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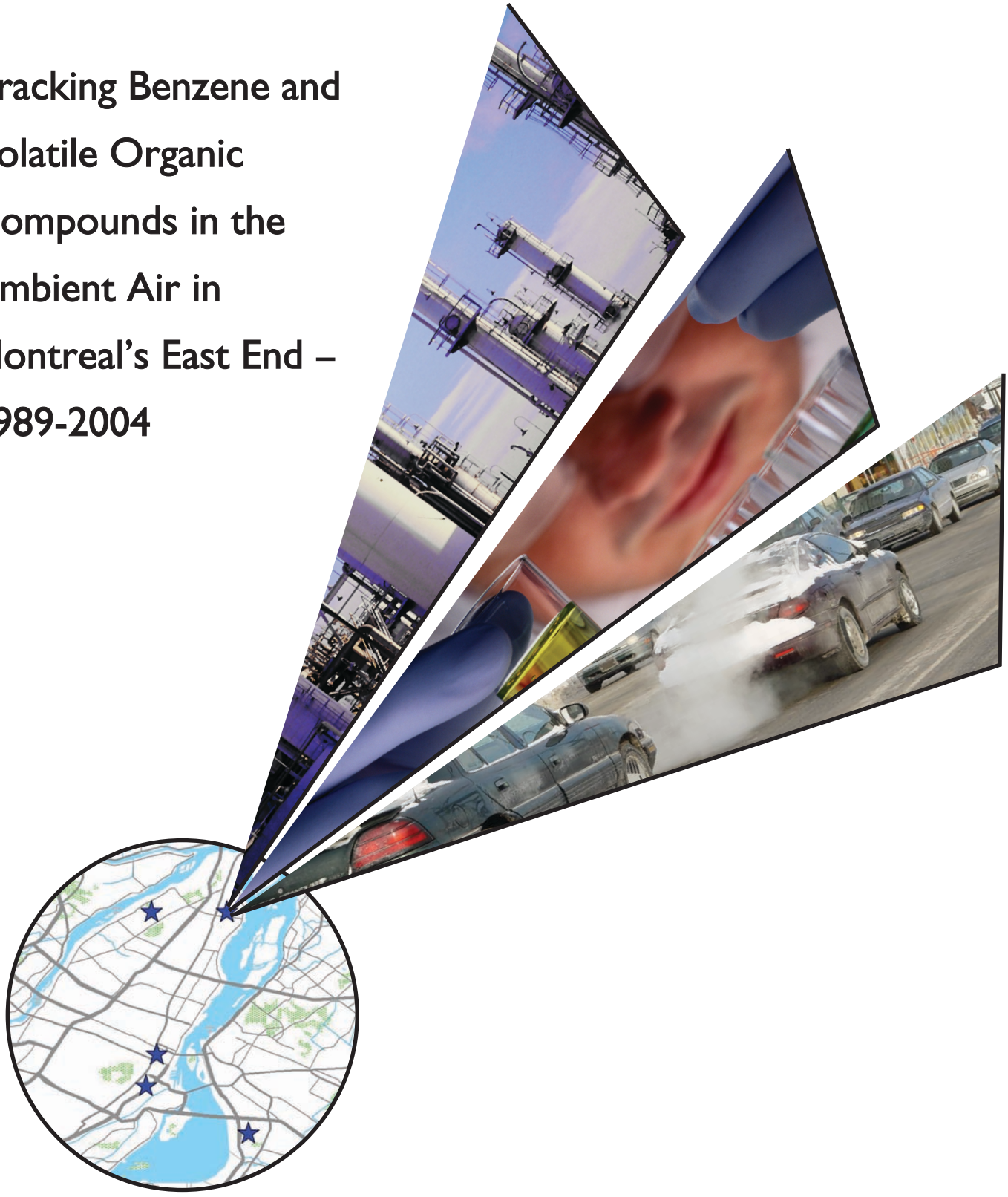
Tracking Benzene and Volatile Organic Compounds in the Ambient Air in Montreal's East End – 1989-2004



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Tracking Benzene and Volatile Organic Compounds in the Ambient Air in Montreal's East End – 1989-2004

Anne-Marie Carter and André Germain

Environmental Protection Operations Division
Environment Canada, Montreal (Quebec) 2006

Comments

Comments concerning the content of this report may be submitted to:

Anne-Marie Carter
Environmental Protection Operations Division
Environment Canada
105 McGill St., 4th Floor
Montreal (Quebec) H2Y 2E7

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Summary

Since 1989, high benzene concentrations have been measured in samples collected on a regular basis at the Pointe-aux-Trembles station. This report examines the impact of the 2003 opening of two petrochemical facilities on the emissions and concentrations of benzene and other volatile organic compounds (VOCs) in ambient air measured at Pointe-aux-Trembles and compares these results with concentrations measured elsewhere in Montreal.

National Pollutant Release Inventory (NPRI)

Six facilities in Montreal's East End reported benzene releases to the NPRI program. The benzene emissions reported declined 86% from 1995 to 2002 and increased 250% in 2004 compared to 2002. The increase is attributed to the re-opening of Coastal Petrochemical of Canada Ltd and the opening of the Interquisa Canada facility in 2003 as well as an increase in emissions by the Petro-Canada refinery. It is expected that corrective action taken by these three firms in 2004 should reduce emissions significantly for 2005.

The facilities in Montreal's East End reported to the NPRI total releases of three xylene isomers (*p*-xylene, *m*-xylene and *o*-xylene): 28 tonnes (t) in 2002, with an increase to 181 t in 2003 and to 319 t in 2004. Interquisa Canada is responsible for a large portion of the increase in releases in 2004. With respect to total VOCs, the bulk of the emissions reported originate from Petro-Canada, Shell Canada, Interquisa Canada, the Ultramar terminal and De Luxe paper products. From 2003 to 2004 both Interquisa Canada and the Ultramar terminal reported a significant increase in total VOC emissions.

Benzene measured at the Pointe-aux-Trembles station

From 1989 to 1997 in Pointe-aux-Trembles, benzene concentrations tended to rise, followed by a decline from 1998 to 2002, and a significant increase in 2003 and 2004. The minimum median annual concentration of benzene measured in 2002 (2.7 $\mu g/m^3$) was followed in 2004 by a 55% increase (4.3 $\mu g/m^3$) compared to 2002. The median annual concentration in 2004 was significantly greater ($p < 0.05$) than the median concentrations for the four previous years. The decrease in benzene concentrations observed as of 1998 can most likely be attributed to the closing of the Coastal Petrochemical of Canada Ltd plant, to benzene release decreases reported by the facilities in eastern Montreal, as well as to the various regulations implemented at that time, including the City of Montreal's Bylaw 90-3 concerning the recovery of gasoline vapours at terminals and service stations and the Benzene in Gasoline Regulations under the *Canadian Environmental Protection Act*. The benzene increase observed in 2004 reflects the increase in emissions reported to the NPRI by the facilities located in Montreal's East End. Preliminary results for benzene 2005 concentrations indicate that corrective measures taken in 2004 by industries resulted in benzene decreases in ambient air to 2002 levels at the Pointe-aux-Trembles station.

Benzene and volatile organic compounds measured in the Montreal region

From 1992 to 2002, benzene concentrations at Pointe-aux-Trembles were slightly higher, although they were in keeping with the levels measured at the Maisonneuve St. station. Nevertheless, in 2003 and 2004, while benzene concentrations increased at the Pointe-aux-Trembles station, they tended to decrease at the Maisonneuve and Ontario streets stations.

At the Pointe-aux-Trembles station, the maximum median concentration of *m*- and *p*-xylene measured in 2003 (5.6 $\mu g/m^3$) was significantly greater than that measured in 2002. This increase could correspond to

the increase in the emissions reported to the NPRI program (from 28 t in 2002 to 181 t in 2003). In 2004, despite the increase in emissions to 319 t reported to the NPRI, the median concentration measured in the ambient air decreased by 10% to 5.0 µg/m^3.

Toluene concentrations are generally higher at the Maisonneuve St. station, followed by the Pointe-aux-Trembles, Ontario St., Rivière-des-Prairies and Brossard stations. At Pointe-aux-Trembles, the annual median concentration decreased in 2002, increased in 2003, decreased in 2004. There is no significant difference among these values. The medians do not reflect trends in emissions reported to the NPRI, but the average values seem more representative. In 2004, the average concentration of toluene increased by 17% to 8.0 µg/m^3, while the toluene emissions reported to the NPRI increased 39% to 135 t in 2004 compared to 2003.

For the period from 1989 to 2004, concentrations of aromatic hydrocarbons were generally higher at the Maisonneuve St. station, followed by the Pointe-aux-Trembles and Ontario St. stations. Concentrations at the Maisonneuve and Ontario St. stations tended to decline from 1989 to 2004. At the Pointe-aux-Trembles station, the concentrations of aromatic hydrocarbons and VOCs reached a peak in 1997, declined until 2002 and then surpassed concentrations at the Maisonneuve St. station in 2003 and 2004.

Polar volatile organic compounds

There have been relatively few fluctuations in the concentrations of polar VOCs at the Pointe-aux-Trembles station since 1990, compared to other VOC families. The median concentration decreased to 9.5 µg/m^3 in 2002, followed by an insignificant increase in 2003 and 2004 (to 10.6 µg/m^3). The trends were similar at the Ontario St. station.

