than 25 µg/m^3. The wind directions most likely to lead to $PM_{2.5}$ concentrations over 25 µg/m^3 are northeast and west-south-west. Figure 3.3.6 shows mean $PM_{2.5}$ concentrations at the RDP station according to wind direction. East to southeast winds were associated with very high concentrations. Locally, east to southeast winds come from the direction of residential neighbourhoods. Southeast winds are also associated with Montreal's petrochemical industry, located around 5 km from the station. Caution must be exercised in interpreting these data, however, since these wind directions occur infrequently at the station (2.7%).

Winds from the west to the west north-west are generally associated with lower particulate matter concentrations than winds from other directions. These winds come from local green space near the station and further away, from Laval and the lower Laurentians to the west. Winds from the north north-east to the east north-east occurred close to 30% of the time and were also associated with high $PM_{2.5}$ concentrations. Upwind areas in this case consist of residential neighbourhoods.

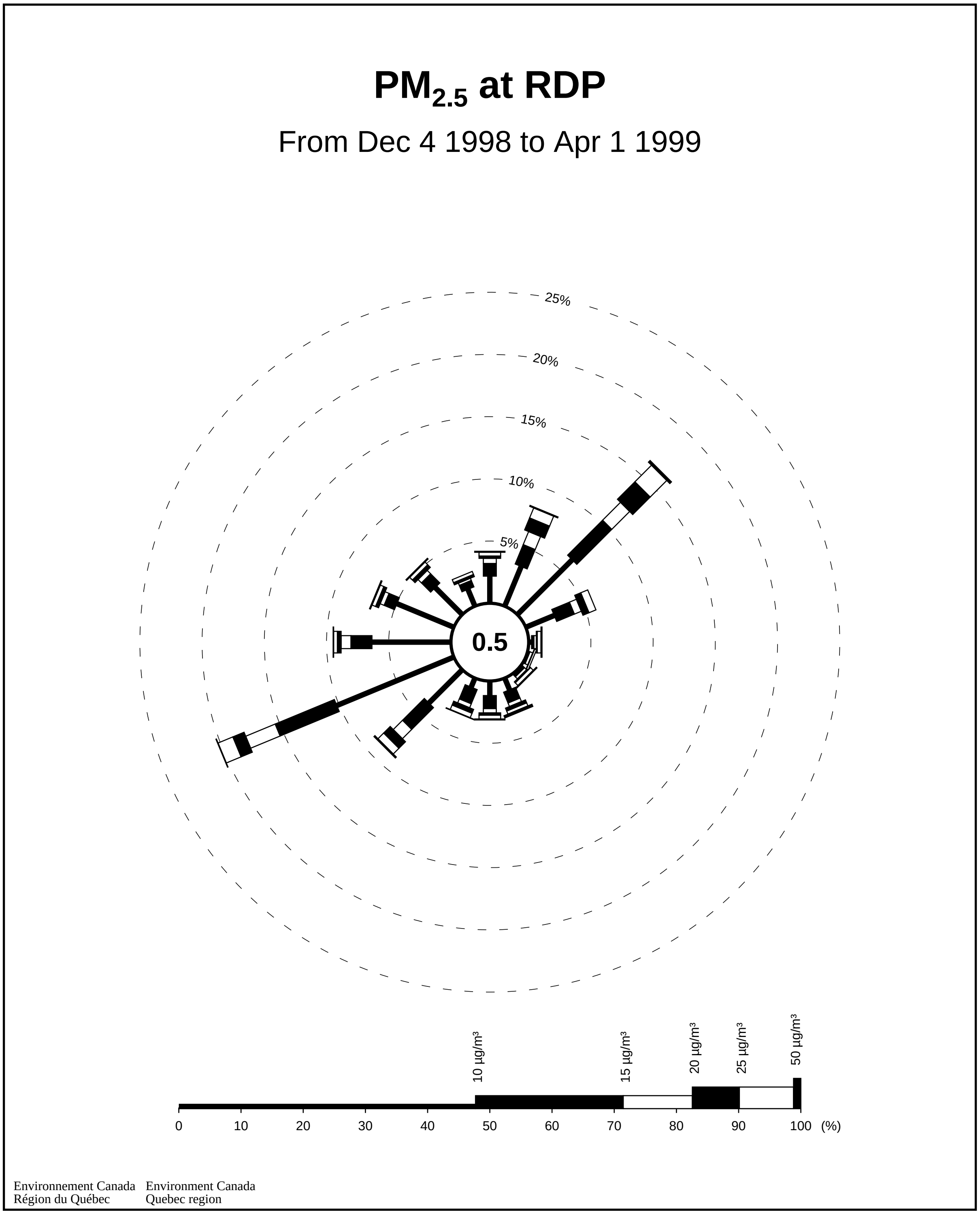
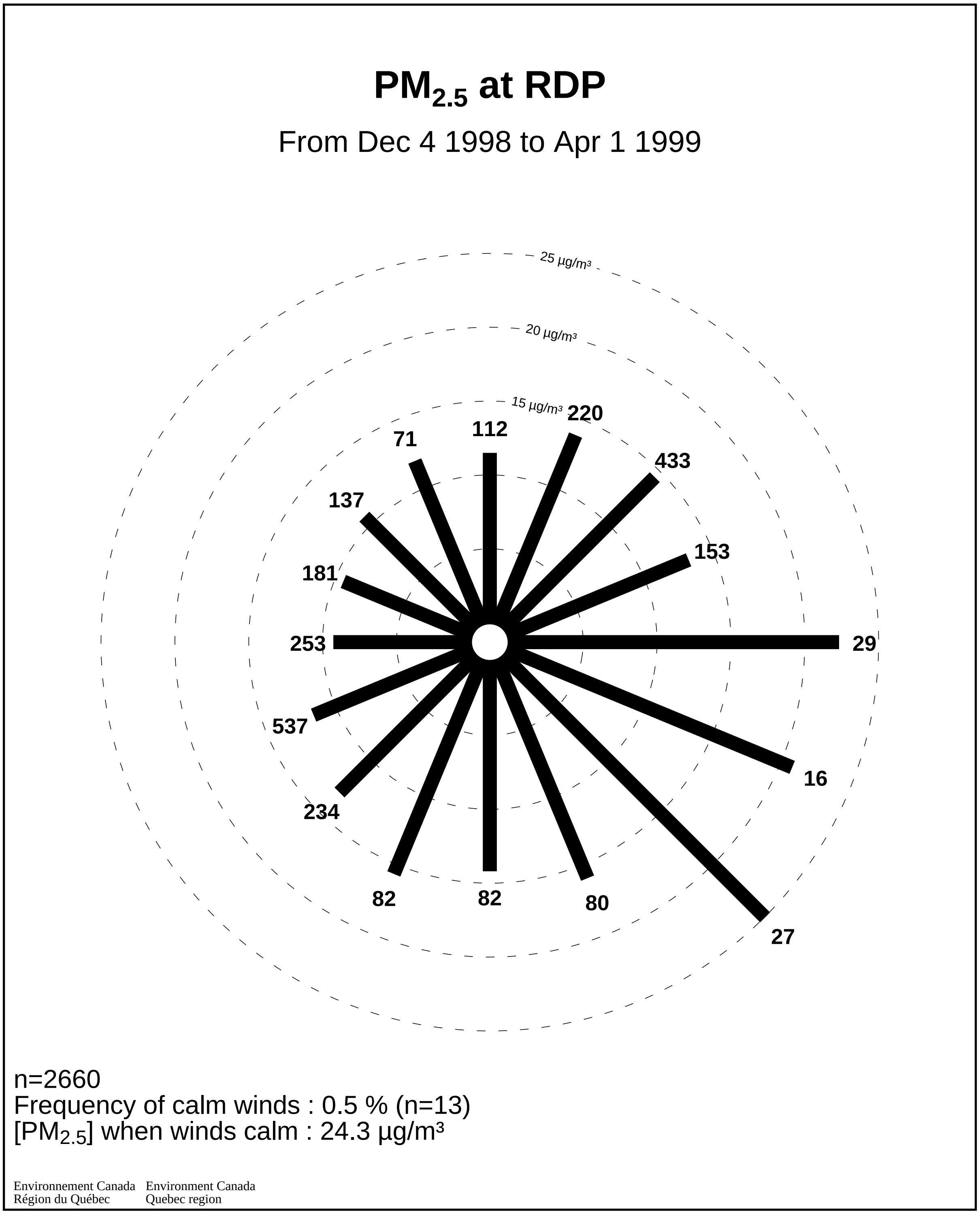


Figure 3.3.5: Frequency of occurrence of certain $PM_{2.5}$ threshold values as a function of wind direction at the RDP station during the winter of 1998-99



PM$_{2.5}$ at RDP

From Dec 4 1998 to Apr 1 1999

n=2660
Frequency of calm winds : 0.5 % (n=13)
[PM$_{2.5}$] when winds calm : 24.3 µg/m³

Environnement Canada
Région du Québec

Environment Canada
Quebec region

Figure 3.3.6: Mean PM$_{2.5}$ concentrations in µg/m^3 by wind direction at the RDP station during the winter of 1998-99

Wind speed is closely linked to the transport of pollutants and their horizontal and vertical dispersion in the atmosphere. Therefore, a negative correlation between PM$_{2.5}$ concentrations measured at a particular station and wind speed can be expected. During the winter of 1998-99, this hypothesis proved to be true for the RDP station. A correlation coefficient of -0.48 was calculated for these two parameters (Figure 3.3.7). In general, the greater the wind speed, the greater the decrease in particulate matter concentrations. This relation was more pronounced during the day than at night, as Figure 3.3.8 shows. During periods of calm winds (wind speed below 1 km/h), fine particulate matter concentrations reached 24.3 µg/m^3.

Table 3.3.3: Frequency distribution (in %) of different PM$_{2.5}$ concentrations (µg/m^3) as a function of wind direction at the Rivière-des-Prairies station during the winter of 1998-99

Total number of observations : 2660 Frequency of calm winds : 0,5 %. [PM$_{2.5}$] with calm winds : 24,3 µg/m^3

Threshold	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	N	%
0-10	3,5	6,2	2,5	0,2	0,1	0,1	1,0	1,2	0,8	3,8	10,2	6,4	5,0	3,1	1,5	2,2	47,6
10-15	1,7	4,0	1,5	0,2	0,1	0,2	0,9	1,1	1,2	2,5	5,2	1,7	0,9	1,1	0,6	1,0	23,8
15-20	1,1	2,0	0,6	0,2	0,2	0,2	0,3	0,3	0,3	1,1	2,6	0,8	0,3	0,4	0,2	0,4	11,1
20-25	1,1	2,0	0,5	0,1	0,0	0,1	0,3	0,2	0,3	0,8	1,0	0,3	0,3	0,3	0,2	0,2	7,6
25-50	0,9	1,9	0,6	0,3	0,2	0,3	0,3	0,3	0,4	0,6	1,3	0,3	0,3	0,3	0,3	0,3	8,4
50 +	0,1	0,2	0,0	0,1	0,0	0,1	0,2	0,1	0,0	0,1	0,0	0,0	0,1	0,1	0,0	0,1	1,1
%	8,3	16,3	5,8	1,1	0,6	1,0	3,0	3,1	3,1	8,8	20,2	9,5	6,8	5,2	2,7	4,2	100,0

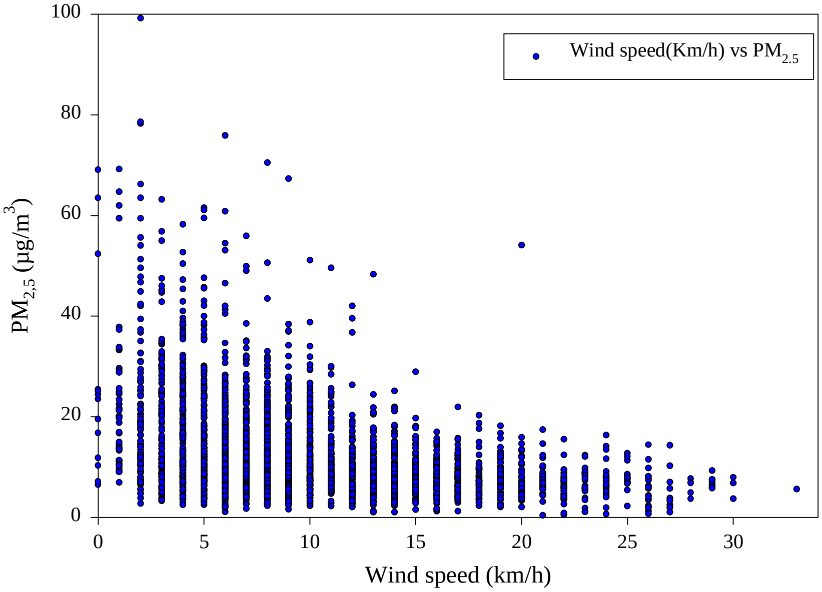


Figure 3.3.7: PM$_{2.5}$ concentrations (µg/m^3) as a function of wind speed (in km/h) recorded at the Rivière-des-Prairies station during the winter of 1998-99

