

**DRAFT  
ÉBAUCHE**

***CANADIAN ENVIRONMENTAL PROTECTION ACT***

**PRIORITY SUBSTANCES LIST**

**SUPPORTING DOCUMENT**

**ENVIRONMENTAL SECTION**

**TETRACHLOROBENZENES**

Government of Canada  
Environment Canada

Draft Date: June 1, 1993

# **DISCLAIMER**

This is an unedited document made available for public information. A published assessment report is available under the title "Canadian Environmental Protection Act, Priority Substances List, Assessment Report, Tetrachlorobenzenes" from

Environmental Health Centre  
Health and Welfare Canada  
Room 104

Tunney's Pasture  
Ottawa, Ontario, Canada  
K1A 0L2

Commercial Chemicals Branch  
Environment Canada  
14th Floor, Place Vincent  
Massey  
351 St. Joseph Boulevard  
Hull, Quebec, Canada  
K1A 0H3

## TABLE OF CONTENTS

1.0	IDENTITY OF SUBSTANCE	3
1.1	Name of Substance	3
1.2	Characteristics of Substance	3
1.3	Analytical Methodology	3
2.0	PHYSICAL AND CHEMICAL PROPERTIES	3
3.0	RELEASES TO THE ENVIRONMENT	3
3.1	Natural Sources	3
3.2	Man-made Sources	3
	3.2.1 Quantities in Use	3
	Production, Volume and Trends	3
	3.2.2 Imports and Exports	4
	Volume of Importation	4
	Volume of Exportation	4
	3.2.3 Manufacturing Processes	5
	3.2.4 Uses	5
	3.2.5 Releases	5
4.0	ENVIRONMENTAL TRANSPORT, TRANSFORMATION AND CONCENTRATIONS	9
4.1	Transport and Distribution Between and Within Media	9
	4.1.1 Air	9
	4.1.2 Water	9
	4.1.3 Soil	10
	4.1.4 Sediment	10
	4.1.5 Biota	11
4.2	Transformation	12
	4.2.1 Biodegradation	12
	4.2.2 Abiotic degradation	12
	4.2.3 Prediction of Environmental Fate using Computer Modelling	14
4.3	Environmental Concentrations	15
	4.3.1 Air	15
	4.3.2 Water	15
	Fresh Water	
	Estuarine and Marine Water	
	Industrial and Municipal Wastewater	
	Runoff	
	Rain	
	4.3.3 Soil/Sediment	17
	4.3.4 Suspended Sediment	18
	4.3.5 Biota	18
5.0	POPULATION EXPOSURES (ROUTES)	20
5.1	Wildlife Population Exposure	20
6.0	TOXICOKINETICS AND METABOLISM	20
6.1	Metabolic Breakdown and Elimination	20
9.0	EFFECTS ON THE ECOSYSTEM	21
	9.1 Aquatic Systems and Components	21
	9.1.1 Bacteria and Primary Producers	21
	9.1.2 Invertebrates	22
	9.1.2.1 Acute Toxicity	22
	9.1.2.2 Chronic Toxicity	23
	9.1.3 Fish	23
	9.1.3.1 Acute Toxicity	23
	9.1.3.2 Chronic Toxicity	25
	9.1.4 Birds and Marine Mammals	26
	9.1.5 Terrestrial Systems and Components	26
10.0	REFERENCES	26

## 11.0 APPENDIX

### LIST OF TABLES (Tables appear at end of document)

Table 2-1:	Physical and Chemical Properties of Tetrachlorobenzenes
Table 3-1:	Summary of Estimated Major Releases of Tetrachlorobenzenes to the Canadian Environment
Table 4-1:	Examples of Bioaccumulation Factor (BAF) for Tetrachlorobenzenes
Table 4-2:	Examples of Half-Lives in Biota
Table 4-3:	Examples of Uptake and Elimination Rate Constants in Biota
Table 4-4:	Half-life Ranges of Tetrachlorobenzenes by Various Reactions
Table 4-5:	The Half-life Ranges of Tetrachlorobenzenes in Various Compartments
Table 4-6:	Estimated Degradation Rate Constants
Table 4-7:	Summary of Level 111 Fugacity Fate Model
Table 4-8:	Air Environmental Concentrations of Tetrachlorobenzenes in Canada
Table 4-9:	Environmental Concentrations of Tetrachlorobenzenes in Water in Canada
Table 4-10:	Examples of Tetrachlorobenzenes Concentrations in Leachates/Effluents/Urban Runoff in Canada
Table 4-11:	Examples of Tetrachlorobenzenes Concentrations in Rain
Table 4-12:	Environmental Concentrations of Tetrachlorobenzenes in Sediment in Canada
Table 4-13:	Examples of Tetrachlorobenzenes Concentrations in Sediment Core Samples
Table 4-14:	Environmental Concentrations of Tetrachlorobenzenes in Suspended Sediment in Canada
Table 4-15:	Examples of Tetrachlorobenzenes Concentrations in Biota ( $\mu\text{g/g}$ )
Table 9-1:	Effects of Tetrachlorobenzenes Isomers on Algae and Bacteria
Table 9-2:	Effects of Tetrachlorobenzenes Isomers on Freshwater Invertebrates
Table 9-3:	Acute Effects of Tetrachlorobenzenes on Fish

### LIST OF FIGURES (Figures appear at end of document)

Figure 1-1:	Molecular structure of tetrachlorobenzenes
Figure 3-1:	Manufacturing processes of tetrachlorobenzenes
Figure 4-1:	Mass balance diagram for tetrachlorobenzenes in Southern Ontario

## **1.0 IDENTITY OF SUBSTANCE**

### **1.1 Name of Substances**

IUPAC Name: 1,2,3,4-tetrachlorobenzene  
1,2,3,5-tetrachlorobenzene  
1,2,4,5-tetrachlorobenzene

Synonym: TeCB, Benzene Tetrachloride

CAS Number: 634-66-2  
634-90-2  
95-94-3

PSL Name: Tetrachlorobenzenes

### **1.2 Characteristics of Substance**

All of the tetrachlorobenzene (TeCB) isomers are solids at 25<sup>0</sup>C (Mackay and Shiu 1981). The empirical formula of TeCB is C<sub>6</sub>H<sub>2</sub>Cl<sub>4</sub>. The structural formulas are given in Figure 1-1.

Major impurities present in several commercial grades of TeCB are trichlorobenzenes and pentachlorobenzene (US EPA 1980b).

### **1.3 Analytical Methodology**

TeCBs can be detected by gas chromatography (GC) equipped with either a photoionization or flame ionization detector, or a electron capture detector. Another common method is by GC Mass Spectrometry (GC/MS) (Oliver and Nicol 1984; Bosma et al. 1988).

## **2.0 PHYSICAL AND CHEMICAL PROPERTIES**

TeCBs are moderately soluble in benzene, carbon tetrachloride, chloroform, ether and carbon disulfide, but insoluble in cold alcohol (US EPA 1980b). Sadtler Research Laboratories (1982) reported that TeCBs absorb infrared radiation, including wavelengths in the 7-13 um region. Other physical and chemical properties are given in Table 2-1.

## **3.0 RELEASES TO THE ENVIRONMENT**

### **3.1 Natural Sources**

With the exception that 1,2,3,4-TeCB has been identified in the oil of a marsh grass (Miles et al. 1973), no natural sources of TeCBs have been identified. It is not clear whether the TeCB in the plant oil could have been present as a contaminant or in the solvents used to extract the grass.

### **3.2 Man-made Sources**

#### **3.2.1 Quantities in Use**

#### **Production, volume and trends**

There are no Canadian producers of TeCBs (Camford 1991).

Chlorinated benzenes, including TeCBs, were initially manufactured, for industrial purposes, in England in 1909. In the United States, production began in 1915 at Niagara Falls, N.Y. (Ontario Ministry of the Environment 1984). Sediment core data from Lake Ontario indicate that most of the chlorobenzenes entered the lake after 1941 (Oliver and Nicol 1982). The US EPA Chemical Update System showed one company (Standard Chlorine of Delaware, Delaware City, Delaware) which reported the manufacture of 1,2,3,4- and 1,2,4,5-TeCBs in both 1986 and 1990. The exact amount is confidential, but it is believed that over  $4.55 \times 10^6$  kg were manufactured (US EPA TSCA 1992).

### 3.2.2 Imports and Exports

#### Volume of Importation

There was no importation of pure TeCBs for the period 1989 to 1991 for commercial use. Small amounts (<1 kg/ year) have been imported periodically into Canada from the United States as a laboratory reagent (Statistics Canada 1991; Environment Canada 1992a).

In the United States, importation of 1,2,4,5-TeCB from 1973 to 1978 ranged from  $2.0 \times 10^4$  to  $6.0 \times 10^5$  kg (US EPA 1980b). In 1986, one company reported importing  $13.4 \times 10^6$  kg (US EPA TSCA 1992).

TeCBs are present in imported products, such as dielectric fluids, and they can also be present in other chlorinated compounds.

In the past, TeCBs, as well as trichlorobenzenes and pentachlorobenzene, were used in combination with polychlorinated biphenyls (PCBs) in dielectric fluids for transformers and capacitors. The percentages of TeCBs have been reported in the literature, as ranging between 26% to 30% for 1,2,3,4-TeCB and 0% to 3% for 1,2,4,5-TeCB. No value for the percentage of 1,2,3,5-TeCB in dielectric fluids was found. This amounted to approximately 8250 kg/year of TeCBs in dielectric fluids imported into Canada for the time period 1980 to 1982 (Environment Canada 1984). However, after regulations prohibiting new use of PCB-containing dielectric fluids were introduced in 1980 (Canada Gazette 1980), this application for TeCBs declined considerably. Results of a recent survey (Brien 1992) indicate that small amounts (660 kg during first six months of 1992) of TeCBs were still imported in dielectric fluids for transformer maintenance in Canada.

Production of chlorobenzene compounds will result in the simultaneous production of lesser and more highly chlorinated derivatives. These additional compounds will be present as impurities in the final products. TeCBs can be found in trichlorobenzenes, pentachlorobenzene and hexachlorobenzene (US EPA 1980b; Patty 1981-1982). No estimations were found for the importation of TeCBs in these chlorinated compounds.

TeCBs can also be formed as a reaction by-product of thermal chlorination, oxychlorination and pyrolysis operations in the manufacture of chlorinated compounds. They are present, or have the potential to be present, at trace levels in certain chlorinated compounds, such as 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene, perchloroethylene and ethylene dichloride. No estimations were found for the importation of TeCBs in these chlorinated compounds.

#### Volume of Exportation

As TeCBs were not produced in Canada, none were exported.

### 3.2.3 Manufacturing Processes

TeCBs are synthesized from the various trichlorobenzenes in the manner shown in Figure 3-1 (US EPA 1980b; Kirk-Othmer 1964). Crystallization of TeCBs is aided by residual hydrogen chloride formed as a byproduct of the chlorination of benzene or chlorobenzenes. 1,2,4,5-TeCB crystals are filtered, centrifuged or decanted, and washed with methanol, ethanol, liquid chlorobenzenes or acetone. The remaining tetrachlorobenzene in the supernatant, will precipitate upon cooling. 1,2,4,5-TeCB can be separated from a mixture of tri-, penta- and other tetra-isomers by fractional crystallization in an acid solution, according to the Kissling method (US EPA 1980b).

### 3.2.4 Uses

In Canada, pure TeCBs are used as a laboratory reagent. The total amount used for this application in Canada is small (<1 kg/year). TeCBs are also used in Canada as a component of dielectric fluids. No other information on TeCBs uses in Canada have been found.

In the United States, 1,2,4,5-TeCB has been used as an intermediate in the production of fungicides, herbicides, defoliants, and insecticides. 1,2,3,4-TeCB and 1,2,4,5-TeCB were used in the production of pentachloronitrobenzene. In 1973, all of the 1,2,4,5-TeCB produced by Dow Chemical Co. was reportedly captively consumed in the manufacture of 2,4,5-trichlorophenol which has germicidal properties and was used in the production of the herbicide 2,4,5-trichlorophenoxyacetic acid. Since the end of the Vietnamese War, the demand for herbicides such as 2,4,5-trichlorophenoxyacetic acid has decreased. 2,4,5-Trichlorophenol is a fungicide and is used as a disinfectant, a preservative for leather, wood and textiles and as an intermediate in production of herbicides and insecticides. It is also used as a component of dielectric fluids. 1,2,4,5-TeCB is used as a temporary fire retardant protection in packaging and as an impregnant for moisture resistance (US EPA 1980b).

1,2,3,4-TeCB is used in chemical syntheses and as a component of dielectric fluids (US EPA 1980b).

1,2,3,5-TeCB may have uses similar to the other TeCB isomers but no information was available regarding its actual use (US EPA 1980b).

In the U.S.A., a mixture of tri-, tetra- and pentachlorobenzene (name-Polystream) has also been used as a pesticide to protect commercially important clams and oysters (Mackenzie 1970).

### 3.2.5 Releases

There are no known natural sources of TeCBs, and essentially no present commercial activity with these compounds. However, significant quantities remain in use in dielectric fluids. Also, as previously mentioned, TeCBs can be formed as by-products or contaminants during the production of other chlorinated organic substances (see Section 3.3 for examples). Therefore entry can occur from releases during storage, use, transport or disposal of dielectric fluids or these compounds. It can also be released during the degradation and metabolism of other chlorinated compounds.

While no readily available quantitative data were identified on the releases of TeCBs to the Canadian environment, amounts were estimated from best sources of the type and range of emissions that are given below and on the volume of importation. A summary is given in Table 3-1. Based on these estimates, the two most significant sources of entry are from spillage of dielectric fluids and from long-range transport and deposition.

### Dielectric Fluids

Based on recent estimates, up to  $1.31 \times 10^6$  kg of TeCBs are associated with dielectric fluids currently in use and  $14 \times 10^5$  kg of TeCBs are associated with dielectric fluids in storage to be destroyed (Environment Canada 1991a; 1984). Given an incineration destruction efficiency of 99.99% (Dibbs 1991), it is estimated that the total amount of TeCBs released from the incineration of all the dielectric fluids currently in the country would be approximately 133 kg. However this estimate does not include fugitive releases or releases resulting from the spillage of dielectric fluids. Fugitive releases can be substantial. For example, the ambient concentration of chlorobenzenes at the Alberta Special Waste Treatment Centre (8124 ng/m<sup>3</sup> +9727, n=31) (pre-test, test and post-test observations) were due to fugitive emissions related to material handling and storage. The ambient concentrations were not related to incinerator stack discharges (Western Research 1991).

Approximately  $3.75 \times 10^5$  kg of dielectric fluids were spilled in Canada in over 1000 separate spill events between 1981 and 1990 (Menzies 1992). Due to clean-up efforts, all but  $1.23 \times 10^5$  kg were recovered. Assuming the spilled liquids contained 9.9% of TeCBs (NRCC 1980), as much as  $3.71 \times 10^4$  kg of TeCBs have been released to soils in various parts of Canada in association with spilled dielectric fluids. However, much of this contaminated soil has been removed and transferred to PCB waste storage facilities (approximately 67%) (Menzies 1992). Thus it is estimated that the amount of TeCBs released into the environment would be  $1.2 \times 10^4$  kg for a 10 year period or  $1.2 \times 10^3$  kg/year. Of this  $1.2 \times 10^3$  kg, it is estimated, based on Environment Canada (1984) figures for chlorobenzene mixtures in dielectric fluids, that  $1.1 \times 10^3$  kg would be 1,2,3,4-TeCB and  $1.0 \times 10^2$  kg would be 1,2,4,5-TeCB.

### Chlorinated Solvent Industries

TeCBs have the potential to be formed in the manufacture of chlorinated solvents, such as carbon tetrachloride, 1,1,1-trichloroethane and tri- and tetrachloroethylene. In Ontario, there were two plants in 1990, that manufactured carbon tetrachloride (ICI in Cornwall, Dow Chemical in Sarnia), and one plant that manufactured tetrachloroethylene (Dow Chemical in Sarnia) (SRI International 1990). Only the chlorinated solvent, carbon tetrachloride is being produced currently by ICI. However, production of all chlorinated solvents ceased at Dow Chemical in April of 1992 (Rankin 1992). Two plants in Shawinigan, Quebec manufactured chlorinated solvents previously but were closed in 1977 and 1984 (CPI 1987a,b; 1990a,b,c).

TeCBs can be present as contaminants in existing chlorinated solvents in low amounts (0.1%). No quantitative information was found for the individual solvents. However, there are no TeCBs in the carbon tetrachloride presently being produced by ICI (ICI 1993).

In Canada, chlorinated solvents are used primarily in the manufacture of fluorocarbons, metal cleaning and in drycleaning (CPI 1990a,b,c). Based on the annual reported domestic demand of the chlorinated solvents for the years 1986 to 1990 of 36.5 to  $38.9 \times 10^6$  kg/year, the dispersive nature of the solvent uses, assuming 10% release and assuming an upper limit concentration of 1 mg/L, it is estimated that up to 4 kg/year of TeCBs are released to the Canadian environment during solvent use.

Quantities of TeCBs generated in the past in Ontario as waste byproducts, which include those found in still bottoms, during the manufacture of carbon tetrachloride and tetrachloroethylene can be estimated using emission factors developed by US EPA (Brooks and Hunt 1984). Based on 1990 production figures (CPI 1990a,b,c), the annual quantity of TeCBs generated in Ontario, up to April 1992, is estimated to be 2.40 to  $6.97 \times 10^5$  kg/year.



Incineration is currently the method for disposal of wastes generated by the chlorinated solvent industry. If incinerators are assumed to have a TeCBs destruction efficiency of at least 99.99% (Environment Canada 1991c; Jacoff et al. 1986), then, up to April 1991, 24 to 69.7 kg is estimated to be the maximum amount released to the atmosphere annually as a result of incineration of wastes from the chlorinated solvent industry. Loading from a Dow Co. landfill in Sarnia, Ontario, used to dispose of chlorinated solvents still bottoms, has been measured by King and Sherbin (1986). The loadings of TeCBs were estimated to be less than 1 kg/year.

Based on concentrations found in Lake Ontario and the Niagara River, Oliver (1984a) estimated that the total loading of 1,2,3,4-TeCB from chemical manufacturing activities, such as the production of chlorobenzenes, chlorinated solvents, including direct discharges and waste disposal site leachates to Lake Ontario from the Niagara River was  $6.6 \times 10^4$  kg with a yearly loading rate of  $7.6 \times 10^2$  kg. The main sources appear to be located mainly around Niagara Falls, N.Y. Historical information from sediment cores have shown that contamination of Lake Ontario by the Niagara River has demonstrated transboundary tributaries entry. Hooker Electrochemical Co. began operation of the first chlorobenzenes plant in the United States with a capacity of  $8.2 \times 10^6$  kg at Niagara Falls, N.Y. in 1915. United States production of chlorobenzenes increased to  $3.2 \times 10^8$  kg in 1970 and  $2.0 \times 10^8$  kg in 1980. Historical information from sediment cores has shown that contamination of Lake Ontario by the Niagara River has diminished (Oliver 1985).

Oliver and Kaiser (1986) found that the major source of TeCBs to the St. Clair River are Dow Chemical Company effluents and Sarnia's Township Ditch which drains one of Dow's waste disposal sites. Tributaries entering the river on both sides of the Canada/United States border contain measurable concentrations, demonstrating transboundary entry.

#### Other Chlorinated Compounds

TeCBs can be formed in low amounts during the manufacturing of other chlorinated compounds, such as trichlorobenzenes and hexachlorobenzene. An estimated  $4.5 \times 10^4$  kg/year of trichlorobenzenes entered Canada between 1988-1990, based on the reported importation volumes (Camford 1991). Assuming 1% release and assuming an upper limit concentration of 5% in trichlorobenzenes, it is estimated that up to 23 kg/year of TeCBs are released to the Canadian environment. No estimation was possible for the other chlorinated compounds as there was no quantitative information found.

#### Incineration of Chlorinated Compounds

TeCBs can be released into the environment from incinerators, either by not being destroyed or by being formed from partial degradation of chlorinated compounds. In an incinerator study, combustion of an organic matrix containing polyethylene and with sodium chloride as the only chlorine source, TeCBs were formed (Lahaniatis et al. 1981). In November 1991, there were 16 large (minimum  $1.5 \times 10^4$  kg per day capacity) operational incineration facilities in Canada, excluding a plant that will come on-line in 1992 (Environment Canada 1991d). The majority of the plants are situated in Ontario and British Columbia, and are generally comprised of 2-stage combination and mass burners. Further, 65% of the facilities are equipped with air pollution control technology (APC) systems such as electrostatic precipitators, dry lime scrubbers, wet spray humidifiers, and fabric filters. The other facilities, including five of six plants in British Columbia, have no APC systems and operate under "low level technology" systems. There are an additional 200 smaller incinerator facilities in Canada, but no information could be found regarding their technology (Environment 1991). In the only study available that quantified TeCBs emissions from a modern Canadian incinerator, Environment Canada (1987) estimated emissions of 1.4 kg/year from a Quebec

City mass burner system. There is insufficient information to estimate TeCBs emissions from other incinerators in Canada.

#### Degradation and Metabolism of other Chlorinated Compounds

TeCBs can also be released into the environment, through the metabolism and degradation of other chlorinated compounds. For example, when lindane (1,2,3,4,5,6-hexachlorocyclohexane) was topically applied to houseflies, between 0 and 0.1%, 1,2,4,5-TeCB and trace amounts of 1,2,3,4-TeCB were formed during metabolism (Reed and Forgash 1970). Rabbits which were orally dosed with lindane produced trace amounts of all of the TeCB isomers as ether-soluble urinary metabolites (Karapally et al. 1973). In addition, TeCBs were reported as metabolites of lindane in pheasant eggs and chicks and in carrot mold (Third Report of the TSCA Interagency Testing Committee 1979). Lettuce exposed to lindane also contained TeCBs as metabolites (US EPA 1980b). Small quantities have also been found from the photodecomposition of pentachloronitrobenzene (Ware and Weast 1977). TeCBs have been identified as metabolites of gamma-pentachlorocyclohexane in corn and pea seedlings (US EPA 1980b). When pentachlorobenzene was added to a culture of mold, the TeCBs were produced as metabolites from the degradation process (Menzie 1978).

#### Other Sources

In addition to transboundary entry from rivers near waste disposal sites, as previously discussed in the section on the chlorinated solvent industries, presence of the compound in the Pacific air mass (Section 4.3.1) indicates long-range transport of the compound is possible (Atlas and Schauffler 1990).

Welch et al. (1991) documented the occurrence of a long-range transport event that deposited approximately  $4.0 \times 10^6$  kg of fine particulates on the District of Keewatin in the central Canadian Arctic. Air mass trajectories, clay mineral composition, soot particles and visible organic remains pointed to Asian sources for the "brown snow" material, probably western China. Based on the concentration of the sum of 1,2,3,4- and 1,2,4,5-TeCBs in the filtered particles from the snow (1.1 ng/g dry weight) the amount deposited by this event was  $4.4 \times 10^3$  kg.

Measurements of TeCBs ( $<0.01$ - $0.19$  ng/L, mean= $0.016$  ng/L for 1,2,3,4-TeCB;  $0.32$ - $0.78$  ng/L, mean= $0.55$  ng/L for 1,2,4,5-TeCB) in various locations across Canada (Muir 1993; Strachan 1993) indicate that it is a contaminant in rainfall (see Section 4.3.2 for further details). The concentrations represent fluxes of  $<0.5$ - $22.2$  ng/m<sup>2</sup> per year for 1,2,3,4-TeCB and  $<0.5$ - $79.51$  ng/m<sup>2</sup> per year for 1,2,4,5-TeCB during 1987 to 1991. Based on the total amount of surface area in Canada, the amounts deposited from rainfall are estimated to range from  $<5$  to 221 kg with a mean of 13.6 kg for 1,2,3,4-TeCB and from  $<5$  to 791 kg with a mean of 242 kg for 1,2,4,5-TeCB.

TeCBs can also be formed by the chlorination of municipal sewage effluents containing small amounts of benzene and benzene derivatives in reactions between benzene and sodium hypochlorite (Hofler et al. 1983). It is believed that only very low amounts are formed (Otson et al. 1982).