Wind

For each wind direction, benzene concentrations were analyzed in relation to the number of hours the wind blew. It was observed that benzene concentrations rose when the wind blew from the south-south-west sector to the west-north-west sector and fell when the wind came from other directions. Thus, the average benzene concentrations in terms of wind direction were five and three times higher when the wind blew from the west and south-west rather from the north-east, reflecting the presence of the industrial sector to the south-west and west of the Pointe-aux-Trembles sampling station. Variations for toluene and xylenes showed results similar to those for benzene.

Conclusion

The results obtained indicate that the maximum benzene concentrations were measured in 1997, followed by a decrease from 1998 to 2002 and an increase in 2003 and 2004. For 2005, preliminary results show a decline in benzene concentration in ambient air to 2002 levels. This report presents the impact of the opening of two petrochemical plants on benzene and other VOC concentrations in ambient air in Montreal's East End.

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- Tom Dann of Environment Canada's Environmental Technology Centre;
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List of abbreviations and acronyms

BRO	Brossard sampling station
CEPA (1999)	*Canadian Environmental Protection Act (1999)*
EPA	US Environmental Protection Agency
km/h	Kilometres per hour
m	Metre
MAI	Maisonneuve St. sampling station
MDDEP	Quebec's Ministère du Développement durable, de l'Environnement et des Parcs
NAPS	National Air Pollution Surveillance network
NO_x	Nitrogen oxides
NPRI	National Pollutant Release Inventory
ONT	Ontario St. sampling station
PAT	Pointe-aux-Trembles sampling station
$PM_{2.5}$	Fine particles with an aerodynamic diameter less than 2.5 µm
RDP	Rivière-des-Prairies sampling station
St.	Street
t	Tonne
Total VOCs	VOCs including the alkane, alkene/alkyne, aromatic hydrocarbon and halogenated organic compound families
VOC	Volatile organic compound
Xylenes	Mixture of three isomers (*p*-xylene, *m*-xylene and *o*-xylene)
$\mu g/m^3$	Microgram (10^{-6} gram) per cubic metre

Chapter 1

Introduction

The ambient air sampling station in Pointe-aux-Trembles, located in a suburb north-east of downtown Montreal, is different from the other stations on the Island of Montreal. The station is located near a petrochemical industry sector where high concentrations of benzene are found. For the period from 1989 to 1998, the average concentration of benzene measured at this station was 9.0 µg/m^3, the maximum concentration 126 µg/m^3. These values are higher than those measured at other sampling stations in Canada (Dann, 2000). The sampling station in Sault Ste. Marie, Ontario, was the only one to have a higher average concentration (10.3 µg/m^3) than Pointe-aux-Trembles during the period from 1989 to 1996 (Dann, 1999). In terms of prevailing winds, the Pointe-aux-Trembles sampling station is downstream from the industrial sector and upstream from the residential sector.

Germain *et al.* (2001) studied the problem of benzene in Montreal's East End and observed that the maximum values were measured when the winds came from the west-south-west, where the industries that report significant benzene emissions into the air are located. Their report concluded that automobile traffic also contributes to benzene emissions. Between 1989 and 2000, benzene concentrations decreased 60%, with the decline being more significant as of 1997. This decrease corresponds to a 62% reduction in emissions reported to the National Pollutant Release Inventory (NPRI) by the three petrochemical industries in Montreal's East End.

In May 2003, Coastal Petrochemical of Canada Ltd re-started its operations in the petrochemical sector in Montreal's East End after a four-year interruption. The company operates its units essentially to produce *p*-xylene, and partially to manufacture benzene. In September 2003, a second company, Interquisa Canada, also started operations, which involve manufacturing purified terephthalic acid from *p*-xylene.

This report deals with benzene and other volatile organic compound (VOC) concentrations measured in the ambient air at Pointe-aux-Trembles and elsewhere in Montreal. The possibility that the opening of two petrochemical facilities had an impact on benzene and aromatic hydrocarbon concentrations in ambient air in the western sector of Pointe-aux-Trembles was verified by analysing trends over time, meteorological and descriptive data, and comparing releases reported to the NPRI.

Chapter 2

History and regulatory framework

In the past century, Montreal's East End lay at the heart of industrial development. Up until the 1980s, the sector included petrochemical industries, with six refineries. However, over the past 20 years or so, economic decisions and re-organization of the petrochemical industries led to the closing of four refineries. Housing development also grew in Montreal's East End. Nevertheless, the sector is still an important chemical and petrochemical centre where five petroleum terminals and two petroleum refineries are now located (Bourassa, 2003).

The most reactive VOCs combine with nitrogen oxides (NO_x), causing photochemical reactions in the atmosphere and forming tropospheric ozone, a major component in smog. VOCs are also pollutants that serve as precursors for the secondary formation of fine particles ($PM_{2.5}$). It is known that ozone and $PM_{2.5}$ have harmful effects on human health and the environment. In 2003, the VOCs that take part in atmospheric photochemical reactions were added to the Toxic Substance List of the *Canadian Environmental Protection Act (1999)* (CEPA [1999]). Moreover, many VOCs are known to have or are suspected of having direct toxic effects on human beings, ranging from carcinogenesis to neurotoxicity. Some VOCs, including benzene, dichloromethane and formaldehyde, have been evaluated and declared toxic under the CEPA (1999) (Environment Canada, 2006).

A number of regulations issued by the City of Montreal and by Environment Canada under the CEPA (1999) have been in effect for several years in order to control or reduce benzene and VOC emissions into the environment. These regulations are presented in Table 1. Table 2 contains a list of events that occurred in the vicinity of the Pointe-aux-Trembles station which may well have had an impact on VOC emissions.

Germain *et al.* (2001) concluded that the closing of Coastal Petrochemical of Canada Ltd and the reduction of industrial emissions had an impact on benzene concentrations in the Pointe-aux-Trembles area. The reopening of Coastal Petrochemical and the opening of Interquisa Canada in 2003 could therefore have an impact on benzene and VOC concentrations in Montreal's East End.

Table 1 Regulations affecting VOC emissions

Effective	Regulation	Authority
1998	Bylaw 90-3, Article 6: recovery of gasoline vapours at terminals and service stations	City of Montreal
1999	Benzene in Gasoline Regulations: prohibits the sale of gas with a concentration of more than 1.5% benzene	CEPA
2000	Bylaw 90-5: addition of emission standards for the manufacturing of organic products by oxidation	City of Montreal
2001	Bylaw 90-6: addition of requirements concerning equipment for refineries, terminals and chemical and petrochemical plants; obligation to install floating roofs with double perimeter seals	City of Montreal
2001	Gasoline and Gasoline Blend Dispensing Flow Rate Regulations: prohibits the use of nozzles to distribute fuels if the flow exceeds 38 litres per minute	CEPA
2004	On-Road Vehicle and Engine Emissions Regulations: new standards for on-road vehicle hydrocarbon emissions, starting with 2004 models	CEPA
2005	Off-Road Small Spark-Ignition Engine Emission Regulations: introduces hydrocarbon emission standards for small engines such as those used on lawn and garden equipment, starting with 2005 models	CEPA

Table 2 Events having an impact on VOC emissions in Montreal's East End

Date	Event
January 1, 1999	Coastal Petrochemical of Canada Ltd ceases operations
January 1, 2000	Closing of a service station approximately 200 m from the Pointe-aux-Trembles sampling station*
May 1, 2003	Coastal Petrochemical of Canada Ltd re-starts operations
September 10, 2003	Interquisa Canada starts operations

* Three other service stations, located approximately 600 m from the Pointe-aux-Trembles sampling station, remain in operation (Bourassa, 2005).

Chapter 3

Sampling sites and schedule

Since 1969, Environment Canada has coordinated the National Air Pollution Surveillance (NAPS) network. The network's measuring stations are operated by the federal, provincial and municipal governments. Samples have been taken at certain stations since 1989 to determine public exposure to VOCs. For this study, the Pointe-aux-Trembles (PAT) sampling station served as the reference as it is located closest to the industrial sector in Montreal's East End (Figure 1). This station was set up to verify the air quality in the vicinity of the petro-chemical industries in Montreal's East End. The Rivière-des-Prairies (RDP) station is located north-west of the industrial sector and is primarily affected by residential wood heating in the winter. Of the other stations considered, two are located in downtown Montreal: the Maisonneuve (MAI) and Ontario (ONT) street stations, primarily affected by automobile traffic. The fifth sampling station is located in Brossard (BRO), a suburb on Montreal's South Shore representative of the semi-urban setting. Table 3 provides some of the characteristics of the five sampling stations.