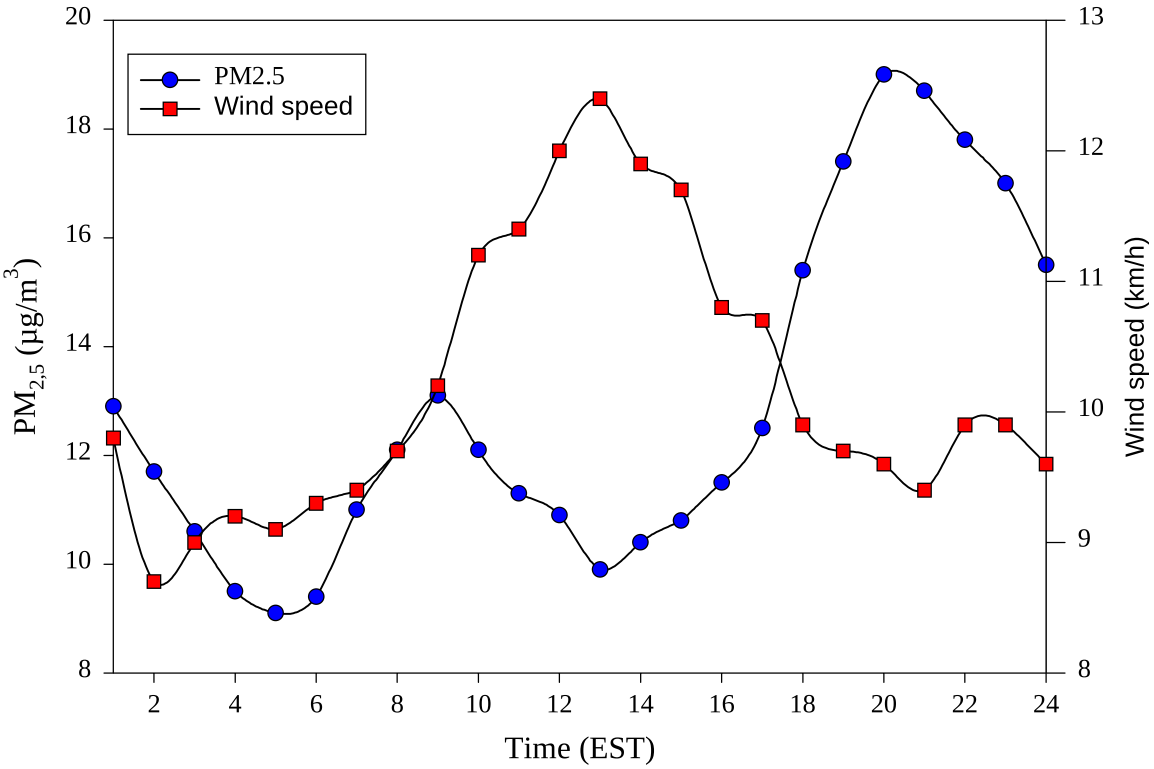


Figure 3.3.8: $PM_{2.5}$ concentrations (µg/m^3) as a function of hourly mean values for wind speed (in km/h) recorded at the Rivière-des-Prairies station during the winter of 1998-99

3.3.5 Relation with visibility

Horizontal visibility was measured at the RDP station in the same way as it is measured at the Aéroport international de Montréal (Montreal-Dorval airport). The amount of fine particulate matter in the atmosphere is thought to affect visibility and this study allowed this hypothesis to be validated in an environment with significant residential wood heating sources. Figure 3.3.9 shows the distribution of particulate matter concentrations as a function of horizontal visibility. This distribution is similar to that obtained for $PM_{2.5}$ and wind speed. The greater the concentration of particulate matter, the lower the visibility. A Spearman correlation coefficient of -0.53 was obtained for these two parameters.

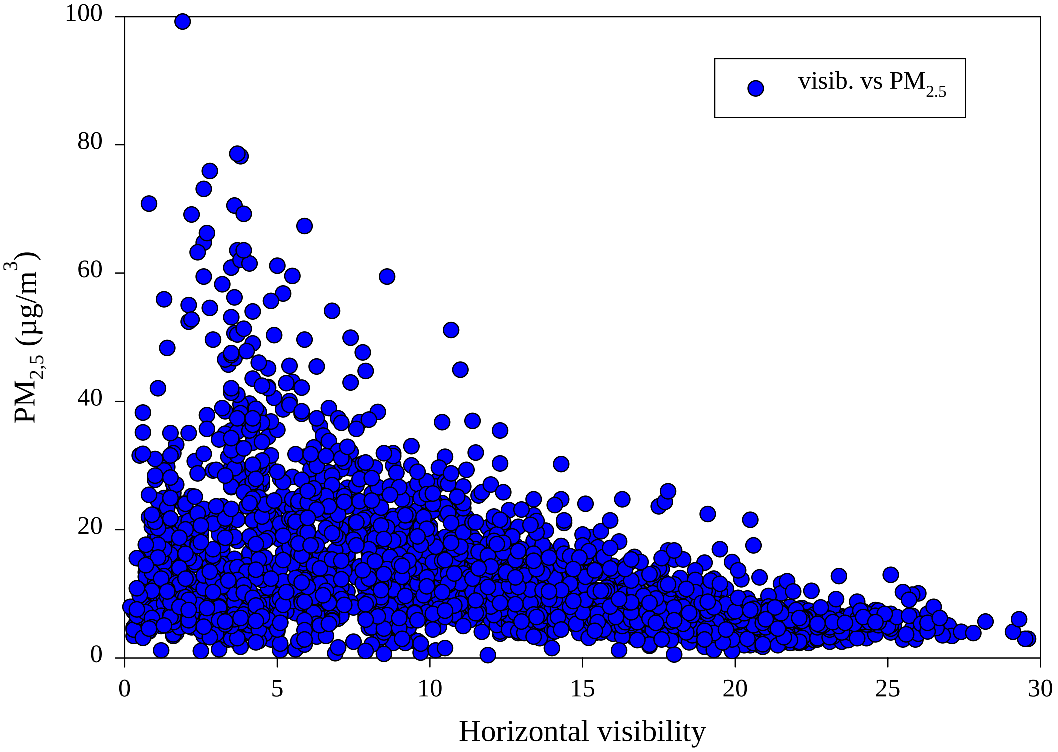


Figure 3.3.9: Horizontal visibility (in km) as a function of $PM_{2.5}$ concentrations ($\mu g/m_3$) recorded at the Rivière-des-Prairies station during the winter of 1998-99.

3.3.6 Comparison with $PM_{2.5}$ values measured with the dichotomous sampler

The 24-hour arithmetic mean (from midnight to midnight) for fine particulate matter was obtained by comparing $PM_{2.5}$ values measured with the TEOM with values measured with the dichotomous sampler (Figure 3.3.10). A considerable difference was found between the two sets of measurements, even though the corresponding Spearman coefficient was 0.897. Despite the very small sample used in the comparison (21), an attempt can be made to compare the two methods statistically. The mean for the 2.5-µm particle fraction obtained with the dichotomous sampler was 16.75 $\mu g/m^3$, compared with 10.17 mg/m^3 for the TEOM; therefore, the mean value obtained with the TEOM represented 60.7% of the mean value obtained with the dichotomous sampler. A similar difference between the two methods has been documented by Moore and Barthelmie (1995). Using 1000 pairs of data, these authors demonstrated that, during periods of high wood combustion, a TEOM equipped with a 10-µm sampling head underestimated by 14% the values obtained with a conventional filter. The percentage was 6% under other conditions. These results suggest that, due to volatilization, greater losses of semivolatile materials occur during periods of biomass combustion. According to Meyer et al. (1992), part of this volatilization may be caused by the TEOM's sampling temperature (40°C in the winter).

Rupprecht and Patashnick (1993) recommend that, in environments with large amounts of volatile organic compounds (environments strongly affected by wood heating, for example), the sampling temperature be decreased to close to 30°C to prevent some of this volatilization.

An examination of Figure 3.3.10 shows that the greatest difference between the two curves occurs in the middle of the graph, which corresponds to the coldest period. Due to the small size of the sample, no conclusions could be drawn on the effects of the sampling temperature, the difference between the outside temperature and the instrument temperature and the filter load on the discrepancy between the results obtained with the two methods.

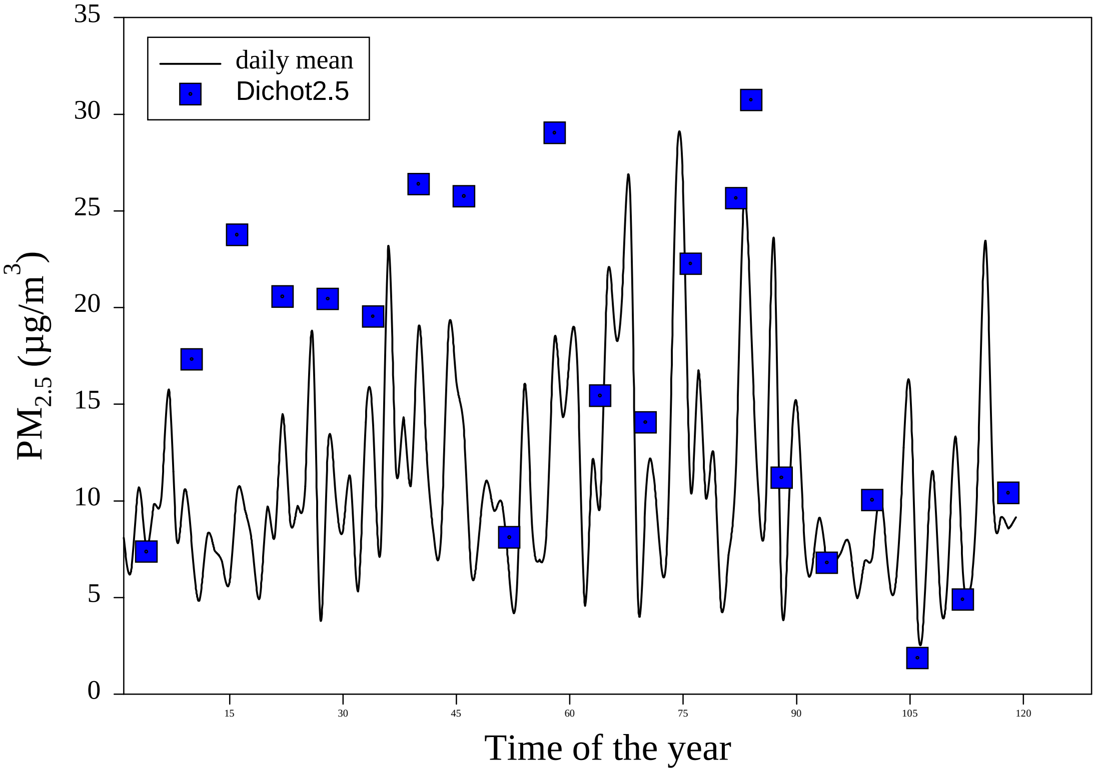


Figure 3.3.10: Comparison between daily $PM_{2.5}$ values measured with the TEOM and dichotomous sampler at the Rivière-des-Prairies station during the winter of 1998-99

Figure 3.3.11 shows the regression line corresponding to the relation between the two sampling methods, which is expressed in the following form:

$$\text{TEOM} = 0.47\ \text{Dichot} + 2.73\ \mu g/m^3 \qquad \text{Equation (2)}$$

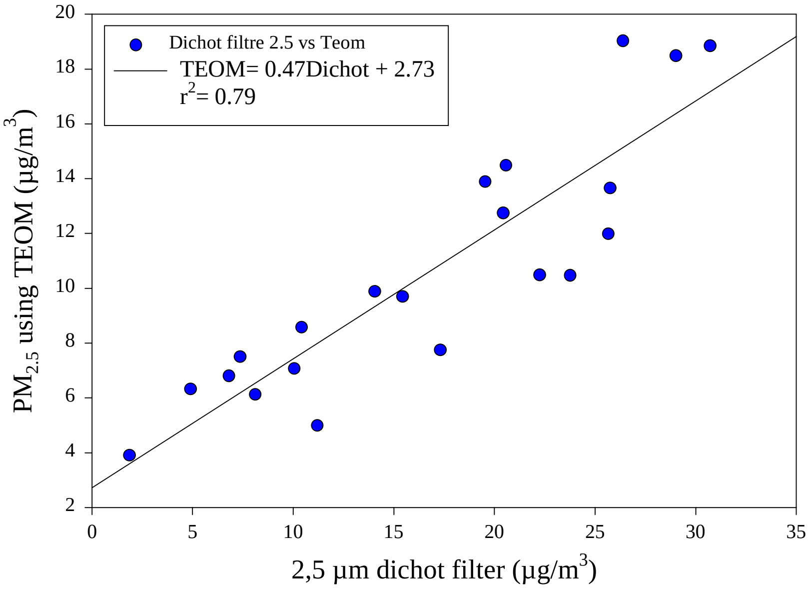


Figure 3.3.11: Relation between $PM_{2.5}$ values obtained with the TEOM and those obtained with the dichotomous sampler at the Rivière-des-Prairies station during the winter of 1998-99

3.3.7 Quantification of local contributions of fine particulate matter

One of the primary objectives of the study was to characterize the contribution from residential wood heating to air quality in a residential neighbourhood. The results of the sampling program carried out in the winter of 1998-99 allow preliminary estimates of the increase in fine particulate matter caused by biomass combustion to be made.