TeCBs have been detected in effluents from pulp and paper mills, iron and steel mills, inorganic and organic chemical plants, petroleum refineries, a textile mill and activated sludge wastewater treatment plants ((Rankin 1993; Ontario Ministry of the Environment 1989; 1990a,b; 1991a,b,c; 1992a,b; Merriman 1988; King and Sherbin 1986; Environment Canada 1979; Oliver and Nicol 1982). The concentrations ranged from nondetectable (detection limits ranged from 0.1 to 10 ng/L depending on the analytical technique used) to 110 000 ng/L for 1,2,3,4-TeCBs, with the highest concentrations found in effluents from inorganic chemical plants, iron and steel mills and pulp and paper mills.

This will be discussed in greater detail in Section 4.3.2. The loading from Ontario's iron and steel industry is 28 kg/year. Loadings from the other sectors are unknown (Ontario Ministry of the Environment 1990a,b; 1991a,b,c; 1992a,b).

In the early 1970, the electrolytic production of chlorine involved electrolytic graphite anode with aromatic coal tar pitch as a binder. Chlorine formed at the anode during the electrolytic process reacted with the binder to form chlorinated organic compounds. It is possible that TeCBs were formed in the tarry residue which was discarded in effluents, sludges and landfills.

The sodium chlorate industries also used graphite anodes which contained a coal tar pitch binder. The anode was used to electrolyze saturated brine solutions of sodium dichromate. The potential formation of TeCBs in this process occurred much the same as with chlorine production.

The available information is insufficient to estimate total TeCBs from chlor-alkali and sodium chlorate industries in the 1970s. However this source has decreased drastically or has been eliminated. Of the 23 chlor-alkali and 18 sodium chlorate plants in Canada in the 1970s, 15 have closed and the remainder have switched to anodes which do not produce chlorobenzenes (Gibertson 1979, Alves and Chevalier 1980).

#### **4.0 ENVIRONMENTAL TRANSPORT, TRANSFORMATION AND CONCENTRATIONS**

##### **4.1 Transport and distribution between and within media**

###### **4.1.1 Air**

It is predictable from their physical-chemical properties, that when TeCBs are released to the air, they eventually are distributed between air and water, with smaller amounts in soil and sediment (Mackay et al. 1992). Washout from the atmosphere in rainwater occur (Muir 1993; Strachan 1993). TeCBs in rainwater are deposited onto soil or water. This will be discussed in further detail in the fate model section (Section 4.2.3).

###### **4.1.2 Water**

Transport and distribution of a substance between and within media in the aquatic environment is dependent upon its solubility, movement of the water itself, exchanges at the air-water interfaces, adsorption to sediment and particulate matter, and bioconcentration in aquatic organisms. The residence time in water is also dependent upon the type of environmental conditions encountered, such as temperatures, wind speeds, currents, ice cover, etc.

For TeCBs, the half-life at 20°C in a river 1 meter deep, flowing at 1 m/sec and with a wind velocity of 3 m/sec, calculated according to the method described by Thomas (1982) for medium-high volatility compounds is approximately 4.5 hours. The volatilization half-life from a model pond, which considers the effect of adsorption, was estimated to be approximately 59.3 days (Asher et al. 1985).

Based on physical-chemical properties, it is predicted that a release of TeCBs to water would result in significant amounts being adsorbed to sediment and particulate matter (Mackay et al. 1992). This is in agreement with the observations of Kuntz and Warry (1983), Oliver (1987b,c) and Oliver and Nicol (1984) for the St. Clair, Detroit and Niagara Rivers who found that most of TeCBs present in the system were adsorbed on to sediment. For example, Oliver

(1984a) estimated that 3300 kg of 1,2,3,4-TeCB in Lake Ontario accumulated in the bottom sediment. Other compartments such as water, suspended sediments and biota retained 210, 4 and 2 kg respectively.

Oliver (1984a) and Oliver and Carey (1986) estimated that the major loss mechanisms of 1,2,3,4-TeCB from the water column of Lake Ontario is by sedimentation of the suspended particulates to bottom sediment (2%), advection to the St. Lawrence River (2%), and volatilization (96%) (Oliver and Carey 1986). The large volatilization loss is due to the low suspended solids level in the Niagara River and in the lake (Oliver 1984a) and to the fact that TeCBs have high activity coefficients in aqueous solutions which cause high equilibrium partial vapour pressures and high rates of evaporation (Mackay and Wolkoff 1973; Mackay and Leinonen 1975).

#### 4.1.3 Soil

When TeCBs are released to the soil, they predominantly remain in the soil compartment. Soil adsorption and mobility are based on the reported and estimated  $K_{oc}$  (organic carbon sorption coefficients) values. According to Kenaga (1980), compounds with a  $K_{oc}$  of  $>100$  are considered immobile. Thus, TeCBs with  $K_{oc}$ s of greater than 100 (Table 2-1) are immobile and would adsorb to soil particles to a great degree. Besides  $K_{oc}$ , parameters that determine if TeCBs will reach groundwater include the soil type (e.g. the organic content of the soil (sandy vs clay)), porosity of the soil, amount of rainfall, depth of the groundwater and extent of degradation.

#### 4.1.4 Sediment

Based on physical-chemical properties, it is predicted that a release of TeCBs to sediment would result in large amounts remaining there (Mackay et al. 1992). Releases from sediments can be facilitated by resuspension (Oliver 1984a; 1985, and Oliver et al. 1989), through biological activities (e.g. bioturbation) (Karickhoff and Morris 1985a,b) or through desorption into pore water and subsequently diffusion into overlying water (Charleton 1983; Oliver and Charleton 1984).

Charleton (1983) and Oliver and Charleton (1984) show that considerable sediment resuspension occurs in Lake Ontario. Field observations indicate that a sediment layer about 1 mm thick in the sedimentation basins (8700 km<sup>2</sup>) is in a constant state of flux. This sediment is almost continually being resuspended then resettling to the bottom. The near bottom temperature in the lake is approximately 4°C and the active layer contains approximately 2% solids. The average desorption half-life under these conditions is approximately 60 days so over the yearly cycle more than 98% of the chemical should be desorbed from this active layer and resorbed by the sediment with some loss to the overlying water (Oliver 1985). Sorption and desorption processes appear to be attributed to a slow binding and release rather than by diffusion of TeCBs through liquid and organic phases (Bales and Szecsody 1990).

At four stations in Lake Ontario near the Niagara River, the 20 and 40 m depth traps contained primarily suspended sediments from the river. The traps at 60 m and 68 m at this location caught more sediments and much of the catch was found to be resuspended bottom sediments. The ratio of 1,2,4,5-TeCB to 1,2,3,4-TeCB was 1.6 in the bottom sediments and only 0.5 on the suspended solids transported from the Niagara River. At the offshore stations in Lake Ontario, a major source for chlorobenzenes in the water column at all depths was resuspended bottom sediments (Oliver and Charlton 1984). With a current the surface sediments can be also redistributed throughout the sedimentation basins in the lake (Oliver 1984a; Oliver et al. 1989). The contribution of TeCB loadings from desorption appeared to be low (12 and 7 kg/yr) for 1,2,4,5- and 1,2,3,4-tetrachloroisomers in comparison to the active sources (760 and

340 kg/yr) from the Niagara River respectively (Oliver 1985). But contamination of Lake Ontario by 1,2,3,4-TeCB from the Niagara River appeared to decrease (Fox and Carey 1989).

TeCBs accounted for 21% of the total chlorobenzenes from di- through hexachlorobenzene in the sediments of Lake Ontario. These values for di-, tri-, penta- and hexachlorobenzene were 12, 31, 9 and 27% respectively (Oliver et al. 1989).

#### 4.1.5 Biota

TeCBs from sediments can be available to benthic invertebrates. The concentrations of 1,2,4,5- and 1,2,3,4-TeCB in the field population of oligochaete worms and amphipods were related to contaminant concentrations in the sediments (Fox et al. 1983). The accumulation of TeCBs by oligochaete worms from Lake Ontario sediments in laboratory aquaria was demonstrated by Oliver (1984b;1987a). The potential for bioaccumulation from sediments appeared to be highly controlled by concentrations of TeCBs in the sediment pore water rather than from ingestion of contaminated sediment particles (Oliver 1987a; Markwell et al. 1989). This is further supported by the observation that fecal pellets contained the same chemical concentration as the sediments and that gut sediment contents made an insignificant contribution to body burden for most chemicals (Oliver 1987a).

Bioaccumulation factors (BAF) of TeCBs have been determined for several organisms. The term bioaccumulation factor was chosen because, for organisms exposed in their natural environment, the pathways (food or water) to the organism are not known. Bioconcentration factors refer only to results obtained in the laboratory data with waterborne exposure and the water concentrations must be defined as the dissolved phase.

$$\text{BAF} = \frac{\text{Concentration of chemical at steady state in organism (wet weight)}}{\text{Mean concentration of chemical in water}}$$

or

$$\text{BAF} = \frac{\text{Uptake rate constant at steady state}}{\text{Elimination rate constant}}$$

"Reported bioaccumulation factors (BAFs) of TeCBs in fish vary between 1778 (fathead minnow-Pimaphales promelas) (Veith et al., 1979) to 12,883 (rainbow trout-Oncorhynchus mykiss) (Oliver and Niimi, 1983) for whole body and between 14,125 (guppy-Poecilla reticulata) (Konemann and van Leeuwen, 1980) to 134,896 (rainbow trout-Oncorhynchus mykiss) (Oliver and Niimi, 1983) for lipid content."

Table 4-1 presents those studies which determined BAF at steady state and under flow through systems for fish. Static systems at steady state were used for the determination of the BAFs of algae and worms. The bioaccumulation factor varies between 1778 (fathead minnow-Pimaphales promelas) (Veith et al., 1979) to 12,883 (rainbow trout-Oncorhynchus mykiss) (Oliver and Niimi, 1983) for whole body and between 14,125 (guppy-Poecilla reticulata) (Konemann and van Leeuwen, 1980) to 134,896 (rainbow trout-Oncorhynchus mykiss) (Oliver and Niimi, 1983) for lipid content. In earthworms, (Eisenia andrei), a bioaccumulation factor of 84 000 was determined (Belfroid et al. 1993). Thus, TeCBs are bioaccumulative compounds. Examples of half-lives which are determined from elimination rate constants ( $t_{1/2} = 0.693/k$ ), and uptake and

elimination rate constants in biota are given in Tables 4-2 and 4-3, respectively.

The uptake of TeCBs by higher plants is more complex. Generally TeCBs can enter terrestrial plants via roots and via foliage (Trapp et al. 1990). Under field conditions the uptake of 1,2,3,5-TeCB from soil was very slow and the equilibrium was not attained within 100 days (Topp et al. 1986). A plant/soil concentration ratio of concentration in whole plant (wet weight)/concentration in dry soil (ug/g) of less than 3 was obtained for barley *Hordeum vulgare* in short-term laboratory model ecosystem (Trapp et al. 1990). It was not under equilibrium conditions (Topp et al. 1986).

Air-plant concentration factors (air-lichen) for TeCBs from the Upper Great Lakes region of Ontario were determined by Muir et al. (1993). They were  $1.4 \times 10^7$  and  $1.12 \times 10^8$  for 1,2,4,5-TeCB and  $6.04 \times 10^7$  and  $4.51 \times 10^7$  for 1,2,3,4-TeCB.

There was no significant aquatic food chain magnification predicted from the model calculations and empirical observations by Thomann (1989). Compounds with log  $K_{ow}$  values of approximately 5.0 or less do not have significant food chain buildup. Uptake from water is more important than from food for this group of compounds. There was also no buildup shown in the field study by Oliver and Niimi (1988).

## **4.2 Transformation**

### **4.2.1 Biodegradation**

In water and soil, biodegradation appears to be the only degradation process of any significance (Howard et al. 1991). Reductive dechlorination mediated by microorganisms is considered as an initial step in the transformation of higher chlorobenzenes (Hagblom 1990). Fathepure et al. (1988) reported dechlorination of hexachlorobenzene in anaerobic sewage sludge via two routes. The major route leads to the formation of 1,3,5-trichlorobenzene (hexachlorobenzene  $\rightarrow$  pentachlorobenzene  $\rightarrow$  1,2,3,5-TeCB  $\rightarrow$  1,3,5-trichlorobenzene). The minor route was hexachlorobenzene  $\rightarrow$  pentachlorobenzene  $\rightarrow$  1,2,4,5-TeCB  $\rightarrow$  1,2,4-trichlorobenzene  $\rightarrow$  dichlorobenzenes. TeCBs are believed to follow basically the same pathways.

The results of Fathepure et al. (1988) were contrary to those reported by Kirk et al. (1989) who found that 1,2,3,4-TeCB and 1,2,4,5-TeCB were not biodegraded in anaerobically incubated sewage sludge during a time period of 32 days. There were overall removals of 61% for 1,2,4,5-TeCB and 33% for 1,2,3,4-TeCB, which were attributed to a process such as volatilization, not biodegradation. 1,2,4,5-TeCB was not biologically-oxidized by benzene-acclimated activated sludge at a concentration of 500 mg/L over 192 hours of incubation (Malaney et al. 1966). Microbial decomposition of 1,2,4,5-TeCB by a *Pseudomonas* sp. or by a mixed culture of soil bacteria yielded 2,3,5,6-tetrachlorophenol (Ballschmiter and Scholz 1980). An analysis of monitoring data from sediment cores indicated insufficient evidence to show occurrence of anaerobic dehalogenation of TeCBs in Lake Ontario sediment (Oliver and Nicol 1983).

### **4.2.2 Abiotic Degradation**

#### **Photolysis**

Direct photolysis of TeCBs were reported in laboratory studies at wavelengths  $> 290$  nm. Reductive dechlorination appeared to be the major photochemical pathway. The major photoreaction products were chlorinated benzenes containing one or two chlorine atoms less than the starting substrate. Direct photolysis of 1,2,3,5-TeCB yielded 1,2,4-trichlorobenzene.

Direct photolysis also gave isomerized TeCBs, which are more photochemically reactive polychlorobiphenyls (Choudhry and Hutzinger 1984; Choudhry et al. 1986). The yields of polychlorobiphenyls were less than one percent of the initial amount. Hydrochloric acid was also a reaction product (Uyeta et al. 1976).

Acetone-sensitized photolysis of 1,2,3,4-, 1,2,3,5- and 1,2,4,5-TeCBs were also reported in laboratory studies with an aqueous solvent mixture (acetonitrile-water) at wavelengths > 290 nm. Reductive dechlorination also appeared to be the major photochemical pathway. The major photoreaction products were chlorinated benzenes containing one or two chlorine atoms less than the starting substrate. Irradiation of a water:acetonitrile (4:6) solution of 1,2,4,5-TeCB containing phenols with wavelengths above 285 nm for 16 hours resulted in a 61% disappearance with the formation of small amounts of chlorodibenzofurans (Choudhry et al. 1983). Irradiation of a water:acetonitrile (4:6) solution of 1,2,4,5-TeCB with wavelengths above 285 nm for 8 hours resulted in a 98% disappearance with the formation of primarily lower chlorobenzenes and small amounts of polychlorinated biphenyls. Addition of acetone as a photosensitizer accelerated the photolysis rate and yielded a higher percentage formation of polychlorinated biphenyls (Choudhry and Hutzinger 1984). However, it should be noted that acetonitrile would not be present in that ratio under normal environmental conditions (Choudhry and Hutzinger 1984; Choudhry and Webster 1985; Choudhry et al. 1979; Choudhry et al. 1986). Some form of hydrogen-donating entity (be it a solvent molecule or another chlorobenzene molecule) appears necessary for the photochemical dechlorination of chlorobenzenes at wavelengths above 290 nm. It has been speculated that such hydrogen-donating "photosensitizers" may be found in naturally occurring organic substances and that photodecomposition may therefore be important as a degradative pathway under this situation (Akermark et al. 1976).

Direct photolysis of pentachlorobenzene in the vapour phase is not expected to be important relative to the OH radical reactions (Bunce et al. 1989).

### Photooxidation

TeCBs are subject to photooxidation in the atmosphere. This occurs in the atmosphere under the influence of various mechanisms such as the reaction with hydroxyl radicals, water, alkoxy- and peroxy radicals, oxygen atoms and ozone. On the basis of the rate constant of each of the reactions and the concentration of the reactants, the reaction with the hydroxyl radical is considered to be the most important (Atkinson 1987;1985; Howard et al. 1991).

The half-life of a chemical in the environment depends not only on the intrinsic properties of the chemical, but also on the nature of the surrounding environment, such as sunlight intensity, hydroxyl radical concentration, the nature of the microbial community, temperature, etc. A summary of the degradation of 1,2,4,4-TeCB by both chemical and biological mechanisms is given below. Both the half-life ranges of 1,2,4,5-TeCB by different reactions (Table 4-4) and the half-life ranges in various compartments are presented in Table 4-5. It is assumed that the other two isomers have similar half-life ranges.

The estimated atmospheric half-life of 1,2,4,5-TeCB ranges from 31.8 - 329 days (0.9 years). It is estimated that 1,2,3,4-TeCBs has the same half-life range (Singleton 1993). Due to the positioning of the chlorine atoms it is estimated that the atmospheric half-life of 1,3,4,5-TeCB is lower (upper range is estimated to be 139 days) (Singleton 1993). Since the atmospheric lifetime of TeCBs are greater than one month, there is potential for long-range transport of this compound.

Gases involved in global warming strongly absorb infrared radiation of wavelengths between 7-13  $\mu\text{m}$ , enabling them to trap and re-radiate the Earth's thermal radiation (Wang et al. 1976; Ramanathan et al. 1985). TeCBs absorb in the 7-13  $\mu\text{m}$  region of the spectrum (Sadler Research Laboratories 1982), which means that they could be contributors to global warming. However, estimation of the global warming potentials of TeCBs is not possible, without quantitative infrared absorption data, which are not available (Singleton 1993).

The ozone depletion potentials (ODP) for TeCBs are calculated using the correlation of Nimitz and Skaggs (1992):

$$\text{ODP} = 0.05013 n_{\text{Cl}}^{1.51} \exp(-3.858/r)$$

where  $r$  (the half-life of TeCBs) is equal to 0.90 years for 1,2,3,4- and 1,2,4,5-TeCBs and 0.38 years for 1,3,4,5-TeCB, and  $n_{\text{Cl}}$  (the number of chlorine atoms) is equal to four. The ODP is 0.0056 for 1,2,3,4- and 1,2,4,5-TeCB and 0.000015 for 1,3,4,5-TeCB. Since there is an uncertainty in the correlation determining  $r$  of about a factor of two (Atkinson 1987) the ODPs of 1,2,3,4- and 1,2,4,5-TeCBs can range from 0.000076 to 0.048 and of 1,3,4,5-TeCB can range from very small to 0.0034. There is little potential for ozone depletion for all three of the TeCBs isomers, especially 1,3,4,5-TeCB. The ODPs calculated for 1,2,3,4- and 1,2,4,5-TeCBs for  $r \times 2$  is comparable to that of HCFC's (such as HCFC-22 for which ODP=0.05) which are proposed as interim replacement materials for CFC's "until environmentally safe alternatives are available" (Singleton 1993).

#### 4.2.3 Predictions of Environmental Fate using Computer Modelling

There are limited "field" data on the environmental behaviour of TeCBs. This has necessitated the use of a modelling technique, namely the Level 111 Fugacity Model of Mackay and Paterson (1991). The fugacity model for southern Ontario accepts as input, the physical and chemical properties of a chemical, its transformation half-lives and emission rates into the environmental media of air, water, soil and sediment. It then calculates the prevailing steady state concentrations, amounts and rates of degradation, advective flow and intermedia transport. The concepts underlying this modelling approach are described by Mackay (1991).

The full computer program output is attached in Appendix A. A brief account of the principal findings are presented below.

The following assumptions were considered for this modelling exercise:

1. 100% of the estimated 2200 kg/year of TeCBs that are released into the Canadian environment enters the environment in southern Ontario.
2. TeCBs are released to the environment in the following proportions:  
air 10% (0.116 mol/h), water, 80% (0.928 mol/h) and soil 10% (0.116 mol/h).
3. Mean degradation rate constants (Table 4-6) were taken from the estimated ranges of Mackay et al. (1992) in Table 4-5 and were entered into the model.
4. Advective outflows in air and water were included corresponding to residence times in those media of 5 days and 500 days respectively (namely Air =  $3.3 \times 10^{12} \text{ m}^3/\text{hour}$  and Water =  $3.3 \times 10^8 \text{ m}^3/\text{hour}$ ).

Table 4-7 and Figure 4-1 summarize the emissions, environmental distributions (%) and the resulting concentrations.



Reaction and advective outflow from the air compartment are the major removal processes from the system, accounting for 4.7% and 95.3% of the removal, respectively. As the major removal process is advective outflow, this suggests that long-range transport of TeCBs can occur. Also the possibility of long-range transport resulting from the advective outflow is increased because of the fairly long half life of TeCBs in the atmosphere (between 31.8 to 318 days).

In the water compartment, the key processes are reaction in water (18.3%), evaporation (69.1%) and advective outflow (12%) with loss to sediment (0.6%) (Figure 4-1).

In the soil compartment, there is no advection (Figure 4-1). The primary loss mechanisms are transfer to water (surface and ground water) by run-off (1.1%), transfer to air (14.9%) and by reaction (84%).

In the sediment compartment, there is no advection (Figure 4-1). The primary loss mechanism is by reaction (100%).

Generally, the results for air, water and sediment from the above mentioned fugacity model fall in the range of field environmental concentrations from uncontaminated sites (Section 4.3). Soil concentrations can not be compared, due to the lack of field data.

#### **4.3 Environmental Concentrations**

##### **4.3.1 Air**

TeCBs concentrations in Canada were measured several locations in Ontario during 1987-1990. The values ranged for total TeCBs from 0.04 to 2.56 ng/m<sup>3</sup> in urban areas and from 0.05 to 0.42 ng/m<sup>3</sup> for rural areas, respectively (Environment Canada 1989;1991b). Additional studies of rural air reported TeCBs concentrations ranging from 0.50 to 1.64 ng/m<sup>3</sup> for 1,2,4,5-TeCB (Muir 1993), and from 0.05 to 2.95 ng/m<sup>3</sup> for 1,2,3,4-TeCB (Hoff et al. 1992; Muir 1993) (Table 4-8).

Similar results were found by Atlas and Schauffler (1990) who measured concentrations of 1,2,3,4-TeCB from 0.02 to 0.11 ng/m<sup>3</sup> and of 1,2,4,5-TeCB from 0.09 to 0.29 ng/m<sup>3</sup> in atmospheric samples from the North Pacific in 1986. Presence of the compound in Pacific air masses substantiates the idea that long-range transport of the compound is possible.

##### **4.3.2 Water**

###### **Fresh Water**

The concentrations of TeCBs in various Canadian lakes and rivers between 1980 and 1991, ranged from nondetectable (detection limits ranged from 0.01 to 1 ng/L, depending on the analytical technique used) to 21 ng/L for 1,2,3,5-TeCB and 1,2,4,5-TeCB and from nondetectable to 125 ng/L for 1,2,3,4-TeCB, as shown in Table 4-9. The highest concentrations were found in Lake Ontario (Niagara Basin), Niagara River and St. Clair River during the early 1980's. Concentrations have since declined. The maximum concentration in water samples collected from the Niagara River at Niagara-on-the-Lake during 1988 and 1989 was reported to be 1.08 ng/L for 1,2,3,4-TeCB (Data Interpretation Group River Monitoring Committee 1990). All mean concentrations were less than 1 ng/L, with the exception of the Niagara River and Lake Ontario (Niagara Basin). 1,2,3,4-TeCB is the prevalent tetrachloroisomer. In 1980, 3 ng/L for 1,2,3,5-TeCB, 31 ng/L for 1,2,4,5-TeCB and 126 ng/L for 1,2,3,4-TeCB were detected at Niagara Falls, N.Y. on the Niagara River, indicating a source of these compounds in the Canadian waters of the Niagara River.