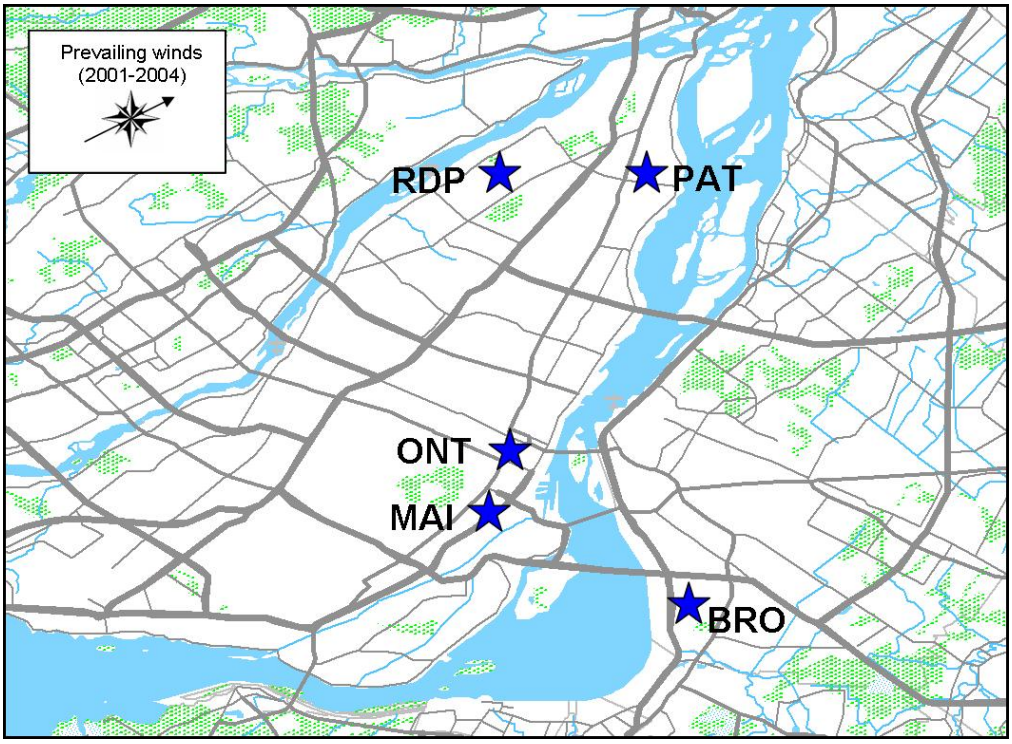


Figure 1 Location of sampling stations and prevailing wind direction

Table 3 Characteristics of sampling stations

Sampling stations	Surrounding area	Distance from the petrochemical industrial zone	Height of the sampling apparatus	Year of start-up
BRO	Residential, semi-urban	20 km	4 m	1993
MAI	Downtown	16 km	5 m	1992
ONT	Downtown	14 km	14 m	1989
PAT	Residential, urban	1 to 3 km	4 m	1989
RDP	Residential, urban	6 km	4 m	1998

The VOC sample collection follows the NAPS schedule, namely every sixth day for a period of 24 hours. In 2003, additional samples were taken at the PAT station, every second day from May to August, and almost every day from September to December, in order to verify the impact of the opening of the petrochemical plants in the industrial sector. Table 4 shows the number of samples taken at each station from 2001 to 2004.

Table 4 Number of samples taken per year

Year	Station				
	BRO	MAI	ONT	PAT	RDP
2001	58	54	53	58	55
2002	61	52	59	50	41
2003	60	58	48	144	56
2004	56	48	58	53	56
Total	235	212	218	305	208

The samples were collected using a *Summa*® 6-litre, stainless steel canister and a *Xontech*® sampler. The air intake flow was approximately 10 to 15 mL/min for a total volume of 14 to 21 L per sample. The samples were analyzed according to United States Environmental Protection Agency (EPA) method TO-14, which involves high resolution gas chromatography and quadrupole mass spectrometry (GC-MSD). The detection limit is 0.1 µg/m^3. The EPA TO-11 method was used to analyze the polar VOCs.

A total of 171 VOCs were measured. The VOCs are grouped into five chemical families:

- 46 alkanes, which contain simple bonds between carbon atoms;
- 43 alkenes and akynes, which contain double or triple bonds;
- 25 aromatic hydrocarbons, which include a benzene ring;
- 41 halogenated organic compounds, with chlorine or bromine atoms; and
- 16 polar VOCs which contain a carbonyl group.

Since polar VOCs are not analyzed at all stations, "total VOCs" refers to the sum of the concentrations of the first four families. A list of all the VOCs is appended.

Wind direction and speed data were obtained from the Montreal-East meteorological station, located 4 km from the PAT sampling station.

The results obtained were studied by comparing the medians to minimize the impact of extreme values. The medians are used to compare data for which there is no normal distribution and they better reflect the status of the environment. It is important to note that public exposure to pollutants is generally expressed by comparison of arithmetic means. To enable those who are interested to make these comparisons, the arithmetic means and median values have been added to the tables and figures.

Results

VOC releases reported to the National Pollutant Release Inventory

The National Pollutant Release Inventory (NPRI) provides information on releases and transfers of pollutants in communities. In Canada, the NPRI is the only national inventory prescribed under the CEPA accessible to the public. Generally, facilities must report to the NPRI if they meet all the criteria concerning type of activity and number of employees and if they manufacture, process or otherwise use a listed substance in quantities greater than the specified thresholds. It should be noted that the releases reported to the NPRI represent only a portion of releases into the Canadian environment. For example, emissions from transportation, residential wood heating and the residential use of solvents, are not included in the inventory.

Emissions of benzene, toluene, the three xylene isomers (*o*-xylene, *m*-xylene and *p*-xylene) and total VOCs in Montreal's East End were examined. Facilities must report these substances when they exceed the threshold of 10 t. Figure 2 indicates the location of these facilities in the sector.

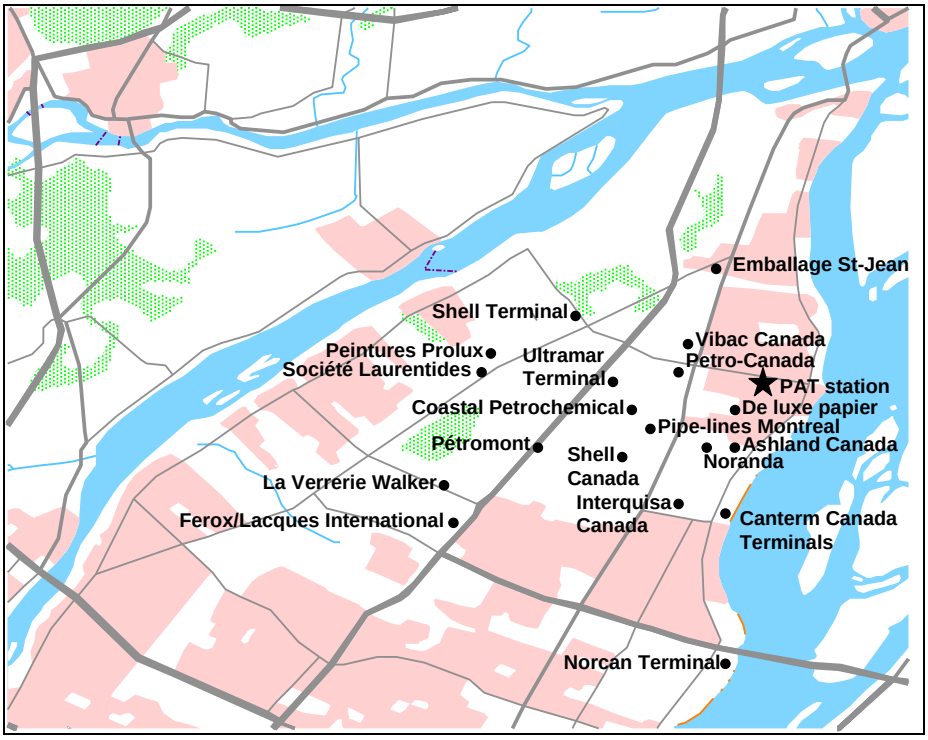


Figure 2 **Location of the PAT sampling station and facilities reporting VOC emissions to the NPRI program**

Six of the facilities in Montreal's East End reported benzene releases to the NPRI (Table 5). The total emissions reported to the NPRI decreased by 86% between 1995 and 2002. In 2004 benzene emissions increased significantly (to 250% of 2002 levels). The increase has three underlying causes: resumption of Coastal Petrochemical operations in 2003; increase in emissions from the Petro-Canada refinery; and opening of the Interquisa facility.

According to Bourassa (2005), the scrubbers at the Interquisa facility were only fully operational as of October 2004. It is expected that benzene emissions will decrease from 10 t in 2004 to 4 t in 2005, then to 1 t in 2006. As for the Petro-Canada facility, a new source of benzene identified at its water treatment plant was for the most part corrected in March 2005. It is therefore expected that emissions will decrease for 2005. Coastal Petrochemical restored its wastewater treatment plant in April 2005, which should also cause benzene emissions to decrease.

Table 5 Benzene releases reported to the NPRI for Montreal's East End from 1995 to 2004*

Year	Benzene releases (tonnes)						
	Interquisa Canada	Petro-Canada	Coastal Petrochemical	Shell Canada	Norcan Terminal	Ultramar Terminal	Total
1995	–	69.2	1.7	25.8	–	–	96.7
1996	–	63.8	5.8	26.3	–	–	95.9
1997	–	39.6	17.9	25.2	–	–	82.7
1998	–	32.7	7.6	14.2	–	–	54.5
1999	–	22.0	–	12.9	–	–	34.9
2000	–	26.4	–	8.6	–	–	35.0
2001	–	18.0	–	8.0	–	–	26.0
2002**	–	9.1	–	3.6	0.51	0.34	13.6
2003	4.8	10.9	3.8	4.0	0.51	0.36	24.4
2004	10.2	21.4	10.9	3.9	0.60	0.68	47.7

* Rounded to the nearest decimal.

** Different reporting criteria for 2002: petrochemical terminals with fewer than 10 employees reported in 2002 for the first time.

Table 6 examines toluene, xylene and total VOC releases for the facilities in Montreal's East End between 2001 and 2004. It should be noted that total VOCs have only been included as Criteria Air Contaminants (CAC) reported to the NPRI since 2002. Moreover, petrochemical terminals with fewer than 10 employees have been required to report their releases to the NPRI since 2002.

