REPORT
1999 April 19

CITY OF BURNABY

ENVIRONMENT AND WASTE MANAGEMENT COMMITTEE

HIS WORSHIP, THE MAYOR
AND COUNCILLORS

RE: GVRD VOLATILE ORGANIC COMPOUNDS REPORT

RECOMMENDATION:

1. ***THAT*** Council request the GVRD to forward a copy of the report entitled "Volatile Organic Compounds in the Ambient Air of Greater Vancouver: 1990 - 1996" to the Simon Fraser Health Region for review and comment.

REPORT

The Environment and Waste Management Committee, at its meeting held on 1999 April 13, received the *attached* correspondence from the GVRD regarding a report on air contaminants known as volatile organic compounds. The objective of this report is to provide a cursory analysis of the trends in levels of total VOC's in the ambient air of Vancouver. A summary of the report is *attached* as Appendix 1.

Arising from discussion, the Committee requested that Council ask the GVRD to send a copy of the report to the Simon Fraser Health Region for review and comment.

Respectfully submitted,

Councillor D. Johnston
Chair

Councillor C. Redman
Member

Councillor D. Lawson
Member

: COPY - CITY MANAGER
- DIRECTOR ENGINEERING
- DIR. PLNG. & BLDG.

Greater Vancouver Regional District
4330 Kingsway, Burnaby, British Columbia, Canada V5H 4G8

General
Telephone (604) 432-6200
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Air Quality Department - Tel (604) 436-6700 Fax (604) 436-6707

March 16, 1999

File: AQ06 CO

City Clerk
City of Burnaby
4949 Canada Way
Burnaby, B.C. V5G 1M2

Dear Sir/Madam:

Re: Volatile Organic Compounds Report

Please find enclosed a copy of the report * "Volatile Organic Compounds in the Ambient Air of Greater Vancouver: 1990-1996.

Detailed data summaries are included within a Technical Appendix. A copy of the Technical Appendix may be obtained by request from the Air Quality Department for a fee of $10.00 (to cover the cost of duplicating and mailing).

We would be happy to respond to any questions or comments you may have with respect to these documents. Please contact me at 436-6747 (FAX: 436-6707) for further information.

Please advise Darlene Mollet (436-6705) of any corrections to the addressee or mailing address for distribution of future air quality reports.

Yours truly,

D. Mollet for KPS

Kenneth P. Stubbs
Administrator, Monitoring and Assessment
Air Quality Department

Enclosure

* COPY OF REPORT AVAILABLE IN CLERKS OFFICE

SUMMARY

VOC'S IN THE AMBIENT AIR OF GREATER VANCOUVER 1990-1996

The GVRD Air Quality Management Plan proposed a number of air contaminant emission reduction measures. As the projected emission reduction changes unfold, it is important to monitor the changes in ambient air quality.

The objective of this report is to provide cursory examination of trends in the levels of total volatile organic compounds (VOC's) in Greater Vancouver. The examination is performed for a *regional* perspective for the seven year period from 1990-1996. The report does not investigate cause and effect relationships. In addition, it is to be noted that the data in this report does not lend to be used for purposes other than *qualitative* assessment due to limitations in the temporal and spatial collection of VOC samples.

What are VOC's ? They are organic substances having one or more carbon atom and a specific (saturation) vapour pressure. Examples of VOC's are benzene, trichloroethylene, formaldehyde, propane. Sources of VOC's in the GVRD include emissions from petroleum refineries, fuel refilling facilities, combustion of fossil fuel (e.g. exhaust from vehicles), industrial and residential solvents, paint and other colouring materials, etc. Some VOC's can pose a human health risk.

The VOC monitoring program in the GVRD is conducted by Environment Canada with the assistance from the GVRD. The GVRD is responsible for sample collection whereas Environment Canada is responsible for sample analysis.

During the study period, nine sample sites were selected in the GVRD. Of these, two were in Burnaby (T4-Kensington Park; T22-7815 Shellmont Street). A total of 902 samples were collected over the seven year period. Sixty-four (7%) of the samples were from T4 and 159 samples (18%) were from T22.

The findings indicate that over the study period, the average concentration of Total VOC's decreased by 27.5%. Trends in the annual mean concentrations of the five toxic VOC's (Carbon Tetrachloride, Benzene, 1,1,1,-Trichloroethene, Vinyl Chloride, and Bromomethane) decreased and were mostly similar to those at sites in Montreal and Toronto.

COMPANION DOCUMENT
FOR ITEM 4(c), REPORTS
ON TONIGHT'S COUNCIL AGENDA

ENVIRONMENT & WASTE MANAGEMENT
COMMITTEE
RE: GVRD REPORT ON VOLATILE
ORGANIC COMPOUNDS

Apr 19, 1999

Volatile Organic Compounds in the Ambient Air of Greater Vancouver 1990 to 1996

Greater Vancouver Regional District

Volatile Organic Compounds in the Ambient Air of Greater Vancouver 1990 to 1996

Greater
Vancouver
Regional
District

Air Quality Department

February, 1999

Notice

Due to limitations in the temporal and spatial collection of VOCs samples, the data presented in this report should not be used for purposes other than *qualitative* assessements. For further information please contact the Air Quality Department of the Greater Vancouver Regional District.

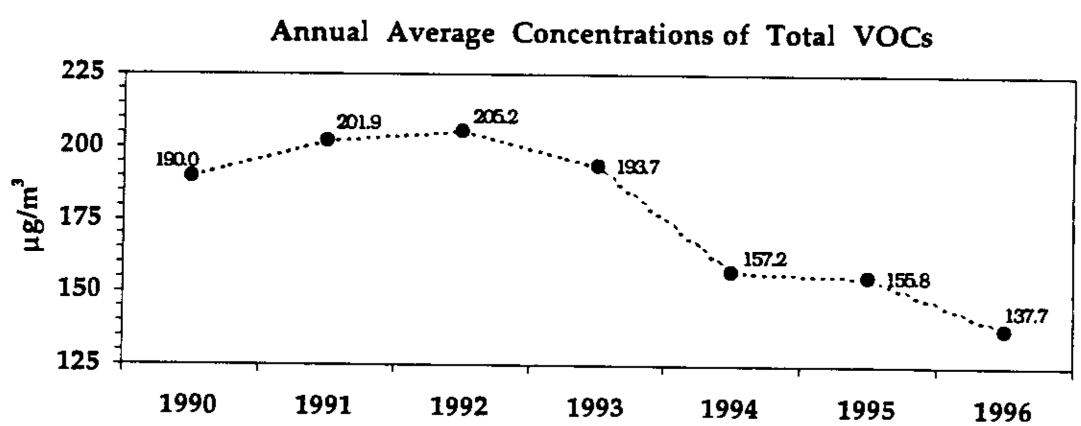
Executive Summary

Volatile organic compounds (VOCs) are organic substances which can exist in the gaseous, liquid and solid phase. The gaseous VOCs in the air can originate from direct gaseous emissions and from the volatilization of substances in the liquid and solid phase. VOCs are present or used in essentially all natural and synthetic materials, as diverse as flavour constituents and fossil fuels. Some VOCs are associated with a number of environmental issues on the local and global scale (e.g. smog and global climate change), while others can pose a human health risk.

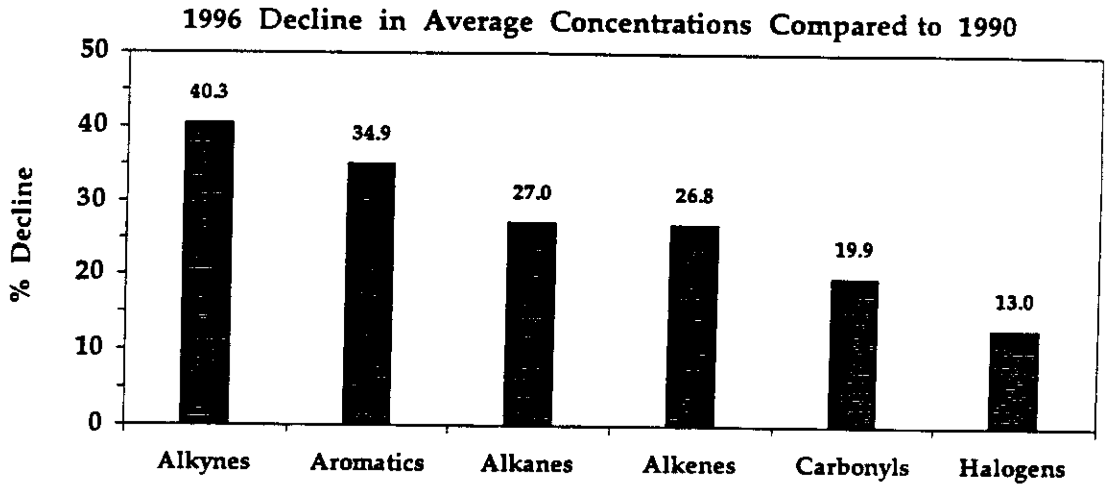
Gaseous concentrations are routinely determined for 166 VOCs in the ambient air of Greater Vancouver. These 166 compounds are collectively designated as Total *VOCs*. They are also classified into six categories according to the basic chemical structure of the compounds: alkanes, alkenes, alkynes, aromatics, halogens, and carbonyls.

The objective of this report is to provide a cursory examination of the trends in the levels of Total VOCs, of each VOC category and of seventeen health-risk VOCs in the ambient air of Greater Vancouver. The examination is performed from a *regional* perspective for the seven year period from 1990 to 1996 (the *study period*). The most abundant compounds over the study period are also identified.

Over the study period, the average concentration of Total VOCs decreased 27.5%, from 190.0 μg/m³ in 1990 to 137.7 μg/m³ in 1996. After increasing between 1990 and 1992, the average Total VOCs concentration decreased somewhat steadily between 1992 and 1996.



Declines also occurred for each of the six VOC categories. In 1996, average concentrations decreased the most for the alkynes and the least for the halogens with declines of 40.3 and 13.0% respectively compared to 1990.



Over the study period, the alkane and aromatic compounds were collectively the most and second most abundant compounds, providing 54.9 and 17.8% respectively of the mass of the average Total VOCs concentration. Compounds of alkenes, carbonyls, halogens and alkynes provided approximately 10.1, 8.0, 6.7 and 2.4% respectively of the mass. On a compound basis, approximately 75% of the mass of the average Total VOCs concentration was provided by only 23 of the 166 compounds. Butane, isopentane and toluene were the three most abundant compounds, and provided 10.5, 9.4 and 6.2% respectively of the mass.

Of seventeen health-risk VOCs considered in this report, annual mean concentrations were lower in 1996 than in 1990 for fifteen of them. The declines ranged from 3.6% for 1,3-butadiene to 78.5% for 1,1,1-trichloroethane. Mean concentrations of benzene declined 52.7%. The mean concentration was higher in 1996 than in 1990 only for formaldehyde, with an increase of 13.9%. Over the study period, trends in the annual mean concentrations of five toxic VOCs and formaldehyde at a Greater Vancouver site were mostly similar to those at sites in Montreal and Toronto.