On the basis of TEOM values, fine particulate matter values were an estimated 24% higher at the RDP station than at the downtown Montreal station (Drummond Street) and 74.3% higher than at Sainte-Anne-de-Bellevue. These estimates do not take account of the much greater mass losses that occurred in the TEOM filter at Rivière-des-Prairies, in an environment rich in semivolatile particles. By applying a correction factor to concentrations obtained with the TEOM filter that takes account of the mean volatilization rate of 14% (Moore and Barthelmie 1995) during a period of wood burning at the reference sites, the Drummond Street and Sainte-Anne-de-Bellevue stations, and of 39.3 % (see Section 3.3.6) at the RDP station, the following relation is obtained:

$$[PM_{2.5}]C = [PM_{2.5}]mes + f[PM_{2.5}]mes \qquad \text{Equation (3)}$$

where: $[PM_{2.5}]C$ is the $PM_{2.5}$ concentration corrected for volatilization
$[PM_{2.5}]mes$ is the $PM_{2.5}$ concentration measured at the station with the TEOM
f is the correction factor used

Table 3.3.4 shows the results of the application of the correction factor to $PM_{2.5}$ measurements obtained with the TEOM to account for volatilization.

Table 3.3.4: Results of correction for underestimation of total mass of fine particulate matter by the TEOM

	Drummond	**RDP**	**SAB**
Daily $PM_{2.5}$ estimated with TEOM	10.4**	10.17 *	7.4**
Correction factor	0.14	0.393	0.14
Corrected $PM_{2.5}$	12.09	16.75	8.44

* Represent the $PM_{2.5}$ daily mean (µg/m^3) measured with TEOM for days where sampling was also done with dichotomous sampler

** Represent the daily mean value for winter 1998-1999.

The application of the correction factor allows values from the different CUM measurement stations to be compared more realistically. Particulate matter values at the RDP station were 1.98 times higher than at the Sainte-Anne-de-Bellevue (SAB) station, which is in a semi-rural area, and 1.39 times higher than at the Drummond Street station, where the main source of $PM_{2.5}$ is vehicle emissions. Therefore, an estimated 38.5% increase occurs in particulate matter levels at RDP compared with those at Drummond Street and an estimated 99.6% increase compared with those at SAB. The 38.5% increase over the Drummond Street station represents the minimum contribution from local sources to increased levels of fine particulate matter in the ambient air at RDP. The 99.6% increase with respect to the SAB station represents the maximum contribution since SAB is not affected by significant local sources and therefore represents background $PM_{2.5}$ levels for the Island of Montreal.

3.4. Comparison between 24-hour PAH and PM values

3.4.1. Continuous measurements

Table 3.4.1 shows various statistical parameters related to continuous measurements of PAH and $PM_{2.5}$ levels at Rivière-des-Prairies. Since the distribution of the data did not meet the criteria for a normal distribution, the geometric mean was used. The geometric mean for PAHs was 40.0 ng/m^3 and for $PM_{2.5}$, 10.2 µg/m^3. The maximum PAH value was five times the value of the 90th percentile and the maximum particulate matter value was four times the value of this percentile.

Table 3.4.1: Distribution of PAH and $PM_{2.5}$ values measured at Rivière-des-Prairies with continuous analyzer

	PAH ng/m^3	$PM_{2.5}$ µg/m^3	PAH/$PM_{2.5}$
Arithmetic mean	445.62	12.90	0.005
Geometric mean	239.88	10.18	0.004
Distribution in centile			
Minimum (0)	5.60	0.40	0
25	103.625	6.5	0.002
Median (50)	247.4	9.9	0.004
75	515.1	15.9	0.007
90	1071.4	24.7	0.010
95	1508.85	31.5	0.012
98	2450.52	44.7	0.015
Maximum (100)	5069.8	99.2	0.064

3.4.2. Comparison of PAHs and fine particulate matter

The relation between PM_{10} and PAHs measured with the modified high-volume sampler was analyzed. A fairly strong relation was found between both total and particulate PAHs (PAHs with a molecular weight greater than or equal to that of fluoranthene) and PM_{10} (Figure 3.4.1). The correlation coefficients calculated were similar, whether for total PAHs and PM_{10} (r: 0.84; $p<0.01$) or for particulate PAHs and PM_{10} (r: 0.80; $p<0.01$).

A fairly strong relation was also found between the two categories of PAHs and $PM_{2.5}$, with correlation coefficients of 0.76 and 0.74 ($p<0.01$) respectively (Figure 3.4.2). Overall, both total and particulate PAHs were found to be correlated with fine particulate matter (PM_{10} and $PM_{2.5}$). Two thirds (68%) of fine particles measured at the RDP station had an aerodynamic diameter of less than 2.5 µm.

The contribution of particulate PAHs less than 1 µm in diameter to the total mass of $PM_{2.5}$ was negligible (Table 3.4.1), close to 0.5% on average. The proportion of PAHs to $PM_{2.5}$ was greatest in January, with a mean of 0.7%, and lowest in March, with a mean of 0.3%. The hourly behaviour of this proportion was similar to that of $PM_{2.5}$. The proportion reached a maximum value of 0.84% around 10:00 pm and a minimum value of 0.27% in the early morning around 5:00 am. Behaviour of the proportion on weekdays versus weekends was also similar to that of $PM_{2.5}$.

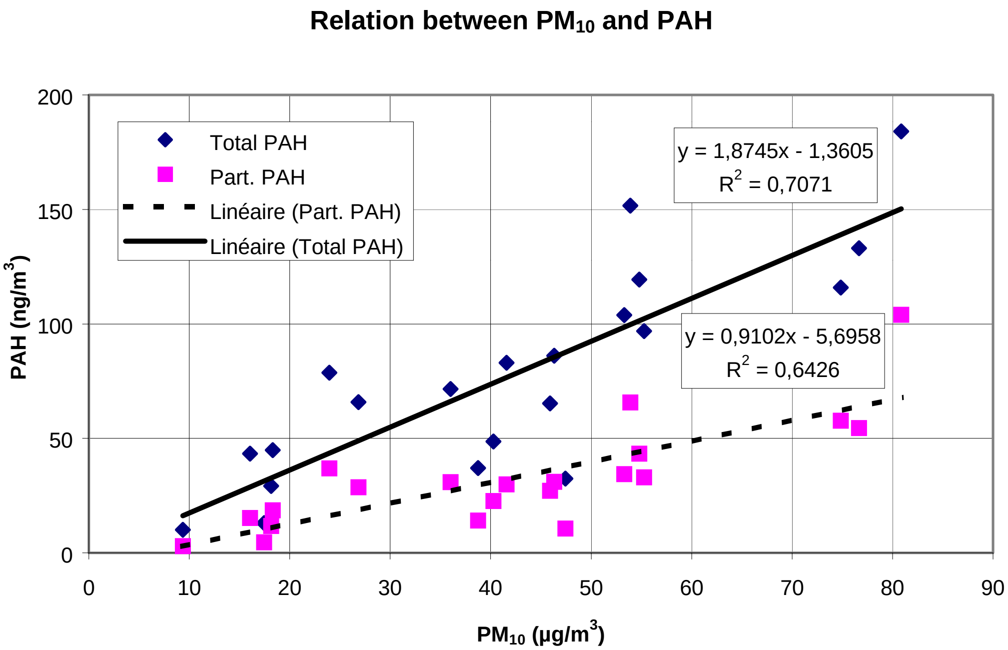


Figure 3.4.1: Relation between total and particulate PAHs measured with the modified high-volume sampler and PM_{10} measured with the dichotomous sampler

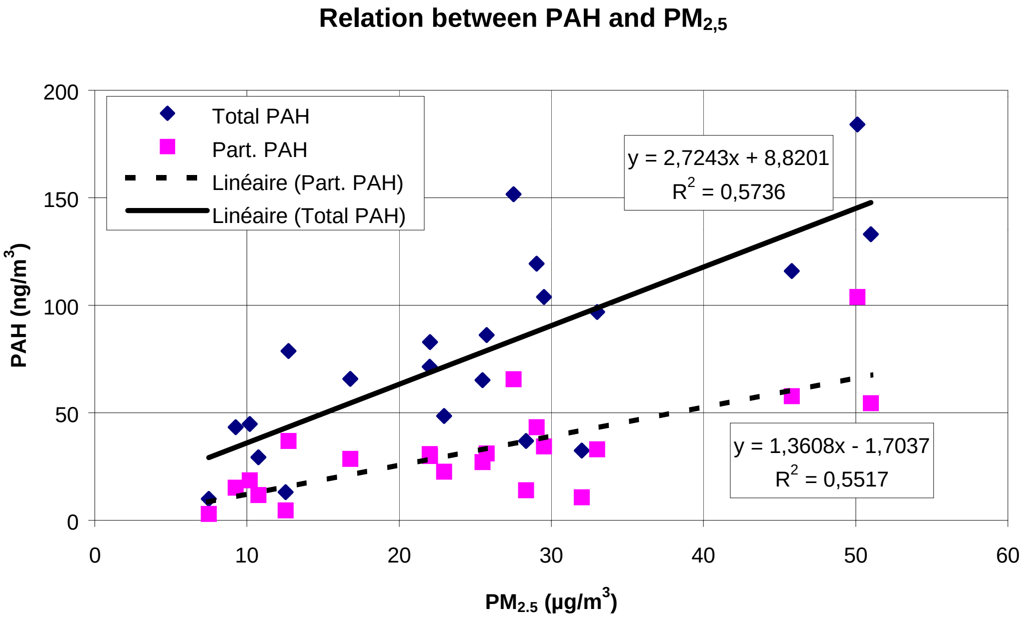


Figure 3.4.2: Relation between total and particulate PAHs measured with the modified high-volume sampler and $PM_{2.5}$ measured with the dichotomous sampler

3.5. Metals

A total of 47 different elements were analyzed in the fine ($PM_{2.5}$) and coarse ($PM_{2.5}$ to PM_{10}) fractions of the samples obtained from the dichotomous samplers at the Rivière-des-Prairies, Anjou and Ontario Street (reference site) stations. Since potassium is one of the trace elements found in atmospheric emissions of particulate matter from wood combustion, we concentrated on potassium and the potassium/iron ratio (K/Fe), particularly in the fine particle fraction (FPWG 1997).

Mean potassium concentrations of 0.137 µg/m^3 were obtained at RDP, based on 21 samples of fine particulate matter taken at the station from December 1998 to March 1999. This mean was 52% to 92% higher than values obtained at the Anjou (0.090 µg/m^3) and Ontario Street (0.071 µg/m^3) stations during the corresponding period (Table 3.5.1). In addition, mean potassium concentrations in the fine particle fraction at the RDP station were roughly 70% higher than in the coarse particle fraction (Table 3.5.2). This strongly suggests the presence of a local source of fine particulate matter containing potassium, typical of wood burning emissions.

The analysis of the K/Fe ratio was also very revealing. As Table 3.5.1 shows, the K/Fe ratio in the fine particle fraction at the Rivière-des-Prairies station (K/Fe=4.88) was twice as high as the ratios measured at the stations in Anjou (K/Fe=2.14) and on Ontario Street (K/Fe=2.22). The high value of the K/Fe ratio in the fine fraction at Rivière-des-Prairies is characteristic (and indicative) of the presence of a wood combustion source. In addition, the correlation coefficient for potassium and iron concentrations, which was lower in the fine fraction than in the coarse fraction, indicates that the source of the two elements in the fine and coarse fractions is different. An analysis of values limited to the 16 days when sampling was carried out at both the RDP and Ontario Street stations shows an even greater difference, with a K/Fe ratio of 5.22 at RDP compared with 2.30 at the reference site on Ontario Street (Table 3.5.3).

Table 3.5.1: Results for the potassium/iron ratio in the fine particle fraction

Station	Number of samples	Mean concentrations (µg/m^3)		Ratio K/Fe	Correlation (K/Fe)
		K	Fe		
RDP	21	0.137	0.052	4.875	0.739
Ontario street	17	0.071	0.043	2.220	0.706
Anjou	12	0.090	0.057	2.135	0.329

Table 3.5.2: Results for the potassium/iron ratio in the coarse particle fraction

Station	Number of samples	Mean concentrations (µg/m^3)		Ratio K/Fe	Correlation (K/Fe)
		K	Fe		
RDP	21	0.080	0.13	0.556	0.893
Ontario street	17	0.070	0.82	0.388	0.926
Anjou	12	0.109	0.253	0.449	0.963

Table 3.5.3: Results for the potassium/iron ratio on the same sampling days

Station	Type of particle	Mean concentrations (µg/m^3)		Ratio K/Fe	Correlation (K/Fe)
		K	Fe		
RDP	Fine	0.126	0.046	5.223	0.728
	Coarse	0.086	0.198	0.540	0.874
Ontatio street	Fine	0.074	0.044	2.302	0.704
	Coarse	0.072	0.187	0.393	0.923

Corrected potassium (K') concentrations can be obtained by systematically subtracting from the total the "normal" proportion of potassium found in typical urban dust in the study area. This is done by applying the following relation:

$$[K'] = [K] - 0.556 [Fe] \qquad \text{Equation (4)}$$

where K and Fe are potassium and iron concentrations expressed in µg/m^3 in the fine particle fraction of each sample and the factor 0.556 is the mean K/Fe ratio in the coarse particle fraction at the Rivière-des-Prairies station, which is representative of the ratio of urban dust. The corrected potassium concentration [K'] is 0.108 µg/m^3, resulting in a correlation coefficient of only 0.21 for K' and Fe. This clearly shows that the source of potassium in the fine particle fraction is not normal urban dust. These results are similar to those obtained by Lewis et al. (1988).