For 2004, the increase in toluene releases was attributed to Vibac Canada Inc., which doubled its releases compared to the previous year (from 36.5 t to 78.3 t). In the NPRI report, this facility states that the increase in releases for 2004 was due to a change in production levels. For the same period, Coastal Petrochemical almost tripled its toluene releases, from 4.5 t to 11.3 t. In the case of the three xylene isomers, the total releases reported to the NPRI by the facilities in Montreal's East End were 27.7 t in 2002, 181.4 t in 2003 and 318.7 t in 2004. Interquisa is responsible for the 2004 increase, with its releases increasing from 90.2 t to 199.2 t. Coastal Petrochemical reported an increase in its xylene releases, from 60.2 t to 84.4 t.

Table 6 Toluene, xylene and total VOC releases reported to the NPRI by facilities located in Montreal's East End from 2001 to 2004

Facility	Substance	Releases (tonnes)			
		2001	2002	2003	2004
Ashland Canada Inc.	Toluene	–	–	–	0.002
Canterm Canadian Terminals Inc.	Total VOCs*	–	–	40.9	62.6
Coastal Petrochemical of Canada Ltd	Toluene	–	–	4.5	11.3
	Xylenes	–	–	60.2	84.4
	Total VOCs	–	–	89.9	132.7
De Luxe produits de papier	Total VOCs	–	–	297.0	275.5
Emballage St-Jean	Total VOCs	–	–	86.2	65.5
Ferox / Laques International	Toluene	4.1	4.0	4.0	1.5
	Xylenes	3.8	3.8	3.8	1.3
Interquisa Canada	Xylenes	–	–	90.2	199.3
	Total VOCs	–	–	265.2	764.4
Noranda	Total VOCs	–	3.1	2.5	1.8
Norcan Terminal	Toluene	–	3.7	3.7	4.3
	Xylenes	–	6.4	6.4	7.5
	Total VOCs	–	56.0	67.3	79.3
Peintures Prolux Paint	Toluene	–	–	0.4	0.5
	Xylenes	–	1.2	1.1	1.2
Petro-Canada	Toluene	21.9	12.4	12.6	14.6
	Xylenes	15.7	3.1	2.9	8.3
	Total VOCs	–	755.0	821.0	834.2
Pétromont	Total VOCs	–	42.7	33.0	26.9
Pipe-lines Montréal Ltd	Total VOCs	–	22.6	22.4	22.4
Shell Canada Limited	Toluene	50.7	18.0	22.4	22.0
	Xylenes	26.8	9.2	13.1	12.4
	Total VOCs	–	1135.0	794.5	791.7
Shell Canada Terminal	Toluene	–	0.8	0.8	0.8
	Total VOCs	–	111.8	99.2	104.3
Société Laurentide Inc.	Total VOCs	–	–	–	56.9
Ultramar Terminal	Toluene	–	1.6	1.3	1.9
	Xylenes	–	1.2	0.8	0.9
	Total VOCs	–	113.8	106.4	279.8
La Verrerie Walker Ltd	Toluene	–	10.8	11.3	–
	Xylenes	–	2.8	2.9	3.4
	Total VOCs	–	30.6	34.8	33.3
Vibac Canada Inc.	Toluene	75.8	54.4	36.5	78.3
	Total VOCs	–	78.5	36.6	78.5
Total reported to the NPRI for Montreal's East End	Toluene	152.5	105.7	97.5	135.2
	Xylenes	46.3	27.7	181.4	318.7
	Total VOCs	–	2349.1	2796.9	3609.8

* Total VOCs include benzene, toluene and xylenes reported to the NPRI program.

With respect to total VOCs, the most significant releases, in descending order, came from Petro-Canada, Shell Canada, Interquisa Canada, the Ultramar terminal and De Luxe produits de papier. From 2003 to 2004, there was a sharp increase in the emissions reported by Interquisa (from 265.2 t to 764.4 t) and the Ultramar terminal (from 106.4 t to 279.8 t). In the 2004 NPRI report, Interquisa indicated that it had encountered major difficulties with various scrubbers and that one of the principal sources of benzene and other VOC emissions, which account for approximately 75% of the total VOCs, was dealt with in the fall of 2004. It also indicated that, in April 2005, another scrubber, which had contributed to the emissions, underwent major modification.

Changes in benzene and VOC concentrations measured at the PAT station over time

Figure 3 illustrates annual variations in benzene concentration in ambient air at the PAT station and benzene releases reported to the NPRI in Montreal's East End. Important variations in benzene concentrations at the PAT station are observed. Benzene concentration increased from 1989 to 1997, declined from 1998 to 2002, and then increased significantly in 2003 and 2004. Also, the 90th percentile values for the years 1989 to 1998 and in 2004 fluctuated significantly, which indicates that certain high concentrations were measured for those years. The maximum annual median was reached in 1997. The minimum annual median for benzene at PAT was measured in 2002 (2.74 µg/m^3) followed by an increase of 55% in 2004 (4.25 µg/m^3) compared to 2002. The annual median in 2004 was significantly higher ($p < 0.05$) than the medians for the four previous years. Preliminary benzene concentration data in ambient air at PAT were obtained and incorporated in figure 3. A 28 % median decrease was observed between 2004 and 2005.

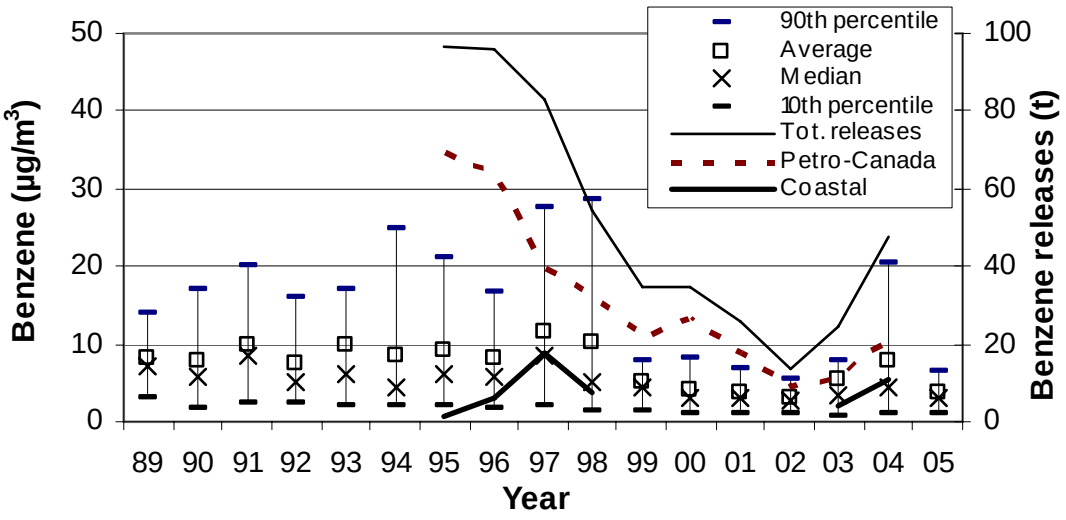


Figure 3 **Annual variations in benzene concentration in ambient air at the PAT station and benzene releases reported to the NPRI in Montreal's East End**

The decrease in benzene concentrations observed between 1998 and 2002 was probably linked to the closing of the Coastal Petrochemical plant, to benzene release decreases reported by the facilities in eastern Montreal and to the various regulations implemented at that time, including City of Montreal Bylaw 90-3 concerning the recovery of gasoline vapours at terminals and service stations and the Benzene in Gasoline Regulations under the CEPA. The increase in benzene concentrations observed in 2004 reflects the increases in benzene emissions reported to the NPRI by Coastal Petrochemical, Interquisa and the Petro-Canada refinery. These three facilities reported benzene emissions of 42.5 t for 2004, compared to 19.5 t for 2003.

In 2004, a program was initiated by the City of Montreal to identify new sources of benzene and address them (Bourassa, 2005). The observed benzene decrease in 2005 reflects the corrective measures taken. It is expected that the measures carried out to reduce industrial benzene emissions could reduce the average annual concentration in the ambient air to approximately 3 $\mu g/m^3$ in 2006, even more in the decade beginning in 2010.

Other substances were also examined at the PAT station to determine if they follow the same trend as benzene. In general, the other VOCs exhibit the same tendencies as benzene over time, namely higher concentrations until 1997 (not indicated in the figures). However, the decrease that began in 1998 continued until 2004, which was not the case for benzene. Table 7 indicates the concentrations of VOC families at the PAT station from 2001 to 2004. Only the annual average for the total aromatic hydrocarbon family increased by approximately 6% in 2004 compared to 2003. For the other families (alkanes, alkenes and alkynes and halogenated organic compounds), annual averages decreased 31%, 14% and 2% respectively. It is interesting to note that only the aromatic hydrocarbon family increased, although the annual average for total VOCs decreased by 19% from 2003 to 2004.