Acknowledgments

This report was prepared by Domenico Mignacca of the GVRD Air Quality Department. The report was partly modeled after the document *Volatile Organic Compounds in the Ambient Air of the Province of Quebec* (February 1995) by Jean Tremblay and Tom Dann of Environment Canada (EC). Comments from Tom Dann and the Air Quality Department office staff were invaluable and their assistance is greatly appreciated. Daniel Wang of EC is also acknowledged for promptly providing all requested VOCs data. Finally, special thanks are extended to the field staff of the Air Quality Department for their dedicated work.

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1 INTRODUCTION

The Greater Vancouver Regional District (GVRD) Air Quality Management Plan (December 1994) proposed a number of air contaminants emission reduction measures (ERMs). Compared to emissions in 1985, the proposed and existing ERMs would together produce a 38% cumulative reduction in the collective emissions of nitrogen oxides, carbon monoxide, sulphur oxides, total suspended particulates and volatile organic compounds by the year 2000. The Plan also anticipated that the majority of any such reduction would occur before 1996, and that emissions would begin to gradually increase shortly after the year 2000 following the expected population growth. As these projected emission changes unfold, it is important to monitor the changes in ambient air quality.

Gaseous concentrations are routinely determined for 166 volatile organic compounds (VOCs) in the ambient air of Greater Vancouver. These 166 compounds are collectively designated as Total *VOCs*. They are also classified into six categories according to the basic chemical structure of the compounds (Section 1.2). A list of the 166 VOCs is provided in Table 1.

The objective of this report is to provide a cursory examination of the trends in the levels of Total VOCs, of each VOC category and of seventeen health-risk VOCs in the ambient air of Greater Vancouver[1]. The examination is performed from a *regional* perspective for the seven year period from 1990 to 1996 (the *study period*). The most abundant compounds over the study period are also identified. Cause and effect relationships are not investigated, while detailed statistical summaries of the concentrations of each of the 166 compounds are provided in a separate appendix (available on request).

It should be noted that, due to limitations in the temporal and spatial collection of the VOCs samples, the data presented in this report should not be used for purposes other than *qualitative* assessements.

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1 Trends in the ambient levels of ground-level ozone, nitrogen dioxide, carbon monoxide, sulphur dioxide and total suspended particulates were examined in the report *Trends in Ambient Air Quality in Greater Vancouver, 1987 to 1996*, GVRD, July 1998.

Table 1: List of the 166 VOCs.

ID #	Alkane Compounds
1	Ethane
2	Propane
3	Butane
4	Isobutane
5	Cyclopentane
6	Pentane
7	Isopentane
8	2,2-Dimethylpropane
9	Cyclohexane
10	Methylcyclopentane
11	2,2-Dimethylbutane
12	2,3-Dimethylbutane
13	3-Methylpentane
14	2-Methylpentane
15	Hexane
16	Methylcyclohexane
17	2,2,3-Trimethylbutane
18	3-Methylheptane
19	2-Methylheptane
20	4-Methylheptane
21	Heptane
22	3-Methylhexane
23	2,2-Dimethylpentane
24	2,4-Dimethylpentane
25	2,3-Dimethylpentane
26	2-Methylhexane
27	cis-1,4-Dimethylcyclohexane and t-1,3-Dimethylcyclohexane (combined)
28	cis-1,3-Dimethylcyclohexane
29	cis-1,2-Dimethylcyclohexane
30	trans-1,4-Dimethylcyclohexane
31	trans-1,2-Dimethylcyclohexane
32	2,2,4-Trimethylpentane
33	2,2-Dimethylhexane
34	Octane
35	2,4-Dimethylhexane
36	2,5-Dimethylhexane
37	2,3,4-Trimethylpentane
38	4-Methyloctane
39	3-Methyloctane
40	2,5-Dimethylheptane
41	2,2,5-Trimethylhexane
42	Nonane
43	3,6-Dimethyloctane
44	Decane
45	Undecane
46	Dodecane

ID #	Alkene Compounds
47	Ethylene (Ethene)
48	1,3-Butadiene
49	1-Butene and Isobutene (Combined)
50	trans-2-Butene
51	cis-2-Butene
52	Cyclopentene
53	Isoprene
54	trans-2-Pentene
55	2-Methyl-1-Butene
56	cis-2-Pentene
57	1-Pentene
58	2-Methyl-2-Butene
59	2-Methyl-1-Pentene
60	Cyclohexene
61	1-Methylcyclopentene
62	2-Ethyl-1-Butene
63	cis-2-Hexene
64	1-Hexene
65	3-Methyl-1-Pentene
66	trans-4-Methyl-2-Pentene
67	cis-4-Methyl-2-Pentene
68	4-Methyl-1-Pentene
69	trans-3-Methyl-2-Pentene
70	trans-2-Hexene
71	cis-3-Methyl-2-Pentene
72	2-Methyl-2-Pentene
73	1-Methylcyclohexene
74	cis-2-Heptene
75	trans-3-Heptene
76	1-Heptene
77	cis-3-Heptene
78	trans-2-Heptene
79	1-Octene
80	cis-2-Octene
81	trans-2-Octene
82	1-Nonene
83	1-Decene
84	Propylene (Propene)

ID #	Alkyne Compounds
85	Acetylene (Ethyne)
86	1-Propyne
87	1-Butyne

ID #	Aromatic Compounds
88	Benzene
89	Toluene (methylbenzene)
90	Styrene
91	Ethylbenzene
92	Indane
93	iso-Propylbenzene
94	n-Propylbenzene
95	sec-Butylbenzene
96	tert-Butylbenzene
97	iso-Butylbenzene
98	Hexylbenzene
99	m-Xylene and p-Xylene (combined)
100	o-Xylene
101	3-Ethyltoluene
102	4-Ethyltoluene
103	1,3,5-Trimethylbenzene
104	2-Ethyltoluene
105	1,2,4-Trimethylbenzene
106	1,2,3-Trimethylbenzene
107	1,3-Diethylbenzene
108	Naphthalene
109	p-Cymene
110	1,4-Diethylbenzene
111	n-Butylbenzene
112	1,2-Diethylbenzene

ID #	Halogen Compounds
113	Freon11 (Trichloromonofluoromethane)
114	Dibromomethane
115	Carbon Tetrachloride
116	Dibromochloromethane
117	Bromoform (Tribromomethane)
118	Bromodichloromethane
119	Chloroform (Trichloromethane)
120	Chloromethane (Methylchloride)
121	Dichloromethane
122	Freon22 (Difluorochloromethane)
123	Bromomethane (Methyl bromide)
124	Bromotrichloromethane
125	cis-1,2-Dichloroethylene (cis-1,2-dichloroethene)
126	Bromoethane (Ethylbromide)
127	Tetrachloroethylene (Tetrachloroethene)
128	Chloroethane
129	Trichloroethylene (Trichloroethene)
130	1,2-Dibromoethane
131	trans-1,2-Dichloroethylene [(E)-1,2-Dichloroethene]
132	1,2-Dichloroethane
133	1,1-Dichloroethane
134	1,1,2-Trichloroethane
135	Freon114 (1,2-dichloro-1,1,2,2-tetrafluoroethane)
136	Freon12 (Dichlorodifluoromethane)
137	1,1-Dichloroethylene (1,1-Dichloroethene)
138	Vinyl chloride (Chloroethene)
139	1,1,1-Trichloroethane
140	1,1,2,2-Tetrachloroethane
141	trans-1,3-Dichloropropene
142	1,2-Dichloropropane
143	cis-1,3-Dichloropropene
144	Hexachlorobutadiene
145	1,4-Dichlorobutane
146	Chlorobenzene
147	1,3-Dichlorobenzene
148	1,4-Dichlorobenzene
149	1,2,4-Trichlorobenzene
150	1,2-Dichlorobenzene

ID #	Carbonyl Compounds
151	Formaldehyde
152	Acetaldehyde (Ethanal)
153	Acetone (2-Propanone)
154	Propionaldehyde (Propanal)
155	Acroleine (2-Propenal)
156	Methyl Ethyl Ketone (2-Butanone)
157	Crotonaldehyde (2-Butenal)
158	Isovaleraldehyde (3-Methylbutanal)
159	Valeraldehyde (n-Pentanal)
160	Hexanal
161	Methyl Isobutyl Ketone (2-Pentanone)
162	Benzaldehyde
163	m-Tolualdehyde
164	o-Tolualdehyde
165	p-Tolualdehyde
166	2,5-Dimethylbenzaldehyde

1.1 VOCs Characteristics

Volatile organic compounds (VOCs) are defined as being *organic* substances containing one or more carbon atoms[2] and having a (saturation) vapour pressure of at least 10 Pa at 25 °C. VOCs can exist in the gaseous, liquid and solid phase. The gaseous VOCs present in the air can originate from direct gaseous emissions and from the volatilization (i.e. changing into the gas phase) of substances in the liquid and solid phase. VOCs are present or used in essentially all natural and synthetic materials. The number of known VOCs, their use and their sources are innumerable. VOCs are present or used in materials as diverse as the air we breathe, fossil fuels, motor vehicle exhaust, solvents, new carpets, wood smoke, alcoholic beverages, biocides, vegetation, fragrances and flavour constituents.

Some VOCs are associated with a number of environmental issues on both the local and global scale. Locally, some VOCs are part of the contaminants found in the urban smog and they are also the precursors of many other contaminants present in the smog (e.g. ground-level ozone and fine particulates). Globally, some VOCs (e.g. greenhouse gases) can contribute to climate change and to the depletion of the stratospheric ozone layer. Other VOCs (e.g. benzene) can also pose a human-health risk.

Sources of VOCs in the GVRD include emissions from the combustion of fossil fuels (e.g. exhaust from motor vehicles), industrial and residential solvents, paint and other coloring materials, vegetation, agricultural activities, petroleum refineries, fuel-refilling facilities, the burning of wood and other vegetative material, large industries, etc.

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2 Excludes carbon dioxide and carbon monoxide.

1.2 VOCs Categories

In this report, the 166 VOCs are classified into six categories according to the basic chemical structure of the compounds: alkanes, alkenes, alkynes, aromatics, halogens and carbonyls. The first four categories are hydrocarbons[3] and these are compounds which contain only hydrogen and carbon atoms. A very brief description of the basic chemical structure of the compounds in each of the six categories is provided below.

Alkanes. Alkanes are compounds in which *all* carbon atoms form a *single* bond with other atoms.

Alkenes. Alkenes are compounds in which *some* carbon atoms form a *double* bond with other carbon atoms.