### Estuarine and Marine Water

No data for tetrachlorobenzene concentrations in Canadian estuarine and marine water were found in the literature.

### Industrial and Municipal Wastewater

Examples of concentrations of TeCBs in wastewater are given in Table 4-10. The highest amounts were found in Ontario pulp and paper mill effluents, in Ontario iron and steel mill effluents, in effluents from the Ontario inorganic sector and in textile plant outfall. Water samples collected from the Truro, Nova Scotia sewer outfall into which the Stanfield plant effluents were discharged and from a sewer manhole near the plant, had concentrations ranging from 110 to 130 ng/L for 1,2,3,5- and 1,2,4,5-TeCBs and from 79 to 900 ng/L for 1,2,3,4-TeCB.

In the Sarnia industrial complex, King and Sherbin (1986) found that total TeCBs were detected up to 110 ng/L in the Dow Chemical Co. plant treated effluents and 27 ng/L in the Dow Chemical landfill treated leachates. Recent values for these sites have shown a decrease (Ontario Ministry of the Environment 1992a; Rankin 1993). Dow Chemical Co. has produced a variety of organic and inorganic compounds, such as caustic soda, chlorine, hydrogen, 1,1,1-trichloroethane, perchloroethylene and carbon tetrachloride. Its landfill was used to dispose of solid waste such as chlorinated tars which are now being routinely incinerated at Dow. Dow Chemical Co. was the principle source of chlorinated hydrocarbons associated with perchloroethylene puddles found on the bottom of St. Clair River. There were no TeCBs detected (<0.1 ng/L) in the Esso Chemical Co., the City of Sarnia Water Pollution Control Plant, and Polysar treated effluents. The levels in leachates from the Sarnia Township Ditch which integrates municipal discharges and industrial and non-industrial runoff, prior to discharging to the river, were from nondetectable to 29 ng/L. The levels in petroleum refinery effluents, following biological treatment were from nondetectable to 13 ng/L. It should be noted that the data do not represent effluent variability, since they were collected during a short-time effluent screening survey to characterize point sources to the St. Clair River in the Sarnia's industrial complex (King and Sherbin 1986).

Traces of 1,2,3,4-TeCB were found in the Ontario and Minnesota final effluents of two bleached kraft pulp and paper mills discharging into the Rainy River, Canada/USA boundary. But, there was no detection in the river water 5 kilometers downstream from the point source at the detection limit of 0.1 ng/g (Merriman 1988). A mean concentration of 20 ng/L 1,2,3,4-TeCB was measured in process effluents of seven refineries in Ontario, during a one year monitoring program conducted by Ontario Ministry of the Environment. With the exception of Shell Canada, all the refineries discharge their effluents directly to the surface watercourses (Ontario Ministry of the Environment 1990a,b) (Table 4-10).

Concentrations of TeCBs in effluents and raw sewage from four activated sludge wastewater treatment plants in Ontario, discharging their effluents into the Grand River and Lake Ontario, ranged between 0.1 to 3 ng/L (Oliver and Nicol 1982).

### Runoff

Occurrence of TeCBs were reported in urban runoff (primarily surface runoff) from the Canadian Great Lakes Basin (Erie, Huron, Ontario, St. Clair, Superior) in 12 urban centres during 122 storm events (Table 4-10). The mean concentrations were from 4.4 to 5 ng/L in street sediments and nondetectable in stormwater respectively. The estimated Canadian Great Lakes basin loadings were 0.8 kg/yr for 1,2,4,5- and 1,2,3,5-TeCBs and 0.8 kg/yr for 1,2,3,4-TeCB.

The loadings did not include possible contributions from combined sewer overflows or illicit point source discharge into storm sewers (Marsalek and Schroeter 1988).

#### Rain

The concentrations of TeCBs in rain at various locations across Canada between 1987 and 1991 are fairly uniform, ranging from <0.01 to 0.19 ng/L, with a mean of 0.016 ng/L for 1,2,3,4-TeCB and 0.32 to 0.78 ng/L, with a mean of 0.55 ng/L for 1,2,4,5-TeCB, as shown in Table 4-11. The fluxes of TeCBs in rain ranged from <0.50 to 22.2 ng/m<sup>2</sup>/year for 1,2,3,4-TeCB and from <0.50 to 79.51 ng/m<sup>2</sup>/year for 1,2,4,5-TeCB.

#### 4.3.3 Soil/Sediment

##### Soil

No information was found in the literature on TeCBs levels in soil in Canada except for the following case. In the mid-1970's, 6800-21000 liters of dielectric fluid containing 70% PCB's and 30% Aroclor 1254 (tri- and TeCBs) were released following the rupture of an underground pipe at a transformer manufacturing plant (NRCC 1980). Much of the contaminated zone was less than 3 m deep. The distribution was heterogeneous, both horizontally and vertically. TeCBs were not measured in all of the 150 test holes, but in the 22 test holes where TeCBs were measured in various depths less than 3 m, levels ranged from nondetectable (detection limit=0.003 ug/g) to 6.3 ug/g (dry weight). Soils at this site are now sealed with a lime-modified asphalt pavement, and a bentonite-containing cutoff wall is in place to contain lateral migration of contaminants (Chang 1992). Despite the fact that over 1000 spills of PCB-containing dielectric fluids have been reported in Canada since 1981, no other Canadian data on TeCB levels in PCB-contaminated soils have been identified.

##### Sediment

Concentrations of TeCBs in surficial sediments collected between 1979 to 1990, ranged from nondetectable (detection limits ranged from 0.1 to 2 ng/g, depending on analytical technique used) to 7 000 ng/g dry weight (Table 4-12). In Canada, the highest concentration in sediment was reported in the St. Clair River, covering a 7 km area in the vicinity of the Sarnia's heavy industry area, along the Canadian shoreline. Upstream (0-3 km) of the Dow Chemical Company the concentration ranged from nondetectable to 5.4 ng/g in 1985 and less than 1 ng/g for all three isomers in 1990. In the vicinity of Dow Chemical Company's waste disposal sites and the effluent outfall, the concentrations ranged from 17 to 7000 ng/g in 1985 and in 1990 ranged from nondetectable for 1,2,3,4-TeCB, from nondetectable to 510 ng/g for 1,2,3,5-TeCB and from nondetectable to 1140 ng/g for 1,2,4,5-TeCB. In both year, the concentrations diminished downstream below the industrial outfall (Oliver and Pugsley 1986; Ontario Ministry of the Environment 1993). Samples were collected at distances of 10, 25 and 100 meters from the Canadian shore. Contaminated sediment were confined to the Canadian shoreline as aerial photographs show discharge plumes following close to the Canadian shoreline for considerable distance downstream (Oliver and Pugsley 1986).

Sediment concentrations of TeCBs were also reported in Lakes Superior, Huron and Erie (Oliver and Nicol 1982), the St. Lawrence River (Kaiser et al. 1990; Merrimen 1987), Nova Scotia (Environment Canada 1979) and lakes in the Northwest Territories (Welch et al. 1991). All mean values were less than 10 ng/g (dry weight) with the exception of Lake Ontario, St. Clair River, and sites near point sources.

In United States, concentrations of 1,2,3,4-TeCB (up to 870 µg/g dry weight) were reported in sediments from the Niagara River, adjacent to the hazardous waste disposal sites in the City of Niagara Falls, N.Y. (Table 4-12). Results of the study confirmed that the dumps were the major source of chlorobenzenes in the area between Canada and United States (Jaffe and Hites 1984).

TeCBs concentrations in sediment cores provided insight into the pattern and magnitude of historical loadings up to 1984-1985, as shown in Table 4-13. Data from the cores collected in the Niagara Basin of Lake Ontario, near the mouth of the Niagara River showed that the loading of TeCBs from the river had decreased in the recent past (Oliver and Nicol 1982; Oliver 1984a; Oliver et al. 1989; Durham and Oliver 1983). The contamination was greatest in the 1960's, i.e., up to 380 ng/g was reported in the core at 7 to 10 cm depth (Durham and Oliver 1983).

No information was found in the literature on environmental levels of TeCBs in pore water. To estimate pore water concentrations for sediments, the equilibrium partition method (Di Toro et al. 1991) was used. The conversion from sediment concentrations ( $C_{\text{sediment}}$ ) to pore water concentrations ( $C_{\text{water}}$ ) is accomplished using distribution coefficients ( $K_{\text{oc}}$ 's) relating the pore water and the organic carbon fraction ( $f_{\text{oc}}$ ) in the sediment as follows:

$$C_{\text{water}} = C_{\text{sediment}} / (K_{\text{oc}} \times f_{\text{oc}})$$

Among the assumptions built into this approach are that nonionic organic chemicals such as TeCBs are associated with sediment organic carbon, and that partitioning of these chemicals between the organic carbon and sediment pore water is at equilibrium.

The organic carbon fraction ( $f_{\text{oc}}$ ) of the sediment was set at 0.015, corresponding to the level measured in the most severely contaminated area - St. Clair River (near the Dow Chemical Co.-Sarnia). With  $C_{\text{sediment}}$  equal to the worst-case scenario of 7000 ng/g in 1985 in Saint Clair River sediment and  $K_{\text{oc}}$  equal to 12,882 (Oliver 1987a,c),  $C_{\text{water}}$  was estimated to be 36,227 ng/L for pore water. Therefore, the estimated pore water concentrations for TeCBs in Canadian sediments ranged from nondetectable to 36,227 ng/L.

#### 4.3.4 Suspended Sediment

Examples of levels in suspended sediment are given in Table 4-14. In suspended sediments, the highest concentrations of TeCBs were reported in the Niagara River at Niagara-on-the Lake ranging up to 320 ng/g dry weight for 1,2,3,4-TeCB and to 160 ng/g-dry weight for 1,2,4,5-TeCB (Sylvestre 1987).

#### 4.3.5 Biota

Levels of TeCBs have been detected in aquatic invertebrates, lichens, fish, birds and marine mammals. Examples of levels in biota are given in Table 4-15.

Two TeCBs isomers, 1,2,3,4-TeCB and 1,2,4,5-TeCB are routinely determined by the Department of Fisheries and Oceans (Muir 1993) in fish and marine mammal samples from the Arctic. Levels of these two isomers in Arctic biota are generally low i.e. <1 ng/g (wet weight) in arctic char and in narwhal and beluga blubber (<10 ng/g).

In various trophic level 4 fish from Lakes Superior, Huron, Erie, and Ontario in the 1980's, TeCBs were found to range from nondetectable to 12 ng/g of wet weight with highest levels reported in Lake Ontario. Levels of TeCB isomers in fish of Great Lakes are highly controlled by concentrations of those chemicals in water (Oliver and Niimi 1983). In 1984, TeCBs occurred in some samples of non-migratory fish including carp, goldfish, and catfish from

the Niagara River watershed, tributaries to Lake Ontario and in the outflow of Lake Ontario to the St. Lawrence (Table 4-15). Highest levels (up to 7400 ng/g on a lipid basis-wet weight) were found in the fish collected nearby dump sites in Niagara Falls, N.Y. The concentrations ranged from nondetectable to 7400 ng/g (on a lipid basis-wet weight) in fish from the American tributaries to Lake Ontario (Jaffe and Hites 1986).

TeCBs were found in fish collected from lakes in northwestern Ontario. The concentrations were <1ng/g (wet weight) (Muir 1993).

Detection was also reported in zooplankton and benthic fauna including amphipods and oligochaetes in Lake Ontario off the Niagara River (Fox et al. 1983; Oliver and Niimi 1988). TeCBs were found to range from 0.1 to 6.1 ng/g for wet weight in 1985 and from 1.8 to 46.2 ng/g for wet weight in 1981.

1,2,3,4- and 1,2,4,5-TeCB are routinely monitored in all Canadian Wildlife Service contaminant programs. In 1990-1991 the frequency of detection was <20% and <30% respectively, usually at levels <2 ng/g. The detection limit usually varied between 0.1 and 5 ng/g, depending on the sample. Levels of 1,2,4,5-TeCB were detected in bald eagle eggs (Haliaeetus leucocephalus) (geometric mean of 3.3, ranging from 1 to 37.4 ng/g with 16/30 samples above the detection limit) and osprey eggs (Pandion haliaetus) (geometric mean of 6.2, ranging from 2.1 to 18.2 ng/g with 10/17 samples above the detection limit) from the Columbia River in British Columbia near pulp mills. No 1,2,3,4-TeCB was detected above the detection limit (1 ng/g) in these samples. Mink (Mustela vison) and otter (Lutra canadensis) liver from the same area contained levels of 1,2,4,5- and 1,2,3,4-TeCB with geometric means and ranges of 2.4, 1.1 to 7.6 ng/g and 0.43, 0.3 to 0.6 ng/g respectively. The levels of 1,2,4,5-TeCB were detected in three non-viable peregrine falcon eggs (Falco peregrinus) from Quyon, Quebec collected in June 1991 with a mean level of 13 ng/g (Environment Canada 1992b). The eggs were also high in DDE (20.7 ng/g), hexachlorobenzene (8.91 ng/g) and total PCBs (10.24 ng/g). As the species is migratory, without a history of the adult female, it is not possible to determine the source of this high contaminant load. However, the bird probably wintered in a contaminated industrial area in Central or South America. 1,2,4,5-TeCB (35 ng/g) was also detected in liver from a juvenile Peregrine Falcon from Ottawa.

The Canadian Wildlife Service, Environment Canada has monitored 1,2,3,4-, and 1,2,4,5-TeCBs in herring gull eggs (Larus argentatus) since 1979 as part of the Surveillance Program for the Great Lakes Water Quality Board of the International Joint Commission (Bishop et al. 1992; Environment Canada 1992b). Herring gulls in the Great Lakes are opportunistic feeders that eat predominantly fish and are therefore are a good indicator of bioaccumulation through the aquatic food chain. Agawa Rock (northern L. Superior) represents colonies distant from industry and has always had TeCB levels close to the detection limit. The colonies at Niagara River, Fighting Island (Detroit River) and Channel Shelter Island (Saginaw River U.S.A.) represent colonies close to point sources of industrial contamination. In the early 1980s, the maximum mean levels of 1,2,3,4-TeCB detected at Niagara River, Fighting Island, Channel shelter Island and Agawa Rocks were 53 ng/g, 16 ng/g, 1749 ng/g and 8 ng/g, respectively. The corresponding levels for 1,2,4,5-TeCB were 20 ng/g, 10 ng/g, 453 ng/g and 13 ng/g, respectively. Levels for 1990 at Channel Shelter Island for 1,2,3,4-, and 1,2,4,5-TeCBs were 41 and 21 ng/g. Levels at the other three colonies were at the detection limit of 2 ng/g and 3ng/g respectively.

Persistent chemicals such as the TeCBs tend to bind to suspended material in the water fraction and are therefore found at higher levels in the sediment. Fox et al. (1983) found high levels of TeCBs in benthos from the mouth of the Niagara River, demonstrating their bioavailability. Benthic feeders such as the Oldsquaw duck (Clangula hyemalis) (which winters in the

Great Lakes and feeds primarily on amphipods) could potentially be exposed to high levels of TeCBs in the diet. Using mean April levels of 1,2,3,4- and 1,2,4,5-TeCBs in amphipods of 41 ng/g-dw and 17.6 ng/g-dw respectively (Fox et al. 1983), the total calculated daily intake by a 1 kg Oldsquaw duck using allometric equations was approximately 3.5 ng/g-bw. 1,2,3,4-TeCB was detected in the breast muscle of a pool of four adult Oldsquaw duck (6 ng/g) and one adult Common Goldeneye (Bucephala clangula) duck (5 ng/g) on the Niagara River in February 1988 (Environment Canada 1992b). 1,2,4,5-TeCB was detected at 2 ng/g in the oldsquaw pool. Both species of duck winter on the Great Lakes and tend to eat benthic invertebrates. In most cases, herbivorous and piscivorous ducks from Lake Ontario did not have levels of TeCBs in breast muscle above detection limits (1 ng/g). 1,2,4,5-TeCB concentrations have also been detected in a Canada Goose (Branta canadensis) from the St. Clair River (9 ng/g), and a pool of four Barrows Goldeneye (Bucephala islandica) (9µg/kg) from Baie des Rochers, Quebec in March 1988 (Environment Canada 1992b).

## **5.0 POPULATION EXPOSURES (ROUTES)**

### **5.1 Wildlife populations exposure**

Information on environmental transport and transformation indicates that TeCBs have the potential to be persistent in the environment. As a result, wildlife populations may potentially be exposed to TeCBs via air, drinking water and food.

Wildlife may be exposed to TeCBs from the following air sources: downwind or near industrial facilities, disposal sites, incinerators or transboundary transport sources. Since TeCBs are soluble to a certain extent in water, washouts from the atmosphere in rainwater can occur. The TeCBs in rainwater are deposited onto soil or water, another potential source of exposure to wildlife. Due to their low solubility and tendency to partition into the sediment and air compartments, direct exposure of wildlife to significant levels of TeCBs from drinking water will be low except in close proximity to industrial effluent, leachates or runoff discharge points. The major sources of potential sources of TeCBs to wildlife will be through direct ingestion of soil or sediment or from consumption of contaminated foods. Sediment contaminated with TeCBs through historical use still persist in Canada. Through sediment resuspension, this TeCB sink could be a major source of exposure to the aquatic food chain. Bioconcentration factors vary between 1778 to 12883 (whole fish basis) and from 14125 to 134896 (lipid basis) (Table 4-1). Benthic feeders such as diving ducks would be exposed through diet and direct ingestion of sediment and pore water. Soil contamination can occur from leachates from contaminated waste sites, spillage of dielectric fluids and wet/dry deposition from air, which can be from a transboundary transport source.

## **6.0 TOXICOKINETICS AND METABOLISM**

### **6.1 Metabolic Breakdown and Elimination**

All three isomers of TeCBs were injected into the frog Rana pipiens. They were converted to metabolites and excreted into the water over a period of 8 days. The 1,2,3,5-, 1,2,4,5- tetrachloroisomers produced trichlorophenols which are the direct dechlorination-hydroxylation products. The 1,2,3,4-isomer gave tetrachlorophenol (Safe et al. 1976).

The 1,2,3,4-TeCB was also administered orally to the dairy cow. Half of the dose was deposited (unmetabolised) in the adipose tissue, with no apparent

excretion in the urine within the 24 hr following administration. But tetrachlorophenols detected in the urine were possible products resulting from oxidative metabolism of TeCBs (Marsden et al. 1986).

The 1,2,3,5-TeCB appeared to be metabolised in higher plants when taken up from soil (Trapp et al. 1990; Topp et al. 1989). The radioactive residues of [ $^{14}\text{C}$ ] 1,2,3,5-TeCB in barley comprised up to 40% of the polar metabolites, and 4.7% insoluble products during a short-term laboratory study. However, since polar metabolites were also formed in soil, and no differentiation between metabolism of 1,2,3,5-TeCB in plants and in soil was made it is not excluded that those metabolites could be taken up by roots and translocated into the shoots. Their nature was not established (Trapp et al. 1990).

## 9.0 EFFECTS ON THE ECOSYSTEM

The acute and chronic toxicity of the three TeCB isomers have been studied in several aquatic species. The toxic mode of action for all three TeCBs isomers to aquatic organisms is narcosis (Veith et al. 1983a,b; Bobra et al. 1985; Abernathy et al. 1986). Therefore, for a given species differences among measures of harmful effects of the three isomers are typically small and effects of exposure to mixtures of TeCB isomers are considered to be additive (McCarty et al. 1992).

### 9.1 Aquatic Systems and Components

#### Aquatic

#### 9.1.1 Bacteria and Primary Producers

Studies on the effects of TeCBs on bacteria and primary producers such as algae are listed in Table 9-1. Studies which listed concentrations greater than the water solubilities were considered unreliable.

The primary productivity of the freshwater green alga Ankistrodesmus falcatus in the presence of TeCBs was monitored by measuring the amount of  $^{14}\text{C}$ -carbonate taken up by the cells in a 4 hour period (Wong et al., 1984). The 4-h EC50 values for 1,2,3,4-, 1,2,3,5- and 1,2,4,5-TeCB were 0.019, 0.014 and 0.023 mM respectively. These values correspond to  $4.10 \times 10^3$ ,  $3.02 \times 10^3$  and  $4.97 \times 10^3$  ug/L.

The influence of TeCBs on biologically active nucleic acids in the diatom Cyclotella meneghiniana was studied by Figueroa and Simmons (1991). The 48-h EC50, measured by % DNA reduction for 1,2,3,4-, 1,2,3,5- and 1,2,4,5-TeCB was  $1.39 \times 10^3$ ,  $1.37 \times 10^3$  and  $0.27 \times 10^3$  ug/L respectively. DNA is a novel sensitive indicator of biomass as it plays a dominant role in cellular processes related to biosynthesis, growth and reproduction. As it is not known how this relates to higher organisms and to environmental assessment, it will not be considered in the assessment of TeCBs.

The 96h-EC50 values for the freshwater green alga Selenastrum capricornutum based on chlorophyll a and cell numbers respectively were 17,200 and 17,700  $\mu\text{g/L}$  for 1,2,3,5-TeCB and 52,900 and 46,800  $\mu\text{g/L}$  for 1,2,4,5-TeCB (US EPA 1980a). In a similar study, the 96h-EC50 values for the marine alga Skeletonema costatum based on chlorophyll a and cell numbers respectively were 830 and 700  $\mu\text{g/L}$  for 1,2,3,5-TeCB and 7100 and 7320  $\mu\text{g/L}$  for 1,2,4,5-TeCB (US EPA 1980a). No experimental conditions were given for either study.

For a QSAR study, Hutchinson et al. (1980) determined photosynthetic inhibition for two green algae, Chlamydomonas angulosa and Chlorella vulgaris when exposed to 1,2,3,5-TeCB for 3 hours under identical conditions. The 3h-

EC50 values were 7.3 and 11.6 mmol/m<sup>3</sup>, respectively. This corresponds to 1576 and 2504 µg/L.

Ikemoto et al. (1992) found that the green algae Chlorella vulgaris did not exhibit toxicity when exposed to 1,2,3,4-TeCB for 5 days. The 5d-EC50 for growth inhibition was >63691 µg/L. Details of experimental conditions are sparse. It is not clearly stated, but assumed that experiment was performed in static, nominal, and possibly unsealed conditions.

Ribo and Kaiser (1983) measured the response of Photobacterium phosphoreum (Microtox test) when exposed to all three TeCBs. The 30-min EC50 measured as a reduction in emitted light for 1,2,3,4-, 1,2,3,5- and 1,2,4,5-TeCB were 1.74, 1.94 and <1.68 log(L/mol) respectively. In units of µg/L these values correspond to 4.02 X 10<sup>3</sup>, 2.48 X 10<sup>3</sup> and >4.51 X 10<sup>3</sup> µg/L. The corresponding 5-min and 15-min EC50 values for each isomer are listed in Table 9-1 (Kaiser and Ribo 1988). Hermens et al. (1985) determined the 15-min Microtox test for 1,2,3,4-TeCB to be 1.88 X 10<sup>3</sup> µg/L.

Blum & Speece (1991), measured the toxic response of two groups of environmental bacteria. Nitrosomonas convert ammonia nitrogen to nitrite as the first step in the biological oxidation of nitrogen and methogens convert organic matter to CO<sub>2</sub> and methane in anaerobic environments. Neither group proved to be sensitive to TeCB isomers below their respective solubilities. For Nitrosomonas, the 24h-EC50 measured by inhibitions of ammonia consumption was 20000 and 9800 µg/L for 1,2,3,4- and 1,2,4,5-TeCB respectively. The 48h-EC50 for anaerobic methogens as measured by inhibition of gas consumption was 20000 µg/L in the presence of 1,2,3,4-TeCB.

#### 9.1.2 Invertebrates

Studies on the effects of TeCBs on invertebrates are listed in Table 9-2. Studies which listed concentrations greater than the water solubilities were considered unreliable.

##### 9.1.2.1 Acute toxicity

In an acute study with D. magna, the log(48h-IC50) (immobilization) for 1,2,3,4-TeCB was 0.40, corresponding to 542 µg/L (Hermens et al. 1984). The calculated 48h-IC50 for all three TeCB isomers based on experimental data from 50 compounds and the corresponding calculated log Kow values was 358 µg/L. This QSAR relationship does not take into account differences in toxicity due to placement of the chlorine groups.