Lastly, Figure 3.5.1 shows the daily variations in the K/Fe ratio at the three sampling stations. It clearly shows that the value of the ratio is consistently greater at the Rivière-des-Prairies station than at the other two stations.

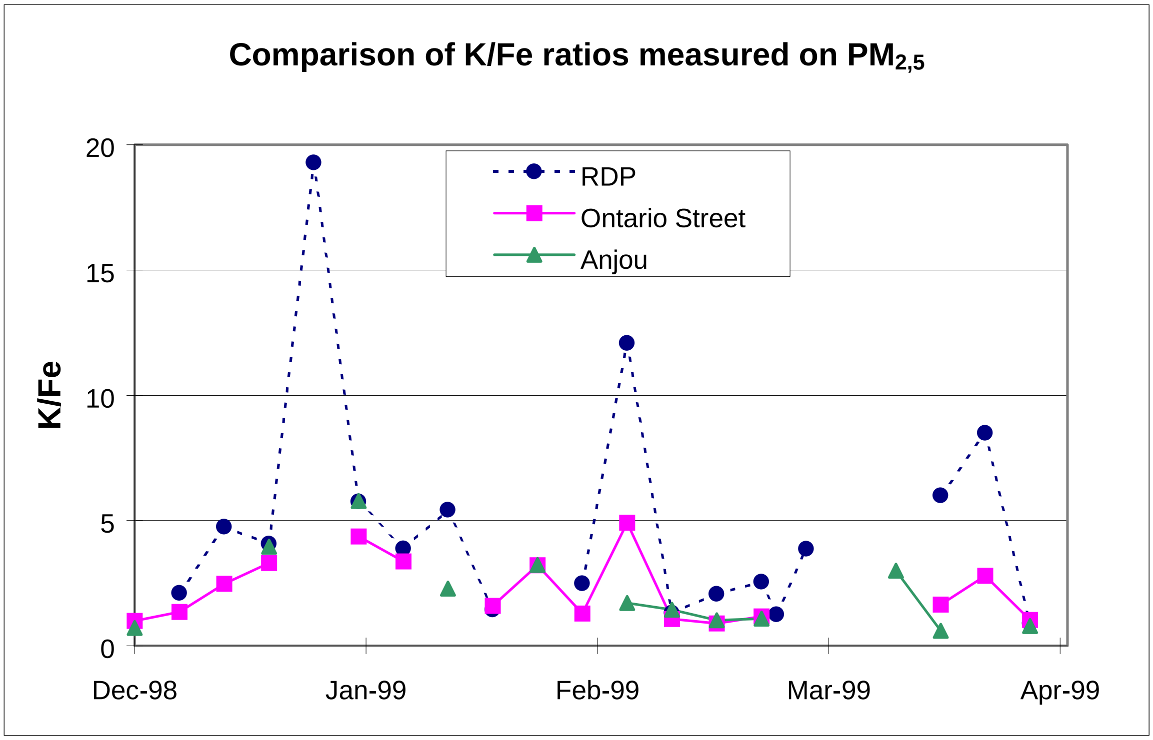


Figure 3.5.1: Daily variations in K/Fe ratio in $PM_{2.5}$

3.6. Volatile organic compounds (VOCs)

Polar and nonpolar VOC concentrations in the ambient air were measured concurrently at the RDP and Ontario Street (control) stations from 24-hour samples taken every six days.

3.6.1. Nonpolar VOCs

Samples and analyses of nonpolar VOCs were carried out at the Rivière-des-Prairies station by MUC personnel in accordance with EPA method TO-17 (USEPA 1999b). A total of 49 different compounds were analyzed in 15 samples taken between December 25, 1998 and March 19, 1999. Table 3.6.1 summarizes the overall results, and the complete dataset is found in Appendix 3.

At the reference site, sampling and analyses were done in accordance with EPA method TO-14 (USEPA 1999c), with analyses carried out by the laboratory at Environment Canada. A total of 152 VOCs were analyzed in 21 samples taken between December 1, 1998 and March 31, 1999. The complete results are provided in Appendix 3 and summarized in Table 3.6.2.

A comparative analysis of the compounds analyzed in both methods allowed the arithmetic means of 31 VOCs to be compared (Table 3.6.3). The table clearly shows that the mean concentrations were extremely similar for almost all compounds. Given the accuracy of both of the methods, no significant differences were observed between the two sites. Only dibromochloromethane had a mean value (0.26 µg/m^3) that was significantly higher at the RDP station than the Ontario Street station (0.02 µg/m^3); no explanation has been found for this significant difference. Concentrations of VOCs associated with vehicle emissions, such as xylenes and substitute benzenes, were generally higher at the Ontario Street station, showing that the Rivière-des-Prairies site is less affected by vehicle emissions. Previous studies have shown that wood combustion does not appear to emit specific nonpolar VOCs in sufficiently high concentrations for these VOCs to be a marker of sectors influenced by wood burning such as Rivière-des-Prairies (GRVD 1998).

Table 3.6.1: Synthesis of results for nonpolar VOCs at the Rivière-des-Prairies station from December 25, 1998 to March 19, 1999 (method TO-17)

Non-polar VOC* (µg/m^3)	n	Mean	Standard deviationσ	Minimum	Maximum
Trichlorofluoromethane	15	1.75	1.62	0.05	6.40
1,1-Dichloroethene	0	< L.D.	< L.D.	< L.D.	0.00
Dichloromethane	15	1.07	1.27	0.14	4.20
trans-1,2-Dichloroethene	0	< L.D.	< L.D.	< L.D.	
1,1-Dichloroethane	0	< L.D.	< L.D.	< L.D.	
cis-1,2-Dichloroethene	0	< L.D.	< L.D.	< L.D.	
2,2-Dichloropropane	0	< L.D.	< L.D.	< L.D.	
Trichloromethane	15	0.20	0.19	0.05	0.55
Bromochloromethane	0	< L.D.	< L.D.	< L.D.	0.00
1,1,1-Trichloroethane	15	0.44	0.10	0.32	0.65
1,2-Dichloroethane	15	0.03	0.01	0.03	0.06
1,1-Dichloropropene	15	0.06	0.04	0.03	0.19
Tetrachloromethane	15	0.55	0.11	0.43	0.81
Benzene	15	2.60	1.33	0.70	5.26
Trichloroethene	15	0.19	0.14	0.05	0.42
1,2-Dichloropropane	0	< L.D.	< L.D.	< L.D.	
Dibromomethane	0	< L.D.	< L.D.	< L.D.	
Bromodichloromethane	0	< L.D.	< L.D.	< L.D.	
cis-1,3-Dichloropropene	13	0.03	0.01	0.03	0.06
trans-1,3-Dichloropropene	15	0.13	0.09	0.05	0.26
Toluene	15	7.57	4.13	1.53	14.89
1,1,2-Trichloroethane	15	0.18	0.11	0.05	0.39
1,3-Dichloropropane	0	< L.D.	< L.D.	< L.D.	0.00
Dibromochloromethane	15	0.26	0.20	0.05	0.71
Tetrachloroethene	15	0.40	0.28	0.12	1.05
1,2-Dibromoethane	0	< L.D.	< L.D.	< L.D.	
Chlorobenzene	0	< L.D.	< L.D.	< L.D.	
1,1,1,2-Tetrachloroethane	0	< L.D.	< L.D.	< L.D.	
Ethylbenzene	15	0.90	0.48	0.24	1.76
m+p-Xylene	15	2.51	1.23	0.99	4.89
Styrene	15	0.20	0.15	0.05	0.59
o-Xylene	15	1.12	0.60	0.30	2.27
Tribromomethane	0	< L.D.	< L.D.	< L.D.	
1,1,2,2-Tetrachloroethane	0	< L.D.	< L.D.	< L.D.	
Isopropylbenzene	15	0.05	0.03	0.03	0.09
1,2,3-Trichloropropane	15	0.09	0.07	0.03	0.21
Bromobenzene	0	< L.D.	< L.D.	< L.D.	
n-Propylbenzene	15	0.20	0.10	0.06	0.34
2-Chlorotoluene	15	0.06	0.05	0.03	0.21
4-Chlorotoluene	15	0.04	0.02	0.03	0.08
1,3,5-Trimethylbenzene	15	0.19	0.12	0.03	0.37
tert-Butylbenzene	15	0.09	0.08	0.03	0.26
1,2,4-Trimethylbenzene	15	0.76	0.33	0.32	1.28
sec-Butylbenzene	0	< L.D.	< L.D.	< L.D.	
1,3-Dichlorobenzene	15	0.11	0.07	0.03	0.25
4-Isopropyltoluene	15	0.04	0.03	0.03	0.12
1,4-Dichlorobenzene	15	0.18	0.13	0.03	0.54
1,2-Dichlorobenzene	0	< L.D.	< L.D.	< L.D.	
n-Butylbenzene	15	0.04	0.03	0.03	0.15

* : Analyzed at the CUM with method TO-17 from U.S. EPA (1999b)   n : number of values greather than the limit of detection

Table 3.6.2: Synthesis of results for nonpolar VOCs at the reference site (Ontario street) from December 1, 1998 to March 31, 1999 (method TO-14)

Non-polar VOC compound (ug/m^3)	n	Mean	Standard deviation	Minimum	Maximum
Ethane	21	4.767	0.953	2.662	6.790
Ethylene	21	5.844	2.843	1.691	10.645
Acetylene	21	3.126	1.342	1.011	5.265
Propylene	21	1.845	0.993	0.432	4.218
Propane	21	4.933	2.212	2.230	10.074
1-Propyne	10	0.216	0.058	0.140	0.290
Isobutane	21	7.677	3.594	2.230	12.590
1-Butene/Isobutene	21	0.897	0.383	0.336	1.704
1,3-Butadiene	21	0.318	0.128	0.088	0.554
Butane	21	9.499	4.441	3.028	17.572
trans-2-Butene	21	0.519	0.228	0.156	0.880
2,2-Dimethylpropane	21	0.049	0.019	0.000	0.076
1-Butyne	21	<L.D.	<L.D.	<L.D.	
cis-2-Butene	21	0.511	0.230	0.132	0.830
Isopentane	21	6.800	2.640	2.636	11.302
1-Pentene	21	0.288	0.110	0.114	0.460
2-Methyl-1-Pentene	0	<L.D.	<L.D.	<L.D.	
2-Methyl-1-butene	21	0.024	0.042	0.000	0.128
Pentane	21	3.073	1.132	1.286	5.022
Isoprene	17	0.030	0.051	0.000	0.150
trans-2-Pentene	21	0.084	0.095	0.000	0.280
cis-2-Pentene	21	0.382	0.161	0.146	0.602
2-Methyl-2-butene	21	0.077	0.082	0.000	0.260
2,2-Dimethylbutane	21	0.487	0.165	0.216	0.807
Cyclopentene	21	0.091	0.033	0.040	0.150
4-Methyl-1-pentene	21	0.003	0.015	0.000	0.070
3-Methyl-1-pentene	21	0.005	0.016	0.000	0.060
Cyclopentane	21	0.204	0.243	0.000	0.736
2,3-Dimethylbutane	21	0.527	0.194	0.222	0.842
trans-4-Methyl-2-pentene	21	0.137	0.152	0.000	0.522
2-Methylpentane	21	2.174	0.820	0.880	3.428
cis-4-Methyl-2-pentene	21	0.173	0.070	0.000	0.264
3-Methylpentane	21	1.422	0.524	0.580	2.202
1-Hexene	21	0.225	0.169	0.000	0.680
Hexane	21	1.406	1.020	0.462	5.320
trans-2-Hexene	21	0.073	0.031	0.026	0.160
2-methyl-2-Pentene	0	<L.D.	<L.D.	<L.D.	
2-Ethyl-1-Butene	21	0.002	0.006	0.000	0.022
trans-3-Methyl-2-pentene	21	<L.D.	<L.D.	<L.D.	
cis-2-Hexene	21	0.044	0.026	0.000	0.100
cis-3-Methyl-2-pentene	21	<L.D.	<L.D.	<L.D.	
2,2-Dimethylpentane	21	0.076	0.023	0.042	0.118
Methylcyclopentane	21	0.915	0.395	0.392	1.652

Table 3.6.2: (cont'd.)