Alkynes. Alkynes are compounds in which *some* carbon atoms form a *triple* bond with other carbon atoms.

Aromatics. Historically, the term *aromatic* was associated with a series of pleasant-smelling compounds. The term now refers to compounds where the carbon atoms occur in a ring-type pattern similar to the benzene ring.

Halogens. Halogens are compounds which, in addition to hydrogen and carbon, contain one or more atoms of bromine, fluorine and chlorine.

Carbonyls. Carbonyls consist of the two groups of compounds referred to as *aldehydes* and *ketones*. These are compounds which, in addition to hydrogen and carbon, contain an oxygen atom. This oxygen atom forms a double bond with a carbon atom. In aldehydes, at least one of the two other bonds of the oxygen-bonded carbon atom is with hydrogen only. In ketones, the two other bonds of the oxygen-bonded carbon atom are both with carbon.

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[3] The alkanes, alkenes and alkynes are collectively referred to as the *aliphatic* hydrocarbons.

2 VOCs MONITORING PROGRAM

VOCs monitoring in Greater Vancouver is conducted by Environment Canada with the assistance of the Air Quality Department of the Greater Vancouver Regional District (GVRD). The Air Quality Department is responsible for the collection of the VOCs samples and Environment Canada is responsible for determining the concentrations of the VOCs in these samples.

VOCs monitoring first began in late 1988. However, because the number of air samples collected in 1988 and 1989 is much lower than those in subsequent years, only the VOCs concentrations for the seven year period from 1990 to 1996 (the *study period*) are considered. During this period, concentrations were determined for 46 alkanes, 38 alkenes, three alkynes, 25 aromatics, 38 halogens and sixteen carbonyls.

2.1 Monitoring Method

VOCs samples are collected automatically by drawing ambient air into Summa-polished canisters over a 24 hour period (midnight to midnight). After collection, the samples are sent to Environment Canada in Ottawa. Various chemical analyses are then performed on these samples to determine the concentration of selected VOCs. The obtained concentrations represent a mean level for the 24-hour sampling period, and they are reported at a temperature of 25 ^{o}C and an atmospheric pressure of 101325 Pa. The average minimum detection limit of each compound in the chemical analyses is approximately 0.1 $\mu g/m^3$.

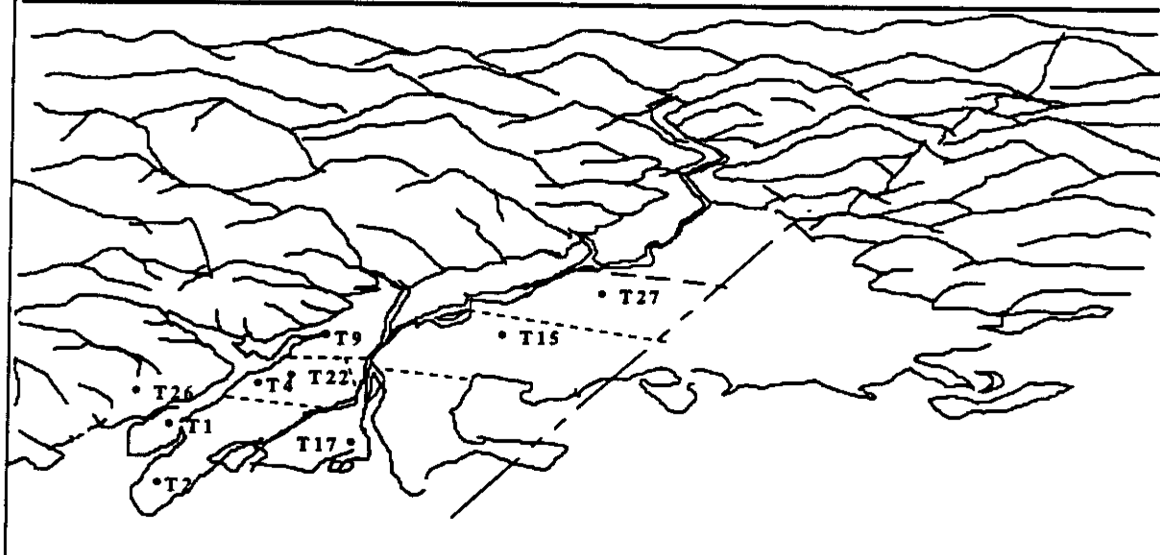
2.2 Sampling Sites

During the study period, VOCs samples were collected at nine sites in Greater Vancouver, as indicated in Table 2. Figure 1 provides an overview of the locations of these sites. It should be noted that concentrations of the carbonyl compounds were only determined at T9.

Table 2: The nine VOCs sampling sites.

Site	Name	Location
T1	Vancouver Downtown	Robson Square
T2	Kitsilano	Kitsilano High School (2550 W 10th Avenue)
T4	North Burnaby	Kensington Park
T9	Port Moody	Rocky Point Park
T15	Surrey East	19000 block of 72nd Avenue
T17	Richmond South	Williams and Aragon Road
T22	Burnaby Burmount	7815 Shellmont Street
T26	North Vancouver	Mahon Park
T27	Langley Central	D.W. Poppy Secondary School (23752 52nd Avenue)

Figure 1. Overview of the locations of the nine VOCs sampling sites.



2.3 Sample Collection Schedule

VOCs samples are mostly collected based on the monitoring schedule of the National Air Pollution Surveillance (NAPS) program of Environment Canada. In this schedule, a sample is scheduled for collection every sixth day. For the study period, however, samples were collected mostly on the NAPS schedule only at T9. Elsewhere, sampling was rotated between sites as determined by need and equipment availability. At T9, samples were also collected every day during July and August 1992. During July and August 1993, additional sampling was conducted at some of the nine sites as part of the Pacific 93 field study in the Lower Fraser Valley. The number of VOCs samples collected during the study period at each of the nine sites are presented in Table 3.

Table 3: Number of VOCs samples collected.

	T1	T2	T4	T9	T15	T17	T22	T26	T27	Total
1990	10	0	13	59	9	9	16	7	0	123
1991	7	0	9	48	7	7	12	10	0	100
1992	7	0	10	93	7	0	20	6	0	143
1993	3	6	5	58	5	7	29	2	7	122
1994	8	0	9	45	9	8	27	9	9	124
1995	7	0	9	73	9	7	29	7	9	150
1996	8	0	9	58	10	10	26	9	10	140
Total	50	6	64	434	56	48	159	50	35	902

3 DATA ANALYSES PROCEDURES

VOCs levels in Greater Vancouver are assessed from a *regional* perspective, and not individually for each of the nine monitoring sites. To achieve this, the VOCs concentrations from the nine sites are combined together by sampling date and *type* of VOC (i.e. Total VOCs, the six categories, and the individual 166 compounds). Statistics are then determined from this combined data.

The statistics presented in this report include: the annual *average* (as defined below) concentrations of Total VOCs and of each of the six VOC categories; the percentage mass contributions to a given average concentration; and the annual mean concentrations of seventeen health-risk VOCs. The percentage mass contributions are also used to identify the most abundant compounds.

Concentrations of Total VOCs and the VOC categories were not determined directly through chemical analyses. In this report, the *average* concentration of Total VOCs for a given time period is defined as being the sum of the means[4] of the individual compounds over that period. Similarly, the average concentration of a category is the sum of the means of the individual compounds within the category.

The percentage mass contribution of a given VOC category to the average Total VOCs concentration is defined as:

$$100 \times \frac{\text{Average concentration (in } \mu g/m^3\text{) of category}}{\text{Average concentration (in } \mu g/m^3\text{) of Total VOCs}}$$

Both averages in this equation are for the same time period. Other percentage mass contributions are similarly defined as in the above equation.

[4] The *mean* as used here is with its usual definition: the mean over a given time period is the sum of all concentrations in the time period divided by the number of concentrations. For Total VOCs and the categories, statistics such as the mean and standard deviation are only presented in the appendix.

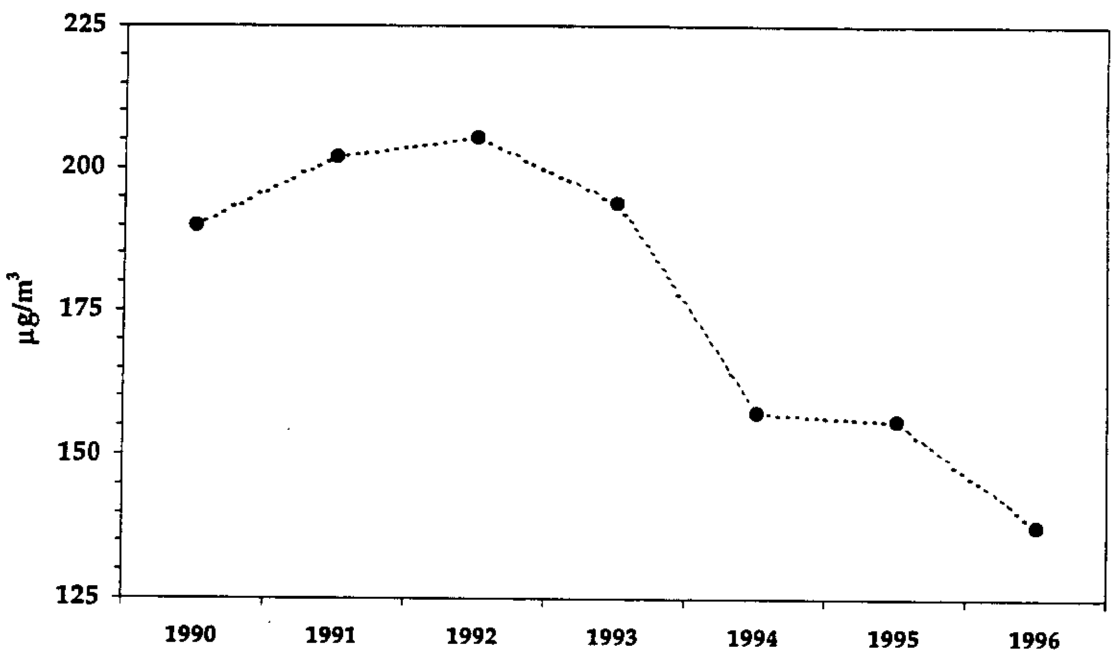
4 TOTAL VOLATILE ORGANIC COMPOUNDS

Concentrations were determined for a total of 166 compounds. A list of these VOCs is provided in Table 1.

Trends

The average concentration of Total VOCs decreased 27.5%, from 190.0 $\mu g/m^3$ in 1990 to 137.7 $\mu g/m^3$ in 1996 (Figure 2). After increasing between 1990 and 1992, the average Total VOCs concentration decreased somewhat steadily between 1992 and 1996.

Figure 2: Annual average concentrations of Total VOCs.