In a study to determine QSAR relationships between acute toxicity of chlorobenzenes to Daphnia magna, the 48-hour EC50 as determined by absence of movement, for 1,2,3,5-TeCB was 4 mmol/m<sup>3</sup>, corresponding to 863 µg/L (Bobra et al. 1983; Bobra et al. 1985; Abernathy et al. 1986). The bioassays were performed in 24 mL, teflon-lined screw-on caps. A saturated TeCB solution was added to the vial and the final concentration was determined by weight based on the water solubility of the compound. No air space was left in the vial and no analysis was done as it was assumed that there was negligible loss of the compound from the saturated solution by volatilization.

In studies with Daphnia magna, the US EPA (1980a) found the 48h-EC50 values for 1,2,3,5-, and 1,2,4,5-TeCB to be 9710 and >530000 µg/L respectively. No experimental conditions are given in this paper. These data are probably part of the data base published by LeBlanc (1980). Using nominal, static test procedures, LeBlanc determined 24-h and 48-hour LC50s of 18,000 and 9700 µg/L for 1,2,3,5-TeCB and both >530000 µg/L for 1,2,4,5-TeCB.

Ikemoto et al. (1992) determined the 96h-LC50 for Daphnia pulex to be 184 µg/L (-Log LC50 = 6.07 M). It is unclear in the paper whether



experimental medium was renewed or measured. However fish toxicities determined in the same paper were measured.

The only salt water species tested is the mysid shrimp Mysidopsis bahia (US EPA 1980a). The 96h-LC50 for 1,2,3,5- and 1,2,4,5-TeCB was 340 and 1480 µg/L respectively.

#### 9.1.2.2 Chronic toxicity

While developing QSAR relationships for chlorohydrocarbons, a group from the Netherlands determined chronic responses of D. magna to 1,2,3,4-TeCB (Hermens et al. 1984, Hermens et al. 1985 and De Wolf et al. 1988).

The 16d-LC50 and 16d-EC50 (reproduction) for 1,2,3,4-TeCB were 320 µg/L and 43 µg/L respectively (Hermens et al. 1984). The corresponding 16d-NOECs for mortality and reproduction were 100 µg/L and 10 µg/L. However as explained for the following study, these numbers may not be the actual concentrations to which the organisms were exposed. Hermens et al. (1985) determined that the log(16d-EC50) and log(16d-NOEC) for reproductive effects for exposure to 1,2,3,4-TeCB were -0.13 and -0.59, where the EC50 and NOEC were in µmol/L. These values correspond to 160 µg/L and 56 µg/L respectively. This study and the previous mentioned one were conducted under static renewal conditions with actual concentrations of 1,2,3,4-TeCB determined for the lowest and highest concentrations just before and after renewal of the test solutions. Chemical analysis showed that the actual amount of 1,2,3,4-TeCB present in the test solutions was 61% of the nominal quantities added. The published effect levels were not corrected for these measured concentrations. When corrected for the actual dose, the 16d-EC50 and 16d-NOEC (reproduction) for 1,2,3,4-TeCB are 98 µg/L and 34 µg/L. This work was repeated by De Wolf et al. (1988) under a similar experimental protocol. The 16d-EC50 value for reproduction and 16d-NOEC values for growth and reproduction corresponded to 90 µg/L, 55 µg/L and 55 µg/L. Although test solutions were measured, the effect concentrations were based on added quantities.

#### 9.1.3 Fish

Studies on the acute and chronic effects of TeCBs on fish are listed in Table 9-3. Studies which listed concentrations greater than the water solubilities were considered unreliable.

##### 9.1.3.1 Acute toxicity

Carlson and Kosian (1987) determined the acute toxicity of 1,2,3,4-TeCB to fathead minnow Pimephales promelas. Under nominal, static conditions the 96h-LC50 was 1100 µg/L. Under measured flow-through conditions, Ahmad et al. (1984) determined the 1,2,3,4-TeCB 96h-LC50 for P. promelas to be 1070 µg/L. Veith et al. (1983a,b) determined the acute toxicity of 1,2,3,4-TeCB to the fathead minnow Pimephales promelas using a measured, flow-through system. The 96h-LC50 for 1,2,3,4-TeCB was determined to be 1080 µg/L. Using a flow-through system, the 96h-LC50 for fathead minnow when exposed to 1,2,3,4- and 1,2,4,5-TeCB was 802 and 305 µg/L respectively (Hall et al. 1984). It is not clear whether the study is measured.

Sub-acute toxicity of the guppy Poecilia reticulata when exposed to all three TeCB isomers was determined as part of a QSAR study (Könemann 1981). The 14d-LC50 values for 1,2,3,4-, 1,2,3,5- and 1,2,4,5-TeCB were 0.57, 0.57 and 0.15 log(mmol/L). These data correspond to 802, 802 and 305 µg/L. The test solution in the closed static, renewal system. No analysis was done.

The 96h- and 192h-LC50s for the guppy using a measured flow-through system were 365 and 244 µg/L respectively for 1,2,3,4-TeCB (Van Hoogen and Opperhuizen, 1988). The concentration of 1,2,3,4-TeCB for each guppy was

determined immediately after the fish died. The average concentration of 1,2,3,4-TeCB in fish dying in the 96h and 192h (8 day) toxicity tests were 499 and 570 ng/g-wet weight fish respectively.

American flagfish (Jordanella floridae) were exposed to 1,2,4,5-TeCB under measured, flow-through conditions (Smith et al. 1991). For week old and juvenile flagfish, the 96h-LC50 values were 1950 µg/L and 2150 µg/L respectively. These values may be artificially high due to an insoluble component still present in the water samples. When the precipitate was removed from the water samples using a 0.22 µm Millipore filter, the 96h-LC50 estimated from the aqueous 1,2,4,5-TeCB concentration was 380 µg/L. The authors suggest that this value is likely a closer estimate of the toxicity of the aqueous phase of 1,2,4,5-TeCB on flagfish. To separate out toxic effects of the soluble and insoluble 1,2,4,5-TeCB, additional static tests were conducted using filtered saturated solutions ([1,2,4,5-TeCB] = 300 - 470 µg/L). No mortalities were observed after 10 days exposure, but signs of toxic action such as loss of equilibrium and lethargy were observed.

Acute toxicity of 1,2,3,5- and 1,2,4,5-TeCB to the bluegill sunfish Lepomis macrochirus, was determined in an open, static system (Buccafusco et al. 1981). The 24h- and 96h-LC50 values for 1,2,3,5-TeCB were 59000 and 6400 µg/L and for 1,2,4,5-TeCB were 5700 and 1600 µg/L. For both isomers, precipitate was visible in the test container and data reported were based on the nominal concentration of the TeCB isomer.

In studies with bluegill sunfish, the US EPA found that the 96h-LC50 value for 1,2,3,5- and 1,2,4,5-TeCB was 6420 and 1550 µg/L respectively (US EPA 1978).

Van Leeuwen et al. (1985) studied the differences in susceptibility of different early life stages of rainbow trout Onchornychus mykiss to 1,2,4,5-TeCB. Embryolarval tests are usually consistent with the much longer duration life cycle tests but are themselves laborious. The premise of this study was to determine which embryolarval stage is most susceptible to acute exposure to 1,2,4,5-TeCB and other priority pollutants. Under nominal, static, daily renewal conditions, 6 stages of development egg (0 h), egg (24 h), early eyed egg (14 d), late eyed egg (28 d), sac fry (42 d) and early fry (77 d) were exposed to 1,2,4,5-TeCB for 96 hours. The 96h-LC50 for 77d early fry was 1200 µg/L. No mortality occurred with the other 5 stages of development suggesting that 1,2,4,5-TeCB is not acutely toxic to early life stages.

Smith and Craig (1981) investigated intraperitoneal injection (ip) of rainbow trout Onchornychus mykiss as an alternative method of testing the acute toxicity of 1,2,4,5-TeCB to fish. It is assumed that compounds are absorbed from the peritoneal cavity via the bloodstream and redistributed to various target organs for detoxification, excretion or storage. It was not possible to determine an LD50 for 1,2,4,5-TeCB as it was insoluble in the carrier (cod liver oil) above 7.5 mM/kg. The 96h-EC50 (loss of equilibrium and buoyancy) for 1,2,4,5-TeCB was 10.6 mM/kg (this volume was achieved by doubling the injection volume). Assuming a fish weight of 35 g and an injection of 1 mL/100 g-wt fish (0.35 mL/35 g-wt fish) this dose corresponds to 2280 ng/g-wet weight.

In their work with rainbow trout, Ribo and Kaiser (1983) determined ip 96h-LD50 values for 1,2,3,4- and 1,2,3,5-TeCB of 1060 and 1680 ng/g fish. The 96h-LD50 for 1,2,4,5-TeCB is >4720 µg/kg. The same group determined the 96h-LC50 values for 1,2,3,4- and 1,2,4,5-TeCB under measured flow-through conditions to be 497 and 1533 µg/L respectively.

McCarty (1986) introduced the concept of establishing internal toxicant concentrations for aquatic organisms. Based on a limited data set for chlorobenzenes (dichlorobenzene, trichlorobenzene and tetrachlorobenzene)

McCarty et al. (1992) calculated the acute critical body residue for fish exposed to chlorobenzenes to be 3-12  $\mu\text{mol/g}$  wet weight and the chronic critical body residue to be 0.2  $\mu\text{mol/g}$  wet weight of fish. The chronic critical body residue for insects was similar (3-13  $\mu\text{mol/g}$  wet weight). If the most sensitive chronic critical body residue is multiplied by the molecular weight of TeCB (215.9 g/mol), then the critical body residue for fish after a chronic exposure to TeCB would range from 64.7  $\mu\text{g/g}$  wet weight. This was divided by a factor of ten in order to derive a no effects level and to account for potential differences in species sensitivity and laboratory versus field conditions, and by an additional factor of 10 to account for the small database and the uncertainty associated with the critical residue method. This results in an "estimated effects threshold" of 0.647  $\mu\text{g/g}$  wet weight.

The 24h-LC50 for killifish, Oryzias latipes, when exposed to 1,2,3,4-TeCB was 1924  $\mu\text{g/L}$  (Ikemoto et al. 1992).

The acute toxicity of the marine sheepshead minnow Cyprinodon variegatus was determined by Heitmuller et al. (1981) under nominal, static conditions. The 24h-, 48h-, 96h-LC50 and 96h-NOEC values for 1,2,3,5-TeCB were >7500, 5600, 4700, 3700 and 1000  $\mu\text{g/L}$ . The corresponding effect values for 1,2,4,5-TeCB were >1800, 900, 800, 800 and 300  $\mu\text{g/L}$ .

#### 9.1.3.2 Chronic toxicity

Carlson and Kosian (1987) determined the chronic toxicity of 1,2,3,4-TeCB to fathead minnow Pimephales promelas from 4-12 h embryos to early juveniles. The toxic endpoint was % normal larvae hatching and survival to the end of the test and final mean live weight. Exposure to 410  $\mu\text{g/L}$  1,2,3,4-TeCB did not effect embryo development. Fish survival from hatch to the end of the test was reduced by 35% and their final weight was reduced by 50% when compared to the control. There were no effects of exposure evident at concentrations  $\leq 250$   $\mu\text{g/L}$ . The chronic value for exposure to 1,2,3,4-TeCB in this study was 320  $\mu\text{g/L}$ .

Under measured flow-through conditions, Ahmad et al. (1984) determined the effects of 1,2,3,4-TeCB in a 33d-embryolarval test (ELS) for P. promelas. The estimated MATC for 1,2,3,4-TeCB based on survival lies between 245 and 412  $\mu\text{g/L}$ .

In embryo-larval tests with the fathead minnow (US EPA 1978), the chronic value for exposure to 1,2,3,4-TeCB was 318  $\mu\text{g/L}$  with a corresponding acute-chronic ratio of 3.4.

Zebra fish (Brachydanio rerio) eggs (6h old) were exposed to 1,2,3,4-TeCB under measured, semi-static conditions for 28 days (van Leeuwen et al., 1990). The mean measured concentrations of 1,2,3,4-TeCB during the test was 55% of the nominal concentration. The 28d-LC50 was 410  $\mu\text{g/L}$  with a corresponding 28d-NOLC of 310  $\mu\text{g/L}$ . Growth was the most sensitive parameter with a 28d-NOEC of 100  $\mu\text{g/L}$ . At the higher concentrations embryonic effects such as skeletal deformities, enlarged yolk sacs and edemas were observed.

Brook trout Salvelinus fontinalis were exposed for a 100 day period, beginning with eyed-up eggs, continuing through the remainder of the embryo stage (10 to 14 days), the entire sac-fry stage (about 70 days) and the free-swimming alevin stage for approximately 20 days (Aquatic Toxicity Research Group 1987). The estimated MATC for impaired hatching success was 347 to 455  $\mu\text{g/L}$  with a chronic value of 397  $\mu\text{g/L}$ . Sac-fry survival to swim-up, 100-day fry survival and growth were all significantly reduced at 243  $\mu\text{g/L}$  with an estimated MATC of < 243  $\mu\text{g/L}$ .

Two age groups of American flagfish (Jordanella floridae), embryo/larval fish and week-old fry were used in simultaneous flow-through exposures to

1,2,4,5-TeCB (Smith et al. 1991). Test solutions in all exposure tanks were analyzed 5 days per week. For the first age group,  $\leq 24$  h eggs were incubated 4-6 days until hatch. The larvae were then held for a 10-d post hatch exposure period. 1,2,4,5-TeCB had no effect on hatching success and 10-day larval survival (estimated MATC  $> 238 \mu\text{g/L}$ ). For the second age group, 1 week old fry were exposed for 28 days. Fry growth was the most sensitive parameter with an estimated 28d-MATC of  $85 \mu\text{g/L}$ . The estimated 28d-MATC for fry survival over 28 days was  $138 \mu\text{g/L}$ .

In embryo-larval tests with the sheepshead minnow (US EPA 1978), the chronic value for sheepshead minnow exposed to 1,2,4,5-TeCB was  $129 \mu\text{g/L}$  with a corresponding acute-chronic ratio of 6.5.

#### **9.1.4 Birds and Marine Mammals**

There is no information in the literature of the effects of TeCB isomers on birds or wild mammals.

#### **9.1.5 Terrestrial Systems and Components**

There is no information in the literature of the effects of TeCB isomers on terrestrial organisms or wild mammals.

### **10.0 REFERENCES**

Abernethy, S.G., A.M. Bobra, W.Y. Shiu, P.G. Wells and D. Mackay. 1986. Acute lethal toxicity of hydrocarbons and chlorinated hydrocarbons to two planktonic crustaceans: the key role of organism-water partitioning. *Aquat. Toxicol.* 8(3): 163-174.

Ahmad, N., D. Benoit, L. Brooke, D. Call, A. Carlson, D. DeFoe, J. Huot, A. Moriarity, J. Richter, P. Shubat, G. Veith and C. Wallbridge. 1984. Aquatic toxicity tests to characterize the hazard of volatile organic chemicals in water: a toxicity data summary - Parts I and II. Environmental Research Laboratory- Duluth, United States Environmental Protection Agency, 111 pp. (EPA-600/3-84-009).

Akermark, B., P. Baeckstrom, U.E. Westlin, R. Gothe and C.A. Wachtmeister. 1976. Photochemical dechlorination of 1,2,4-trichlorobenzene. *Acta Chem. Scan.* B30: 49-52.

Alves, H.H.D. and M. Chevalier. 1980. L'hexachlorobenzene dans l'environnement quebecois: Production utilisation et presence. Service de la Protection de L'environnement, Environnement Canada, EPS-3 QR-80-1. Montreal, Quebec.

Aquatic Toxicity Research Group (ARTG). 1987. Aquatic toxicity studies of multiple organic compounds. Part I: chlorinated benzenes and chlorinated phenols summary report. (Interim). Ontario Ministry of the Environment and Environment Canada, 277 pp.

Asher, S., K. Lloyd, D. MacKay, S. Paterson and J.R. Roberts. 1985. A Critical Examination of Environmental Modelling - Modelling the Environmental Fate of Chlorobenzenes Using the Persistence and Fugacity Models. National research Council of Canada, Associate Committee on Scientific Criteria for Environmental Quality, Ottawa, Ontario, Publ. No. NRCC 23990. 206 pp.

Atkinson, R. 1985. Kinetics and mechanisms of the gas-phase reactions of the hydroxyl radical with organic compounds under atmospheric conditions. *Chem. Rev.* 85: 69-201.

Atkinson, R. 1987. A Structure-Activity Relationship for the Estimation of Rate Constants for the Gas-Phase Reactions of OH Radicals with Organic Compounds. *International Journal of Chemical Kinetics* 19, 799-828.

Atkinson, R., S.M. Aschmann, A.M. Winner, Jr. and J.N. Pitts. 1985. Atmospheric gas phase loss process of chlorobenzene, benzotrifluoride and 4-chlorobenzotrifluoride and generalization of predictive technique for atmospheric life times of aromatic compounds. *Arch. Environ. Contam. Toxicol.* 14, 417-425.

Atlas, E.L. and S. Schauffler. 1990. Concentration and Variation of Trace Organic Compounds in the North Pacific Atmosphere. In: Long Range Transport of Pesticides. D.A. Kurtz. Ed. Lewis Publishers, Inc., pp. 161-183.

Bales, R.G. and J.E. Szecsody. 1990. Microscale processes in porous media. In: Melchior D.C. and R.L. Bassett, eds. Chemical Modelling of Aqueous Systems II. Chpt. 41. ACS Symp. Ser. 416 527-538.

Ballschmiter, K. and C. Scholz. 1980. Microbial decomposition of chlorinated aromatic substances. VI. Formation of dichlorophenols and dichloropyrocatechol from dichlorobenzenes in a micromolar solution by Pseudomonas species. *Chemosphere* 9 (7-8):457-467.

Banerjee, S., P. H. Howard, A.M. Rosenberg, A.E. Dombrowski, H. Solla and D.L. Tullis. 1984a. Development of a general kinetic model for biodegradation and its application to chlorophenols and related compounds. *Environ. Sci. Technol.* 18, 416-422.

Banerjee, S., R.H. Sugatt and D.P. O'Grady. 1984b. A simple method for determining bioconcentration parameters of hydrophobic compounds. *Environ. Sci. Technol.* 18, 79-81.

Banerjee, S., S.H. Yalkowsky and S. Valvani. 1980. Water solubility and octanol/water partition coefficients of organics. Limitations of the solubility-partition coefficient correlation. *Environ. Sci. Technol.* 14, 1227-1229.

Banerjee, S., P.H. Howard and S.S. Lande. 1990. General structure vapour pressure relationship for organics. *Chemosphere* 21, 1173-1180.

Barrows, M.E., S.R. Petrocelli, K. J. Macek and J.J. Carroll. 1980. Bioaccumulation and elimination of selected water pollutants by bluegill sunfish (Lepomis macrochirus). In: R. Haque, ed. Dynamics, Exposure and Hazard Assessment of Toxic Chemicals. Ann Arbor Science Publishers Inc., Ann Arbor, Michigan, pp. 379-392.

Belfroid, A, A. van Wezel, M. Sikkenk, K. van Gestel, W. Seinen and J. Hermens. 1993. The toxicokinetic behavior of chlorobenzenes in earthworms (Eisenia andrei): Experiments in water. *Ecotoxicol. Environ. Safety* 25: 154-165.

Biberhofer, J. and R.J.J. Stevens. 1987. Organochlorine Contaminants in Ambient Waters of Lake Ontario. Environment Canada-Scientific Series No. 159-WQB, Burlington, Ont.

Bishop, C.A., D.V. Wesloh, N.M. Burgess, J. Struger, R.J. Norstrom, R. Turle and K.A. Logan. 1992. An atlas of contaminants in eggs of fish-eating

colonial birds of the Great Lakes (1970-1988) Vol II. Technical Report Series No. 153, Canadian Wildlife Service, Ontario Region.

Blum, D.K.W. and R.A. Speece. 1991. A database of chemical toxicity to environmental bacteria and its use in interspecies comparisons and correlations. Res. J. Water Pollut. Cont. Fed. 63(3): 198-207.

Bobra, A.M. W.Y. Shiu and D. Mackay. 1983. A predictive correlation for the acute toxicity of hydrocarbons and chlorinated hydrocarbons to the water flea (Daphnia magna). Chemosphere 12(9/10): 1121-1129.

Bobra, A., W.Y. Shiu and D. Mackay. 1985. Quantitative structure-activity relationships for the acute toxicity of chlorobenzenes to Daphnia magna. Environ. Toxicol. Chem. 4: 297-305.

Bosma, T.N.P., J.R. van der Meer, G. Schraa, M. E. Tros and A. J.B. Zehnder. 1988. Reductive dechlorination of all trichloro- and dichlorobenzene isomers. FEMS Microbiol. Ecol. 53: 223-229.

Brien, E.D. 1992. Environment Canada. Hull Quebec. Personal communication.

Briggs, G.G. 1981. Theoretical and experimental relationships between soil adsorption, octanol-water partition coefficients, water solubilities, bioconcentration factors and the Parachor. J. Agric. Food Chem. 29, 1050-1059.

Brooks, G.W. and G.I. Hunt. 1984. Source assessment for hexachlorobenzene. Radian Corporation, prepared for Research Triangle Park, U.S. Environment Protection Agency, North Carolina EPA No. 68-02-3818.

Bruggeman, W.A., J. Van Der Steen and O. Hutzinger. 1982. Reversed-phase thin layer chromatography of polynuclear aromatic hydrocarbons and chlorinated biphenyls. Relationship with hydrophobicity as measured by aqueous solubility and octanol-water partition coefficient. J. Chromatogr. 238, 335-346.

Buccafusco, R.J. S.J. Ellis and G.A. LeBlanc. 1981. Acute toxicity of priority pollutants to bluegill (Lepomis macrochirus). Bull. Environ. Contam. Toxicol. 26: 446-452.

Bunce et al. 1989. Environ. Sci. Technol. 23, 213.

Burkhard, L.P. and D.W. Kuehl. 1986. n-Octanol/water partition coefficients by reversed phase liquid chromatography/mass spectrometry for eight tetrachlorinated planar molecules. Chemosphere 15, 163-167.

Camford. 1991. Chlorobenzene CPI product profile. Don Mills, Camford Information Services. Ontario. 4 pp.

Canada Gazette. 1980. Chlorobiphenol Regulations No. 1, amendment. Canada Gazette Part 11, Vol. 114, No. 13 (SOR/80-461 20 June 1980).

Carey, J.H. and M.E. Fox. 1987. Distribution of Chlorinated Benzenes in the Niagara River Plume. Environment Canada-NWRI-87-86.

Carlson, A.R. and P.A. Kosian. 1987. Toxicity of chlorinated benzenes to fathead minnows (Pimephales promelas). Arch. Environ. Contam. Toxicol. 16: 129-135.

Chan, C.H. and J. Kohli. 1987. Surveys of trace contaminants in the St. Clair River, 1985. Environment Canada, Inland Waters/Land Dir., Ont. Region, Water Qual. Branch, Burlington, Ont., Tech. Bull. No. 158, 10 pp.