Non-polar VOC compound (ug/m^3)	n	Mean	Standard deviation	Minimum	Maximum
2,4-Dimethylpentane	21	0.198	0.071	0.084	0.312
2,2,3-Trimethylbutane	21	0.006	0.012	0.000	0.030
1-Methylcyclopentene	21	0.040	0.025	0.000	0.090
Benzene	21	2.878	1.644	1.124	6.702
Cyclohexane	21	0.367	0.248	0.144	1.188
2-Methylhexane	21	0.831	0.304	0.364	1.340
2,3-Dimethylpentane	21	0.356	0.120	0.168	0.526
Cyclohexene	21	0.014	0.026	0.000	0.064
3-Methylhexane	21	0.918	0.318	0.448	1.426
1-Heptene	13	0.162	0.151	0.000	0.520
2,2,4-Trimethylpentane	21	0.557	0.275	0.178	1.318
trans-3-Heptene	21	0.005	0.004	0.000	0.010
cis-3-Heptene	3	<L.D.	<L.D.	<L.D.	
Heptane	21	0.682	0.230	0.360	1.116
trans-2-Heptene	21	0.035	0.023	0.000	0.060
cis-2-Heptene	21	0.039	0.047	0.000	0.110
2,2-Dimethylhexane	21	0.037	0.010	0.020	0.056
Methylcyclohexane	21	0.524	0.233	0.232	0.980
2,5-Dimethylhexane	21	0.151	0.046	0.074	0.222
2,4-Dimethylhexane	21	0.192	0.066	0.076	0.322
2,3,4-Trimethylpentane	21	0.188	0.074	0.076	0.360
Toluene	21	5.985	2.160	1.998	8.976
2-Methylheptane	21	0.406	0.131	0.200	0.680
1-Methylcyclohexene	21	0.014	0.022	0.000	0.070
4-Methylheptane	21	0.150	0.054	0.076	0.260
3-Methylheptane	21	0.356	0.133	0.056	0.640
cis-1,3-Dimethylcyclohexane	21	0.116	0.054	0.050	0.248
trans-1,4-Dimethylcyclohexane	21	0.063	0.028	0.030	0.122
2,2,5-Trimethylhexane	21	0.049	0.027	0.018	0.150
1-Octene	0	<L.D.	<L.D.	<L.D.	
Octane	21	0.301	0.135	0.128	0.670
trans-1,2-Dimethylcyclohexane	21	0.081	0.042	0.034	0.178
trans-2-Octene	21	0.007	0.017	0.000	0.060
cis-1,4/t-1,3-Dimethylcyclohexane	21	0.050	0.017	0.028	0.082
cis-2-Octene	0	<L.D.	<L.D.	<L.D.	
cis-1,2-Dimethylcyclohexane	10	0.023	0.022	0.000	0.060
Ethylbenzene	21	1.174	0.423	0.468	1.900
2,5-Dimethylheptane	0	<L.D.	<L.D.	0.000	0.000
m and p-Xylene	21	4.238	1.573	1.570	7.010
4-Methyloctane	0	<L.D.	<L.D.	<L.D.	
3-Methyloctane	0	<L.D.	<L.D.	<L.D.	
Styrene	21	<L.D.	<L.D.	<L.D.	
o-Xylene	21	1.561	0.541	0.670	2.591
1-Nonene	0	<L.D.	<L.D.	<L.D.	
Nonane	21	0.290	0.141	0.120	0.580

Table 3.6.2: **(cont'd.)**

Non-polar VOC compound (ug/m^3)	n	Mean	Standard deviation	Minimum	Maximum
iso-Propylbenzene	21	0.163	0.118	0.060	0.512
3,6-Dimethyloctane	21	0.046	0.023	0.000	0.099
n-Propylbenzene	21	0.456	0.371	0.150	1.570
3-Ethyltoluene	21	1.682	1.559	0.460	6.346
4-Ethyltoluene	21	0.819	0.777	0.200	3.072
1,3,5-Trimethylbenzene	21	1.029	1.060	0.200	4.138
2-Ethyltoluene	21	0.667	0.549	0.200	2.292
1-Decene	3	<L.D.	<L.D.	<L.D.	
tert-Butylbenzene	21	0.001	0.004	0.000	0.020
1,2,4-Trimethylbenzene	21	3.183	3.163	0.720	12.396
Decane	21	0.416	0.179	0.150	0.884
iso-Butylbenzene	21	0.034	0.012	0.020	0.066
sec-Butylbenzene	21	0.040	0.013	0.020	0.078
1,2,3-Trimethylbenzene	21	0.636	0.536	0.170	2.236
p-Cymene	21	0.064	0.028	0.030	0.131
Indane	21	0.188	0.096	0.060	0.473
1,3-Diethylbenzene	21	0.081	0.040	0.030	0.195
1,4-Diethylbenzene	21	0.251	0.162	0.070	0.709
n-Butylbenzene	21	0.067	0.030	0.030	0.157
1,2-Diethylbenzene	21	0.036	0.024	0.020	0.132
Undecane	21	0.358	0.179	0.110	0.770
Naphthalene	21	0.344	0.171	0.110	0.690
Dodecane	21	0.193	0.129	0.044	0.550
Hexylbenzene	21	0.042	0.027	0.000	0.100
Freon22	19	58.717	76.310	0.000	237.790
Chloromethane	21	1.267	0.211	1.012	1.650
Freon114	21	0.182	0.043	0.136	0.302
Vinylchloride	21	0.009	0.009	0.000	0.020
Bromomethane	21	0.105	0.021	0.078	0.140
Chloroethane	21	0.073	0.034	0.000	0.140
Freon11	21	1.718	0.092	1.520	1.906
Freon12	21	3.030	0.464	2.290	3.996
Ethylbromide	21	0.094	0.112	0.000	0.290
1,1-Dichloroethylene	21	0.016	0.016	0.000	0.040
Dichloromethane	21	1.060	0.547	0.320	2.180
trans-1,2-Dichloroethylene	21	0.003	0.007	0.000	0.020
1,1-Dichloroethane	21	0.177	0.204	0.000	0.550
cis-1,2-Dichloroethylene	21	0.005	0.010	0.000	0.030
Bromochloromethane	0	<L.D.	<L.D.	<L.D.	
Chloroform	21	0.137	0.030	0.098	0.210
1,2-Dichloroethane	21	0.068	0.014	0.044	0.090
1,1,1-Trichloroethane	21	0.421	0.023	0.380	0.483
Carbontetrachloride	21	0.639	0.035	0.560	0.700
Dibromomethane	21	0.054	0.012	0.034	0.070
1,2-Dichloropropane	21	0.000	0.000	0.000	0.000

Table 3.6.2: (cont'd.)

Non-polar VOC compound (ug/m^3)	n	Mean	Standard deviation	Minimum	Maximum
Bromodichloromethane	5	0.000	0.000	0.000	0.000
Trichloroethylene	11	0.167	0.094	0.092	0.414
cis-1,3-Dichloropropene	21	<L.D.	<L.D.	<L.D.	
trans-1,3-Dichloropropene	21	<L.D.	<L.D.	<L.D.	
1,1,2-Trichloroethane	21	0.004	0.011	0.000	0.030
Bromotrichloromethane	6	<L.D.	<L.D.	<L.D.	
Dibromochloromethane	21	0.022	0.013	0.000	0.040
EDB	21	0.004	0.010	0.000	0.032
Tetrachloroethylene	21	0.833	0.869	0.200	4.422
Chlorure de benzyle	21	0.033	0.009	0.020	0.060
Chlorobenzene	21	<L.D.	<L.D.	<L.D.	
Bromoform	21	0.017	0.017	0.000	0.044
1,4-Dichlorobutane	21	<L.D.	<L.D.	<L.D.	
1,1,2,2-Tetrachloroethane	21	0.017	0.014	0.000	0.040
1,3-Dichlorobenzene	21	<L.D.	<L.D.	<L.D.	
1,4-Dichlorobenzene	21	1.596	0.707	0.566	3.230
1,2-Dichlorobenzene	21	0.002	0.009	0.000	0.040
1,2,4-Trichlorobenzene	21	0.037	0.041	0.000	0.100
Hexachlorobutadiene	21	<L.D.	<L.D.	<L.D.	

* Analysed by Environment Canada with method TO-14 of US EPA (1999c)

n : number of values

Table 3.6.3: Comparison of two sampling sites for nonpolar VOCs (arithmetic means for December 25, 1998 to March 19, 1999)

Non-polar VOC (µg/m^3)	Sampling station	
	Rivière-des-Prairies *	Ontario street **
Trichlorofluoromethane	1.75	1.72
Dichloromethane	1.07	1.06
Trichloromethane	0.20	0.14
1,1,1-Trichloroethane	0.44	0.42
1,2-Dichloroethane	0.03	0.07
1,1-Dichloropropene	0.06	N.A.
Tetrachloromethane	0.55	0.64
Benzene	2.60	2.88
Trichloroethene	0.19	0.17
cis-1,3-Dichloropropene	0.03	< L.D.
trans-1,3-Dichloroprope	0.13	< L.D.
Toluene	7.57	5.99
1,1,2-Trichloroethane	0.18	< L.D.
Dibromochloromethane	0.26	0.02
Tetrachloroethene	0.40	0.83
Ethylbenzene	0.90	1.17
m+p-Xylene	2.51	4.24
Styrene	0.20	< L.D.
o-Xylene	1.12	1.56
Isopropylbenzene	0.05	0.16
1,2,3-Trichloropropane	0.09	N.A.
n-Propylbenzene	0.20	0.46
2-Chlorotoluene	0.06	N.A.
4-Chlorotoluene	0.04	N.A.
1,3,5-Trimethylbenzene	0.19	1.03
tert-Butylbenzene	0.09	< L.D.
1,2,4-Trimethylbenzene	0.76	3.18
1,3-Dichlorobenzene	0.11	< L.D.
4-Isopropyltoluene	0.04	N.A.
1,4-Dichlorobenzene	0.18	1.60
n-Butylbenzene	0.04	0.07

< L.D. : lower than limit of detection

N.A. = data not available.

* CUM laboratory, method TO-17

** Environment Canada laboratory, method TO-14

3.6.2 Polar VOCs

The mean concentrations obtained for most of the 16 aldehydes and ketones measured at the two sampling stations using EPA method TO-11 (USEPA 1999a) were very similar, except for acrolein (Tables 3.6.4 and 3.6.5). This substance is included in IARC's Group 3 (IARC 1999), meaning that it is unclassifiable with regard to its carcinogenicity in humans. It is also classified in the EPA's Group C as a possible human carcinogen, based on limited animal carcinogenicity data (USEPA 1999d). Concentrations of m-tolualdehyde and benzaldehyde at the Rivière-des-Prairies station were also noteworthy.

The mean value for acrolein was 0.77 µg/m^3 at the Rivière-des-Prairies station, compared with 0.26 µg/m^3 at the reference site (Ontario Street). Maximum daily values reached 3.50 µg/m^3 and 0.70 µg/m^3 respectively at these stations. The mean value of 0.52 µg/m^3 and the maximum value of 1,05 µg/m^3 recorded for m-tolualdehyde at Rivière-des-Prairies were much higher than at Ontario Street, which had mean and maximum values of only 0.02 µg/m^3 and 0.09 µg/m^3 respectively. Although smaller differences were found for benzaldehyde, they still merit our attention.

Table 3.6.4: Synthesis of results for polar VOCs at the RDP station from December 1, 1998 to March 31, 1999

Aldehydes and ketone	n	Mean	Satandard deviation	Minimum	Maximum
Formaldehyde	18	3.28	1.74	0.88	7.59
Acétaldehyde	18	1.98	0.95	0.51	3.53
Acrolein	18	0.77	1.17	< L.D.	3.50
Acetone	18	2.61	0.78	1.20	4.25
Propionaldehyde	18	0.52	0.41	< L.D.	1.31
Crotonaldehyde	18	0.13	0.22	< L.D.	0.85
2-butanone (MEK)/butyraldehyde	18	0.96	0.48	< L.D.	1.57
Benzaldehyde	18	0.43	0.22	0.06	0.91
Isovaleraldehyde	18	0.11	0.20	< L.D.	0.63
Valéraldehyde	18	0.28	0.29	< L.D.	0.85
o-Tolualdehyde	18	0.03	0.14	< L.D.	0.59
m-Tolualdehyde	18	0.53	0.32	< L.D.	1.05
p-Tolualdehyde	18	< L.D.	< L.D.	< L.D.	0.00
Methyl Isobutyl ketone(MIBK)	18	0.17	0.19	< L.D.	0.63
Hexanaldehyde	18	0.17	0.15	< L.D.	0.59
2,5-Dimethylbenzaldehyde	18	< L.D.	< L.D.	< L.D.	0.00
Mean total Concentration	18	11.72	5.44	3.83	21.23

n : number of samples

Table 3.6.5: Synthesis of results for polar VOCs at the Ontario Street station from December 1, 1998 to March 31, 1999

Aldehydes and ketone	n	Mean	Standard deviation	Minimum	Maximum
Formaldéhyde	20	3.10	0.65	1.97	3.93
Acétaldéhyde	20	2.23	0.79	1.21	3.57
Acroléine	20	0.26	0.18	0.03	0.70
Acétone	20	3.43	0.90	2.12	4.96
Propionaldéhyde	20	0.51	0.12	0.34	0.77
Crotonaldéhyde	20	0.06	0.03	< L.D.	0.11
2-butanone (MEK)/butyraldéhyde	20	1.17	0.40	0.50	1.77
Benzaldéhyde	20	0.17	0.07	0.07	0.37
Isovaléraldéhyde	20	0.12	0.09	< L.D.	0.28
Valéraldéhyde	20	0.14	0.10	< L.D.	0.29
o-Tolualdéhyde	20	< L.D.	< L.D.	< L.D.	0.04
m-Tolualdéhyde	20	0.02	0.03	< L.D.	0.09
p-Tolualdéhyde	20	< L.D.	< L.D.	< L.D.	0.00
Méthyl Isobutyl cétone(MIBK)	20	0.12	0.08	< L.D.	0.25
Hexanaldéhyde	20	0.16	0.10	< L.D.	0.35
2,5-Diméthylbenzaldéhyde	20	< L.D.	< L.D.	< L.D.	0.00
Mean total Concentration	20	11.47	2.80	6.62	15.20

n : number of samples

A detailed comparison of mean acrolein, benzaldehyde and m-tolualdehyde concentrations shows that mean concentrations of acrolein and m-tolualdehyde recorded at the Rivière-des-Prairies station differed significantly from those at the other sampling stations. Table 3.6.6 gives the annual mean concentrations for these compounds in 1998 at the three CUM stations.