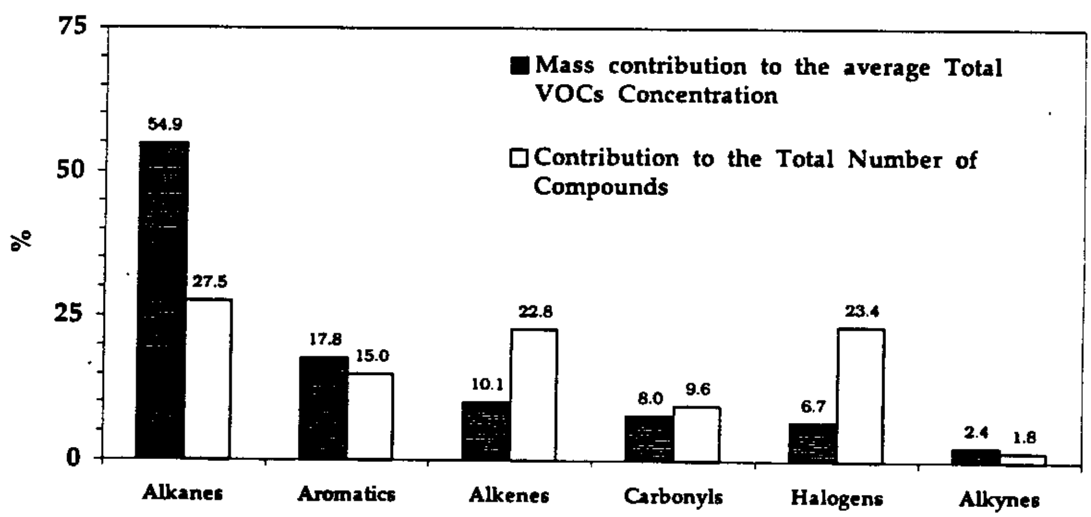


Most Abundant Compounds

The average Total VOCs concentration for the period 1990 to 1996 was 180.1 $\mu g/m^3$. The alkane and aromatic compounds were collectively the most and second most abundant compounds, providing 54.9 and 17.8% respectively of the mass of this average (Figure 3). Compounds of alkenes, carbonyls, halogens and alkynes provided approximately 10.1, 8.0, 6.7 and 2.4% respectively of the mass.

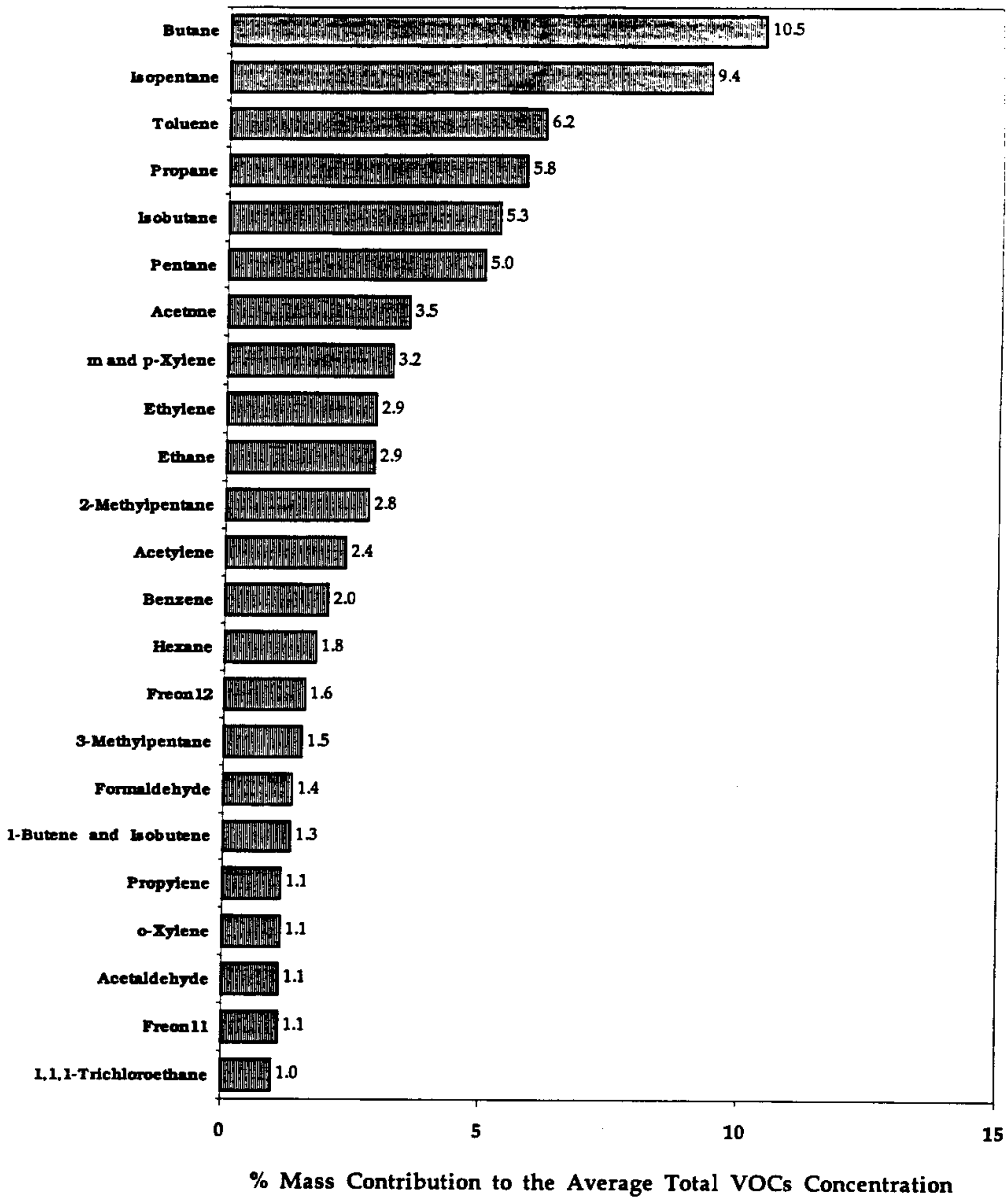
Figure 3 also includes the contributions to the total number of compounds. For the alkanes, although they provided 27.5% of the total number of compounds, the mass contribution was more than double this value. For the alkenes and halogens, however, although they each provided approximately 23% of the total number of compounds, the mass contribution was less than half of this value for both of them. For the aromatics, carbonyls and alkynes, the percentage mass contributions were more similar to their respective contributions to the total number of compounds.

Figure 3: Distribution of the mass of the average Total VOCs concentration and of the total number of compounds for the period 1990 to 1996.



On a compound basis, only 23 of the 166 compounds provided 1% or more of the mass of the average Total VOCs concentration, and thirteen of these provided 2% or more (Figure 4). Collectively, these 23 compounds provided approximately 75% of the mass. The contributions of the remaining 144 compounds were, therefore, relatively small. Five of the six most abundant compounds were alkanes. Butane and isopentane were the first and second most abundant compounds, providing 10.5 and 9.4% respectively of the mass of the average. Toluene was the third most abundant compound and the first most abundant non-alkane compound, providing 6.2% of the mass.

Figure 4: Most abundant compounds for the period 1990 to 1996.



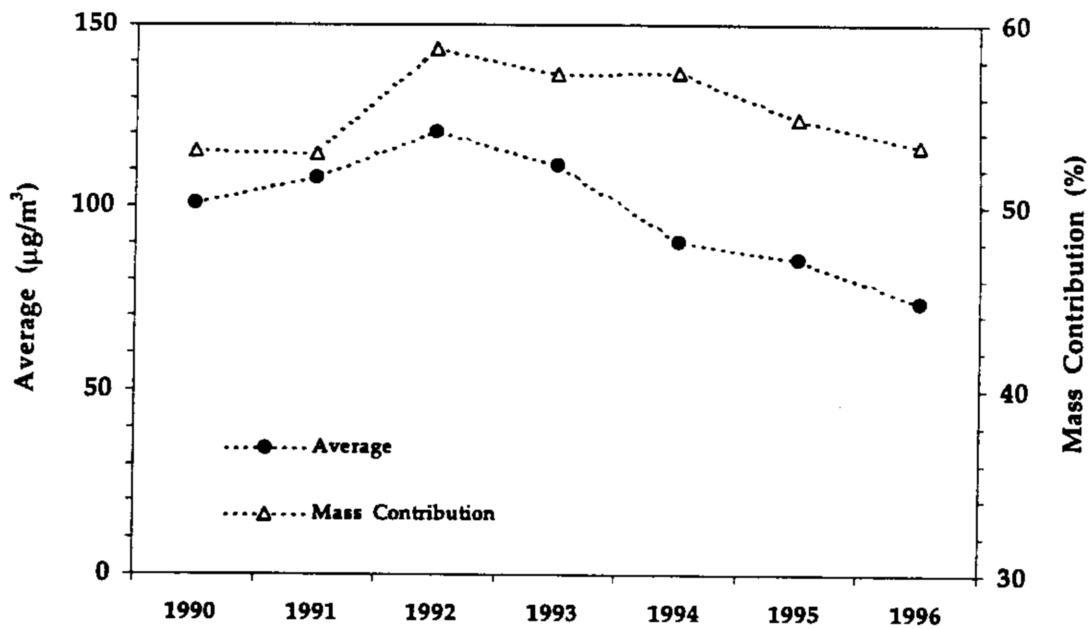
5 ALKANE COMPOUNDS

Concentrations were determined for 46 alkane compounds. A list of these compounds is provided in Table 1.

Trends

The average concentration of total alkanes decreased 27.0%, from 100.7 μg/m³ in 1990 to 73.5 μg/m³ in 1996 (Figure 5). After increasing between 1990 and 1992, the average total alkanes concentration decreased somewhat steadily between 1992 and 1996. In 1996, the alkane compounds provided 53.4% of the mass of the average Total VOCs concentration, remaining essentially unchanged from 1990 (53.0%).