- Chang, V. 1992. Saskatchewan Department of the Environment, Regina Saskatchewan.  
Personal communication to P. Doyle, Environment Canada.
- Charleton, M.N. 1983. Downflux of sediment, organic matter and phosphorus in the Niagara River area of Lake Ontario. *J. Great Lakes Res.* 9, 201-211.
- Chiou, C.T. 1985. Partition coefficients of organic compounds in lipid-water systemd and correlations with fish biocentration factors. *Environ. Sci. Technol.* 19, 57-62.
- Choudhry, G.G., A.A.M. Roof and O. Hutzinger. 1979. Photochemistry of halogenated benzene derivatives. I. Trichlorobenzenes: reductive dechlorination, isomerization and formation of polychlorobiphenyls. *Tetrahedron Letters*, 22: 2059-2062.
- Choudhry, G.G., J.A. van den Broecke and O. Hutzinger. 1983. *Chemosphere* 12, 487.
- Choudhry, G.G. and O. Hutzinger. 1984. Acetone-sensitized and nonsensitized photolyses of tetra-, penta-, and hexachlorobenzenes in acetonitrile-water mixtures: photoisomerization and formation of several products including polychlorobiphenyls. *Environ. Sci. Technol.* 18(4): 235-241.
- Choudhry, G.G. and G.R.B. Webster. 1985. Photochemistry of halogenated benzene derivatives. V. Photolytic reductive dechlorination and isomerization of tetrachlorobenzenes in acetonitrile-water mixtures. *Toxicol. Environ. Chem.* 9: 291-308.
- Choudhry, G.G., G.R.B. Webster and O. Hutzinger. 1986. Environmentally significant photochemistry of chlorinated benzenes and their derivatives in aquatic systems. *Toxicol. Environ. Chem.* 13, 27-83.
- CPI (Corpus Profile Information). 1987a. Trichloroethylene (trichlor). CPI Product Profiles, Don Mills, Ontario.
- CPI (Corpus Profile Information). 1987b. Perchloroethylene (tetrachloroethylene). CPI Product Profiles, Don Mills, Ontario.
- CPI (Corpus Profile Information). 1990a. Carbon tetrachloride (tetrachloromethane). CPI Product Profiles, Don Mills, Ontario.
- CPI (Corpus Profile Information). 1990b. Trichloroethylene (trichlor). CPI Product Profiles, Don Mills, Ontario.
- CPI (Corpus Profile Information). 1990c. Perchloroethylene (tetrachloroethylene). CPI Product Profiles, Don Mills, Ontario.
- Data Interpretation Group River Monitoring Committee. 1988. Joint Evaluation of Upstream/Downstream Niagara River Monitoring Data 1986-87.
- Data Interpretation Group River Monitoring Committee. 1990. Joint Evaluation of Upstream/Downstream Niagara River Monitoring Data 1988-89.
- DeBruijn, J., F. Busser, W. Seinen and J. Hermens. 1989. Determination of octanol/water partition coefficients for hydrophobic organic chemicals with the slow stirring method. *Environ. Toxicol. Chem.* 8, 499-512.
- De Wolf W., J.H. Canton, J.W. Deneer, R.C.C. Wegman and J.L.M. Hermens. 1988. Quantitative structure-activity relationships and mixture-toxicity studies of alcohols and chlorohydrocarbons: reproducibility of effects on growth and reproduction of Daphnia magna. *Aquat. Toxicol.* 12(1), 39-49.

- Dibbs, H.P. 1991. The VESTA Test Program: Data Review and Assessment. Environment Canada, PCB Technology Division. unpublished report. 40 pp.
- DiToro, D.M., C.S.Zarba, D.J.Hansen, W.J.Berry, R.C. Swartz, C.E. Cowan, S.P.Pavlou, H.E. Allen, N.A. Thomas and P.R. Paquin. 1991. Technical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. Environ. Toxicol. Chem. 10: 1541-1583.
- Doucette, W.J. and A.W. Andren. 1988. Estimation of octanol/water partition coefficients: Evaluation of six methods for highly hydrophobic aromatic hydrocarbons. Chemosphere 17, 345-359.
- Dow. 1992. Dow Chemical Canada Inc. Sarnia, Ontario.
- Dow. 1993. Dow Chemical Canada Inc. Sarnia, Ontario.
- Durham, R.W. and B.G., Oliver. 1983. History of Lake Ontario contamination from the Niagara River by sediment radiodating and chlorinated hydrocarbons analysis. J. Great Lakes Res. 9(2), 160-168.
- Ellington, J.J., F.E. Stancil, Jr., W.D. Payne and C.D. Trusty. 1988. Measurement of hydrolysis rate constants for evaluation of hazardous waste land disposal: volume 3. Data on 70 chemicals. Office of Research and Development, United States Environmental Protection Agency, 29 pp. (EPA/600/3-88/028).
- Environment Canada. 1979. Report on an Environmental Survey for Chlorobenzenes at Four Coastal Sites in Nova Scotia. (Unpublished Report)
- Environment Canada. 1983. Sampling of industrial sources of pentachlorobenzene. Prepared by IEC Beak Consultants Ltd. DSS 12SD.KE303-2-0064.
- Environment Canada. 1984. Commercial Chemicals Branch, Ottawa, Ontario. Unpublished data.
- Environment Canada. 1987. The National Incinerator Testing and Evaluation Program (NITEP): The Combustion Characterization of Mass Burning Technology-Quebec City. Environmental Protection Service, Environment Canada, Ottawa, Ontario.
- Environment Canada. 1989. Windsor air sampling site, July 1987-September 1988. Walpole Island air sampling site, January 1988-September 1988. River Road Environmental Technology Centre, Ottawa, Ont., Detroit Incinerator Monitoring Program. Data Report No. 3, 41 pp. PMD-89-8 (unpubl.)
- Environment Canada. 1990. Detroit Incinerator Monitoring Program. Data Report #4 (Appendices B to G), Windsor and Walpole Island air sampling sites. Environmental Protection Service, River Road Environmental Technology Centre, Ottawa, PMD-90-8.
- Environment Canada, Ottawa, Ontario. Environment Canada. 1991a. National Inventory of PCB in Use and PCB Wastes in Storage in Canada-December 1991. Prepared for the Canadian Council of Ministers of the Environment by the Office of Waste Management, Conservation and Protection, Environment Canada, 40 pp.
- Environment Canada. 1991b. Update and Summary Report-Measurement Program for Toxic Contaminants in Canadian Urban Air. River Road Environmental Technology Center-March 1991-PMD-91-2.



- Environment Canada. 1991c. National guidelines for hazardous waste incineration facilities: Volume 11, supporting document. Environmental Protection Service, Environment Canada, Ottawa, Ontario.
- Environment Canada. 1991d. List of incinerator facilities in Canada. River Road Environmental Technology Center, Ottawa, Ontario.
- Environment Canada 1992a. Commercial Chemicals Branch, Ottawa, Ontario. Unpublished data.
- Environment Canada. 1992b. Canadian Wildlife Service, Ottawa, Ontario. Unpublished data.
- Fathpure, B.Z., J.M. Tiedje and S.A. Boyd. 1988. Reductive dechlorination of hexachlorbenzene to tri- and dichlorobenzenes in anaerobic sewage sludge. Appl. Environ. Microbiol. 54(2), 327-330.
- Figueroa, I.C. and M.S. Simmons. 1991. Structure-activity relationships of chlorobenzenes using DNA measurement as a toxicity parameter in algae. Environ. Toxicol. Chem. 10(3), 323-329.
- Fox, M.E. and J.H. Carey. 1986. Transport of Selected Organochlorine contaminants in the Niagara River Plume. Environment Canada, Burlington, Ont. NWRI-CCIW, NWRI-86-40.
- Fox, M.E. and J.H. Carey. 1989. Dynamics of Plume Dispersion of 1,2,3,4-Tetrachlorobenzene from the Niagara River into Lake Ontario. Environment Canada, Burlington, Ont. NWRI-CCIW, NWRI-89-52.
- Fox, M.E., J.H. Carey and B.G. Oliver. 1983. Compartmental distribution of organochlorine contaminants in the Niagara River and the Western Basin of Lake Ontario. J. Great Lakes Res. 9(2), 287-294.
- Garst, J.E. 1984. Accurate, wide-range, automated, high-performance liquid chromatographic method for the estimation of octanol/water partition coefficients. II: Equilibrium in partition coefficient measurements, additivity of substituent constants, and correlation of biological data. J. Pharm. Sci. 73, 1623-1629.
- Gibertson, M. 1979. Hexachlorobenzene (HCB) in Canada. Environmental Protection Service, Environment Canada, Ottawa, Ontario. Unpublished report.
- Gobas, F.A.P.C., K. Clark, W.Y. Shiu and D. Mackay. 1989a. Bioconcentration of polybrominated benzenes and biphenyls and related superhydrophobic chemicals in fish: role of bioavailability and elimination into the feces. Environ. Toxicol. Chem. 8, 231-245.
- Haggbloom, M. 1990. Mechanism of bacterial degradation and transformation of chlorinated monoaromatic compounds. J. Basic Microbiol. 30(20) 115-141.
- Hall, H.L., L.B. Keir and G. Phipps. 1984. Structure-activity relationship studies on the toxicities of benzene derivatives: I. An additivity model. Environ. Toxicol. Chem. 3: 355-365.
- Hammers, W.E., G.L. Meurs and C.L. DeLigny. 1982. Correlations between liquid chromatographic capacity ratio data on Lichrosorb RP-18 and partition coefficients in the octanol-water system. J. Chromatogr. 247, 1-13.
- Heitmuller, P.T., T.A. Hollister and P.R. Parrish. 1981. Acute toxicity of 54 industrial chemicals to sheepshead minnows (Cyprinodon variegatus). Bull. Environ. Contam. Toxicol. 27, 596-604.

Hermens, J., F. Busser, P. Leeuwangh and A. Nusch. 1985. Quantitative structure relationships: Mixture Toxicity of Organic Chemicals on Photobacterium phosphorum in Microtox Test. *Ecotoxicol. Environ. Safety* 9: 17-25.

Hermens, J., E. Broekhuizen, H. Canton, R. Wegman. 1985. Quantitative structure relationships and mixture toxicity studies of alcohols and chlorohydrocarbons: effects on growth of Daphnia magna. *Aquatic Toxicol.* 6, 209-217.

Hermens, J., H. Canton, P. Janssen and R. de Jong. 1984. Quantitative structure-activity relationships and toxicity studies of mixtures of chemicals with an anaesthetic potency: acute lethal and sublethal toxicity to Daphnia magna. *Aquat. Toxicol.* 5, 143-154.

Hodson, P.V., D.G. Dixon and K.L.E. Kaiser. 1988. Estimating the Acute Toxicity of Water Borne Chemicals in Trouts from Measurements of Median Lethal Dose and the Octanol-Water Partition Coefficient. *Environ. Tox. and Chem.* 7, 443-454.

Hoff, R.M., D.C.G. Muir and N.P. Grift. 1992. Annual Cycle of Polychlorinated Biphenyls and Organohalogen Pesticides in Air in Southern Ontario. 1. Air Concentration Data. *Environ. Sci. Technol.* 26, 2, 266-275.

Hofler, M., E.S. Lahaniatis, D. Bieniek and F. Korte. 1983. Reaktionsverhalten von Benzol-in ppm konzentrationen-Bei der Chlorierung mit NaOCl in wässriger Lösung. *Chemosphere* 12, 217-224.

Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan and E.M. Michalenko. 1991. *Handbook of Environmental Degradation Rates*. Lewis Publishers, Inc., Chelsea, Michigan.

Hutchinson, T.C., Hellebust, J.A., Tam, D., Mackay, D., Mascarenhas, R.A., and Shiu, W.Y. 1978. The correlation of the toxicity to algae of hydrocarbons and halogenated hydrocarbons with their physical-chemical properties. pp. 577-586. In Hydrocarbons and Halogenated Hydrocarbons in the Aquatic Environment. B.K. Afghan and D. MacKay (eds.) Plenum Press, New York, N.Y.

ICI. 1993. Personal communication.

Ikemoto, Y. K. Motoba, T. Suzuki and M. Uchida. 1992. *Environ. Toxicol. Chem.* 11: 931-939.

Jacoff, F.S., R. Scarberry and D. Rosa. 1986. Source assessment of hexachlorobenzene from the organic chemical manufacturing industry. Hexachlorobenzene: Proceedings of an International Symposium, Lyon, France, June 24-28, 1985. C.R. Morris and J.R.P. Cabral (Eds.) IARC Scientific Publications No. 77, Lyon, France.

Jaffe, R. and R.A. Hites. 1984. Environmental impact of two, adjacent, hazardous waste disposal sites in the Niagara River watershed. *J. Great Lakes Res.* 10(4), 440-448.

Jaffe, R. and R.A. Hites. 1986. Anthropogenic, polyhalogenated, organic compounds in non-migratory fish from the Niagara River area and tributaries to Lake Ontario. *J. Great Lakes Res.* 12(1), 63-71.

Kaiser, L.E., B.G. Oliver, M.N. Charlton, K.D. Nicol and M.E. Comba. 1990. Polychlorinated Biphenyls in St. Lawrence River Sediments. *The Science of the Total Environment* 97/98, 495-506.

Kaiser, K.L.E. and J.M. Ribo. 1988. Photobacterium phosphoreum Toxicity Bioassay. II. Toxicity data compilation. *Inter. J.*, 3: 195-237.

- Karapally, J.C., J.C. Saha and Y.W. Lee. 1973. Metabolism of Lindane-<sup>14</sup>C in the Rabbit: Ether-Soluble Urinary Metabolites. J. Agr. Food Chem. 21,5, 811-818.
- Karickhoff, S.W. and K.R. Morris. 1985a. Impact of tubificid oligochaetes on pollutant transport in bottom sediments. Environ. Sci. Technol. 19 (1), 51-56.
- Karickhoff, S.W. and K.R. Morris. 1985b. Sorption dynamics of hydrophobic pollutants in sediment suspensions. Environ. Toxicol. Chem. 4, 467-479.
- Kenaga, E.E. 1980. Predicted bioconcentration factors and soil sorption coefficients of pesticides and other chemicals. Ecotoxicol. Environ. Saf., 4, 26-38.
- King, L. and G. Sherbin. 1986. Point sources of toxic organic to the upper St. Clair River. Water Pollut. Res. J. Canada 21(3), 433-443.
- Kirk, P.W.W., H.R. Rogers and J.N. Lester. 1989. The fate of Chlorobenzenes and Permethrins during anaerobic sewage sludge digestion. Chemosphere 18, 9/10, 1771-1784.
- Kirk-Othmer. 1964. Encyclopedia of Chemical Technology-2nd Edition. John Wiley and Sons.
- Kitano, M. 1978. Biodegradation and bioaccumulation test on chemical substances. OECD Tokyo Meeting. Reference Book TSU-No. 3. 1978.
- Kishi, H., N. Kogure and Y. Hashimoto. 1990. Contribution of soil constituents in adsorption coefficient of aromatic compounds, halogenated alicyclic and aromatic compounds in soil. Chemosphere 12 (7), 867-876.
- Konemann, H. 1981. Quantitative structure-activity relationships in fish toxicity studies. Toxicology 19, 209-221.
- Konemann, H. and K. van Leeuwen. 1980. Toxicokinetics in fish: accumulation and elimination of six chlorobenzenes by guppies. Chemosphere 9, 3-19.
- Konemann, H., R. Zelle and F. Busser. 1979. Determination of log P<sub>oct</sub> values of chlorosubstituted benzenes, toluenes and anilines by high-performance liquid chromatography on ODS-silica. J. Chromatogr. 178, 559-565.
- Kuntz, K.W. and N.D. Warry. 1983. Chlorinated organic contaminants in water and suspended sediments of the lower Niagara River. J. Great Lakes Res. 9(2), 241-248.
- Lahaniatis, E.S., R. Roas, D. Bieniek, W. Klein and F. Korte. 1981. Bildung von Chlorierten Organischen Verbindungen Bei Der Verbrennung Von Polyathylen in Gegenwart Von Natriumchlorid. Chemosphere 10, 1312-1326.
- LeBlanc, G.A. 1980. Acute toxicity of priority pollutants to water flea (Daphnia magna). Bull. Environ. Contam. Toxicol. 24, 684-691.
- LeBlanc, G.A. 1984. Interspecies relationships in acute toxicity of chemicals to aquatic organism. Environ. Toxicol. Chem. 3: 47-60.
- Liu, D. and K. Thomson. 1983. Toxicity assessment of chlorobenzenes using bacteria. Bull. Environ. Contam. Toxicol. 31, 105-111.

- Lyman, W.J., W.F. Reehl and D.H. Rosenblatt. 1982. Handbook on Chemical Property Estimation Methods. Environmental Behaviour of Organic Compounds. McGraw-Hill, New York.
- Mackay, D. 1991. "Multimedia Environmental Models: The Fugacity Approach", Lewis Publishers, Inc.
- Mackay, D. and P.J. Leinonen. 1975. Rate of Evaporation of Low Solubility Contaminants from Water Bodies to Atmosphere. Environ. Science and Technology 9, 1178-1180.
- Mackay, D. and S. Paterson. 1991. "Evaluating the multimedia fate of organic chemicals : A Level III fugacity model", Environ. Sci. Technol. 25, 427.
- Mackay, D. and W.Y. Shiu. 1981. A critical review of Henry's law constants for chemicals of environmental interest. J. Phys. Chem. Ref. Data 10, 1175-1199.
- Mackay, D., A.M. Bobra, D.W. Chan and W.Y. Shiu. 1982a. Vapour pressure correlation for low-volatility environmental chemicals. Environ. Sci. Technol. 16, 645-649.
- Mackay, D., W.Y. Shiu and K.C. Ma. 1992. The Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals. Volume 1, Monoaromatics Hydrocarbons, Chlorobenzenes and Polychlorinated Biphenyls, Lewis Publishers, Inc.
- Mackay, D. and A. W. Wolkoff. 1973. Rate of evaporation of low-solubility contaminants from water bodies to atmosphere. Environ. Sci. Technol. 7(7): 611-614.
- Mackenzie, C.L. 1970. Control of Oyster Drills, Eupleura Caudata and Urosalpinx Cinerea with the Chemical Polystream. U.S. Fish and Wildlife Service Fishery Bulletin 68,2, 285-297.
- Mailhot, H. 1987. Prediction of algae bioaccumulation and uptake rate of nine organic compounds by ten physicochemical properties. Environ. Sci. Technol. 21, 1009-1013.
- Malaney, G.W. and R.E. McKinney. 1966. Water Sewage Works. 113: 302.
- Markwell, R.D., D.W. Connell and A.J. Gabric. 1989. Bioaccumulation of lipophilic compounds from sediments by oligochaetes. Water Res. 23,11, 1443-1450.
- Marsden, P.J., E.N. Amick, F.L. Shore, L.R. Williams, V.R. Bohman and C.R. Blincoe. 1986. Characterization of bovine urine and adipose interlaboratory performance evaluation samples containing biologically incorporated chlorophenols. J. Agric. Food Chem. 34: 795-800.
- Marsalek, J. and H. Schroeter. 1988. Annual loadings of toxic contaminants in urban runoff from the Canadian Great Lakes basin. Water Pollut. Res. J. Can. 23(3), 360-378.
- McCarty, L.S. 1986. The relationship between aquatic toxicity QSARs and bioconcentration for some organic chemicals. Environ. Tox. Chem. 5, 1071-1080.
- McCarty, L.S., D. Mackay, A.D. Smith, G.W. Ozburn and D.G. Nixon. 1992. Residue-based interpretation of toxicity and bioconcentration QSARs from

- aquatic bioassays: neutral narcotic organisms. Environ. Tox, Chem. 11, 917-930.
- Menzie, C.M. 1978. Metabolism of Pesticides Update 11. US Department of the Interior Fish and Wildlife Service. Special Scientific Report-Wildlife No. 212.
- Menzies, J. 1992. Unpublished information from: National Analysis of Trends in Emergencies System (NATES). Environment Canada. Environmental Emergencies Branch, Ottawa, Ontario.
- Merriman, J.C. 1988. Distribution of organic contaminants in water and suspended solids of the Rainy River. Water Pollut. Res. J. Cnd. 23(4), 590-600.
- Merriman, J.C. 1987. Trace organic contaminants in sediment of the international section of the St. Lawrence River, 1981. Environment Canada, Inland Waters/Lands Dir., Water Quality Branch, Burlington, Ont., Technical Bull. No. 148, 10 pp.
- Metcalf, J.L. and M.N. Charlton. 1990. Freshwater Mussels as Biomonitoring for Organic Industrial Contaminants and Pesticides in the St. Lawrence River. The Science of the Total Environment 97/98, 595-615.
- Miller, M.M., S. Ghodbane, S.P. Wasik, Y.B. Tewari and D.E. Martire. 1984. Aqueous solubilities, octanol/water partition coefficients and entropies of melting of chlorinated benzenes and biphenyls. J. Chem. Eng. Data 29, 184-190.
- Miles, D.H., N.V. Mody and J.P. Minyard. 1973. Constituents of marsh grass: survey of the essential oils in Juncus roemerianus. Phytochemistry 12:1399-1404.
- Muir, D.C.G. 1993. Department of Fisheries and Oceans, Central and Arctic Region, Winnipeg, Manitoba. Unpublished data.
- Muir, D.C.G., C.A. Ford, N.P. Grift, R.E.A. Stewart and T.F. Bidleman. 1992. Organochlorine contaminants in narwhal (Monodon monoceros) from the Canadian Arctic. Environmental Pollution 75, 307-316.
- Muir, D.C.G., M.D. Segstro, P.M. Welbourn, D. Toom, S.J. Eisenreich, C.R. Macdonald and D.M. Whelpdale. 1993. Patterns of accumulation of airborne organochlorine contaminants in lichens from the upper Great Lakes region of Ontario. Environ. Sci. Technol. In press.
- NRCC. 1980. A Case Study of a Spill of Industrial Chemicals - Polychlorinated Biphenyls and Chlorinated Benzenes. National Research Council of Canada, Environmental Secretariat, Ottawa, Publ. No. NRCC 17586.
- Niimi, A.J. and B.G. Oliver. 1989. Distribution of Polychlorinated Biphenyls Congeners and other Halocarbons in Whole Fish and Muscle among Lake Ontario Salmonids. Environ. Sci. & Technol. 23, 93-88.
- Nimitz, J.S. and S.R. Skaggs. 1992. Estimating tropospheric lifetimes and ozone-depletion potential of one- and two-carbon hydrofluorocarbons and hydrochlorofluorocarbons. Environ. Sci. Technol. 26: 739-744.
- Nirmalakhandan, N.N. and R.E. Speece. 1988. QSAR model for predicting Henry's law constant. Environ. Sci. Technol. 1349-1357.

- Oliver, B.C. 1984a. Distribution and pathways of some chlorinated benzenes in the Niagara River and Lake Ontario. *Water Pollut. Res. J. Canada*. 19 (1), 47-59.
- Oliver, B.G. 1984b. The relationship between bioconcentration factor in rainbow trout and physical-chemical properties for some halogenated compounds. In: *QSAR in Environmental Toxicology*. Kaiser, K.L.E. (Ed.), pp.300-317. D. Reidel Publishing Co.
- Oliver, B.G. 1985. Desorption of chlorinated hydrocarbons from spiked and anthropogenically contaminated sediments. *Chemosphere* 14: 1087-1106.
- Oliver, B.G. 1987a. Biouptake of chlorinated hydrocarbons from laboratory-spiked and field sediments by oligochaete worms. *Environ. Sci. Technol.* 21(8): 785-790.
- Oliver, B.G. 1987b. Fate of some chlorobenzenes from the Niagara River in Lake Ontario. In: *Sources and Fates of Aquatic Pollutants*. Hite, R.A., Eisenreich, S.J., Eds., pp. 471-489. *Advances in Chemistry Series 216*, Am. Chem. Soc., Washington, D.C.
- Oliver, B.G. 1987c. Partitioning relationships for chlorinated organics between water and particulates in the St. Clair, Detroit and Niagara Rivers. In: Kaiser, K.L.E., ed., *QSAR in Environmental Toxicology-II*, D. Reidel Publishing Company, Boston, pp. 251-260.
- Oliver, B.G. and R.A. Bourbonniere. 1985. Chlorinated contaminants in surficial sediments of Lakes Huron, St. Clair, and Erie: implications regarding sources along the St. Clair and Detroit Rivers. *J. Great Lakes Res.* 11 (3): 366-372.
- Oliver, B.G. and J.H. Carey. 1986. Photodegradation of wastes and pollutants in aquatic environment. In: Pelizzetti, E. and Serpone, N. eds, Homogenous and Heterogenous Photocatalysis, pp. 629-650.
- Oliver, B.G. and M.N. Charlton. 1984. Chlorinated organic contaminants on settling particulates in the Niagara River vicinity of Lake Ontario. *Environ. Sci. Technol.* 18(12): 903-908.
- Oliver, B.G., M.N. Charlton and R.W. Durham. 1989. Distribution, redistribution, and geochronology of polychlorinated biphenyl congeners and other chlorinated hydrocarbons in Lake Ontario sediments. *Environ. Sci. Technol.* 23(2): 200-208.
- Oliver, B.G. and K.L.K. Kaiser . 1986. Chlorinated organics in nearshore waters and tributaries of the St. Clair River. *Water Poll. Res. J. Canada* 21(3): 344-350.
- Oliver, B.G. and K.D. Nicol. 1982. Chlorobenzenes in sediments, water, and selected fish from Lakes Superior, Huron, Erie, and Ontario. *Environ. Sci. Technol.* 16(8): 532-536.
- Oliver, B.G. and K.D. Nicol. 1983. Reply to comment on "Chlorobenzenes in sediments, water, and selected fish from Lakes Superior, Huron, Erie and Ontario". *Environ. Sci. Technol.* 17(8): 505.
- Oliver, B.G. and K.D. Nicol. 1984. Chlorinated contaminants in the Niagara River, 1981-1983. *Sci. Total Environ.* 39: 57-70.
- Oliver, B.G. and A.J. Niimi. 1983. Bioconcentration of chlorobenzenes from water by rainbow trout: correlations with partition coefficients and environmental residues. *Environ. Sci. Technol.* 17: 287-291.