Table 7 Concentrations of VOC families measured at the PAT station from 2001 to 2004

Family	Year	Number of samples	Concentration ($\mu g/m^3$)				
			Average	Median	Standard deviation	Minimum	Maximum
Total aromatic hydrocarbons	2001	58	23.8	22.1	13.7	5.1	78.9
	2002	50	17.8	16.9	9.8	2.5	46.8
	2003	144	24.9	22.0	22.5	1.9	176.2
	2004	53	26.5	22.1	19.1	3.7	81.5
Total alkanes	2001	58	66.7	69.7	38.6	12.1	160.3
	2002	50	61.8	50.2	50.8	9.5	314.1
	2003	144	75.4	64.1	85.6	5.0	663.4
	2004	53	52.0	53.0	32.5	7.2	142.7
Total alkenes and alkynes	2001	58	18.8	17.0	9.2	5.4	48.4
	2002	50	15.9	14.3	8.4	4.5	47.8
	2003	144	13.5	9.3	25.9	1.2	289.8
	2004	53	11.7	10.2	6.4	2.2	28.5
Total halogenated organic compounds	2001	58	12.2	12.0	2.1	8.7	18.3
	2002	50	11.3	11.1	1.6	8.7	17.0
	2003	144	10.3	9.9	1.9	7.9	17.3
	2004	53	10.1	9.3	2.8	7.1	25.1
Total VOCs	2001	58	121.6	124.5	58.7	34.7	250.0
	2002	50	106.9	97.9	63.0	29.6	374.0
	2003	144	124.2	106.3	122.4	16.2	1033.3
	2004	53	100.3	97.3	55.0	22.2	259.6

Changes in benzene and VOC concentrations measured in the Montreal region over time

Figure 4 compares the annual median concentrations of benzene, total aromatic hydrocarbons and total VOCs measured at the PAT, MAI and ONT stations from 1989 to 2004. Generally, benzene concentrations were slightly higher at the PAT station, but they followed the same trends as the concentrations measured at the MAI station. The benzene concentrations were clearly higher at the PAT station in 1997 and increased significantly from 2003 to 2004, while benzene concentrations continued to decrease at the MAI and ONT stations.

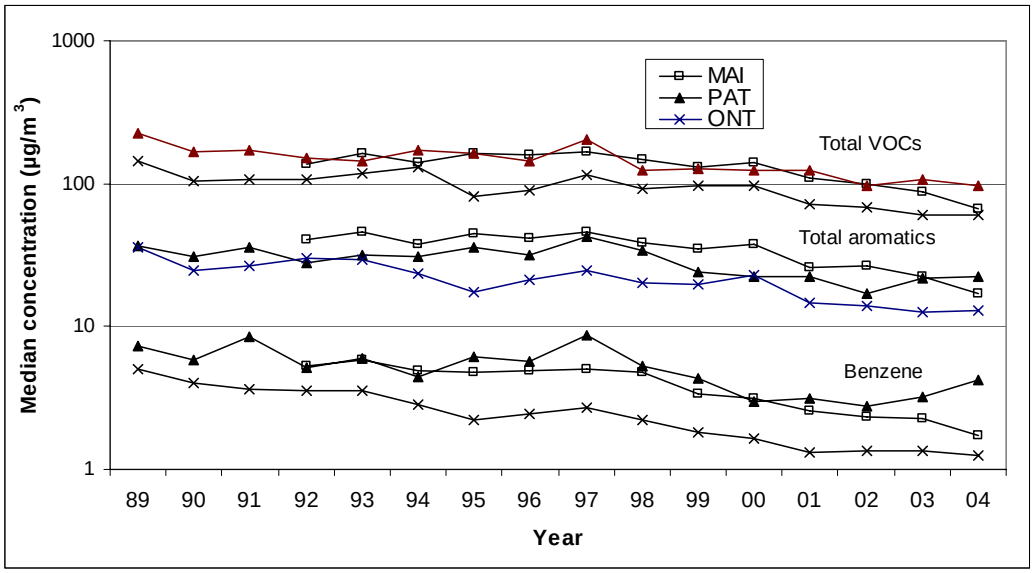


Figure 4 **Annual median variations of benzene, total aromatic hydrocarbons and total VOC concentrations at the PAT, MAI and ONT stations from 1989 to 2004**

In general, total aromatic hydrocarbon concentrations were highest at the MAI station, followed by the concentrations measured at the PAT and ONT stations for the period from 1989 to 2002. At the MAI and ONT stations, concentrations tended to decrease from 1989 to 2004. At the PAT station, concentrations of aromatic hydrocarbons and total VOCs attained their maximum levels in 1997, decreased until 2002, and then exceeded concentrations at the MAI station in 2003 and 2004. Minimum annual median concentrations of aromatic hydrocarbons and total VOCs were measured in 2002 at the PAT station. Between 2002 and 2004, concentrations of total aromatic hydrocarbons increased 30%, while total VOCs stabilized (difference of 0.6%) during this same period.

Figure 5 shows the annual concentration variations of benzene, *m*- and *p*-xylenes and toluene at the five sampling stations between 2001 and 2004.

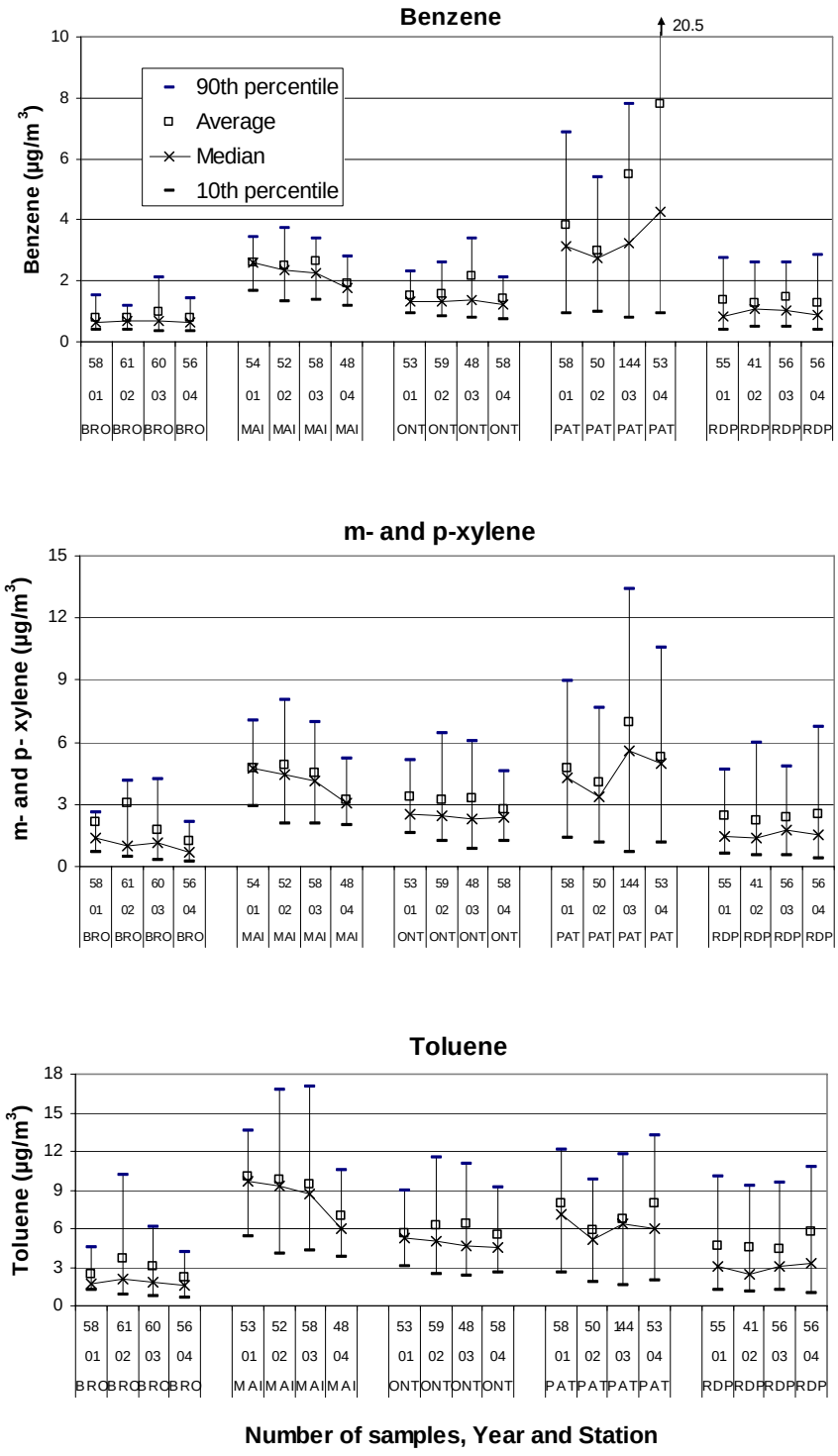


Figure 5 **Annual variations in benzene, *m*- and *p*-xylene and toluene concentrations at the five sampling stations from 2001 to 2004**

The PAT station had the highest concentrations of benzene and *m*- and *p*-xylene, followed by the MAI, ONT, RDP and BRO stations. Generally, the median concentrations of benzene and *m*- and *p*-xylene decreased at all the stations from 2001 to 2004, with the exception of the PAT station. The benzene concentration was significantly higher ($p < 0.05$) in 2004 compared to the previous years. At the PAT station, the maximum median concentration of *m*- and *p*-xylene measured in 2003 (5.57 µg/m^3) was significantly higher than that measured in 2002. This increase could correspond to the increase in emissions reported to the NPRI program (from 28 t in 2002 to 181 t in 2003). In 2004, although an increase in emissions was reported to the NPRI (up to 319 t), the median concentration measured in the ambient air decreased by 10% to 4.98 µg/m^3.

Toluene concentrations were generally higher at the MAI station, followed by the PAT, ONT, RDP and BRO stations. At the PAT station, the annual median concentration decreased in 2002, increased in 2003, and decreased in 2004. There was no significant difference among these values. Although the medians do not follow the trends with respect to the emissions reported to the NPRI, the average concentrations seem more representative. In 2004, the average concentration of toluene increased by 17% to 7.95 µg/m^3, while the toluene emissions reported to the NPRI also increased by 39% to 135 t in 2004 compared to 2003.