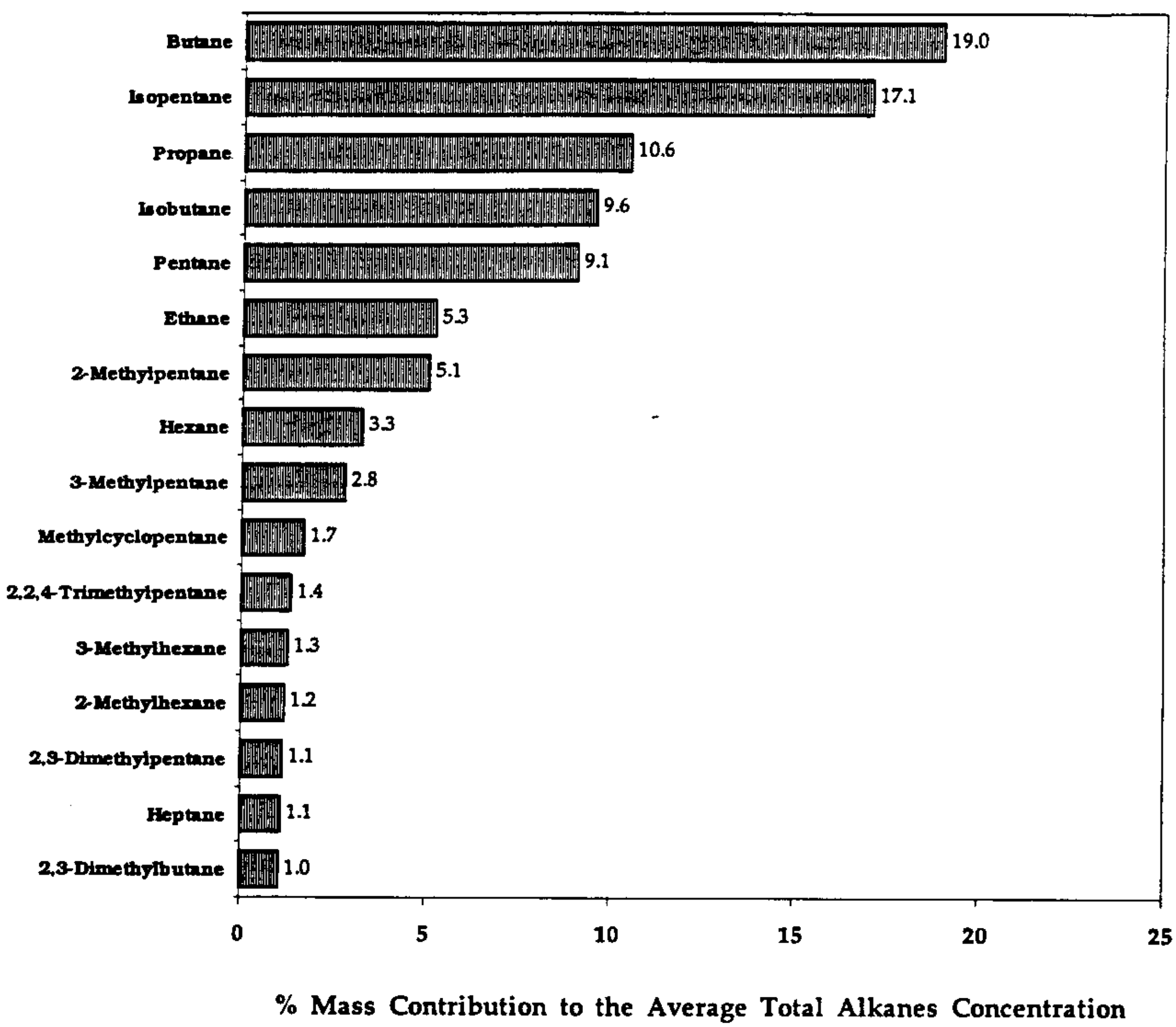
Figure 5: Annual average concentrations of total alkanes and mass contributions to the average Total VOCs concentrations.



Most Abundant Alkanes

The average total alkanes concentration for the period 1990 to 1996 was 98.4 $\mu g/m^3$. Of the 46 alkane compounds considered, only sixteen provided 1% or more of the mass of this average, and nine of these provided 2% or more (Figure 6). Collectively, these sixteen compounds provided approximately 90% of the mass of the average. Butane, isopentane and propane were the three most abundant alkanes, providing 19.0, 17.1% and 10.6% respectively of the mass.

Figure 6: Most abundant alkanes for the period 1990 to 1996.



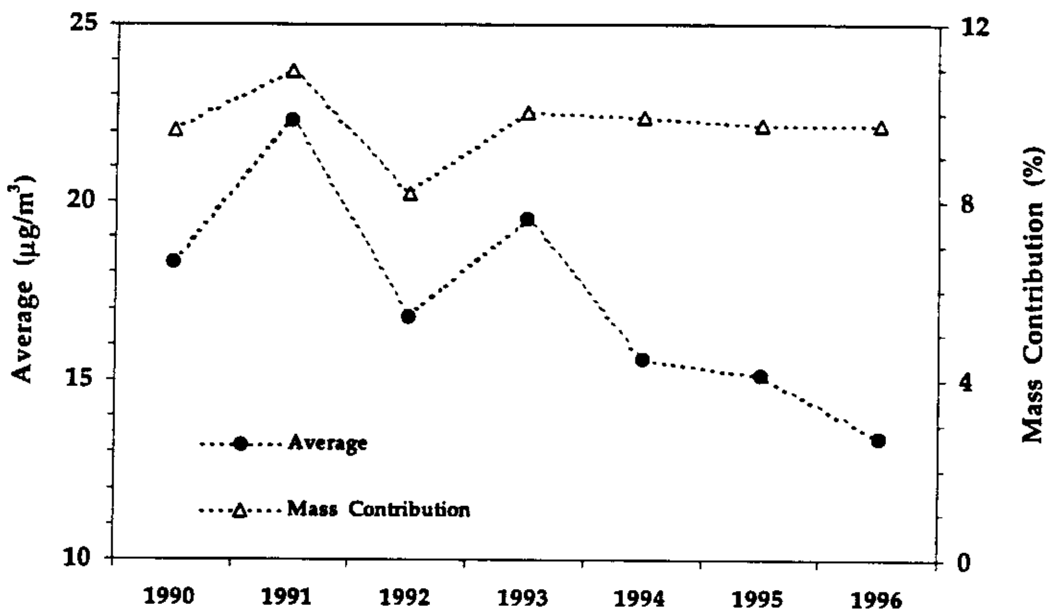
6 ALKENE COMPOUNDS

Concentrations were determined for 38 alkene compounds. A list of these compounds is provided in Table 1.

Trends

The average concentration of total alkenes decreased 26.8%, from 18.3 μg/m³ in 1990 to 13.4 μg/m³ in 1996 (Figure 7). Most of this decline occurred between 1993 and 1996. In 1996, the alkene compounds provided 9.7% of the mass of the average Total VOCs concentration, remaining essentially unchanged from 1990 (9.6%).

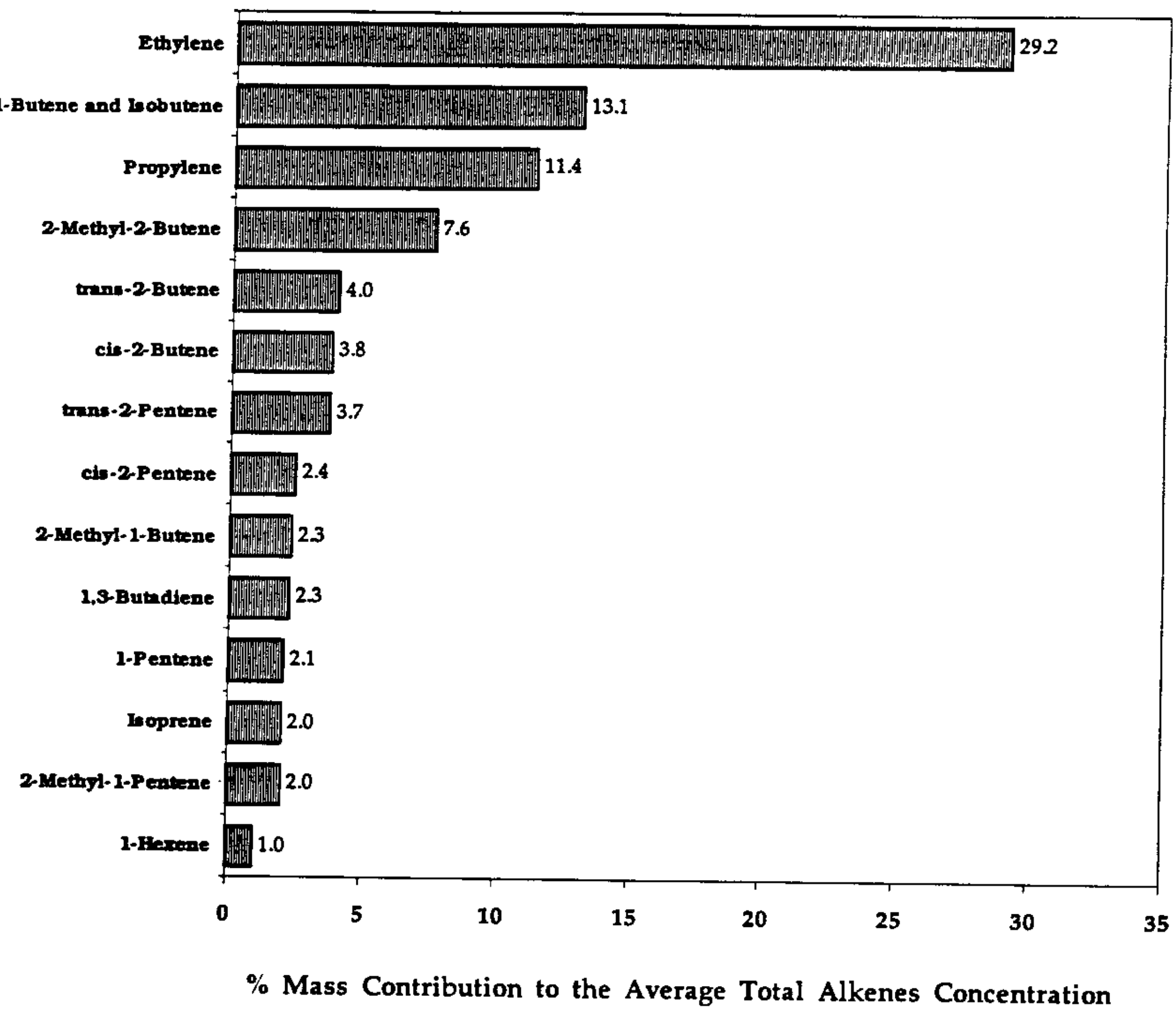
Figure 7: Annual average concentrations of total alkenes and mass contributions to the average Total VOCs concentrations.



Most Abundant Alkenes

The average total alkenes concentration for the period 1990 to 1996 was 18.1 $\mu g/m^3$. Of the 38 alkene compounds considered, only fourteen provided 1% or more of the mass of this average (Figure 8). Collectively, these fourteen compounds provided 87.0% of the mass. Ethylene was the most abundant alkene, providing 29.2% of the mass of the average. Isobutene and 1-butene (combined) and propylene were the second and third most abundant alkenes, and provided 13.1% and 11.3% respectively of the mass.

Figure 8: Most abundant alkenes for the period 1990 to 1996.