- Oliver, B.B. and A.J. Niimi. 1985. Bioconcentration factors of halogenated organics for rainbow trout: limitations in their use for prediction of environmental residues. *Environ. Sci. Technol.* 19, 842-849.
- Oliver, B.G. and A.J. Niimi. 1988. Trophodynamic Analysis of polychlorinated Biphenyl Congeners and other Chlorinated Hydrocarbons in the Lake Ontario Ecosystem. *Environ. Sci. Technol.* 22: 388-397.
- Oliver, B.G. and C.W. Pugsley. 1986. Chlorinated contaminants in St. Clair River sediments. *Water Pollut. Res. Can.* 21(3): 368-379.
- Ontario Ministry of the Environment. 1993. Unpublished data.
- Ontario Ministry of the Environment. 1992a. Organic manufacturing (OCM) sector twelve month report-data from Oct 01/89 to Sept 30/90. Municipal Strategy for Abatement (MISA).
- Ontario Ministry of the Environment. 1992b. Twelve month monitoring data report inorganic chemical sector (Dec 01/89 to Nov 30/90; Feb 01/90 to Jan 31/91. May 1992. Municipal Strategy for Abatement (MISA).
- Ontario Ministry of the Environment. 1991a. Status report on the effluent monitoring data for the iron and steel sector for the period from Nov 01/89 to Oct 31/90. Municipal Strategy for Abatement (MISA).
- Ontario Ministry of the Environment. 1991b. Preliminary Report on the First Six Months of Process Effluent Monitoring in the MISA pulp and paper sector (Jan 01/90 to June 30/90) Municipal Strategy for Abatement (MISA).
- Ontario Ministry of the Environment. 1991c. Preliminary Report on the Second Six Months of Process Effluent Monitoring in the MISA pulp and paper sector (July 01/90 to Dec 31/90) Municipal Strategy for Abatement (MISA).
- Ontario Ministry of the Environment. 1990a. Preliminary Report on the First Six Months of Monitoring in the Petroleum Refining Sector (Dec 01/88 to May 31/89) Municipal Strategy for Abatement (MISA).
- Ontario Ministry of the Environment. 1990b. Second Report on the Monitoring Data for the Petroleum Refining Sector (June 01/89 to Nov 30/89). July 1990. Municipal Strategy for Abatement (MISA).
- Ontario Ministry of the Environment. 1988. Thirty-seven municipal water pollution control plants. Vol. I, MISA, Interim report, Ontario Ministry of the Environment. December, 1988. 97 pp.
- Ontario Ministry of the Environment. 1987. Preliminary report St. Clair River. MISA Pilot-site investigation, Vol. 1.
- Ontario Ministry of the Environment. 1984. Chlorinated Benzenes in the Aquatic Environment. Scientific Criteria Document from Standard Development No.3-84.
- Otson, R., D.T. Williams and D.C. Biggs. 1982. Relationship between raw water quality, treatment and occurrence of organics in Canadian potable water. *Bull. Environ. Contam. Toxicol.*, 28:396-403.
- Patty Industrial Hygiene and Toxicology 3rd ed. Volume 2A,B and C. 1981-82. p. 3626.
- Paya-Perez, B., M. Riaz and B.R. Larsen. 1991. Soil sorption of 20 PCB congeners and six chlorobenzenes. *Ecotoxicol. Environ. Safety* 21, 1-17.

- Pereira, W.E., C.E. Rostard, C.T. Chiou, T.I. Brinton and L.B. Barber, II., D.K. Demcheck and C.R. Demas. 1988. Contamination of estuarine water, biota, and sediment by halogenated organic compounds: a field study. *Environ. Sci. Technol.* 22(7), 772-778.
- Ramanathan, V., R.J. Cicerone, H.B. Singh and J.T. Kiehl. 1985. Trace gas trends and their potential role in climate change. *J. Geophysical Research* 90: 5547-5566.
- Rankin, M. 1993. Dow Chemical Company, Sarnia, Ontario. Personal Communication.
- Rankin, M. 1992. Dow Chemical Company, Sarnia, Ontario. Personal Communication.
- Reed, W.T. and A.J. Forgash. 1970. Metabolism of Lindane to Organic-Soluble Products by Houseflies. *J. Agr. Food Chem.* 18,3,475-481.
- Reischl, A., M. Reissinger, H. Thoma and O. Hutzinger. 1989. Uptake and accumulation of PCDD/F in terrestrial plants: basic considerations. *Chemosphere* 19, 467-474.
- Ribo, J.M. and K.L.E. Kaiser. 1983. Effects of selected chemicals to photoluminescent bacteria and their correlations with acute and sublethal effects on other organisms. *Chemosphere* 12(11/12): 1421-1442.
- Sadtler Research Laboratories. 1982. Infrared spectra of priority pollutants and toxic chemicals. Sadtler Research Laboratories, Philadelphia, PA.
- Safe, S., D.J. Jones, J. Kohli, L.O. Ruzo, O. Hutzinger and G. Sundstrom. 1976. The metabolism of chlorinated aromatic pollutants by the frog. *Can. J. Zool.* 54: 1818-1823.
- Singleton, D. 1993. National Research Council Canada, Ottawa, Ontario. Personal communication.
- Smith, A.D., A. Bharath, C. Mullard, D. Orr, K. Smith, J.A. Sutton, J. Vukmanich, L.S. McCarty and G.W. Ozburn. 1991. The acute and chronic toxicity of ten chlorinated organic compounds to the American flagfish (*Jordanella floridae*). *Arch. Environ. Contam. Toxicol.* 20: 94-102.
- Smith, A.D., A. Bharath, C. Mullard, D. Orr, L.S. McCarty and G.W. Ozburn. 1990. Bioconcentration kinetics of some chlorinated benzenes and chlorinated phenols in the American flagfish (*Jordanella floridae*). *Chemosphere* 20, 379-386.
- Smith, I.R. and G.C. Craig. 1981. Prediction of organic contaminant aquatic toxicity utilizing intraperitoneal injections and structure-activity relationships. *Can. Tech. Rep. Fish. Aquat. Sci.* 1151: 122-135.
- SRI International. 1990. 1990 Directory of chemical producers: Canada. SRI International, Menlo Park, California.
- Statistics Canada. 1991. Trade of Canada, Imports, Merchandise Trade Commodity Detail, 1990. Statistics Canada, External Trade Division, trade Information Unit, Ottawa, Ontario.
- Stephenson, R.M. and A. Malanowski. 1987. Handbook of the Thermodynamics of Organic Compounds. Elsevier, New York.



Stevens, R.J.J. and M.A. Neilson. 1989. Inter- and intralake distribution of trace contaminants in surface waters of the Great Lakes, J. Great Lakes Res. 15(3): 377-393.

Strachan, W.M.J. 1993. Environment Canada. Unpublished data.

Sylvestre, A. 1987. Organochlorines and polyaromatic hydrocarbons in the St. Lawrence River at Wolf Island, 1982/84. Environment Canada, Inland Waters/Land Dir., Ont. Region, Water Qual. Branch, Burlington, Ont., Tech. Bull. No. 144, 11 pp.

Third Report of the TSCA Interagency Testing Committee. 1979. Environmental Protection Agency. EPA/OTS.

Thomas, R.G., Volatilization In: Handbook of Chemical Properties Estimation Methods. Lyman, Reehl and Rosenblatt, Eds. McGraw-Hill Book Co., New York, New York (1982).

Thomann, R.V. 1989. Bioaccumulation model of organic chemical distribution in aquatic food chains. Environ. Sci. Technol. 23(6): 699-707.

Topp, E., I. Scheunert, A. Attar and F. Korte. 1986. Factors Affecting the Uptake of <sup>14</sup>C-labelled Organic Chemicals by Plants from Soil. Ecotoxicol. Environ. Saf. 11: 219-228.

Topp, E., I. Scheunert and F. Korte. 1989. Kinetics of uptake of <sup>14</sup>C-labeled chlorinated benzenes from soil by plants. Ecotoxicol. Environ. Saf. 17: 157-166.

Trapp, S., M. Matthies, I. Schdeunert and E. M. Topp. 1990. Modelling the bioconcentration of organic chemicals in plants. Environ. Sci. Technol. 24: 1246-1252.

US EPA TSCA. 1992. Office of Toxic Substance. Chemical Commercial Information Search for November 1992 (Nonconfidential information). US EPA Information Management Division.

US EPA 1978. In-depth studies on health and environmental impacts of water pollutants. United States Environmental Protection Agency (Contract No. 68-01-4646).

US EPA. 1980a. Ambient water quality criteria for chlorinated benzenes. Office of Water Regulations and Standards, United States Environmental Protection Agency (EPA-440/5-80-028).

US EPA. 1980b. Materials Balance for Chlorobenzenes. Level 1-Preliminary. United States Environmental Protection Agency (EPA-560/13-80-001).

Uyeta, M. et al. 1976. Nature 264:583.

Van Leeuwen, C.J., D.M.M. Adema and J. Hermens. 1990. Quantitative structure-activity relationships for fish early life stage toxicity. Aquat. Toxicol. 16: 321-334.

Van Leeuwen, C.J., P.S. Griffin, W.H.A. Vergouw and J.L. Maas-Diepeveen. 1985. Differences on susceptibility of early life stages of rainbow trout to environmental pollutants. Aquatic Toxicol. 7: 59-78.

Van Hoogen, G. and A. Opperhuizen. 1988. Toxicokinetics of chlorobenzenes in fish. Environ. Toxicol. Chem. 7: 213-219.

Veith G.D., D.J. Call and L.T. Brooke. 1983a. Estimating the acute toxicity of narcotic industrial chemicals to fathead minnows. In: W.E. Bishop, R.D. Cardwell and B.B. Heidolph, eds. Aquatic Toxicology and Hazard Assessment: Sixth Symposium. ASTM STP 802, American Society for Testing and Materials, Philadelphia, pp. 90-97.

Veith G.D., D.J. Call and L.T. Brooke. 1983b. Structure-toxicity relationships for the fathead minnow, Pimephales promelas: Narcotic industrial chemicals. Can. J. Fish. Aquat. Sci. 40: 743-748.

Veith G.D., K.J. Macek, S.R. Petrocelli and J. Carroll. 1980. An evaluation of using partition coefficients and water solubility to estimate bioconcentration factors for organic chemicals in fish. Aquatic Toxicology. ASTM STP 707, Eaton, J.G., Parrish, P. R., Hendricks, A.C., Eds., pp 116-129. American Society for Testing and Materials, Philadelphia.

Veith, G.D., D.L. Defor and B.V. Bergstedt. 1979. Measuring and estimating the bioconcentration factor of chemicals in fish. J. Fish. Res. Board Can. 26, 1040-1048.

Wang, W.C., Y.L. Yung, A.A.Lacis, T. Mo and J.E. Hansen. 1976. Greenhouse effects due to man-made perturbations of trace gases. Science 194:685-689.

Ware, S.A. and W.L. Weast. 1977. Investigation of selected potential environmental contaminants: halogenated benzenes. US EPA Report, EPA 560/2-77-004; NTIS PB 273 206, pp. 297.

Wateral, H., M. Tanaka and N. Suzuki. 1982. Determination of partition coefficients of halobenzenes in heptane/water and 1-octanol/water systems and comparison with the scaled particle calculation. Anal. Chem. 54, 702-705.

Weast, R.C., Ed. 1972-1973. Handbook of Chemistry and Physics. 53th ed. CRC Press, Cleveland.

Welch, H.E., D.C.G. Muir, B.N. Billeck, W.L. Lockhart, G.J. Brunskill, H.J. Kling, M.P.Olson and R.M. Lemoine. 1991. Brown Snow: A Long-Range Transport Event in the Canadian Arctic. Environ. Sci. Technol. 25, 2, 280-286.

Western Research. 1991. VESTA Model 100 Mobile Incinerator, Trial Burn Report. Volume 11. Testing and Analytical Data. Report submitted to Waste Management Branch, Environment Canada, March 15, 1991.

Wong, P.T.S., Y.K. Chau, J.S. Rhaney and M. Docker. 1984. Relationship between Water Solubility of Chlorobenzenes and Their Effects on a Freshwater Green Alga. Chemosphere 13, 991-996.

Yalkowsky, S.H., R.J. Orr and S.C. Valvani. 1979. Solubility and partitioning. 3. The solubility of halobenzenes in water. Ind. Eng. Chem. Fundam. 18, 351-353.

Yalkowsky, S.H., S.C.Valvani and D.Mackay. 1983. Estimation of the aqueous solubility of some aromatic compounds. Residue Rev. 85, 43-55.

APPENDIX

# APPENDIX

TecB

date: 04-24-1993

time: 10:17:20

## LEVEL 3 FUGACITY MODEL

Predicted fate of TecB in Southern Ontario

### compound properties

molecular weight	215.90 g/mol
aqueous solubility	1.2700E+00 g/m <sup>3</sup> or 5.8824E-03 mol/m <sup>3</sup>
vapour pressure	7.2000E-01 pa or 7.1058E-06 atm or 5.4004E-03 mm Hg
henry's constant	1.2240E+02 pa m <sup>3</sup> /mol
octanol-water part coeff (log)	4.50
temperature	25.0 deg C or 298.2 K

bulk compartment	volume m <sup>3</sup>	height/ depth (m)	area m <sup>2</sup>	Z mol/m <sup>3</sup> .Pa	density kg/m <sup>3</sup>
1 bulk air	4.000E+14	2.000E+03	2.000E+11	4.035E-04	1.19
2 bulk water	4.000E+12	5.000E+01	8.000E+10	8.437E-03	1000.01
3 bulk soil	1.200E+10	1.000E-01	1.200E+11	2.551E+00	1500.24
4 bulk sediment	8.000E+08	1.000E-02	8.000E+10	3.064E+00	1420.00

total area (m<sup>2</sup>) 2.000E+11

subcompartment	volume m <sup>3</sup>	Z mol/m <sup>3</sup> .Pa	density kg/m <sup>3</sup>	mass fraction organic content	volume fraction
1., 1 air	4.000E+14	4.034E-04	1.19		1.00E+00
1., 3 air particles	8.000E+03	3.362E+03	2400.00		2.00E-11
2., 2 water	4.000E+12	8.170E-03	1000.00		1.00E+00
2., 3 water particles	2.000E+07	5.097E+01	2400.00	0.20	5.00E-06
2., 4 biota	4.000E+06	1.240E+01	1000.00		1.00E-06
3., 1 soil air	2.400E+09	4.034E-04	1.19		2.00E-01
3., 2 soil water	3.600E+09	8.170E-03	1000.00		3.00E-01
3., 3 soil solids	6.000E+09	5.097E+00	2400.00	0.02	5.00E-01
4., 2 pore water	5.600E+08	8.170E-03	1000.00		7.00E-01
4., 3 sed. solids	2.400E+08	1.019E+01	2400.00	0.04	3.00E-01

# Reaction Parameters

bulk compartments	rate constant h-1	half-life h	D value mol/pa.h
1 bulk air	4.0760E-04	1.7002E+03	6.5784E+07
2 bulk water	1.2600E-04	5.5000E+03	4.2523E+06
3 bulk soil	1.2600E-04	5.5000E+03	3.8570E+06
4 bulk sediment	4.0800E-05	1.6985E+04	1.0000E+05

## Subcompartments

1., 1 air	0.0000E+00	0.0000E+00	0.0000E+00
1., 3 air particles	0.0000E+00	0.0000E+00	0.0000E+00
2., 2 water	0.0000E+00	0.0000E+00	0.0000E+00
2., 3 water particles	0.0000E+00	0.0000E+00	0.0000E+00
2., 4 biota	0.0000E+00	0.0000E+00	0.0000E+00
3., 1 soil air	0.0000E+00	0.0000E+00	0.0000E+00
3., 2 soil water	0.0000E+00	0.0000E+00	0.0000E+00
3., 3 soil solids	0.0000E+00	0.0000E+00	0.0000E+00
4., 2 pore water	0.0000E+00	0.0000E+00	0.0000E+00
4., 3 sed. solids	0.0000E+00	0.0000E+00	0.0000E+00

## Advective Parameters

compartment	flow m3/h	inflow concn mol/m3	rate constant h-1	D value mol/pa.h	residence time h
1 bulk air	3.30E+12	0.00E+00	8.25E-03	1.33E+09	1.21E+02
2 bulk water	3.30E+08	0.00E+00	8.25E-05	2.78E+06	1.21E+04
3 bulk soil	0.00E+00	0.00E+00	0.00E+00	0.00E+00	infinity
4 bulk sediment	0.00E+00	0.00E+00	0.00E+00	0.00E+00	infinity

Transfer to higher altitude, sediment burial and leaching from soil to groundwater

process	velocity m/y	velocity m/h	flow m3/h	rate constant h-1	D value mol/pa.h	residence times h y	
transfer to higher alt	9.00E+01	1.03E-02	2.05E+09	5.14E-06	8.29E+05	1.95E+05	2.22E+01
leaching from soil	3.40E-01	3.88E-05	4.66E+06		3.81E+04		
sediment burial	3.00E-04	3.42E-08	2.74E+03	1.14E-05	2.79E+04	8.76E+04	1.00E+01

# Transfer parameters between compartments

## Total D Values and Fluxes

compartment				D (mol/h*pa)	flux mol/h	tau(i,j) h
from	1	to	2	1.653E+07	-6.424E-01	1.183E+03
from	2	to	1	1.631E+07	6.424E-01	1.183E+03
from	1	to	3	1.062E+06	-1.747E-02	2.294E+04
from	3	to	1	7.234E+05	1.747E-02	2.294E+04
from	2	to	4	4.961E+05	5.672E-03	4.714E+04
from	4	to	2	3.193E+05	-5.672E-03	4.781E+03
from	3	to	2	5.202E+04	1.298E-03	4.078E+05

## Individual D Values, Flows and Velocities

compartments				by	D (mol/h*pa) <sup>3</sup>	flow (m3/h)	flow (m3/y)	velocity (m/h)	velocity (m/y)
from	1	to	2	diffusion	1.631E+07				
				rain	6.342E+04	7.763E+06	6.800E+10	9.703E-05	8.500E-01
				wet deposition	1.044E+05	3.105E+01	2.720E+05	3.881E-10	3.400E-06
				dry deposition	5.809E+04	1.728E+01	1.514E+05	1.080E+01	3.000E-03 (m/s)
from	2	to	1	diffusion	1.631E+07				
from	1	to	3	diffusion	7.234E+05				
				rain	9.513E+04	1.164E+07	1.020E+11	9.703E-05	8.500E-01
				wet deposition	1.566E+05	4.658E+01	4.080E+05	3.881E-10	3.400E-06
				dry deposition	8.714E+04	2.592E+01	2.271E+05	1.080E+01	3.000E-03 (m/s)
from	3	to	1	diffusion	7.234E+05				
from	2	to	4	diffusion	3.099E+05				
				deposition	1.862E+05	3.653E+03	3.200E+07	4.566E-08	4.000E-04
from	4	to	2	diffusion	3.099E+05				
				resuspension	9.309E+03	9.132E+02	8.000E+06	1.142E-08	1.000E-04
from	3	to	2	water flow	3.805E+04	4.658E+06	4.080E+10	3.881E-05	3.400E-01
				soil flow	1.396E+04	2.740E+03	2.400E+07	2.283E-08	2.000E-04

# Input Transport Parameters

## Mass Transfer Coefficients (MTC) (m/h)

Air-Water	air-side MTC	3.00E+00
	water-side MTC	3.00E-02
	overall water-side MTC	2.49E-02

Air-Soil	air-side MTC	1.000E+00
----------	--------------	-----------

Water-Sediment	water-side MTC	1.000E-02
----------------	----------------	-----------

## Diffusivities

air molecular diffusivity	0.40E-01	m2/h	air effective diffusivity	0.75E-03	m2/h	mean path length	0.0500	m
water molecular diffusivity	0.40E-05	m2/h						
	soil		water effective diffusivity	0.29E-06	m2/h	mean path length	0.0500	m
	sediment		water effective diffusivity	0.25E-05	m2/h	mean path length	0.0050	m

## D Values for Diffusive Flow in Soil Air and Water

Soil	air diffusion	7.286E+05
	water diffusion	5.693E+03

## D Value for Diffusive Flow in Sediment Pore Water

Sediment	water diffusion	3.254E+05
----------	-----------------	-----------

## Bulk Compartments

compartment	amount mol	percent	concentrations			fugacity Pa
			mol/m3	microg/g	microg/m3	
1 bulk air	8.957E+01	3.876	2.239E-13	4.078E-08	4.834E-05	5.550E-10
2 bulk water	1.349E+03	58.357	3.372E-10	7.279E-08	7.279E-02	3.996E-08
3 bulk soil	7.642E+02	33.065	6.368E-08	9.164E-06	1.375E+01	2.496E-08
4 bulk sediment	1.087E+02	4.702	1.358E-07	2.065E-05	2.933E+01	4.434E-08
Total	2.311E+03	100.000				

## Subcompartments

compartment	amount mol	percent	concentrations			fugacity Pa
			mol/m3	microg/g	microg/m3	
1., 1 air	8.955E+01	3.875	2.239E-13	4.078E-08	4.834E-05	5.550E-10
1., 3 air particles	1.493E-02	0.001	1.866E-06	1.678E-04	4.028E+02	5.550E-10
2., 2 water	1.306E+03	56.508	3.265E-10	7.049E-08	7.049E-02	3.996E-08
2., 3 water particles	4.074E+01	1.763	2.037E-06	1.832E-04	4.397E+02	3.996E-08
2., 4 biota	1.982E+00	0.086	4.956E-07	1.070E-04	1.070E+02	3.996E-08
3., 1 soil air	2.417E-02	0.001	1.007E-11	1.834E-06	2.174E-03	2.496E-08
3., 2 soil water	7.342E-01	0.032	2.039E-10	4.403E-08	4.403E-02	2.496E-08
3., 3 soil solids	7.634E+02	33.032	1.272E-07	1.145E-05	2.747E+01	2.496E-08
4., 2 pore water	2.028E-01	0.009	3.622E-10	7.820E-08	7.820E-02	4.434E-08
4., 3 sed. solids	1.085E+02	4.693	4.519E-07	4.066E-05	9.758E+01	4.434E-08

## summary of 4 bulk compartment mass balances (mol/h)

	emissions	inflow	reaction	outflow	net flux out to other compts
bulk air	1.160E-01	0.000E+00	3.651E-02	7.389E-01	-6.599E-01
bulk water	9.280E-01	0.000E+00	1.699E-01	1.113E-01	6.468E-01
bulk soil	1.160E-01	0.000E+00	9.628E-02	0.000E+00	1.877E-02
bulk sediment	0.000E+00	0.000E+00	4.434E-03	0.000E+00	-5.672E-03
Total	1.160E+00	0.000E+00	3.072E-01	8.502E-01	

total input (emissions and inflow) 1.160E+00 mol/h

total output (reactions and outflow) 1.160E+00 mol/h

residence time (hours) 1992.29  
(days) 83.01207persistence 7524.032  
persistence 313.5014



# Transfer and Transformation rates (mol/h)

	Bulk air	Bulk water	Soil	Sediment	Total
emissions	1.160E-01	9.280E-01	1.160E-01	0.000E+00	1.160E+00
advective inflow	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
advective outflow	7.389E-01	1.113E-01	0.000E+00	0.000E+00	8.502E-01
reaction	3.651E-02	1.699E-01	9.628E-02	4.434E-03	3.072E-01
transfer to higher altitude	4.601E-04				4.601E-04
leaching from soil			9.499E-04		9.499E-04
sediment burial				1.238E-03	1.238E-03
transfer to air from	0.000E+00	6.424E-01	1.747E-02	0.000E+00	6.599E-01
transfer to water from	-6.424E-01	0.000E+00	1.298E-03	-5.672E-03	-6.468E-01
by diffusion air-water	9.049E-03				
by diffusion water-air	-6.516E-01				
net diffusion	-6.426E-01				
by rain	3.520E-05				
by wet deposition	5.793E-05				
by dry deposition	3.224E-05				
by water runoff			9.499E-04		
by soil runoff			3.486E-04		
transfer to soil from	-1.747E-02	-1.298E-03	0.000E+00	0.000E+00	-1.877E-02
by diffusion air-soil	4.014E-04				
by diffusion soil-air	-1.806E-02				
net diffusion	-1.766E-02				
by rain	5.279E-05				
by wet deposition	8.689E-05				
by dry deposition	4.836E-05				
transfer to sediment from	0.000E+00	5.672E-03	0.000E+00	0.000E+00	5.672E-03
by diffusion water-sediment		1.239E-02			
by diffusion sediment-water		-1.374E-02			
net diffusion		-1.356E-03			
by sediment deposition		7.440E-03			
by sediment resuspension		-4.127E-04			

Now we require advection rates (m<sup>3</sup>/h) and the corresponding inflow concentrations (mol/m<sup>3</sup>)

Normally only air and water advection are included, and the background concentrations are zero. If no values are entered, zero will be assumed.