The concentrations of polar VOCs measured at the PAT station are shown in Figure 6. Since 1990, there has been relatively little fluctuation in concentrations compared to the other VOC families. The median concentration also decreased to 9.5 µg/m^3 in 2002, followed by a non significant increase in 2003 and 2004 (to 10.6 µg/m^3). The trends were similar at the ONT station (not shown in the figure). Several polar VOCs (including formaldehyde, acetaldehyde, benzaldehyde and *m*-tolualdehyde) were also studied. Concentrations of these substances tended to decline from 1999 to 2004.

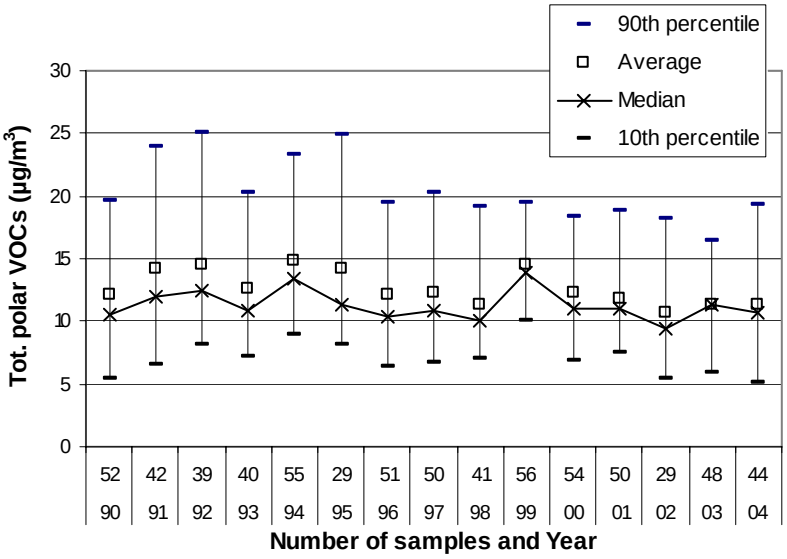


Figure 6 Annual variations in total polar VOCs at the PAT station from 1990 to 2004

Days for which high concentrations were measured at the PAT station

Table 8 indicates the days when benzene concentrations measured at the PAT station were greater than 20 µg/m^3. On May 17, 2003, the benzene concentration was 130 µg/m^3, approximately 25 times greater than the average concentration of 5.2 µg/m^3 measured during the period from 2001 to 2004, whereas the usual values were measured for the other VOCs. For that day, the prevailing winds blew from the north-east to the east. No explanation has been found to account for the high benzene concentrations measured that day.

On October 20, 2003, the benzene concentration climbed to 120 µg/m^3, and the values measured for the other VOCs were also greater than average. On that day, prevailing winds were light, from the south-west to the west. Considering the direction of the wind, it is possible that an industrial incident was responsible for these high values.

In 2001 and 2002, the benzene concentrations did not exceed 20 µg/m^3, whereas they surpassed this level on two and six occasions in 2003 and 2004. Generally, when benzene concentration increases, concentrations of other VOCs, such as the alkane, alkene and alkyne families, also increase.

The second part of Table 8 shows the days for which the total VOC concentrations measured at the PAT station were greater than 250 µg/m^3. On September 17, 2003, the concentration of total VOCs measured was 1033 µg/m^3. The alkane family was ten times the average whereas the alkene and alkyne families were 20 times the average. A very light wind was blowing from the south to the west.

On May 19, 2003, the concentration of total VOCs was 825 µg/m^3. The values for the alkane, alkene and alkyne families were 10 times greater than average.

We looked into a possible relationship between days for which VOC concentrations were high and reported smog days. The smog days considered were those when the concentration of ozone or fine particles ($PM_{2.5}$) was greater than 82 parts per billion or 35 µg/m^3, respectively. No smog warnings were issued for the days indicated in Table 8, with the exception of February 27, 2004. On that day, the smog was caused by a high $PM_{2.5}$ concentration.

On all the days for which total VOC concentrations were high, the prevailing winds were light from south-west to west. The petrochemical industrial sector is located in this zone and is likely responsible for these high values.

Table 8 Days for which benzene and VOC concentrations were high, wind direction and average daily wind speed from 2001 to 2004

	Date	Concentration (µg/m^3)						Prevailing wind direction and number of hours	Wind speed (km/h)
		Benzene	Total aromatic hydrocarbons	Total alkanes	Total alkenes and alkynes	Total halogenated organic compounds	Total VOCs		
2001-2004 period	**Median**	3.2	21.0	58.6	11.6	10.5	104.8	–	–
	Average	5.2	23.8	67.4	14.6	10.8	116.7	–	–
In decreasing order of benzene concentration above 20 µg/m^3	2003-05-17	130.1	149.4	70.9	9.3	11.0	240.6	N-E to E: 16 hrs S to S-E: 8 hrs	7.9
	2003-10-20	120.1	176.2	298.5	39.9	10.6	525.1	S to W: 19 hrs N to E: 4 hrs	10.7
	2004-05-27	41.9	74.4	64.1	12.2	11.0	161.6	S-E to W: 22 hrs	7.7
	2004-01-10	25.5	44.2	116.3	17.9	10.8	189.3	S to W: 23 hrs	12.1
	2004-02-15	24.4	41.7	68.4	14.4	8.7	133.1	S-W to W: 17 hrs	13.7
	2004-08-01	23.7	55.5	83.8	9.9	9.6	158.7	S-W to W: 24 hrs	14.7
	2004-01-16	21.8	40.9	109.2	16.5	10.5	177.1	W: 24 hrs	25.7
	2004-06-20	21.4	42.5	72.1	11.1	8.0	133.6	W: 23 hrs	17.7
In decreasing order of total VOC concentration above 250 µg/m^3	2003-09-17	11.6	65.7	663.4	289.8	14.4	1033.3	S to W: 24 hrs	6.6
	2003-05-19	7.3	83.2	614.1	110.5	17.2	825.0	S: 9 hrs	5.6
	2003-10-20	120.1	176.2	298.5	39.9	10.6	525.1	S-W to W: 19 hrs N to E: 4 hrs	10.7
	2002-10-05	3.8	26.9	314.1	22.9	10.1	374.0	S to W: 22 hrs	21.4
	2003-09-10	10.0	79.0	182.7	23.9	14.2	299.8	S-W to W: 21 hrs	11.7
	2003-07-08	5.2	35.9	234.9	15.4	10.6	296.9	S-W to W: 19 hrs N-W to N: 4 hrs	15.5
	2003-10-24	15.4	34.3	223.7	28.3	9.5	295.8	S-W to W: 21 hrs N-W: 3 hrs	14.5
	2003-10-28	7.1	33.2	233.6	16.0	8.6	291.4	S-W to W: 17 hrs N to N-E: 7 hrs	10.5
	2004-02-27	13.8	77.4	142.7	27.4	12.1	259.6	S-W to N-W: 19 hrs N-E to E: 5 hrs	7.6
	2001-10-22	5.4	39.5	160.3	37.3	12.9	250.0	S-W to W: 17 hrs S-W to S: 4 hrs	9.0

Wind rose

Figure 7 shows the wind rose for the period from 2001 to 2004 with 16 compass directions and the distribution of wind speed. There are two axes for the prevailing winds: wind that blows from the south-west to the west (approximately 40% of the time) and wind that blows from the north-north-east to the north-east (approximately 17% of the time). Calm wind, namely wind blowing at less than 1 km/h, occurs only 0.5% of the time, whereas winds from 1 to 10 km/h and from 11 to 20 km/h occur 44% and 48% of the time, respectively.