Table 3.6.6: Mean concentrations (μg/m^3) of acrolein, benzaldhyde and m-tolualdehyde

Compound	Sampling Site				
	RDP	Ontario Street	PAT*	Ontario Street	ADM**
	12/01/98 - 03/31/99		1998		
Acrolein	0.77	0.26	0.14	0.17	0.11
Benzaldehyde	0.43	0.17	0.16	0.24	0.36
m-Tolualdehyde	0.53	0.02	0.03	0.13	0.12

*PAT : Pointe-aux-Trembles

**ADM : Montreal airport station

The respective increases of 150% and 200% in mean acrolein and benzaldehyde concentrations at the RDP station suggest that there is a significant local source for these two substances. According to the EPA (1993), wood combustion is a well-known source of acrolein (20 to 120 mg/kg of wood burned). Therefore, there is every reason to believe that these increases are due to the heavy use of wood stoves in this sector.

In addition, an examination of the data on these three compounds in the report by Tremblay and Dann (1995) shows that acrolein concentrations were generally much higher at the Rivière-des-Prairies station, both in terms of the mean and the 24-hour maximum. In an urban environment, mean acrolein concentrations ranged between 0.06 µg/m^3 and 0.16 µg/m^3 from 1990 to 1993, while the 24-hour maximums ranged from 0.37 µg/m^3 to 0.87 µg/m^3, except in 1992, when the maximum was 2.10 µg/m^3.

4. Conclusion

Many but not all of the objectives of the sampling project on wood heating during the winter of 1998-99 were achieved. Greater concentrations of various pollutants were found in the RDP neighbourhood, where the main local source of ambient air emissions is residential wood heating. Concentrations of fine particulate matter, polycyclic aromatic hydrocarbons and some metals and volatile organic compounds measured at the main Rivière-des-Prairies station were higher than in the rest of the MUC territory during the winter of 1998-99. It is estimated that wood heating in the study area contributes 40% to 60% of the polycyclic aromatic hydrocarbons found, as well as the same percentage of some metals and volatile organic compounds, and over 40% of fine particulate matter.

Additional studies would allow us to:

a) confirm the results obtained
b) verify some of the hypotheses proposed to quantify the impact of wood heating at the local level
c) develop predictive tools for air pollution episodes caused by wood combustion that adequately integrate chemical and meteorological factors.

5. Recommendations

The authors propose a series of recommendations that are essential to thoroughly understand the issues surrounding wood combustion. Such short- and medium-term recommendations deal specifically with the environment and health (i.e., population exposure studies).

5.1. Recommendations involving the environment

In the short term:

- Assess the performance of the continuous sampler in measuring fine particulate matter in an environment affected by wood combustion:
  - Assess the effect of the TEOM sampling temperature on the volatilization rate in semi-volatile materials;
  - Assess the TEOM's ability to reproduce measurements;
  - Increase the sampling frequency for fine particulate matter ($PM_{2.5}$), using a dichotomous sampler to assess the TEOM results in an environment heavily influenced by wood heating;
- Determine the composition of particles to be able to better identify sources. In particular, determining quantities of elemental carbon is suggested;
- Measure carbon monoxide continuously at the RDP station;
- Measure PAH values simultaneously at the RDP station and reference site (Ontario Street station);
- Whenever possible, continue the sampling program in both summer and winter to be able to more easily determine the impact of wood heating on the levels of the various pollutants measured.

In the medium term:

- Evaluate if it is possible to forecast periods of high concentrations of particulate matter in the winter;
- Take measurements over a second complete season (summer and winter) to confirm the observations already made;
- Estimate the contribution of residential wood heating to dioxin and furan levels by measuring them at the RDP and Ontario Street sites;
- Compare the results for nonpolar VOCs obtained with the TO-14 and TO-17 methods (measurements already taken at RDP);
- Improve the monitoring over time of specific wood combustion indicators using the sequential dichotomous sampler;
- Ensure the representativeness of the RDP station in order to be able to assess the impact of wood combustion on air quality;
- Determine if a better tracer is available for wood combustion in an urban environment.

5.2 Recommendations involving health

There are five recommendations involving health.

In the short and medium term:

- Determine the geographical distribution of hot spots in Montreal for the use of wood burning systems (this involves the detailed analysis of the survey carried out in partnership with the DSP, EC, Quebec Environment Department and the MUC);
- Characterize habits of users of wood heating systems in the MUC to improve emission inventories (this information will also be obtained from the survey carried out in partnership with the DSP, EC, Quebec Environment Department and the MUC);
- Determine the impact, in terms of population exposure, of the use of wood heating systems (DSP pilot study funded under the joint Health Canada and EC research program, the Toxic Substances Research Initiative).

In the long term:

- The pilot study should allow us to develop measurement tools that can be easily adapted to other neighbourhoods. This will also allow us to undertake short-term sampling programs in various neighbourhoods targeted according to the prevalence of wood burning systems;
- If necessary, should the pilot study on exposure to pollutants emitted by wood combustion reveal significant exposure levels in some groups of individuals (both users and nonusers of wood heating systems), a study design, even an indirect approach, should be developed to assess the impacts of this contaminant source on health.

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APPENDICES

Appendix 1: Photos of the site

Appendix 2: Characteristics and detection limits (ng/m^3 assuming 1000 m^3 sampled) for the different PAHs measured in samples taken with the modified high-volume sampler

Compound analyzed	Abreviation	Carcinogenic Potential	Carc. Pot. for human	Molecular weight	Number of cycles	Limit of detedction
Acenaphtylene	Acy	*		152	3	< 0.005
Acenaphtene	Ace			154	3	< 0.006
Fluorene	Flu	none		166	3	< 0.005
2-Methyl-fluorene	2-MeFlu			180	3	< 0.005
Phenanthrene	Phe	none		178	3	< 0.005
Anthracene	Antc	none		178	3	< 0.005
Fluoranthene	Flt	none		202	4	< 0.005
Pyrene	Pyr	none		202	4	< 0.005
Benzo(a)fluorene	BaFlu	none		216	4	< 0.005
Benzo(b)fluorene	BbFlu	none		216	4	< 0.053
1-Methyl-pyrene	1-MePyr			216	4	< 0.053
Benzo(g,h,i)fluoranthene	BghiFlt	none		226	5	< 0.005
Benz(a)anthracene	BaAnt	weak	probable	228	4	< 0.053
Chrysene	Chr	Very weak	possible	228	4	<0.013 - < 0.014
Triphenylene	Trip			228	4	<0.013 - < 0.014
7-Me-Benz(a)anthracene	7-MeBaAnt			240	4	< 0.012 - < 0.053
Benzo(b)fluoranthene	BbFlt	Average	probable	252	5	< 0.005
Benzo(k)fluoranthene	BkFlt	Average	probable	252	5	< 0.005
Benzo(e)pyrene	BeP	None		252	5	< 0.013
Benzo(a)pyrene	BaP	High	probable	252	5	< 0.013
Perylene	Per	None		252	5	< 0.013 - < 0.052
3-Methylcholanthrene	3-MCho	High		268	5	< 0.013 - < 0.052
Indeno(1,2,3-cd)pyrene	IndPyr	Average	probable	276	6	< 0.005
Dibenz(a,h)+(a,c)anthracene	DBahA	High	probable	278	5	< 0.013 - < 0.052
Benzo(b)chrysene	BbChr			278	5	< 0.013 - < 0.055
Benzo(g,h,i)perylene	BghiPer	Very weak		276	6	< 0.005
Anthantrene	Ant	Average	possibly	276	6	< 0.013 - < 0.056

Appendix 3: Complete results for polar and nonpolar VOCs (TO-17) measured at RDP

Aldehydes and ketone	Dec. 19 (µg/m3)	Dec. 25 (µg/m3)	Dec. 31 (µg/m3)	Jan. 6 (µg/m3)	Jan. 12 (µg/m3)	Jan. 24 (µg/m3)	Jan. 30 (µg/m3)	Feb. 5 (µg/m3)	Feb. 11 (µg/m3)
Formaldehyde	7.59	4.60	4.08	2.40	4.23	2.06	5.97	2.09	3.06
Acetaldehyde	3.44	2.60	2.68	1.80	2.84	1.27	3.53	1.22	1.60
Acrolein	0.59	0.00	0.00	0.00	0.13	0.18	1.00	0.39	0.40
Acetone	4.25	3.02	2.70	2.58	3.15	1.84	3.03	1.98	2.26
Propionaldehyde	1.27	0.50	1.00	0.67	1.06	0.46	1.31	0.30	0.45
Crotonaldehyde	0.21	0.15	0.12	0.00	0.15	0.07	0.85	0.22	0.00
MEK/butyraldehyde	1.35	0.95	1.02	1.38	1.42	0.53	1.46	0.88	0.99
Benzaldehyde	0.87	0.91	0.39	0.25	0.43	0.39	0.56	0.41	0.41
Isovaleraldehyde	0.32	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Valeraldehyde	0.11	0.07	0.16	0.13	0.18	0.38	0.41	0.00	0.58
o-Tolualdehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
m-Tolualdehyde	0.86	0.92	0.29	0.39	0.42	0.26	1.00	0.49	0.69
p-Tolualdehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIBK	0.18	0.00	0.09	0.63	0.24	0.11	0.29	0.16	0.20
Hexanaldehyde	0.18	0.10	0.09	0.10	0.00	0.59	0.20	0.19	0.08
2,5-Dimethylbenzaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean Total Concentration	21.23	13.82	12.70	10.33	14.26	8.14	19.62	8.34	10.74

Aldehydes and ketone	Feb. 17 (µg/m3)	Feb. 23 (µg/m3)	Feb. 25 (µg/m3)	March 1 (µg/m3)	March 7 (µg/m3)	March 13 (µg/m3)	March 19 (µg/m3)	March 25 (µg/m3)	March 31 (µg/m3)
Formaldehyde	2.89	4.60	4.53	1.62	2.27	2.46	0.88	1.21	2.46
Acetaldehyde	1.87	3.14	2.85	1.54	0.90	1.42	0.51	0.52	1.88
Acrolein	2.34	3.50	3.29	0.00	0.00	1.89	0.07	0.09	0.00
Acetone	2.51	3.74	3.36	2.07	2.15	1.90	1.20	1.90	3.30
Propionaldehyde	0.23	0.42	0.46	0.08	0.00	0.61	0.13	0.00	0.33
Crotonaldehyde	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00
MEK/butyraldehyde	0.92	1.57	1.29	0.21	0.00	1.12	0.24	0.50	1.41
Benzaldehyde	0.06	0.48	0.61	0.36	0.28	0.54	0.19	0.14	0.39
Isovaleraldehyde	0.00	0.63	0.56	0.17	0.00	0.15	0.00	0.00	0.00
Valeraldehyde	0.69	0.58	0.74	0.00	0.85	0.17	0.00	0.00	0.06
o-Tolualdehyde	0.00	0.00	0.00	0.00	0.59	0.00	0.00	0.00	0.00
m-Tolualdehyde	0.90	0.60	1.05	0.00	0.71	0.33	0.18	0.11	0.42
p-Tolualdehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIBK	0.08	0.23	0.25	0.00	0.00	0.00	0.00	0.00	0.58
Hexanaldehyde	0.07	0.05	0.20	0.29	0.00	0.05	0.42	0.26	0.19
2,5-Dimethylbenzaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean Total Concentration	12.57	19.54	19.18	3.98	7.64	9.28	3.83	4.72	11.03