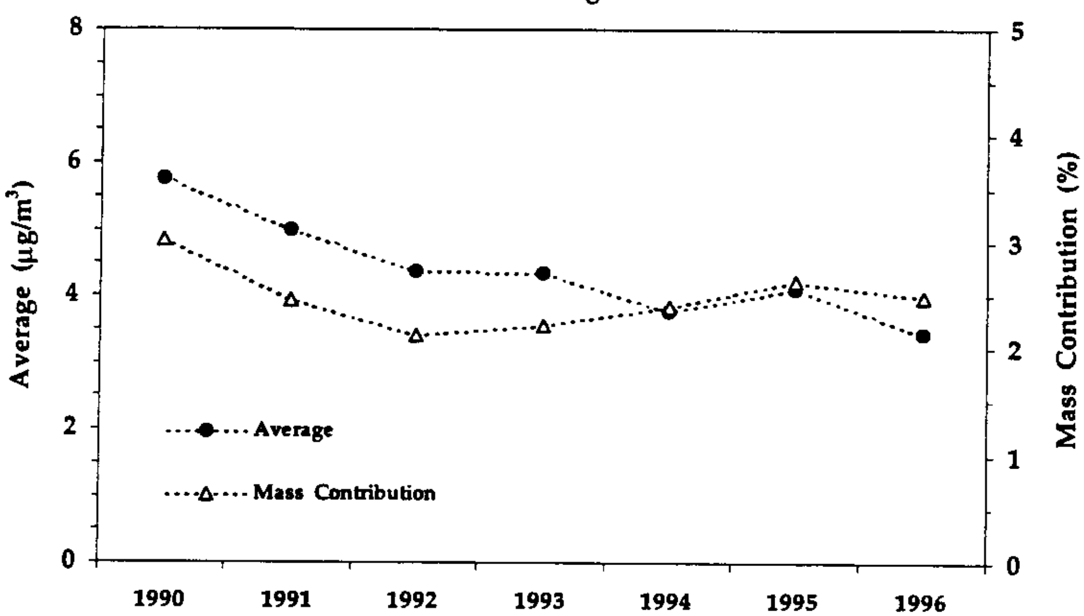
7 ALKYNE COMPOUNDS

Concentrations were determined for only three alkyne compounds, acetylene, 1-propyne and 1-butyne.

Trends

The average concentration of total alkynes decreased 40.3%, from 5.7 μg/m³ in 1990 to 3.4 μg/m³ in 1996 (Figure 9). This decline occurred gradually throughout the seven year period. In 1996, the alkyne compounds provided 2.5% of the mass of the average Total VOCs concentration, a decrease of 16.7% from 1990 (3.0%).

Figure 9: Annual average concentrations of total alkynes and mass contributions to the average Total VOCs concentrations.



Most Abundant Alkynes

The average total alkyne concentration for the period 1990 to 1996 was 4.7 $\mu g/m^3$. Acetylene was by far the most abundant of the three alkyne compounds considered, providing 81.1% of the mass of this average. 1-propylene and 1-butyne provided approximately 18.8 and 0.05% respectively of the mass.

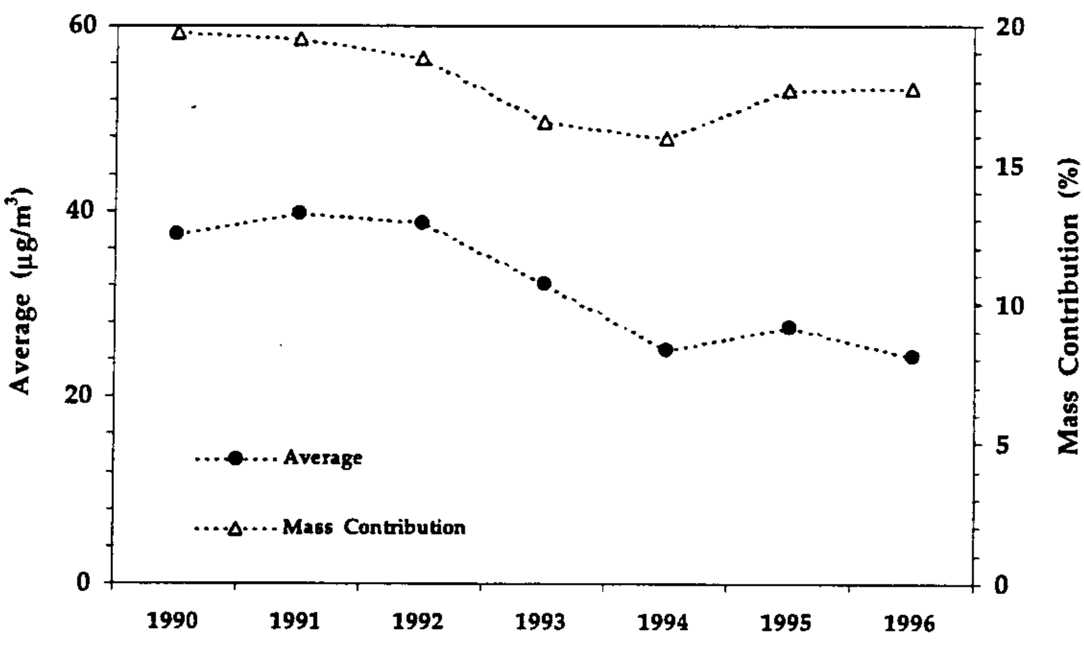
8 AROMATIC COMPOUNDS

Concentrations were determined for 25 aromatic compounds. A list of these compounds is provided in Table 1.

Trends

The average concentration of total aromatics decreased 34.9%, from 37.5 $\mu g/m^3$ in 1990 to 24.4 $\mu g/m^3$ in 1996 (Figure 10). This decline occurred mostly between 1990 and 1994. Between 1994 and 1996 the annual average remained essentially unchanged. In 1996, the aromatic compounds provided 17.7% of the mass of the average Total VOCs concentration, a decrease of 10.2% from 1990 (19.7%).

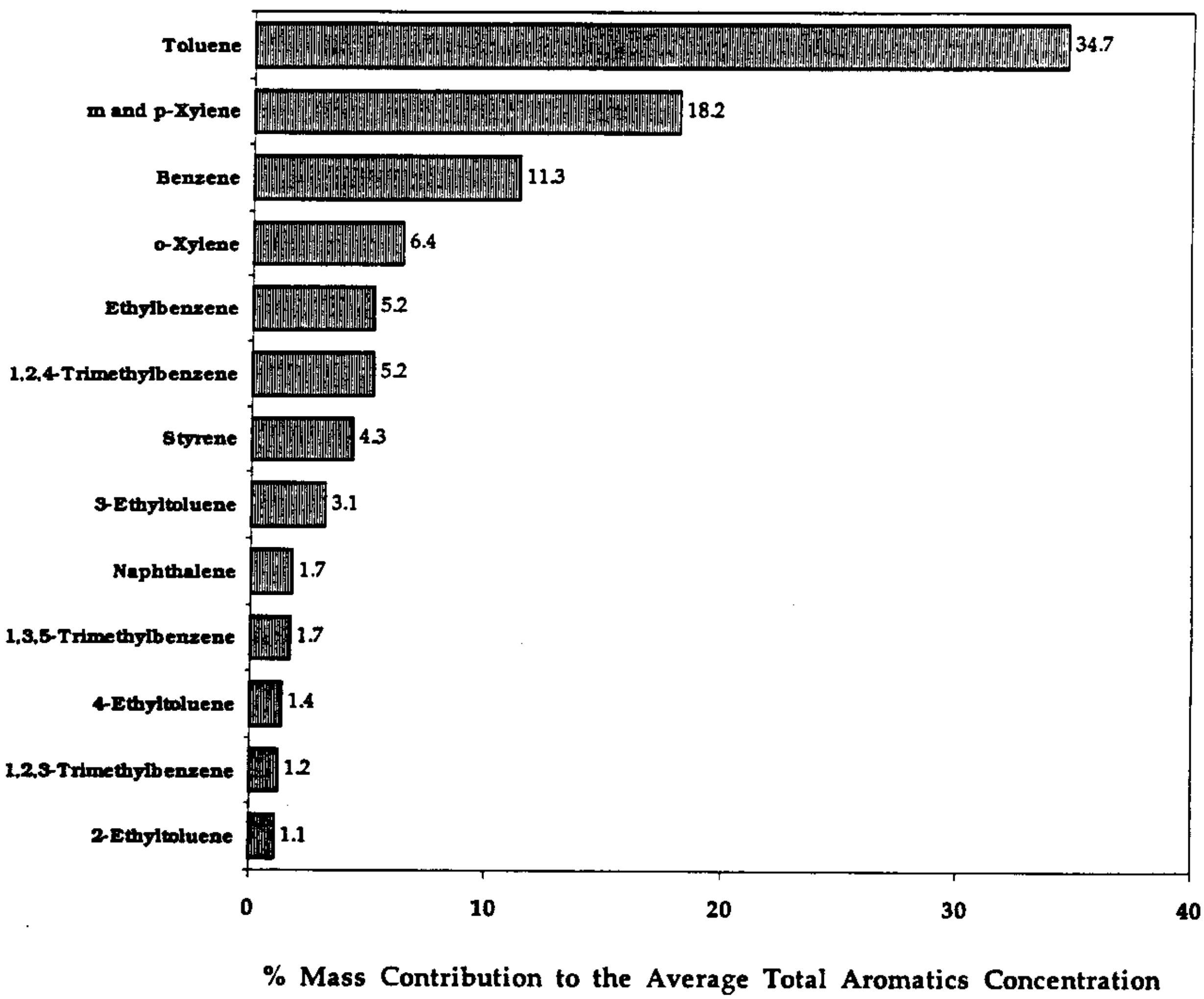
Figure 10: Annual average concentrations of total aromatics and mass contributions to the average Total VOCs concentrations.



Most Abundant Aromatics

The average total aromatics concentration for the period 1990 to 1996 was 31.9 $\mu g/m^3$. Of the 25 aromatic compounds considered, thirteen provided 1% or more of the mass of this average, and eight of these provided 3% or more (Figure 11). Collectively, these thirteen compounds provided 95.6% of the mass. Toluene was the most abundant aromatic, providing 34.7% of the mass of the average. m and p-xylene (combined) and benzene were the second and third most abundant aromatics, and provided 18.2 and 11.3% respectively of the mass.

Figure 11: Most abundant aromatics for the period 1990 to 1996.