The same procedure is followed as for reaction rate constants except that the requested numbers are: compartment no, advective flow rate (m<sup>3</sup>/h) and input concentration separated by commas. Advection may only be into bulk compartments (1 - 4)

a specimen input for Southern Ontario is 1,3.3e12,3e-12 indicating an inflow of 3.3e12 m<sup>3</sup>/h of air with a background concentration of 3e-12 mol/m<sup>3</sup>

do you want to enter an (or another) advective flow rate? y/n? y

? 1,3.3e12,0

TABLES

Table 2-1: Physical and Chemical Properties of TeCBs

1,2,3,4-TeCB

Property	Value	Reference
Molecular weight	215.9 g/mol	
Boiling point	254 °C	Mackay and Shiu 1981
Melting point	47.5°C 48.0 47.0	Mackay and Shiu 1981 Yalkowsky et al. 1983 Miller et al. 1984
Vapour pressure (25°C)	5.21 Pa (solid phase)	calculated from the liquid phase vapour pressure-Weast 1972-1973
Water solubility (25°C) Experimental results	4.31 mg/L 3.42 12.2 7.18 5.92 12.1	Yalkowsky et al. 1979 Konemann 1981 Miller et al. 1984 Chiou 1985 Banerjee et al. 1980 Doucette and Andren 1988
Selected value*	7.8	Mackay et al. 1992
Henry's law constant	261 Pa·m <sup>3</sup> /mol 1100 70	calculated, Mackay and Shiu 1981  calculated, Bobra et al. 1985 experimental result, Oliver 1985
Selected value*	144	Mackay et al. 1992
Log octanol water partition coefficient (log K <sub>ow</sub> ) Experimental results	4.46 4.37 4.94 4.75 4.41 4.55 4.60 4.65 4.60 4.635	Konemann et al. 1979 Wateral et al. 1982 Bruggeman et al. 1982 Bruggeman et al. 1982 Hammers et al. 1982 Miller et al. 1984 Chiou 1985 Burkhard and Kuehl 1986 Pereira et al. 1988 DeBruijn et al. 1989
Selected value*	4.5	Mackay et al. 1992
Log organic carbon partition coefficient (log K <sub>oc</sub> )	5.00 4.1-6.0 5.2 3.48-3.91 4.28	Oliver and Charlton 1984 Oliver 1987a,c Oliver 1987a,c Kishi et al. 1990 Paya-Perez et al. 1991
Selected value*	4.11	Mackay et al. 1992

\* Criteria of selection were based on

1. the age of the data and acknowledgement of previous conflicting or supporting values;
2. the method of determination;
3. the perception of the objectives of the authors, not necessarily as an indication of competence, but often as an indication of the need of the authors for accurate values;
4. information derived from the Quantitative-Structure-Property-Relationships.

## 1,2,3,5-TeCB

Property	Value	Reference
Molecular weight	215.9 g/mol	
Boiling point	246 °C	Miller et al. 1984
Melting point	54.5°C 51.0 50.7	Mackay and Shiu 1981 Yalkowsky et al. 1983 Miller et al. 1984
Vapour pressure (25°C)	9.8 Pa 9.56	selected experimental-Mackay et al. 1982 Stephenson and Malanowski 1987
Selected value*	9.8 (solid phase)	Mackay et al. 1992
Water solubility (25°C) Experimental results	3.50 mg/L 4.02 4.11 2.48 5.10 2.89 3.23 4.32	Yalkowsky et al. 1979 Banerjee et al. 1980 Veith et al. 1980 Konemann 1981 Banerjee et al. 1980 Miller et al. 1984 Chiou 1985 Doucette and Andren 1988
Selected value*	3.6	Mackay et al. 1992
Henry's law constant	159 Pa·m <sup>3</sup> /mol 593 160 41 590	experimental, Mackay and Shiu 1981 calculated, " experimental, Nirmalakahandan & Speece 1988 calculated, Nirmalakahandan & Speece 1988 calculated, Bobra et al. 1985
Selected value*	588	Mackay et al. 1992
Log octanol water partition coefficient (log K <sub>ow</sub> ) Experimental results	4.50 4.92 4.46 4.46 5.0 4.52 4.56 4.53 4.51 4.61-4.73 4.59 4.59 4.658	Konemann et al. 1979 Konemann et al. 1979 Veith et al. 1979 Veith et al. 1980 Veith et al. 1980 Banerjee et al. 1980 Wateral et al. 1982 Hammers et al. 1982 Miller et al. 1984 Garst 1984 Chiou 1985 Pereira et al. 1988 DeBruijn et al. 1989
Selected value*	4.5	Mackay et al. 1992

Log organic carbon partition coefficient (log $K_{oc}$ )	4.25	Paya-Perez et al. 1991
Selected value*	4.11	Mackay et al. 1992

\* Criteria of selection were based on

1. the age of the data and acknowledgement of previous conflicting or supporting values;
2. the method of determination;
3. the perception of the objectives of the authors, not necessarily as an indication of competence, but often as an indication of the need of the authors for accurate values;
4. information derived from the Quantitative-Structure-Property-Relationships.

## 1,2,4,5-TeCB

Property	Value	Reference
Molecular weight	215.9 g/mol	
Boiling point	243 °C	Mackay and Shiu 1981
Melting point	140°C 139	Mackay and Shiu 1981 Yalkowsky et al. 1983
Vapour pressure (25°C)	0.72 Pa 0.64 0.615 0.22	experimental-Mackay et al. 1982a calculated-" calculated-Banerjee et al. 1990 Stephenson & Malanowski 1987
Selected value*	0.72 (solid phase)	Mackay et al. 1992
Water solubility (25°C) Experimental results	0.595 mg/L 0.29 2.35 0.465	Yalkowsky et al. 1979 Konemann 1981 Miller et al. 1984 Banerjee et al. 1980
Selected value*	1.27	Mackay et al. 1992
Henry's law constant	261 Pa·m <sup>3</sup> /mol 101 122	calculated, Mackay and Shiu 1981  experimental result, Oliver 1985 calculated, Bobra et al. 1985
Selected value*	122	Mackay et al. 1992
Log octanol water partition coefficient (log K <sub>ow</sub> ) Experimental results	4.82 4.56 4.46 4.52 4.51 4.70 4.60 4.604 4.70	Konemann et al. 1979 Konemann et al. 1979 Wateral et al. 1982 Hammers et al. 1982 Miller et al. 1984 Chiou 1985 Mailhot 1987 DeBruijn et al. 1989 Pereira et al. 1988
Selected value*	4.5	Mackay et al. 1992
Log organic carbon partition coefficient (log K <sub>oc</sub> )	3.25 5.1 4.7	Briggs 1981 Oliver and Charlton 1984 Oliver and Charlton 1984
Selected value*	4.11	Mackay et al. 1992

\* Criteria of selection were based on

1. the age of the data and acknowledgement of previous conflicting or supporting values;
2. the method of determination;
3. the perception of the objectives of the authors, not necessarily as an indication of competence, but often as an indication of the need of the authors for accurate values;
4. information derived from the Quantitative-Structure-Property-Relationships.

Table 3-1: Summary of Estimated Major Releases of Tetrachlorobenzenes to the Canadian environment

<u>SOURCES</u>	<u>RELEASES</u> kg/year
TeCBs Released Due to Dielectric Fluid Spills (after clean-up) <sup>a</sup>	1200
TeCBs Released from Dielectric Fluid Incineration <sup>b</sup>	133
Manufacture of Chlorinated Solvents <sup>c</sup> (before April 1992) (after April 1992)	(24-70) none expected
Use of Chlorinated Solvents <sup>d</sup>	4
From Other Chlorinated Compounds	unknown
Degradation and Metabolism of other Chlorinated Compounds <sup>e</sup>	unknown
Long Range Transport and Deposition <sup>f</sup>	1016
Effluents from Activated Sludge Wastewater Treatment Plants, a Textile Plant, Pulp and Paper Mills, Iron and Steel Mills, Inorganic and Organic Chemical Plants and Petroleum Refineries <sup>g</sup>	greater than 28
From Landfill Sites <sup>h</sup>	greater than 1

<sup>a</sup> based on  $1.22 \times 10^4$  kg for a 10 year period and 67% removal from the initial spill due to recovery efforts (Menzies, 1992); of this total,  $1.1 \times 10^3$  kg would be 1,2,3,4-TeCB and  $1 \times 10^2$  kg would be 1,2,4,5-TeCB (Environment Canada, 1984). These estimates do not include fugitive releases which can be substantial (Western Research, 1991).

<sup>b</sup> the incineration release assumes a destruction efficiency of 99.99% (Dibbs, 1991); annual quantities not known. Assuming 100% release in one year.

<sup>c</sup> before April 1992, approximately 24 to 70 kg were released annually from incineration of waste by-products (based on 1990 production figures (CPI 1990a;b;c), emission factors by the US EPA (Brooks and Hunt, 1984), incineration efficiency of 99.99% (Environment Canada, 1991c, Jacoff et al., 1986)); since April of 1992, chlorinated solvents were no longer produced in Canada other than one plant which manufactures carbon tetrachloride in Ontario. No TeCBs are expected to be released into the environment from this source (ICI, 1993).

<sup>d</sup> based on domestic demand in Canada (Camford, 1991) multiplied by an upper limit concentration of 1 mg/L, and assuming 10% release

<sup>e</sup> TeCBs can be released into the environment, through the metabolism and degradation of other chlorinated compounds, such as lindane (Reed and Forgash, 1970; Karapally et al., 1973; US EPA, 1980b), pentachloronitrobenzene (Ware and Weast, 1977), gamma-pentachlorocyclohexane (US EPA, 1980b) and pentachlorobenzene (Menzie, 1978).

<sup>f</sup> transboundary entry from waste disposal sites (Oliver, 1984; 1985; Oliver and Kaiser, 1986); and in Canadian rainfall (Muir, 1993; Strachan, 1993) and snow (Welch et al., 1991).

<sup>g</sup> Loadings from Ontario Iron and Steel Mills; for the other plants, loadings are unknown (Environment Canada, 1979; Ontario Ministry of the Environment, 1990a;b; 1991a;b;c; 1992a;b; Rankin, 1993; Merriman, 1988; King and Sherbin, 1986).

<sup>h</sup> Loading from only one site was obtained (a chemical company landfill in Sarnia, Ontario, used to dispose of chlorinated solvents still bottoms) (King and Sherbin, 1986).

Table 4-1: Examples of Bioaccumulation Factor (BAF) for TeCBs

Organism/Conditions	log BAF	Reference
<u>1,2,3,4-TeCB</u>		
rainbow trout	3.72-4.08	Oliver and Niimi 1983
<u>Oncorhynchus mykiss</u>		
"	3.89	" 1985
"	3.80-3.91	" 1985
" , lipid basis	4.80-5.13	" 1983
"	3.70	Banerjee et al. 1984b
fathead minnow	3.38	Carlson and Kosian 1987
guppy, lipid basis	4.86	Konemann and van Leeuwen 1980
<u>Poecilla reticulata</u>		
earthworm	4.92	Belfroid et al. 1993
<u>Eisenia andrei</u>		
<u>1,2,3,5-TeCB</u>		
rainbow trout, lipid basis	4.80-5.13	Oliver and Niimi 1983
fathead minnow	3.25	Veith et al. 1979
guppy, lipid basis	4.86	Konemann et al. 1979
" " "	4.15	Konemann and van Leeuwen 1980
guppy-lipid phase	4.73	Gobas et al. 1989
" " "	4.86	"
bluegill sunfish	3.26	Barrows et al. 1980
<u>Lepomis macrochirus</u>		
bluegill sunfish	3.46	Banerjee et al. 1984b
<u>1,2,4,5-TeCB</u>		
green algae	3.89	Mailhot 1987
rainbow trout	3.72-4.11	Oliver and Niimi 1983
" , lipid basis	4.80-5.13	Oliver and Niimi 1983
American flagfish	3.61	Smith et al. 1990
" -lipid phase	4.70	"



Table 4-2: Examples of Half-Lives in Biota

Organism	Half-life (day)	Reference
<u>1,2,3,4-TeCB</u>		
Worms	<5	Oliver 1987a
<u>Tubifex tubifex/Limnodrilus hoffmeisteri</u>		
<u>1,2,3,5-TeCB</u>		
Bluegill Sunfish	>2	Barrows et al. 1980
<u>Lepomis macrochirus</u>		
"	<4	"
<u>1,2,4,5-TeCB</u>		
Worms	<5	Oliver 1987a
<u>Picea omorika</u>	33	Reischl et al. 1989

Table 4-3: Examples of Uptake Rate and Elimination Rate Constants in Biota

Organism	Uptake Rate ( $k_1$ ) day <sup>-1</sup>	Elimination Rate ( $k_2$ ) day <sup>-1</sup>	Reference
<u>1,2,3,4-TeCB</u>			
Rainbow Trout	3360	0.504	Banerjee et al. 1984b
<u>1,2,3,5-TeCB</u>			
Guppy	15000	0.26	Konemann and van Leeuwen 1980
Bluegill Sunfish	1776	0.626	Banerjee et al. 1984b
Guppy	1000	0.26	Gobas et al. 1989
<u>1,2,4,5-TeCB</u>			
American flagfish	1630	0.4	Smith et al. 1990
- lipid	171000	0.34	Smith et al. 1990

Table 4-4: Half life Ranges of 1,2,4,5-TeCB by Various Reactions

Reaction-Compartment		Half life Range (Days)	Comments
Photooxidation	Air	31.8-318	Based upon measured rate data for the vapour phase reaction with hydroxyl radicals in air (Atkinson 1987; Howard et al. 1991).
		329	Using estimated rate constant of $k(\text{OH}) = 8.4 \times 10^{13}$ (Singleton 1993)
Photolysis	Air		No data available (Howard et al. 1991).
Photooxidation	Water		No data available (Howard et al. 1991).
Photolysis	Water		No data available (Howard et al. 1991).
Aerobic Biodegradation	Water	28-180	Based upon unacclimated aerobic screening test data (Kitano 1978; Howard et al. 1991)
Anaerobic	Water	120-720	Based upon estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).
Hydrolysis		$>3.2 \times 10^5$	First-order hydrolysis half-life. Scientific judgement based upon rate constant ( $0.9 \text{ M}^{-1} \text{ hr}^{-1}$ ) extrapolated to pH 7 at 25 °C from 1% disappearance after 16 days at 85°C and at pH 9.7 (Ellington et al. 1988). Base rate constant ( $\text{M}(\text{OH}^-)\text{-hr}^{-1}$ ): Scientific judgement based upon 1% disappearance after 16 days at 85°C and a pH 9.7 (Ellington et al. 1988; Howard et al. 1991)
"		insignificant	No hydrolyzable groups in 1,2,4,5-TeCB (Lyman et al. 1982)
Reduction			No data available (Howard et al. 1991).

Table 4-5: Half-Life Ranges of 1,2,4,5-TeCB in Various Compartments

Environmental Compartment	Half life Ranges (Days)	Comments
Air	31.8-318	Based upon photooxidation half life in air (Howard et al. 1991).
	41.7-125	Mackay et al. 1992
Surface Water	28-180	Based upon estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).
	125-417	Mackay et al. 1992
Sediment	56-360	Based upon estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).
	417-1250	Mackay et al. 1992
Soil	28-180	Based upon estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).
	125-417	Mackay et al. 1992

Table 4-6: Estimated Degradation Rate Constants

COMPARTMENT	DEGRADATION HALF-LIFE (HOURS)	RATE CONSTANT (H <sup>-1</sup> )
AIR	1700	0.000408
WATER	5500	0.000126
SOIL	5500	0.000126
SEDIMENT	17000	0.000041

Table 4-7: Summary of Level 111 Fugacity Fate Model

Compartment	Emission mol/hour	Environmental distribution %	Concentrations
Air	0.116	3.9	$4.8 \times 10^{-5}$ ug/m <sup>3</sup>
Water	0.928	58.4	$7.3 \times 10^{-2}$ ng/L
Soil	0.116	33.1	$9.2 \times 10^{-6}$ ug/g
Sediment	0	4.7	$2.1 \times 10^{-5}$ ug/g

ADVECTION AND REACTION RESIDENCE TIME 83.0 days  
 REACTION RESIDENCE TIME 313.5 days

Table 4-8: Air Environmental Concentrations (ng/m<sup>3</sup>) of Tetrachlorobenzenes inside and outside Canada

Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
Windsor (Ont)	1987/88	0.03				0.37(0.04-2.56)38	v
	1988/89	0.03				0.2( )32	zz
Walpole Isl. (Ont)	1988	0.03				0.19(0.05-0.42)26	v
	1988/89	0.03				0.14( )30	zz
Egbert (Ont)	1988			1.07(0.50-1.64)2	2.08(1.86-2.30)2		cc
"	1988-89				(up to 0.046)143*		dd
Experimental Lake Area NW Ont.	1990			(0.53)1	(2.95)1		cc
North Pacific	1986			(0.09-0.29)	(0.02-0.11)		ee

DL- detection limit, n- number of samples, ND- not detectable

- \* - there was breakthrough in the foam plugs in the summer months  
 - should be considered minimum of the air concentration.

v Environment Canada 1991b

cc Muir 1993

dd Hoff et al. 1992

ee Atlas and Schauffler 1990

zz Environment Canada 1990

Table 4-9: Examples of Environmental Concentrations of Tetrachlorobenzenes in Water (ng/L) in Canada

Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
L. Superior	1986	0.01			0.03(0.02-0.04)19		a
L. Huron	1980	0.05	(ND)5	(ND)5	0.05(0.04-0.06)5		b
	1986	0.01			0.080(ND-0.53)17		a
(Georgian Bay)	1986	0.01			0.04(0.03-0.05)7		a
St. Clair R.	1985	0.02	(ND)52	(ND)52	(ND-0.08)52		c
Niagara River# (upstream of Grand Island and Niagara, N.Y.)	1980	0.1	(ND)5	(ND)5	0.06()5		b
Niagara R.# (Niagara Falls, N.Y.-downstream of waste disposal dump)	1980	0.1	1()1	4()1	6()1		b
Niagara R.# (Niagara Falls, N.Y.-downstream from chemical manufacturing company effluent discharge)	1980	0.1	3()1	31()1	126()1		b
Niagara R. (NOTL)	1980	0.1	0.2()6	2()6	3()6		b
"	1982			2()20	3.7()20		j
(NOTL)	1981	0.05		(1.2)1	(2.6)1		r
(Fort Erie)		0.05		(ND)1	(0.06)1		r

Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
Niagara R. (NOTL)	1981-83	0.02	0.41(0.1-1.4)104	2.0(0.4-9.3)104	4.5(1.4-36)104		w
(water fraction) <sup>†</sup>	1986-87	0.04			0.72(ND-0.9)38		g
(water fraction and suspended sediment) <sup>†</sup>					1.03 ( )38		
(water fraction) <sup>†</sup>	1988-89	0.04			0.5(ND-0.6)44		h
(water fraction)	1988-89				(ND-1.08)44		h
(water fraction and suspended sediment) <sup>†</sup>					0.6(ND-0.7)44		
(Fort Erie)	1986-87				(ND)44		g
	1988-89				(ND)51		h
Niagara R. (Niagara Basin)	1983	0.1			8.0(5.2-10.7)2 5.6(4.8-6.3)2 6.6(6.3-6.9)2		d
	1983				3.8( )1		y
	1985				1.45(1.31-1.59)2		e
L. Ontario	1980	0.05	(ND)5	0.1(ND-0.3)	0.1(ND-0.5)5		b
	1983	0.01	0.04(ND-0.322)14**	0.04(ND-0.322)14**	0.09(ND-0.572)14		p
	1986	0.01			0.10(ND-0.50)31		a
L. Ontario (Niagara Basin)	1985				0.8(0.15-1.61)22		e
	1982	1	3.1(ND-21)37**	3.1(ND-21)37**	13.7(ND-125)37		f
(Niagara R. plume)	1983	0.01			4(0.5-8.2)44 1.8(ND-10.3)33 2.9(0.03-7.1)31		d
	1983				0.14(0.07-0.27)8		y



Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
L. Ontario	1984		0.018(0.017-0.019)7	0.073(0.054-0.092)7	0.140(0.121-0.159)7		u
	1985				0.5(0.15-1.64)22		e
Grand R. (Ont.)	1980	0.05	(ND)10	(ND)10	0.05(ND-0.2)10		b
Rainy R. (Ontario/ Minnesota- upstream of pulp and paper mills)	1986	0.1	(ND)5	(ND)5	(ND)5		1
(5 km. downstream)			(ND)5	(ND)5	(ND)5		
Lake Erie	1986	0.01			0.05(ND-0.09)21		a
Northwestern Ontario							
Orange Lake	1990-91			(<0.01-0.01)3	(<0.01-0.01)3		cc
Green Lake	1990-91			(<0.01-0.04)3	(<0.01-0.01)3		
Musclow Lake	"			(<0.01-0.02)3	(<0.01-0.01)3		
Lake Nipigon	"			(<0.01-0.01)8	(<0.01-0.02)8		
Sydney Lake	"			(<0.01-0.01)3	(0.01-0.02)3		
Trout Lake	"			(<0.01-0.01)3	(<0.01-0.13)3		
Ling Lake	"			(<0.01-0.03)3	(<0.01-0.01)3		

DL- detection limit, n- number of samples, ND- not detectable, NOTL- Niagara-on-the-Lake, #- on the United States side  
 \*\*1,2,3,5-Tetrachlorobenzene and 1,2,4,5-Tetrachlorobenzene analyzed together  
 ! mean and 90% confidence intervals for the mean. The mean was calculated using the maximum likelihood estimation method and is a lognormal distribution. Statistics take into account all samples (i.e. detected and nondetected).

a Stevens and Neilson 1989  
 b Oliver and Nicol 1982

c Chan and Kohli 1987  
d Carey and Fox 1987  
e Fox and Carey 1989  
f Fox and Carey 1986  
g Data Interpretation Group River Monitoring 1988  
h Data Interpretation Group River Monitoring 1990  
j Oliver and Charlton 1984  
l Merriman 1988  
p Biberhofer and Stevens 1987  
r Fox et al. 1983  
u Oliver and Niimi 1988  
w Oliver and Nicol 1984  
y Oliver 1984a  
cc Muir 1993