Appendix 3 : (continued)

non-polar VOC	25-Dec-98 (µg/m3)	31-Dec-98 (µg/m3)	06-Jan-99 (µg/m3)	12-Jan-99 (µg/m3)	24-Jan-99 (µg/m3)	30-Jan-99 (µg/m3)	05-Feb-99 (µg/m3)	11-Feb-99 (µg/m3)	17-Feb-99 (µg/m3)	23-Feb-99 (µg/m3)
Trichlorofluoromethane	6.40	3.41	1.54	0.95	1.00	2.28	2.93	1.00	1.81	1.85
1,1-Dichloroethene										
Dichloromethane	3.69	1.76	4.20	1.26	0.46	0.28	0.45	0.18	0.25	1.44
trans-1,2-Dichloroethene										
1,1-Dichloroethane										
cis-1,2-Dichloroethene										
2,2-Dichloropropane										
Trichloromethane	0.51	0.28	0.05	0.05	0.33	0.45	0.05	0.05	0.05	0.20
Bromochloromethane										
1,1,1-Trichloroethane	0.54	0.57	0.41	0.53	0.65	0.48	0.38	0.33	0.46	0.51
1,2-Dichloroethane	0.03	0.06	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.06
1,1-Dichloropropene	0.05	0.05	0.05	0.05	0.05	0.19	0.05	0.05	0.05	0.05
Tetrachloromethane	0.47	0.62	0.46	0.52	0.81	0.61	0.47	0.46	0.43	0.73
Benzene	2.65	3.95	2.59	5.26	2.45	3.99	1.50	2.00	1.82	4.73
Trichloroethene	0.32	0.30	0.42	0.38	0.34	0.16	0.16	0.05	0.05	0.27
1,2-Dichloropropane										
Dibromomethane										
Bromodichloromethane										
cis-1,3-Dichloropropene			0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.06
trans-1,3-Dichloropropene	0.21	0.19	0.25	0.26	0.18	0.17	0.05	0.05	0.05	0.22
Toluene	10.99	10.62	13.68	14.89	9.94	8.17	5.41	4.97	5.17	10.97
1,1,2-Trichloroethane	0.21	0.26	0.27	0.39	0.24	0.13	0.10	0.17	0.05	0.39
1,3-Dichloropropane										
Dibromochloromethane	0.18	0.39	0.71	0.41	0.59	0.17	0.17	0.05	0.16	0.45
Tetrachloroethene	0.26	0.57	1.05	0.61	0.86	0.26	0.26	0.18	0.22	0.66
1,2-Dibromoethane										
Chlorobenzene										
1,1,1,2-Tetrachloroethane										
Ethylbenzene	0.85	0.90	1.31	1.43	1.08	1.76	0.59	0.66	0.56	1.72
m+p-Xylene	2.43	2.29	3.50	3.77	3.03	4.89	1.57	1.67	1.47	4.69
Styrene	0.21	0.15	0.32	0.38	0.29	0.23	0.05	0.05	0.05	0.59
o-Xylene	1.23	1.11	1.52	1.72	1.42	2.27	0.72	0.73	0.65	2.12
Tribromomethane										
1,1,2,2-Tetrachloroethane										
Isopropylbenzene	0.03	0.06	0.07	0.09	0.08	0.09	0.03	0.03	0.03	0.09
1,2,3-Trichloropropane	0.19	0.13	0.12	0.19	0.21	0.03	0.07	0.03	0.06	0.06
Bromobenzene										
n-Propylbenzene	0.21	0.22	0.25	0.32	0.33	0.34	0.16	0.11	0.14	0.34
2-Chlorotoluene	0.03	0.03	0.07	0.21	0.07	0.09	0.03	0.03	0.03	0.09
4-Chlorotoluene	0.03	0.03	0.03	0.03	0.07	0.08	0.03	0.03	0.03	0.07
1,3,5-Trimethylbenzene	0.23	0.19	0.27	0.31	0.32	0.33	0.16	0.03	0.03	0.37
tert-Butylbenzene	0.03	0.03	0.03	0.03	0.03	0.25	0.12	0.08	0.09	0.26
1,2,4-Trimethylbenzene	0.84	0.70	0.96	1.10	1.28	1.20	0.57	0.38	0.46	1.23
sec-Butylbenzene										
1,3-Dichlorobenzene	0.03	0.25	0.03	0.03	0.03	0.18	0.13	0.09	0.10	0.19
4-Isopropyltoluene	0.03	0.03	0.03	0.03	0.12	0.07	0.03	0.03	0.03	0.06
1,4-Dichlorobenzene	0.54	0.25	0.18	0.19	0.35	0.03	0.13	0.08	0.10	0.18
1,2-Dichlorobenzene										
n-Butylbenzene	0.03	0.03	0.03	0.03	0.15	0.03	0.03	0.03	0.03	0.03

Appendix 3 : (continued)

non-polar VOC	25-Feb-99 (µg/m3)	07-Mar-99 (µg/m3)	13-Mar-99 (µg/m3)	19-Mar-99 (µg/m3)
Trichlorofluoromethane	1.38	0.05	0.05	0.05
1,1-Dichloroethene				
Dichloromethane	0.35	0.45	0.31	0.14
trans-1,2-Dichloroethene				
1,1-Dichloroethane				
cis-1,2-Dichloroethene				
2,2-Dichloropropane				
Trichloromethane	0.05	0.26	0.55	0.05
Bromochloromethane				
1,1,1-Trichloroethane	0.34	0.35	0.34	0.32
1,2-Dichloroethane	0.03	0.03	0.03	0.03
1,1-Dichloropropene	0.05	0.05	0.08	0.03
Tetrachloromethane	0.48	0.55	0.52	0.53
Benzene	2.79	1.25	1.48	0.70
Trichloroethene	0.05	0.05	0.05	0.05
1,2-Dichloropropane				
Dibromomethane				
Bromodichloromethane				
cis-1,3-Dichloropropene	0.03	0.03	0.03	0.03
trans-1,3-Dichloropropene	0.05	0.05	0.05	0.05
Toluene	5.30	2.19	2.95	1.53
1,1,2-Trichloroethane	0.18	0.09	0.05	0.05
1,3-Dichloropropane				
Dibromochloromethane	0.16	0.05	0.15	0.05
Tetrachloroethene	0.24	0.12	0.21	0.12
1,2-Dibromoethane				
Chlorobenzene				
1,1,1,2-Tetrachloroethane				
Ethylbenzene	0.88	0.28	0.49	0.24
m+p-Xylene	2.32	1.03	1.81	0.99
Styrene	0.18	0.05	0.05	0.14
o-Xylene	1.06	0.34	0.60	0.30
Tribromomethane				
1,1,2,2-Tetrachloroethane				
Isopropylbenzene	0.03	0.03	0.03	0.03
1,2,3-Trichloropropane	0.03	0.03	0.03	0.03
Bromobenzene				
n-Propylbenzene	0.21	0.07	0.10	0.06
2-Chlorotoluene	0.06	0.03	0.03	0.03
4-Chlorotoluene	0.03	0.03	0.03	0.03
1,3,5-Trimethylbenzene	0.22	0.03	0.14	0.03
tert-Butylbenzene	0.17	0.03	0.07	0.03
1,2,4-Trimethylbenzene	0.81	0.32	0.50	0.33
sec-Butylbenzene				
1,3-Dichlorobenzene	0.13	0.10	0.14	0.10
4-Isopropyltoluene	0.03	0.03	0.03	0.03
1,4-Dichlorobenzene	0.13	0.10	0.14	0.10
1,2-Dichlorobenzene				
n-Butylbenzene	0.03	0.03	0.03	0.03

Appendix 4: Detection limits for polar VOCs (method TO-11)

Aldehydes and ketone	Limit of detection* (µg/m^3)
Formaldehyde	0,01
Acetaldehyde	0,01
Acrolein	0,01
Acetone	0,01
Propionaldehyde	0,01
Crotonaldehyde	0,06
2-butanone (MEK)/butyraldehyde	0,05
Benzaldehyde	0,01
Isovaleraldehyde	0,08
Valeraldehyde	0,05
o-Tolualdehyde	0,03
m-Tolualdehyde	0,01
p-Tolualdehyde	0,04
Methyl Isobutyl ketone (MIBK)	0,08
Hexanaldehyde	0,04
2,5-Dimethylbenzaldehyde	0,06

* Assuming a flowrate of 1L/min over 24 hours

Appendix 5: Detection limits for nonpolar VOCs (method TO-17)

VOC (non-polar)	Limit of detection* (µg/m^3)
Trichlorofluoromethane	0.09
1,1-Dichloroethene	0.04
Dichloromethane	0.04
trans-1,2-Dichloroethene	0.04
1,1-Dichloroethane	0.04
cis-1,2-Dichloroethene	0.04
2,2-Dichloropropane	0.04
Trichloromethane	0,13
Bromochloromethane	0.09
1,1,1-Trichloroethane	0.04
1,2-Dichloroethane	0.04
1,1-Dichloropropene	0.04
Tetrachloromethane	0.04
Benzene	0.04
Trichloroethene	0.09
1,2-Dichloropropane	0.04
Dibromomethane	0.04
Bromodichloromethane	0.04
cis-1,3-Dichloropropene	0.04
trans-1,3-Dichloropropene	0.09
Toluene	0.04
1,1,2-Trichloroethane	0.04
1,3-Dichloropropane	0.04
Dibromochloromethane	0.09
Tetrachloroethene	0.04
1,2-Dibromoethane	0.04
Chlorobenzene	0.04
1,1,1,2-Tetrachloroethane	0.09
Ethylbenzene	0.04
m+p-Xylene	0.04
Styrene	0.09
o-Xylene	0.04
Tribromomethane	0.09
1,1,2,2-Tetrachloroetha	0.09
Isopropylbenzene	0.04
1,2,3-Trichloropropane	0.04
Bromobenzene	0.04
n-Propylbenzene	0.04
2-Chlorotoluene	0.04
4-Chlorotoluene	0.04
1,3,5-Trimethylbenzene	0.09
tert-Butylbenzene	0.04
1,2,4-Trimethylbenzene	0.04
sec-Butylbenzene	0.04
1,3-Dichlorobenzene	0.04
4-Isopropyltoluene	0.04
1,4-Dichlorobenzene	0.04
1,2-Dichlorobenzene	0.09
n-Butylbenzene	0.09

* Assuming a flowrate of 15 ml/min over 24 hours

Appendix 6a: Daily 24-hour PAH values measured at Riviere-des-Prairies from December 7, 1998 to March 31, 1999

Compounds (ng/m^3)	7-Dec-98	13-Dec-98	19-Dec-98	25-Dec-98	31-Dec-98	6-Jan-99	12-Jan-99	18-Jan-99	24-Jan-99	30-Jan-99
Acenaphthylene	1.80	4.01	21.94	13.75	10.44	10.88	19.15	8.89	1.77	11.63
Acenaphthene	0.00	1.04	3.36	2.82	3.02	3.18	6.59	2.18	0.95	2.58
Fluorene	3.20	4.65	8.49	8.06	6.22	8.97	14.04	14.54	5.75	9.54
2-Me-Fluorene	0.00	0.00	1.84	1.43	0.98	2.08	2.40	3.05	1.70	1.89
Phenanthrene	11.48	14.44	30.17	25.60	16.02	25.21	39.96	42.69	14.57	28.12
Anthracene	1.05	1.76	3.59	3.42	1.46	2.70	3.83	4.66	1.46	4.37
Fluoranthene	3.14	5.40	9.71	8.22	7.41	8.10	15.72	12.87	5.19	12.49
Pyrene	2.53	4.04	7.67	6.47	5.06	6.14	12.42	9.82	3.76	10.28
Benzo(a)Fluorene	0.37	0.54	0.82	0.87	0.63	0.55	1.32	0.88	0.36	1.44
Benzo(b)Fluorene	0.15	0.27	0.51	0.55	0.34	0.36	0.86	0.60	0.17	0.75
1-Me-Pyrene	0.20	0.32	0.51	0.52	0.32	0.37	0.88	0.56	0.18	1.06
Benzo(g,h,i)Fluoranthene	0.52	0.75	1.45	1.49	1.18	0.97	2.21	1.40	0.37	2.94
Benzo(a)Anthracene	0.48	0.93	1.56	1.42	1.00	1.35	3.39	1.79	0.40	3.50
Chrysene	0.67	1.63	2.23	2.06	2.31	1.96	5.58	2.56	1.46	5.35
Triphenylene	0.17	0.40	0.63	0.57	0.56	0.81	1.56	0.68	0.41	0.00
7-Me-Benzo(a)Anthracene	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Benzo(b)Fluoranthene	1.00	2.68	2.94	2.80	2.90	3.43	8.67	4.30	2.33	6.95
Benzo(k)Fluoranthene	0.31	0.84	0.77	0.86	0.77	0.79	1.68	0.91	0.58	0.97
Benzo(e)Pyrene	0.52	1.46	1.41	1.34	1.40	1.55	3.48	1.87	1.30	3.25
Benzo(a)Pyrene	0.41	0.81	1.21	0.99	0.76	0.94	2.58	1.45	0.41	2.89
Perylene	0.12	0.37	0.16	0.14	0.09	0.14	0.26	0.19	0.00	0.00
2-Me-Cholanthrene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indeno(1,2,3-cd)Pyrene	0.44	0.92	1.16	1.14	0.99	0.98	2.02	1.37	0.69	2.52
Dibenzo(a,c)&(a,h)Anthracene	0.06	0.15	0.15	0.14	0.12	0.15	0.32	0.19	0.13	0.32
Benzo(b)Chrysene	0.04	0.07	0.09	0.08	0.05	0.06	0.15	0.10	0.03	0.18
Benzo(g,h,i)Perylene	0.50	0.96	1.28	1.24	1.07	1.21	2.26	1.57	0.85	2.41
Anthanthrene	0.07	0.12	0.16	0.13	0.10	0.11	0.27	0.21	0.03	0.41
Total PAH	29.25	48.57	103.81	86.11	65.23	82.95	151.63	119.34	44.85	115.89
TSP(μg/m^3)	21.47	34.64	59.33	57.70	54.42	41.74	53.93	47.78	22.92	95.14