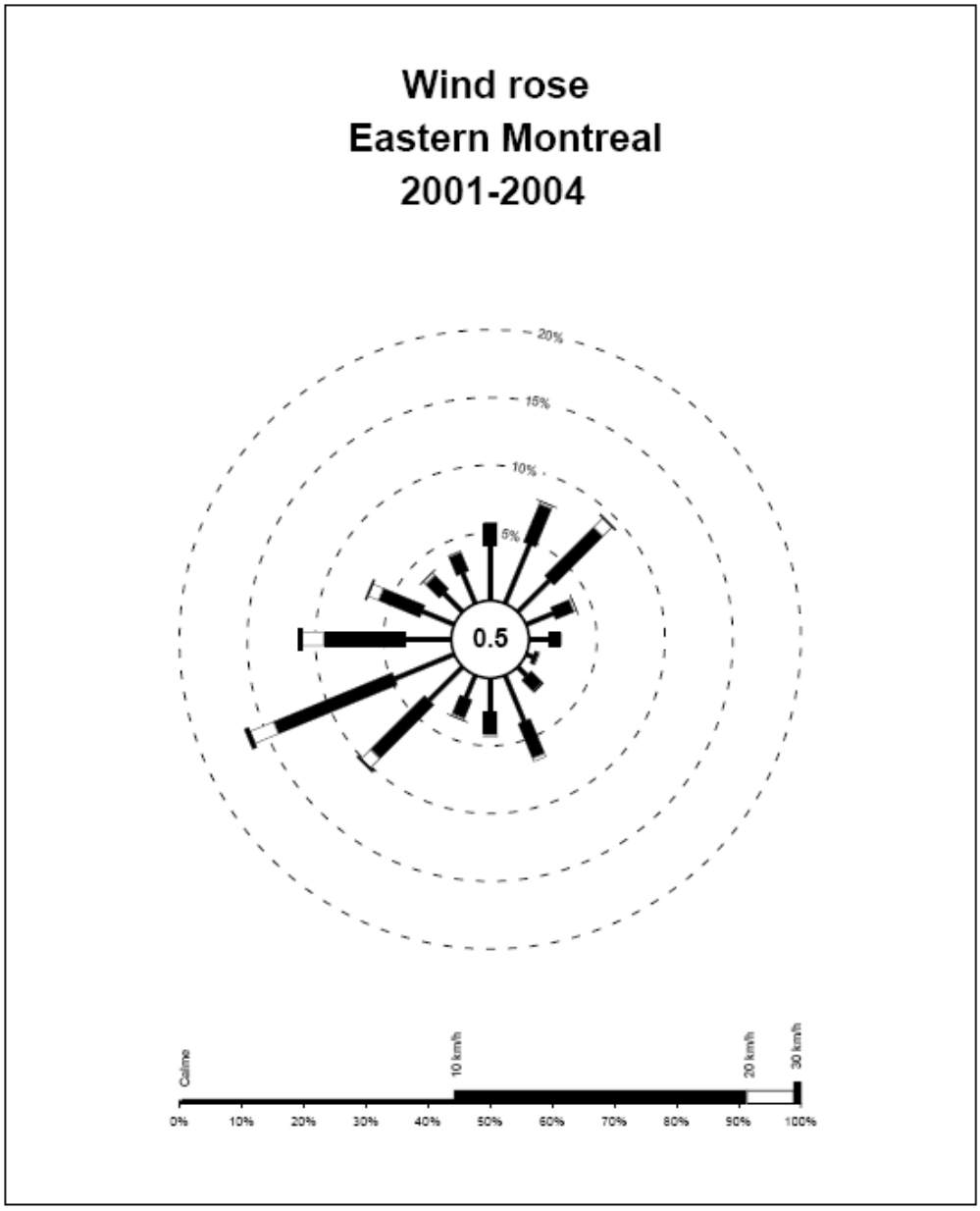


Figure 7 Wind rose and distribution of wind speed from 2001 to 2004

Relationship between benzene concentration and wind direction

In Figure 8, for each wind direction, the concentrations of benzene were analyzed along with the number of hours during which the wind blew between 2001 and 2004. Two dates were withdrawn from this analysis, namely May 17 and October 20, 2003, because the high benzene concentrations affected the averages. Benzene concentrations increase when the wind blows from the south-south-west to the west-north-west and decrease when the wind blows from other directions. Figure 9 provides more detail showing that the benzene concentrations increase when the wind blows from 240º to 260º, namely from the location of the facilities operated by Coastal Petrochemical, Pétromont and the Shell refinery. These results are similar to those obtained by Germain *et al*. (2001), with the exception of a slight shift in wind direction, from 250º to 270º, for the period from 1989 to 2000.

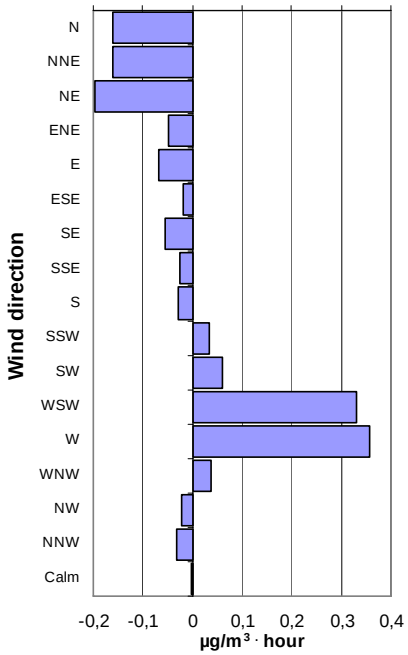


Figure 8 Variations in the rate of increase (decrease) in benzene concentration with wind direction at the PAT station from 2001 to 2004

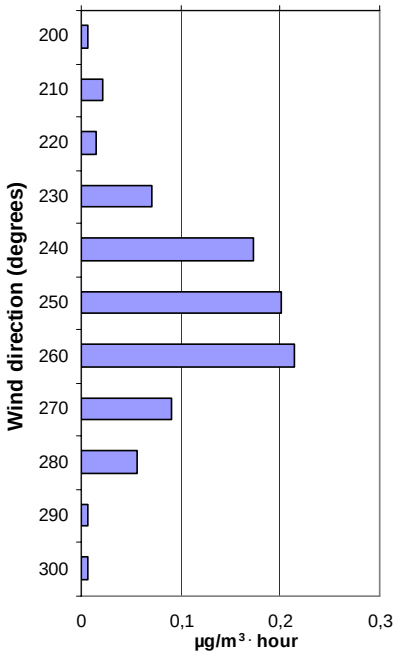
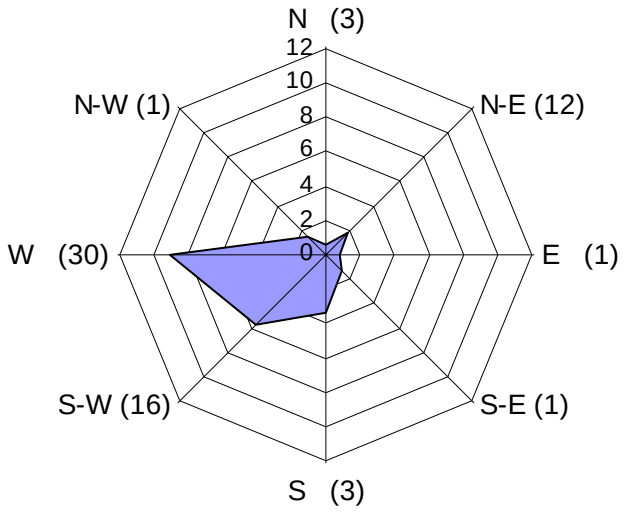


Figure 9 Variations in the rate of increase (decrease) in benzene concentration with wind direction at the PAT station from 2001 to 2004

Figure 10 shows average concentration of benzene in relation to wind direction for the days the wind blew for 15 hours or more by direction, from May 2003 to December 2004. The figures in parentheses represent the number of values used to calculate the averages for a possible total of 173 sampling days. Although the wind rose was divided into eight compass points in order to obtain more data per direction, only three points included a sufficient number of samples. When the wind blew from the south-west or the west for 15 hours or more, the average benzene

concentrations were 5.7 and 9.0 µg/m^3 respectively. When the wind blew from the north-east for 15 hours or more, the average concentration was only 1.7 µg/m^3. Analysis for toluene and xylenes revealed results similar to those for benzene.



Legend. – The units on the axis represent benzene concentrations. The numbers in parentheses represent the number of days the wind blew 15 hours or more for each direction.

Figure 10 Benzene concentration (µg/m^3) when wind blows 15 hours or more per direction

Contribution of VOCs

The relative presence, in percentage, of each of the VOCs was examined at the PAT and MAI stations. Table 9 indicates the contribution of the 15 VOCs most commonly found as well as the changes in rank that occurred from 2002 to 2004. At the MAI station, the concentrations of total VOCs decreased by 35% from 2002 to 2004, whereas a slight increase of 6.1% was noted for VOC concentrations at the PAT station during the same period. The 15 VOCs most commonly found account for approximately 62% and 68% of the total for the MAI and PAT stations, respectively.

In 2002, toluene was the substance most frequently found at the MAI station, followed by the three alkanes; whereas isopentane dominated at the PAT station, followed by butane, isobutane and toluene. The large amount of alkanes found at the PAT station can be explained by the presence of the petrochemical industry in Montreal's East End (Refining Process Services, 2002). In 2004, isopentane was still the dominant substance at the PAT station, but its concentration had declined by 27% (from 11.50 µg/m^3 to 8.41 µg/m^3; does not appear in the table). Concentrations and contributions of butane and isobutane decreased, but increased for such aromatic hydrocarbons as toluene, benzene and *m*- and *p*-xylene at the PAT station in 2004.

Table 9: Contribution (%) of the 15 most common VOCs at the MAI and PAT stations in 2002 et 2004

Rank	MAI station				PAT station			
	2002		2004		2002		2004	
	Substance	%	Substance	%	Substance	%	Substance	%
1	Toluene	8.4	Toluene	9.1	Isopentane	10.6	Isopentane	8.4
2	Isobutane	6.2	Isopentane	5.8	Butane	10.1	Toluene	7.9
3	Ethane	6.2	Ethylene	5.1	Isobutane	6.9	Benzene	7.8
4	Isopentane	5.7	Hexane	5.1	Toluene	5.4	Butane	7.6
5	Ethylene	4.7	Butane	4.6	Propane	5.1	Isobutane	6.1
6	Butane	4.7	Ethane	4.5	Pentane	4.7	m and p-Xylene	5.3
7	Propane	4.5	m and p-Xylene	4.3	m and p-Xylene	3.8	Propane	4.9
8	m and p-Xylene	4.2	Isobutane	4	Ethylene	3.4	Pentane	3.6
9	Freon12	2.8	Propane	3.8	2-Methylpentane	3	Ethylene	3.2
10	Pentane	2.5	Freon12	3.6	Ethane	2.9	Ethane	2.9
11	Dichloromethane	2.3	Freon11	3.1	Benzene	2.8	2-Methylpentane	2.7
12	Freon11	2.3	Freon22	2.5	Freon12	2.6	Freon12	2.6
13	Acetylene	2.3	Benzene	2.5	Freon11	1.8	Hexane	2.1
14	2-Methylpentane	2.2	Pentane	2.3	3-Methylpentane	1.8	3-Methylpentane	1.7
15	Benzene	2.1	Acetylene	2.3	Hexane	1.7	Freon11	1.7
	Total of 15 most common VOCs:	61.1%		62.6%		66.6%		68.5%
	Total VOCs:	100%		100%		100%		100%
	Tot.VOCs ($\mu g/m^3$):	116.1		75.9		106.9		100.3

The relative presence of benzene, which is of particular interest among the VOCs, increased from 2.1% to 2.5% between 2002 and 2004 at the MAI station, although the annual average concentration in the ambient air decreased from 2.52 µg/m^3 to 1.90 µg/m^3 (not indicated in the table). At the PAT station, the contribution of benzene increased from 2.8% to 7.8% over the same period, as did ambient air concentrations, from 3.00 µg/m^3 to 7.81 µg/m^3.