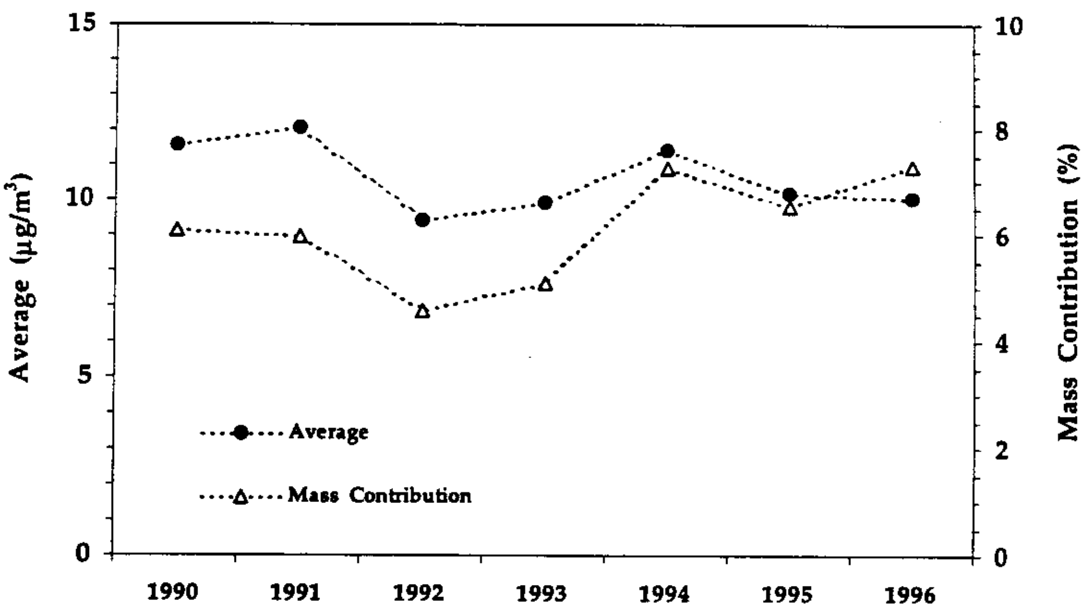
9 HALOGEN COMPOUNDS

Concentrations were determined for 38 halogen compounds. A list of these compounds is provided in Table 1.

Trends

The average concentration of total halogens decreased 13.0%, from 11.5 μg/m^3 in 1990 to 10.0 μg/m^3 in 1996 (Figure 12). Most of this decline occurred between 1990 and 1992. Between 1993 and 1996 the annual average changed little. In 1996, the halogen compounds provided 7.3% of the mass of the average Total VOCs concentration, an increase of 19.7% from 1990 (6.1%).

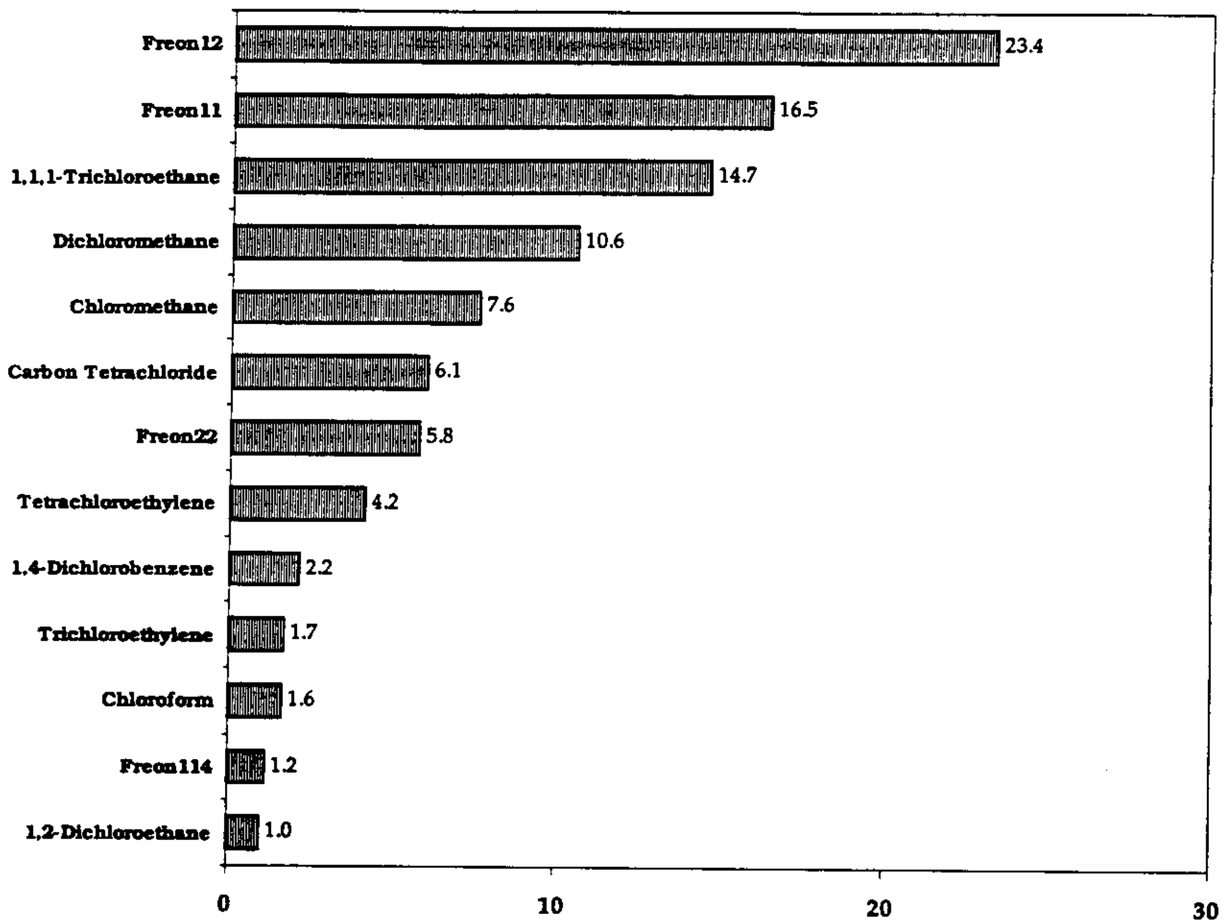
Figure 12: Annual average concentrations of total halogens and mass contributions to the average Total VOCs concentrations.



Most Abundant Halogens

The average total halogens concentration for the period 1990 to 1996 was 12.5 $\mu g/m^3$. Of the 38 halogen compounds considered, only twelve provided 1% or more of the mass of this average (Figure 13). Collectively, these twelve compounds provided 95.4% of the mass. Freon12 was the most abundant halogen, providing 23.4% the mass. Freon 11 and 1,1,1-trichloroethane were the second and third most abundant halogens, providing 16.5% and 14.7% of the mass respectively.

Figure 13: Most abundant halogens for the period 1990 to 1996.



% Mass Contribution to the Average Total Halogens Concentration

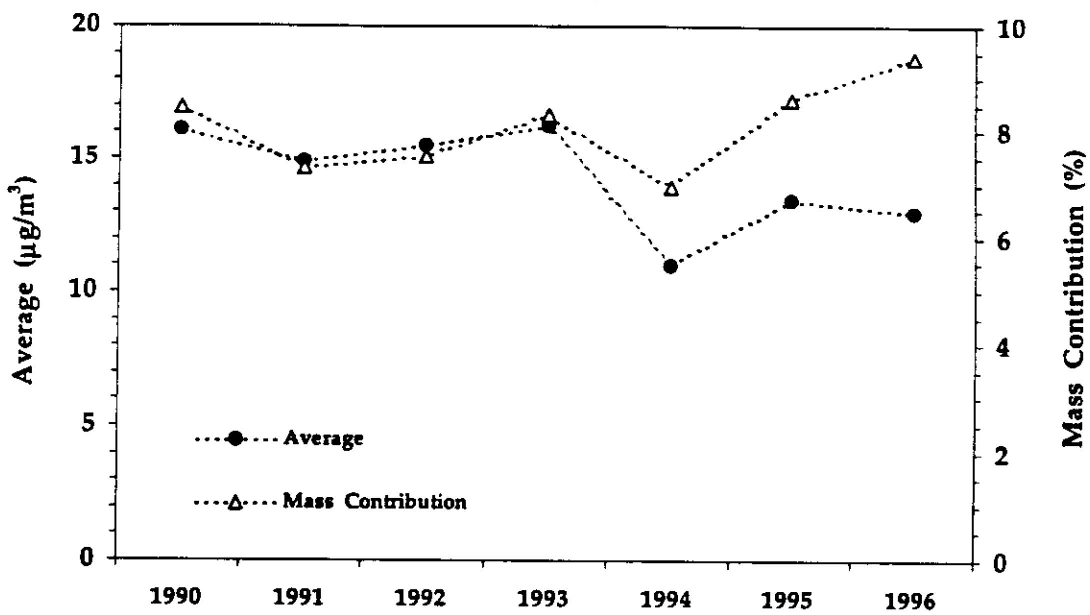
10 CARBONYL COMPOUNDS

Concentrations were determined for sixteen carbonyl compounds. A list of these compounds is provided in Table 1.

Trends

The average concentration of total carbonyls decreased 19.9%, from 16.1 $\mu g/m^3$ in 1990 to 12.9 $\mu g/m^3$ in 1996 (Figure 14). After decreasing between 1993 and 1994, the average concentration experienced a small increase between 1994 and 1996. In 1996, the carbonyl compounds provided 9.4% of the mass of the average Total VOCs concentration, an increase of 10.6% from 1990 (8.5%).