Appendix 6b: Daily 24-hour PAH values measured at Riviere-des-Prairies from December 7, 1998 to March 31, 1999 (continued)

Compounds (ng/m^3)	5-Feb-99	11-Feb-99	17-Feb-99	23-Feb-99	25-Feb-99	1-Mar-99	7-Mar-99	13-Mar-99	19-Mar-99	25-Mar-99	31-Mar-99
Acenaphthylene	5.75	6.30	15.70	20.52	12.21	6.54	4.72	7.74	0.67	0.86	3.36
Acenaphthene	1.37	2.20	4.14	2.81	6.21	2.18	1.39	1.87	0.41	0.55	0.95
Fluorene	3.78	6.71	10.32	11.56	13.21	6.40	4.12	6.00	1.28	1.54	4.16
2-Me-Fluorene	0.82	1.68	1.73	4.04	2.17	1.49	0.94	1.08	0.29	0.33	1.24
Phenanthrene	8.88	20.95	28.43	34.60	41.58	23.33	15.03	19.05	4.02	4.86	12.10
Anthracene	1.14	2.79	3.57	4.97	4.77	1.87	1.95	1.45	0.36	0.31	1.11
Fluoranthene	3.12	7.28	9.87	14.31	21.96	10.22	4.69	8.11	1.20	1.51	4.03
Pyrene	2.40	5.52	7.07	11.67	15.80	6.56	3.61	5.43	0.77	1.08	2.82
Benzo(a)Fluorene	0.31	0.61	0.80	1.54	1.81	0.66	0.42	0.43	0.06	0.08	0.34
Benzo(b)Fluorene	0.14	0.31	0.41	0.85	0.79	0.33	0.25	0.21	0.03	0.04	0.14
1-Me-Pyrene	0.19	0.36	0.48	1.02	1.16	0.29	0.25	0.20	0.03	0.05	0.19
Benzo(g,h,i)Fluoranthene	0.53	1.38	1.18	2.77	2.71	0.76	0.68	0.79	0.11	0.20	0.63
Benzo(a)Anthracene	0.46	1.44	1.40	3.17	5.40	0.88	0.67	0.67	0.03	0.12	0.49
Chrysene	0.68	2.76	2.18	3.88	11.57	3.28	0.91	2.16	0.15	0.24	0.78
Triphenylene	0.15	0.54	0.50	0.00	0.00	0.84	0.20	0.52	0.05	0.06	0.22
7-Me-Benzo(a)Anthracene	0.00	0.00	0.00	0.07	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Benzo(b)Fluoranthene	0.88	3.71	2.93	3.86	16.25	5.22	1.05	3.45	0.21	0.37	1.33
Benzo(k)Fluoranthene	0.27	1.04	0.82	1.09	4.05	1.32	0.36	1.18	0.05	0.10	0.38
Benzo(e)Pyrene	0.43	1.89	1.45	1.79	7.69	2.69	0.51	1.84	0.10	0.18	0.65
Benzo(a)Pyrene	0.00	1.22	1.30	2.57	4.53	0.87	0.49	1.00	0.04	0.14	0.50
Perylene	0.09	0.00	0.00	0.53	0.00	0.10	0.05	0.07	0.00	0.02	0.11
2-Me-Cholanthrene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indeno(1,2,3-cd)Pyrene	0.43	1.19	1.11	2.28	4.44	1.21	0.43	1.12	0.08	0.18	0.61
Dibenzo(a,c)&(a,h)Anthracene	0.05	0.16	0.16	0.30	0.72	0.21	0.05	0.15	0.00	0.00	0.07
Benzo(b)Chrysene	0.03	0.08	0.09	0.21	0.29	0.05	0.03	0.04	0.00	0.00	0.04
Benzo(g,h,i)Perylene	0.43	1.22	1.09	2.03	4.29	1.41	0.43	1.14	0.08	0.20	0.61
Anthanthrene	0.06	0.14	0.20	0.58	0.45	0.05	0.06	0.09	0.00	0.02	0.09
Total PAH	32.40	71.50	96.91	133.00	184.08	78.76	43.32	65.78	10.01	13.04	36.97
TSP(μg/m^3)	75.61	77.73	79.00	110.82	95.03	25.85	24.01	37.72	30.44	41.42	73.52

Appendix 6c: Daily PAH values measured from 4:00 pm to midnight at Riviere-des-Prairies from December 7, 1998 to March 31, 1999

Compounds (ng/m^3)	7-Dec-98	13-Dec-98	19-Dec-98	25-Dec-98	31-Dec-98	6-Jan-99	12-Jan-99	18-Jan-99	24-Jan-99	30-Jan-99
Acenaphthylene	4.15	8.23	3.85	58.89	12.76	15.28	34.20	30.56	2.02	11.95
Acenaphthene	1.55	1.93	0.78	8.52	3.25	5.44	4.47	4.26	1.76	2.93
Fluorene	2.99	4.06	1.79	18.07	7.27	7.24	10.32	10.36	2.42	8.62
2-Me-Fluorene	0.00	0.01	0.29	3.27	1.09	1.93	1.91	2.11	0.94	7.77
Phenanthrene	9.35	11.29	5.84	52.99	15.32	23.42	27.76	37.79	8.46	23.53
Anthracene	1.10	1.93	0.47	7.64	1.57	2.26	3.07	4.12	0.80	3.88
Fluoranthene	3.03	5.21	2.07	10.49	6.20	4.33	11.67	9.81	5.34	6.64
Pyrene	2.45	4.16	1.35	7.95	3.96	3.04	9.72	6.88	3.64	5.91
Benzo(a)Fluorene	0.44	0.60	0.18	1.13	0.58	0.31	1.30	0.67	0.30	1.14
Benzo(b)Fluorene	0.19	0.29	0.09	0.69	0.32	0.17	0.95	0.44	0.14	0.60
1-Me-Pyrene	0.23	0.36	0.09	0.63	0.25	0.24	0.99	0.46	0.13	0.77
Benzo(g,h,i)Fluoranthene	0.64	1.05	0.34	2.15	1.17	0.52	2.43	1.00	0.31	1.97
Benzo(a)Anthracene	0.56	1.03	0.28	1.84	0.73	0.44	3.46	1.02	0.30	2.34
Chrysene	0.85	1.41	0.52	3.36	2.08	0.49	3.30	1.05	1.58	3.37
Triphenylene	0.20	0.35	0.23	0.99	0.65	0.30	1.06	0.68	0.42	0.73
Chrysene&Triphenylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7-Me-Benzo(a)Anthracene	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Benzo(b)Fluoranthene	1.09	1.93	0.77	4.44	2.76	1.02	5.73	2.42	2.54	4.38
Benzo(k)Fluoranthene	0.32	0.58	0.21	1.30	0.67	0.27	1.37	0.64	0.56	1.28
Benzo(b)&(k)Fluoranthene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzo(e)Pyrene	0.55	0.93	0.36	2.11	1.28	0.47	2.56	1.11	1.39	2.11
Benzo(a)Pyrene	0.46	0.82	0.25	1.15	0.50	0.31	2.60	0.65	0.36	1.89
Perylene	0.00	0.22	0.01	0.16	0.01	0.01	0.29	0.11	0.01	0.56
2-Me-Cholanthrene	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Indeno(1,2,3-cd)Pyrene	0.50	0.94	0.30	1.75	0.96	0.43	1.93	0.91	0.80	1.94
Dibenzo(a,c)&(a,h)Anthracene	0.07	0.13	0.01	0.22	0.12	0.01	0.26	0.13	0.13	0.25
Benzo(b)Chrysene	0.05	0.07	0.01	0.12	0.01	0.01	0.15	0.01	0.02	0.14
Benzo(g,h,i)Perylene	0.54	0.98	0.32	1.89	1.02	0.53	2.11	0.96	0.86	1.90
Anthanthrene	0.08	0.17	0.01	0.19	0.08	0.01	0.27	0.11	0.03	0.31
Total PAH	31.38	48.68	20.38	191.97	64.58	68.44	133.88	118.26	35.24	96.91
TSP (µg/m³)	28.64	44.50	20.38	113.78	92.21	30.94	63.60	48.80	35.70	101.46

Appendix 6d: Daily PAH values measured from 4:00 pm to midnight at Riviere-des-Prairies from December 7, 1998 to March 31, 1999 (continued)

Compounds (ng/m^3)	5-Feb-99	11-Feb-99	17-Feb-99	23-Feb-99	25-Feb-99	1-Mar-99	7-Mar-99	13-Mar-99	19-Mar-99	25-Mar-99	31-Mar-99
Acenaphthylene	8.82	11.27	24.06	25.18	24.68	11.53	6.39	12.64	2.01	2.88	11.58
Acenaphthene	2.01	4.02	7.47	7.17	3.75	6.48	2.38	4.25	0.83	0.94	2.79
Fluorene	5.17	7.96	14.97	13.00	14.89	8.40	5.59	9.82	1.76	1.84	6.62
2-Me-Fluorene	1.00	1.30	5.44	5.24	2.26	1.66	1.37	2.01	0.40	0.39	1.49
Phenanthrene	12.33	22.27	39.73	35.27	51.93	33.88	19.27	32.16	6.11	6.80	22.42
Anthracene	1.70	2.35	5.37	5.55	7.62	2.36	2.25	2.60	0.51	0.36	2.79
Fluoranthene	4.73	7.32	12.75	16.65	23.51	15.50	6.15	13.64	1.93	2.37	6.83
Pyrene	3.56	5.24	9.61	14.51	18.06	9.43	4.54	8.81	0.98	1.50	4.54
Benzo(a)Fluorene	0.51	0.65	1.33	2.18	2.41	0.85	0.60	0.78	0.06	0.11	0.54
Benzo(b)Fluorene	0.22	0.32	0.70	1.22	1.20	0.42	0.34	0.39	0.01	0.06	0.23
1-Me-Pyrene	0.32	0.37	0.84	1.63	1.44	0.32	0.39	0.34	0.01	0.07	0.29
Benzo(g,h,i)Fluoranthene	1.04	1.17	2.11	2.93	3.36	1.01	0.99	1.56	0.14	0.32	1.06
Benzo(a)Anthracene	0.81	1.09	2.60	4.18	4.98	1.16	1.07	1.29	0.01	0.18	0.67
Chrysene	1.38	2.26	2.94	3.92	6.88	6.09	1.38	4.82	0.21	0.38	1.34
Triphenylene	0.30	0.56	0.54	0.70	1.64	1.87	0.42	1.39	0.09	0.13	0.35
Chrysene&Triphenylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7-Me-Benzo(a)Anthracene	0.01	0.01	0.01	0.08	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Benzo(b)Fluoranthene	1.84	2.98	3.74	4.63	8.68	10.21	1.65	8.39	0.35	0.64	2.16
Benzo(k)Fluoranthene	0.51	0.76	1.09	1.36	2.52	2.48	0.52	1.92	0.07	0.17	0.53
Benzo(b)&(k)Fluoranthene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzo(e)Pyrene	0.88	1.47	1.76	2.22	4.22	5.27	0.77	4.18	0.16	0.30	1.03
Benzo(a)Pyrene	0.56	0.84	2.15	3.50	4.10	0.95	0.65	1.86	0.01	0.22	0.50
Perylene	0.18	0.01	0.55	0.66	1.03	0.11	0.08	0.15	0.01	0.01	0.20
2-Me-Cholanthrene	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Indeno(1,2,3-cd)Pyrene	0.86	1.04	2.18	2.69	3.29	2.14	0.68	2.29	0.12	0.30	1.01
Dibenzo(a,c)&(a,h)Anthracene	0.11	0.14	0.28	0.37	0.50	0.38	0.08	0.30	0.01	0.01	0.12
Benzo(b)Chrysene	0.06	0.01	0.20	0.30	0.32	0.01	0.01	0.08	0.01	0.01	0.01
Benzo(g,h,i)Perylene	0.86	1.04	2.07	2.79	3.34	2.47	0.65	2.37	0.12	0.32	0.91
Anthanthrene	0.09	0.10	0.36	0.79	0.62	0.01	0.10	0.15	0.01	0.01	0.01
Total PAH	49.86	76.55	144.84	158.73	197.24	124.97	58.33	118.19	15.85	20.28	69.99
TSP (µg/m^3)	132.39	105.48	129.29	164.92	81.47	53.61	51.21	76.49	57.85	60.95	86.56