Compliance with standards

There are few standards that apply to benzene concentrations in the ambient air, either in Canada or internationally. Quebec's Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP) has set a provisional management criterion for benzene of 10 µg/m^3 over a 24-hour period. This criterion is defined as a reference threshold to manage air quality and is determined from a critical effect level, considering both environmental and socio-economic factors. It is tied to an acceptable level of risk (Government of Quebec, 2002). Table 10 indicates the number of sampling days for which the provisional management criterion for benzene was exceeded. In 2002 2%, and in 2004 26%, of the samples exceeded the criterion. Taking into account the industrial corrections made in 2004 (see page 8, a significant reduction in the number of days that exceed the provisional management criterion is expected for 2005 and 2006.

Table 10 Provisional management criterion for benzene exceeded in Montreal

Year	Number of days that exceed the provisional management criterion (%)		
	PAT	MAI	ONT
1990	26.4	*	0.0
1995	37.7	1.7	0.0
2000	5.4	0.0	0.0
2001	5.2	0.0	0.0
2002	2.0	0.0	0.0
2003	6.3	1.7	2.1
2004	26.4	0.0	0.0

* No sample.

Chapter 5

Conclusion

Benzene is of particular interest because high concentrations have been measured at the Pointe-aux-Trembles sampling station since 1989. This report demonstrates the impact of the opening of two petrochemical facilities in 2003 and provides an opportunity to examine the emissions and concentrations of benzene as well as the other aromatic hydrocarbons and VOCs measured at Pointe-aux-Trembles and compare the results with those for other sampling stations in Montreal.

Six facilities located in Montreal's East End reported benzene releases to the NPRI program. The benzene releases reported decreased by 86% between 1995 and 2002 and increased by 250% in 2004 compared to 2002. This increase is attributed to the re-opening of Coastal Petrochemical of Canada Ltd, the increase in emissions at the Petro-Canada refinery and the opening of the Interquisa Canada facility.

Benzene concentrations tended to increase at Pointe-aux-Trembles from 1989 to 1997, then decreased from 1998 to 2002. The decrease in benzene concentrations, which began in 1998, can probably be attributed to the reduction in emissions that followed the closing of the Coastal Petrochemical Canada Ltd plant and the various regulations implemented at that time, including the City of Montreal's Bylaw 90-3 concerning the recovery of gas vapours at terminals and services stations and the Benzene in Gasoline Regulations under the CEPA. A minimum annual median benzene concentration of 2.74 $\mu g/m^3$ was measured at Pointe-aux-Trembles in 2002. Following this, benzene concentrations increased by 55% in 2004 (4.25 $\mu g/m^3$) compared to 2002. This increase reflects the increase in emissions reported to the NPRI program by the facilities located in Montreal's East End. Preliminary results for 2005 indicate a decrease of benzene concentrations to 2002 levels. This decrease corresponds to corrective measures taken in 2004 to reduce industrial emissions in the sector.

From 1992 to 2002, benzene concentrations at Pointe-aux-Trembles were slightly higher than, although in keeping with, the concentrations measured at the Maisonneuve St. station. Nevertheless, in 2003 and 2004, while benzene concentrations were increasing at the Pointe-aux-Trembles station, they were decreasing at the Maisonneuve and Ontario St. stations. Moreover, at Pointe-aux-Trembles, despite the fact that total VOC concentrations decreased by 19% between 2003 and 2004, concentrations of the aromatic hydrocarbon family increased by 6%. This family includes toluene, benzene and *m*- and *p*-xylene.

For each wind direction, benzene concentrations were analyzed in relation to the number of hours during which the wind blew. It was noted that the benzene concentrations increased when the wind blew from the south-south-west to the west-north-west and decreased when the wind blew from other directions. The average benzene concentrations were five and three times higher when the wind blew from the west and the south-west rather than from the north-east. Variations for toluene and xylenes showed results similar to those for benzene. The industrial sector is located in the south-west sector to the west of the Pointe-aux-Trembles sampling station.

Recommendations

It is appropriate to continue to measure benzene and VOC concentrations at Pointe-aux-Trembles in order to observe future trends. It would be interesting to observe the medium-term impact of the start-up of operations at Coastal Petrochemical of Canada Ltd and the opening of the Interquisa Canada facility in 2003, as well as the effects of the corrective measures implemented at various plants in the industrial sector in 2004.

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Appendix

Table of 171 VOCs, listed within the five chemical families

Alkanes	Alkenes et alkynes	Halogenated organic compounds	Aromatic hydrocarbons	Polar VOCs
Ethane	Acetylene	Freon11	Benzene	Formaldehyde
Propane	Ethylene	Dibromomethane	Toluene	Acetaldehyde
Butane	1-Propyne	Carbontetrachloride	Styrene	Acrolein
Isobutane	Propylene	Dibromochloromethane	Ethylbenzene	Acetone
Cyclopentane	1,3-Butadiene	Bromoform	Indane	Propionaldehyde
Pentane	1-Butyne	Bromodichloromethane	iso-Propylbenzene	Crotonaldehyde
Isopentane	1-Butene/Isobutene	Chloroform	n-Propylbenzene	MEK
2,2-Dimethylpropane	trans-2-Butene	Chloromethane	sec-Butylbenzene	Benzaldehyde
Cyclohexane	cis-2-Butene	Bromochloromethane	tert-Butylbenzene	2-Pentanone/Isovaleraldeh.
Methylcyclopentane	Cyclopentene	Dichloromethane	iso-Butylbenzene	Valeraldehyde
2,2-Dimethylbutane	Isoprene	Freon22	Hexylbenzene	o-Tolualdehyde
2,3-Dimethylbutane	trans-2-Pentene	Bromomethane	m and p-Xylene	m-Tolualdehyde
3-Methylpentane	2-Methyl-1-butene	Bromotrichloromethane	o-Xylene	p-Tolualdehyde
2-Methylpentane	cis-2-Pentene	cis-1,2-Dichloroethylene	3-Ethyltoluene	MIBK
Hexane	1-Pentene	Ethylbromide	4-Ethyltoluene	Hexanal
Methylcyclohexane	2-Methyl-2-butene	Tetrachloroethylene	1,3,5-Trimethylbenzene	2,5-Dimethylbenzaldehyde
2,2,3-Trimethylbutane	3-Methyl-1-butene	Chloroethane	2-Ethyltoluene	
3-Methylheptane	2-Methyl-1-pentene	Trichloroethylene	1,2,4-Trimethylbenzene	
2-Methylheptane	Cyclohexene	EDB	1,2,3-Trimethylbenzene	
4-Methylheptane	1-Methylcyclopentene	trans-1,2-Dichloroethylene	1,3-Diethylbenzene	
Heptane	2-Ethyl-1-butene	1,2-Dichloroethane	Naphthalene	
3-Methylhexane	cis-2-Hexene	1,1-Dichloroethane	p-Cymene	
2,2-Dimethylpentane	1-Hexene	1,1,2-Trichloroethane	1,4-Diethylbenzene	
2,4-Dimethylpentane	3-Methyl-1-pentene	Freon114	n-Butylbenzene	
2,3-Dimethylpentane	trans-4-Methyl-2-pentene	1,1-Dichloroethylene	1,2-Diethylbenzene	
2-Methylhexane	cis-4-Methyl-2-pentene	Vinylchloride		
cis-1,4/t-1,3-Dimethylcyclohexane	4-Methyl-1-pentene	1,1,1-Trichloroethane		
cis-1,3-Dimethylcyclohexane	trans-3-Methyl-2-pentene	1,1,2,2-Tetrachloroethane		
cis-1,2-Dimethylcyclohexane	trans-2-Hexene	trans-1,3-Dichloropropene		
trans-1,4-Dimethylcyclohexane	cis-3-Methyl-2-pentene	1,2-Dichloropropane		
trans-1,2-Dimethylcyclohexane	2-Methyl-2-pentene	cis-1,3-Dichloropropene		
2,2,4-Trimethylpentane	1-Methylcyclohexene	Hexachlorobutadiene		
2,2-Dimethylhexane	cis-2-Heptene	1,4-Dichlorobutane		
Octane	trans-3-Heptene	Chlorobenzene		
2,4-Dimethylhexane	1-Heptene	1,3-Dichlorobenzene		
2,5-Dimethylhexane	cis-3-Heptene	1,4-Dichlorobenzene		
2,3,4-Trimethylpentane	trans-2-Heptene	1,2,4-Trichlorobenzene		
4-Methyloctane	1-Octene	1,2-Dichlorobenzene		
3-Methyloctane	cis-2-Octene	Freon12		
2,5-Dimethylheptane	trans-2-Octene	Benzylchloride		
2,2,5-Trimethylhexane	1-Nonene	Freon113		
Nonane	1-Decene			
3,6-Dimethyloctane	1-Undecene			
Decane				
Undecane				
Dodecane				