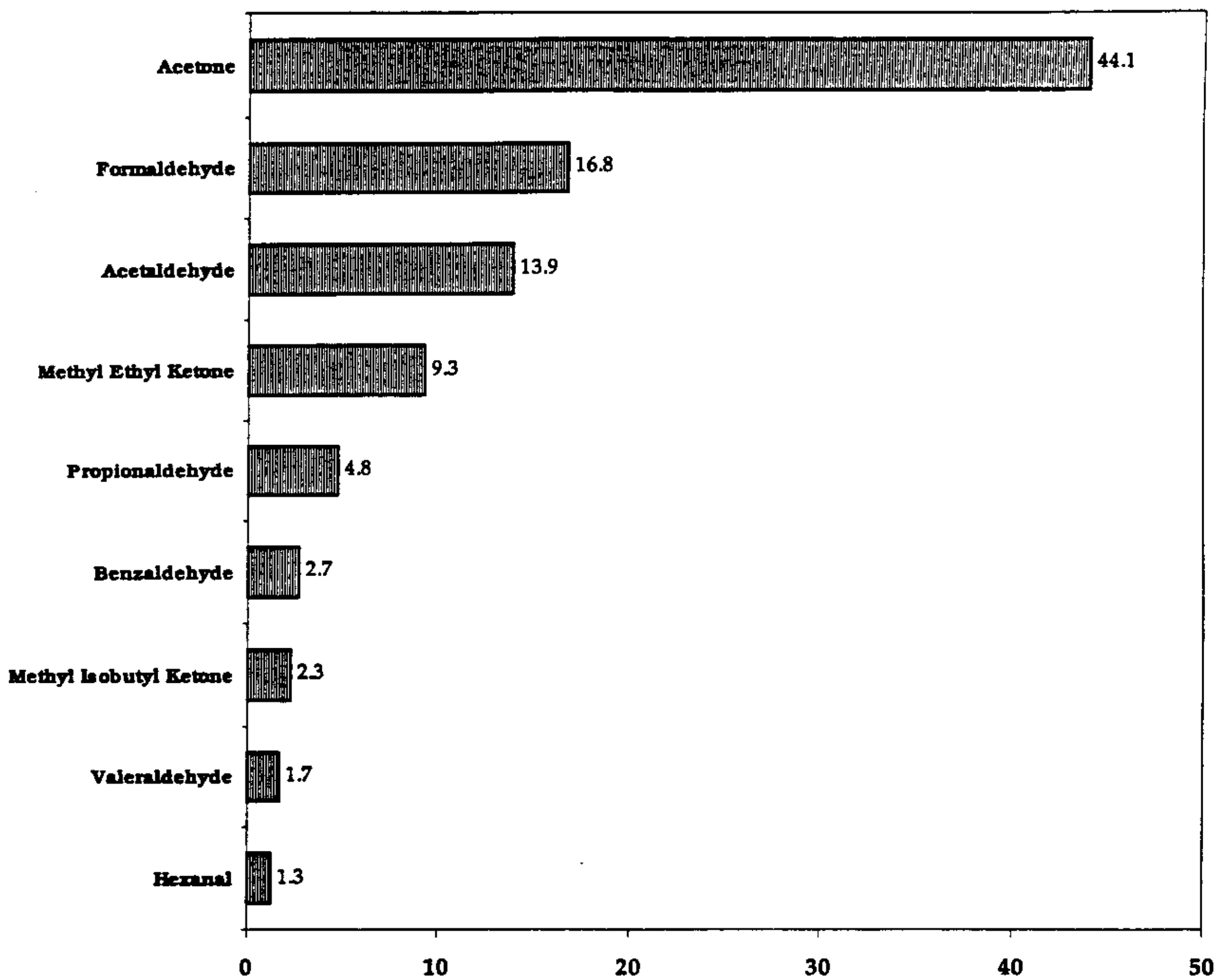
Figure 14: Annual average concentrations of total carbonyls and mass contributions to the average Total VOCs concentrations.



Most Abundant Carbonyls

The average total carbonyls concentration for the period 1990 to 1996 was 14.4 $\mu g/m^3$. Of the sixteen carbonyl compounds considered, nine provided 1% or more of the mass of this average (Figure 15). Collectively, these nine compounds provided 96.8% of the mass of the average. Acetone was the most abundant carbonyl, providing 44.1% of the mass. Formaldehyde and acetaldehyde were the second and third most abundant carbonyls, providing 16.8 and 13.9% respectively of the mass of the average.

Figure 15: Most abundant carbonyls for the period 1990 to 1996.



% Mass Contribution to the Average Total Carbonyls Concentration

11 HEALTH RISK VOCs

In the proposed federal regulation Bill C-32 (the amended Canadian Environmental Protection Act), 26 substances are defined as *toxic*. Also, in a report[5] prepared for the GVRD, 22 substances were identified as *Category 1* hazardous air pollutants (HAPs) for the Lower Fraser. Of these toxic substances and Category 1 HAPs, seventeen of them are VOCs which are part of the 166 compounds considered in this report. These seventeen VOCs are comprised of three toxic substances, twelve Category 1 HAPs, and two substances which are both toxic (under Bill C-32) and Category 1 HAPs.

This Section presents the annual means of the seventeen VOCs mentioned above. A very brief description of the toxicity classification of the five toxic VOCs is also included. The levels of the five toxic VOCs and formaldehyde are also compared with the levels in Montreal and Toronto.

11.1 Toxic VOCs

The five toxic VOCs are listed in Table 4. The United States Environmental Protection Agency classifies benzene as a human carcinogen and carbon tetrachloride as a probable human carcinogen; bromomethane and 1,1,1-trichloroethane are not currently classifiable as to human carcinogenicity. Vinyl chloride is classified as a human carcinogen by the US Department of Health and Human Services.

Annual mean concentrations of vinyl chloride and bromomethane were less than the minimum detection limit (0.1 $\mu g/m^3$) for most of the seven year period (Table 4). For the other three toxic VOCs, the mean concentrations in 1996 were lower than those in 1990, with declines of 78.5% for 1,1,1-trichloroethane, 52.7% for benzene and 20.2% for carbon tetrachloride.

[5] *Assessment of Hazardous Air Pollutants in the Lower Fraser Valley and the Development of Emission Management Options*, Levelton Engineering Ltd., April 24, 1998.

Table 4: Annual means (in $\mu g/m^3$) of five toxic VOCs.

	1990	1991	1992	1993	1994	1995	1996	% Change (96 vs 90)
Carbon Tetrachloride (C1)	0.84	1.01	0.58	0.76	0.74	0.64	0.67	-20.2
Benzene (C1)	4.88	4.63	4.47	3.87	2.94	2.70	2.31	-52.7
1,1,1-Trichloroethene	3.11	4.59	1.82	2.12	1.67	1.07	0.67	-78.5
Vinyl chloride	0.01	0.01	0.00	0.00	0.00	0.00	0.01	***
Bromomethane		0.05	0.03	0.06	0.24	0.07	0.12	***

C1 = Compound also identified as *Category 1 HAP* for the Lower Fraser Valley.

*** Change not indicated because most means are less than the minimum detection limit.

It should be noted that carbon tetrachloride and 1,1,1-trichloroethane have very long atmospheric residence time. This allows them to be transported over large distances away from their original emission locations. As such, their presence in the air could be due to emissions from both local and remote sources.

11.2 Category 1 HAPs

The fourteen Category 1 HAPs and their annual means are presented in Table 5. Mean concentrations of acroleine, 1,1,2-trichloethane and 1,2-dibromoethane were less than the minimum detection limit for most of the seven year period. In 1996, the mean concentrations of the other twelve Category 1 VOCs were mostly lower than those in 1990. Declines ranged from 3.6% for 1,3-butadiene to 60.9% for dichloromethane. Mean concentrations were higher in 1996 than in 1990 only for formaldehyde, with an increase of 13.9%.

Table 5: Annual means (in µg/m³) of Category 1 HAPs.

	1990	1991	1992	1993	1994	1995	1996	% Change (96 vs 90)
1,3-Butadiene	0.28	0.38	0.72	0.52	0.39	0.31	0.27	-3.6
Acetaldehyde	2.02	2.04	2.64	2.05	1.43	1.80	1.83	-9.4
Carbon Tetrachloride (T)	0.84	1.01	0.58	0.76	0.74	0.64	0.67	-20.2
Chloromethane		1.39	0.62	1.07	1.05	0.85	0.99	-28.8
1,2-Dichloroethane	0.16	0.24	0.11	0.10	0.09	0.09	0.10	-37.5
Tetrachloroethylene	0.71	0.57	0.50	0.56	0.46	0.37	0.42	-40.8
Styrene	1.79	0.99	2.24	1.52	0.78	1.28	0.87	-51.4
Benzene (T)	4.88	4.63	4.47	3.87	2.94	2.70	2.31	-52.7
Chloroform	0.30	0.28	0.22	0.20	0.16	0.12	0.14	-53.3
Dichloromethane	1.92	1.21	2.24	1.35	0.82	0.81	0.75	-60.9
Formaldehyde	2.02	2.66	2.84	2.98	1.75	2.40	2.30	13.9
Acroleine	0.04	0.03	0.04	0.07	0.42	0.13	0.13	***
1,1,2-Trichloroethane	0.05	0.10	0.00	0.00	0.00	0.01	0.01	***
1,2-Dibromoethane	0.00	0.03	0.00	0.00	0.00	0.01	0.02	***

T = Compound also defined as *toxic* under Bill C-32.

*** Change not indicated because most means are less than the minimum detection limit.

11.3 Comparison With Other Canadian Cities

Mean concentrations of the five toxic VOCs and formaldehyde measured at T9 are compared to those at an urban site in Montreal (Montreal-Maisonneuve) and Toronto (Toronto-Junction). It should be noted, however, that these comparisons may not provide an accurate indication of concentration differences between the cities because the location of the monitoring sites are not necessarily comparable.

Annual means of vinyl chloride and bromomethane were mostly less than the minimum detection limit in all three cities, and they are therefore not presented. The annual means of the other three toxic VOCs and formaldehyde are presented in Table 6.

Table 6: Annual means (in $\mu g/m^3$) of three toxic VOCs and formaldehyde in Canada's three largest cities.

Benzene	1990	1991	1992	1993	1994	1995	1996	% Change (96 vs 90)
Vancouver-T9	5.65	4.67	4.45	4.67	3.65	3.45	2.83	-49.9
Montreal-Maisonneuve			5.59	6.14	5.44	5.12	5.59	0***
Toronto-Junction	3.12	2.66	2.52	2.52	2.24	3.15	1.97	-36.9
Carbon tetrachloride	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**% Change (96 vs 90)**
Vancouver-T9	0.85	1.00	0.57	0.77	0.74	0.65	0.69	-18.8
Montreal-Maisonneuve			0.63	0.80	0.78	0.69	0.69	9.5***
Toronto-Junction	0.92	1.00	0.65	0.74	0.72	0.65	0.69	-25.0
1,1,1-Trichloroethane	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**% Change (96 vs 90)**
Vancouver-T9	2.92	3.67	1.88		1.48	0.99	0.67	-77.1
Montreal-Maisonneuve			2.52		2.67	1.51	0.97	-61.5***
Toronto-Junction	3.38	3.79	2.39		2.15	1.58	0.98	-71.0
Formaldehyde	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**% Change (96 vs 90)**
Vancouver-T9	2.02	2.66	2.84	2.98	1.75	2.40	2.30	13.9
Toronto-Junction	3.82	3.48	3.21	2.78		10.02	7.51	96.6

*** These changes are between 1996 and 1992.

Mean concentrations of benzene have decreased in Vancouver-T9 and Toronto-Junction, and remained relatively constant at Montreal-Maisonneuve. The mean concentrations at Vancouver-T9 were higher than those at Toronto-Junction and lower than those at Montreal-Maisonneuve. Mean concentrations of carbon tetrachloride have decreased at all three sites, with the levels also being similar at all three sites. This similarity is probably a reflection of the observation that concentrations of carbon tetrachloride are close to uniform throughout the Northern Hemisphere. Mean concentrations of 1,1,1-trichloroethane have decreased constantly at all three sites since 1990, with the means being the lowest at Vancouver-T9 in all years.

For formaldehyde, mean concentrations have increased at both Vancouver-T9 and Toronto-Junction[6] with the annual means being consistently lower at Vancouver-T9. At Toronto-Junction, the large increase in mean levels in 1995 and 1996 is due to some very high concentrations which were measured on a number of days in both years. This possibly resulted from a direct impact of emissions from a nearby point source.

[6] Formaldehyde concentrations were not determined at Montreal-Maisonneuve.

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