Table 4-10: Examples of Tetrachlorobenzenes Concentrations in Leachates/Effluents/Urban Runoff (ng/L) in Canada

Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
Sarnia Dow Chem. landfill treated leachate	1985	2	5()1		4()1	27()1	m
Sarnia Dow Chemical effluents	1985	2				(ND-110)6	m
Sarnia Dow Chemical effluents	1988	10	ND	(25.3)1	ND		1992a
"	1992		<3(<3-4)69	<7(<7-9.6)73	<4(<4-6.4)69		hh
Sarnia Polysar effluents	1985	2				ND	m
Sarnia Township ditch	1985	2	(20-27)2		(ND-10)2	(27-29)2	m
Waste water treatment plant effluents	1980	0.05	0.4(0.1-1)4	1.2(0.3-2)4	1.6(0.2-3)4		b
	1985	2				ND	m
Final effluent from bleached kraft pulp and paper mill -Water	1986	0.1	(ND)5	(ND)5	(0.11-0.22)2		l
-Suspended Solids			(ND)5	(ND)5	(ND)5		
Petroleum Ontario refineries effluents	1988-89	10			20(ND-200)10		1990ab

Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
Pulp and Paper Ont. Mills effluents	1990	10	451 (ND-4500) 170	54 (ND-300) 205	1366 (ND-110000) 309		1991b,c
Iron and Steel Ont. Mills effluents	1989-90	10	(ND-5400) 87	(ND-5300) 100	(ND-9100) 68		1991a
Inorganic Sector Ont. effluents	1989-91	10	(22-5400) 2	(38-5400) 2	(64-5434) 2		1992b
Refinery effluents-following biological treated process	1985	2				(ND-13)	m
Truro, N.S. (Stanfield's textile plant outfall)	1979	2	(110-130) 2**	(110-130) 2**	(79-900) 2		n
Urban Runoff/ stormwater Great Lakes Basin	1979/83	1	(ND) 122	(ND) 122	(ND) 122		o
Urban Runoff/ street sediment Great Lakes ng/g	1979/83	5	5 ( ) 99**	5 ( ) 99**	4.4 ( ) 99		o

DL- detection limit, n- number of samples, ND- not detectable

\*\*1,2,3,5-Tetrachlorobenzene and 1,2,4,5-Tetrachlorobenzene analyzed together

b Oliver and Nicol 1982

l Merrimen 1988

m King and Sherbin 1986

n Environment Canada 1979

o Marsalek and Schroeter 1988

1992a Ontario Ministry of the Environment 1992a

1992b Ontario Ministry of the Environment 1992b

1991a Ontario Ministry of the Environment 1991a

1991b Ontario Ministry of the Environment 1991b

1991c Ontario Ministry of the Environment 1991c

1990a Ontario Ministry of the Environment 1990a

1990b Ontario Ministry of the Environment 1990b

hh Rankin 1993



Table 4-11: Examples of TeCB Concentrations in Rain

1,2,3,4-TeCB

YEAR	LOCATION	CONCENTRATIONS ng/L Mean (Range) n	FLUX ng/m <sup>2</sup> /year
1987-89 1987-90 1990 1987-90  (Strachan 1993)	Pacific/Yukon region:  Tofino  Kanaka Ucluelet Yoho	0.017 (<0.01- 0.034) 3 <0.01 (<0.01) 4 0.022 (0.022) 1 0.027 (<0.01- 0.072) 4	3.43 (<0.9-10.3) 3  (<0.9) 4 (<0.9) 1 (<0.9) 4
1987-90 1987-90  (Strachan 1993)	Western/Northern region:  Suffield  McCreary	<0.01 (<0.01) 4  <0.01 (<0.01) 3	(<0.9) 4  (<0.9) 3
1989-90  (Strachan 1993)	Quebec region:  Lac Laflamme	<0.01 (<0.01) 2	(<0.9) 2
1990 1990 1990 1990 1990 1991 1991 1991  1990  (Rainfall May- Nov.)  (Muir 1993)  1989 1989  (Strachan 1993)	Ontario region:  NW Ontario          Point Petrie Jack's Lake	         0.12 (0.04-0.19) 2  <0.01 (<0.01- 0.017) 2 <0.01 (<0.01) 2	<0.50 <0.50 2.67 0.58 3.27 <0.50 <0.50 2.69   (4.8-22.2) 2 (<0.9) 2

1,2,4,5-TeCB

YEAR	LOCATION	CONCENTRATIONS ng/L Mean (Range) n	FLUX ng/m <sup>2</sup> /year
1990	Ontario Region:  NW Ontario		23.70
1990			79.51
1990			56.13
1990			<0.50
1990			28.86
1991			<0.50
1991			6.17
1991			<0.50
1990		0.55 (0.32-0.78) 2	
(Rainfall May- Nov.)			
(Muir 1993)			

Table 4-12: Examples of Environmental Concentrations (ng/g-dry weight) of Tetrachlorobenzenes in Sediment in Canada

Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
L. Superior	1980	0.2	0.1(ND-0.3)13	0.3(ND-1)13	0.3(ND-1)13		b
L. Huron	1980	0.2	0.4(0.1-0.7)42	1(0.2-9)42	1(0.2-8)42		b
(Southern)	1980	0.2		1.1(0.3-1.7)9	1.1(0.4-1.6)9		i
St. Clair R. (0-3km upstream of Dow Chemical Co.-Sarnia area)	1985	0.2				0.36(ND-5.4)18	k
(Near Dow Chemical Co.)						845(17-7000)20	
(0-2km downstream of Dow Co.)						69(12-190)12	
St. Clair R. (0-7km upstream of Dow Chemical Co.-Sarnia area)	1990	1	(ND)11	(ND)11	(ND)11		ff
(0-2km Dow Chemical Co.)	1990	<1	(ND-510)8	(ND-1140)8	(ND)8		ff
(2-7km downstream of Dow Co.)	1990	<1	(ND-20)18	(ND-40)18	(ND)18		ff
(Further downstream)	1990	<1	(ND)27	(ND)27	(ND)27		ff
L. St. Clair	1982	0.2		5.6(3.3-7.8)2	1.0(0.8-1.1)2		i
L. Erie	1980	0.2	0.3(0.1-0.9)5	1(0.3-4)5	0.7(0.2-2)5		b
(Western)	1982			1.7(0.6-5.3)9	0.9(0.4-1.8)9		i
(Central)	1982			0.6(0.2-0.9)22	0.4(0.1-0.7)22		
(Eastern)	1982			0.6(0.2-1.0)15	0.6(0.3-1.0)22		



Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
L. Ontario	1982			68(34-102)12	41(28-54)12		j
	1981		6.5(ND-16)38	41.9(3.9-110)38	31.6(4.6-72)38		t
(Niagara Basin)	1985				19.8(1.03-36.9)6		e
(Niagara Basin)	1982				17		t
mean core conc. (0-3cm)							
mean basin conc.					31		
(Mississauga Basin)							
mean core conc. (0-3cm)					20		
mean basin conc.					39		
(Rochester Basin)							
mean core conc. (0-3cm)					20		
mean basin conc.					32		
L. Ontario	1981			80(36-210)9	44(23-110)9		r
L. Ontario	1980	0.2	6(1-13)11	52(6-160)11	33(4-86)11		b
St. Lawrence R. (between Kingston and Cornwall)	1981	1			(ND-2)7		q
(Lac St. Francois)	1985	0.2	(0.47)1	(0.75-0.86)2	(0.50-0.62)2		bb
0-1 cm							
1-2 cm			(0.39-1.20)2	(1.20-1.70)2	(0.85-0.92)2		
2-3 cm			(0.54-1.60)2	(1.40-2.20)2	(0.92-1.20)2		
(Lac St. Louis)	1985			(1.30)1	(0.90-1.40)2		
0-1 cm							
1-2 cm			(1.10)1	(0.80-2.00)2	(0.67-1.40)2		
2-3 cm			(1.10)1	(2.10)1	(1.30)1		

Region	Year	DL	1235-TeCB mean(range) n	1245-TeCB mean(range) n	1234-TeCB mean(range) n	Total	Reference
(Lac des Deux Montagnes) 1-2 cm					(0.27) 1		
2-3 cm					(0.52) 1		
(Lac St. Pierre) 0-1 cm			(0.14) 1	(0.18) 1	(0.25) 1		
1-2 cm				(0.18) 1	(0.39) 1		
2-3 cm				(0.15) 1	(0.27) 1		
Niagara R. (Niagara Falls, NY#)	1981	0.5			(ND-870,000) 10		x
Abercrombie Point N.S. (chlor-alkali chemical plant -Canso Chemical outfall and nearby Pulp Mill)	1979	2	(ND-3) 12**	(ND-3) 12**	(ND-3) 12		n
Economy River, N.S.	1979	2	(ND) 10**	(ND) 10**	(ND) 10		n
Truro, N.S. (Stanfield's textile plant outfall)	1979	2	(ND-6) 10**	(ND-6) 10**	(ND-4) 10		n
Hawk Lake, NWT (0-1.25 cm depth)	1988			0.2***	0.2***		gg
Far Lake, NWT (0-1.25 cm depth)	1988			0.2***	0.2***		gg

DL- detection limit, n- number of samples, ND- not detectable, #- on the United States side

\*\*\*1,2,3,4-TeCB and 1,2,4,5-TeCB analyzed together

\*\*1,2,3,5-TeCB and 1,2,4,5-TeCB analyzed together

b Oliver and Nicol 1982

c Fox and Carey 1989

i Oliver and Bourbonniere 1985  
j Oliver and Charlton 1984  
k Oliver and Pugsley 1986  
n Environment Canada 1979  
q Merrimen 1987  
r Fox et al. 1983  
t Oliver et al. 1989  
u Oliver and Niimi 1988  
x Jaffe and Hites 1984  
bb Kaiser et al. 1990  
ff Ontario Ministry of the Environment 1993  
gg Welch et al. 1991

Table 4-13: Examples of Tetrachlorobenzenes Concentrations (dry weight) in Sediment Core Samples

Tetrachlorobenzene Concentrations (ng/g) in Lake Ontario Sediment Core from the Niagara Basin (Oliver & Nicol 1982)

Sediment Interval (cm)	Year	Concentration		
		1,2,3,5	1,2,4,5 ng/g	1,2,3,4
0-1 cm	1976-1980	11	170	76
1-2 cm	1971-1976	15	210	68
2-3 cm	1965-1971	14	110	32
3-4 cm	1958-1965	7	48	12
4-5 cm	1950-1958	4	30	9
5-6 cm	1941-1950	1	11	4
6-7 cm	1932-1941	0.2	1	1
7-8 cm	1923-1932	ND	0.6	0.5

Detection Level = 0.2ng/g

Tetrachlorobenzenes Concentrations (ng/g) in Lake Ontario Sediment Core near Niagara River (Durham & Oliver 1983)

Sediment Interval	Year	Concentration	
		1,2,4,5	1,2,3,4
0-1	1980-81	36	36
1-2	1978-80	90	50
2-3	1976-78	91	40
3-4	1974-76	220	58
4-5	1972-74	160	62
5-6	1969-72	150	85
6-7	1967-69	190	95
7-8	1965-67	380	210
8-9	1962-65	330	250
9-10	1959-62	320	140
10-11	1956-59	74	78
11-12	1953-56	99	67
12-13	1950-53	94	44
13-14	1947-50	130	58
15-16	1940-44	93	33
17-18	1932-36	120	32
19-20	1921-27	130	19
21-22	1909-16	46	10
23-24	1898-1904	4	0.6
25-26	1886-92	ND	ND
27-28	1868-78	ND	ND

Detection Level = 0.2 ng/g

Tetrachlorobenzenes Concentrations (ng/g) in Lake Ontario Sediment Core (Niagara Basin) (Oliver et al. 1989)

Sediment Interval	Age	Concentration		
		1,2,3,5-	1,2,4,5-	1,2,3,4-
0-0.34	0.59	2.4	14	14
0.34-0.94	2.1	3.2	18	18
0.94-1.55	3.6	2.0	12	12
1.55-2.15	5.3	2.8	16	14
2.15-2.73	6.5	4.2	25	20
2.73-3.16	7.4	4.0	28	21
3.16-3.76	8.8	4.3	32	24
3.76-4.32	10.1	4.6	34	27
4.32-4.84	11.4	4.7	35	29
4.84-5.41	12.4	4.7	29	27
5.41-5.96	13.8	4.2	29	26
5.96-6.52	15.4	4.4	27	23
6.52-7.12	17.4	4.2	20	15
7.12-7.69	19.1	4.7	22	15
7.69-8.26	20.7	3.4	17	12
8.26-8.76	22.2	2.6	14	8.7
8.76-9.33	24.0	1.2	7.3	4.3
9.33-9.91	25.6	2.4	13	7.0
9.91-10.50	27.5	2.8	15	9
10.5-11.09	29.3	-	-	-
11.09-12.04	32.4	1.9	11	7
12.04-13.36	36.6	0.9	5	3
13.36-14.36	39.6	0.3	2.9	1.5
14.36-15.53	43.4	0.1	1.6	0.8

Detection Level = 0.2 ng/g

Tetrachlorobenzenes Concentrations (ng/g) in Lake Ontario Sediment Core (Mississauga Basin) (Oliver et al. 1989)

Sediment Interval	Age	Concentration		
		1,2,3,5-	1,2,4,5-	1,2,3,4-
0-0.34	1.05	3.6	17	18
0.34-0.93	3.41	2.9	14	16
0.93-1.45	6.15	2.0	10	12
1.45-2.07	9.56	4.7	20	21
2.07-2.70	13.36	5.4	24	24
2.70-3.28	17.02	6.3	29	28
3.28-3.86	20.31	6.1	29	28
3.86-4.47	24.2	5.0	25	20
4.47-5.05	28.6	4.5	22	16
5.05-5.62	33.4	3.3	17	12
5.62-6.25	40.1	2.8	15	10
6.25-6.85	46.9	1.9	15	10
6.85-7.41	53.5	0.8	5.9	3.8
7.41-8.01	62	0.4	2.9	1.9
8.01-8.64	70	ND	1.1	0.9

Detection Level = 0.2 ng/g

Tetrachlorobenzenes Concentrations (ng/g) in Lake Ontario Sediment Core (Rochester Basin) (Oliver et al. 1989)

Sediment Interval	Age	Concentration		
		1,2,3,5-	1,2,4,5-	1,2,3,4-
0-0.44	0.88	4.3	21	18
0.44-0.98	2.29	4.5	21	18
0.98-1.55	3.84	3.7	17	15
1.55-2.06	5.40	4.9	22	19
2.06-2.67	7.11	7.2	30	24
2.67-3.31	9.10	8.6	34	28
3.31-3.92	11.26	4.6	23	12
3.92-4.48	13.44	3.4	20	8.9
4.48-5.01	15.33	3.6	21	10
5.01-5.45	17.77	2.5	16	8.0
5.45-5.97	20.00	1.9	14	6.8
5.97-6.44	22.57	1.4	14	6.7
6.44-6.95	24.54	1.4	14	7.0
6.95-7.58	26.93	0.8	10	5.5
7.58-8.26	29.91	0.5	7.5	3.7
8.26-8.87	31.66	0.2	2.8	0.9
8.87-9.52	34.49			
9.52-10.15	36.81	ND	0.5	0.1

Detection Level = 0.2 ng/g



Table 4-14: Environmental Concentrations (ng/g-dry weight) of Tetrachlorobenzenes in Suspended Sediment in Canada

Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
Rainy R. (Ontario/ Minnesota)	1983	5	(ND)5	(ND)5	(ND)		l
Niagara R. (NOTL)	1980			28(5-51)28	71(19-123)28		z
	1986/87				27.6(17.1-41.6)42		g
	1988/89				11.7(7.9-16.5)41		h
(Fort Erie)	1981	5		(ND)1	6()1		r
	1986/87	2.7		ND()45	ND()45		g
	1988/89	2.7		ND	ND		h
(NOTL) <75 um	1981			20.5(14-27)2	63(29-97)2		s
75-175um				26(16-42)3	55(38-69)3		
175-300um				81(24-160)3	169(58-290)3		
300-500um				60(26-81)3	185(86-320)3		
500-700um				58(19-110)3	105(56-130)3		
>700um				89(51-120)3	247(120-320)3		
L. Ontario	1982			14(7-24)6	18.3(12-27)6		j
(Niagara Basin)	1982			13()	23()		j
20 meters depth							
40 meters				15()	23()		
60 meters				19()	21()		
68 meters				21()	20()		
(Niagara Basin)	1985				9.8((5.6-16.4)3		e

Tetrachlorobenzene Concentrations (ng/g) in a lake (L375) in the Experimental Lakes Areas (near Kenora, Ontario) Sediment Core (Muir 1993)

Dated Sediment Core (Year)	1,2,3,5	Concentration 1,2,4,5 ng/g	1,2,3,4
1983		0.27	0.24
1972		0.61	0.32
1961		0.43	0.19
1950		0.23	0.13
1936		0.26	0.14
1924		0.27	<0.01

Detection Level = 0.01 ng/g

1,2,3,4-Tetrachlorobenzene Masses (kg) in Sediments of the Three Major Lake Ontario Sedimentation Basins (Oliver 1984a)

Sediment Interval cm	Mass Niagara Basin	Mass Mississauga Basin	Mass Rochester Basin
0.0-0.5	24	28	33
0.5-1.0	49	46	61
1.0-1.5	27	32	60
1.5-2.0	50	63	73
2.0-2.5	27	100	94
2.5-3.0	26	140	84
3.0-3.5	31	200	140
3.5-4.0	41	110	150
4.0-4.5	49	140	100
4.5-5.0	50	78	130
5.0-5.5	62	48	110
5.5-6.0	43	39	79
6.0-6.5	33	17	57
6.5-7.0	35	13	32
7.0-7.5	36	5	31
7.5-8.0	25	ND	28
8.0-8.5	17	ND	25
8.5-9.0	23	ND	21
9.0-9.5	24	ND	18
9.5-10	23	ND	15
10-11	21	ND	9
11-12	17	ND	4
12-13	6	ND	ND
13-14	3	ND	ND

Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
(Niagara Basin)	1982-85	0.2	(0.9-3.1)5	(5.4-21)5	(6.7-24)5		t
(Niagara Basin) 20 meters depth	1984-86	0.2	(ND-2)2	(4.7-13)2	(7.0-15)2		t
40 meters			(ND-2.2)2	(3.7-15)2	(6.2-17)2		t
60 meters			(1.9-3.2)2	(5.3-13)2	(7.5-15)2		
80 meters			(1.8)2	(4.9-12)2	(7.0-14)2		
90 meters			(0.4-1.9)2	(2.4-13)2	(3.1-15)2		t
98 meters			(0.9-1.8)2	(5.4-11)2	(6.8-13)2		
(Mississauga Basin)	1982-85	0.2	(ND-3.1)5	(3.2-20)5	(3.4-24)5		t
(Mississauga Basin) 20 meters depth	1984-86	0.2	(ND-1.4)2	(2.2-10)2	(3.5-11)2		t
60 meters			(ND-1.6)2	(0.9-11)2	(1.3-13)2		t
100 meters			(ND-1.7)2	(2.5-12)2	(3.6-14)2		
140 meters			(ND-1.6)2	(2.7-12)2	(2.8-13)2		
166 meters			(ND-1.7)2	(3.5-12)2	(4.0-14)2		t
174 meters			(0.6-1.6)2	(4.0-11)2	(4.8-13)2		
(Rochester Basin)	1983-85	0.2	(ND-1.7)4	(2.7-14)4	(2.4-11)4		t
(Rochester Basin) 20 meters depth	1984	0.2	(ND)1	(ND)1	(4.6)1		t
60 meters			(ND)1	(ND)1	(3.0)1		t
100 meters			(ND)1	(ND)1	(4.6)1		
140 meters			(ND)1	(2.8)1	(2.9)1		

Region	Year	DL	1235-TeCB mean(range)n	1245-TeCB mean(range)n	1234-TeCB mean(range)n	Total	Reference
180 meters			(ND)1	(3.6)1	(3.5)1		t
174 meters			(0.6-1.6)2	(4.0-11)2	(4.8-13)2		
L.Ontario	1982-86	0.2	1.9(1.2-2.6)10	14(11.1-17.9)10	15(9.6-20.4)10		u
"	1982-85	0.2	(ND- 3.1)14	(2.7-21)14	(2.4-24)		t
St. Lawrence R. (Kingston- Cornwall)	1981	1		2.6(ND-4)10	1.3(ND-2)10		q
(Lac St. Francois)	1985	0.2		(0.58)1	(0.70)1		bb
(Lac St. Pierre)					(0.17-0.70)4		
Wolfe Island	1982/84	5			14(ND-95)28		s

DL- detection limit, n- number of samples, ND- not detectable

e Fox and Carey 1989

g Data Interpretation Group River Monitoring 1988

h Data Interpretation Group River Monitoring 1990

j Oliver and Charlton 1984

l Merrimen 1988

q Merrimen 1987

r Fox et al. 1983

s Sylvestre 1987

u Oliver and Niimi 1988

t Oliver et al. 1989

z Kuntz and Werry 1983

bb Kaiser et al. 1990

Table 6-14: Tetrachlorobenzenes Concentrations in Biota (ng/g-wet weight)

Region	Species	1,2,3,5-	1,2,4,5-	1,2,3,4-	Reference
L. Ontario/1982	Plankton n=3 phytoplankton zooplankton	0.06	0.6	0.4	Oliver & Niimi 1988
" /1981,1984	mysids n=2 <u>Mysis relicta</u>	0.2	0.5	1.5	"
" /1981	" n=1		20 (d.w.) 2.9 <sup>#</sup>	19 (d.w.) 2.8 <sup>#</sup>	Fox et al.1983
" /1985	amphipods n=6 <u>Pontoporeia affinis</u>	0.5	5.5	6.1	Oliver & Niimi 1988
" /1981	" n=10		8.1-210 (d.w.) 1.8-46.2 <sup>#</sup>	9-130 (d.w.) 2.0-28.6 <sup>#</sup>	Fox et al. 1983
" /1985	oligochaetes n=6 <u>Tubifex tubifex</u> <u>Limnodrilus hoffmeisteri</u>	0.1	1.5	0.3	Oliver & Niimi 1988
" /1981	" n=9		ND-110 (d.w.) ND-18.7 <sup>#</sup>	ND-69 (d.w.) ND-11.7 <sup>#</sup>	Fox et al. 1983
" /1986	sculpin (composite) <u>Cottus cognatus</u>	ND	ND	0.9	Oliver & Niimi 1988
" /1982	alewife (composite)	ND	ND	ND	"
" /1986	small smelts n=6 <u>Osmerus mordax</u>	ND	ND	ND	"

Region	Species	1,2,3,5-	1,2,4,5-	1,2,3,4-	Reference	
L.Ontario/1982	large smelts (composite)	ND	ND	ND	"	
" /1981,1982	fish (n = 60) <u>Oncorhynchus velinus</u> <u>namaycush</u> <u>Oncorhynchus mykiss</u> <u>Salvelinus namaycush</u> <u>Salmo trutta</u>	ND	ND	1.8	"	
" 1981/82	<u>Salmo trutta</u> whole fish			5(2-12)10	Niimi & Oliver 1989	
	muscle			2(ND-5)10	"	
" "	<u>Salvelinus namaycush</u> whole fish			4(2-6)10	Niimi & Oliver 1989	
	muscle			2(ND-5)10	"	
" "	<u>Oncorhynchus mykiss</u> small whole fish			1(ND-2)8	Niimi & Oliver 1989	
	muscle			(ND)8	"	
" "	<u>Oncorhynchus mykiss</u> large whole fish			(ND)12	Niimi & Oliver 1989	
	muscle			(ND)12	"	

Region	Species	1,2,3,5-	1,2,4,5-	1,2,3,4-	Reference
Lake Ontario 1981/82	<u>Oncorhynchus kisutch</u> small whole fish				1(ND-2)10 Niimi & Oliver 1989
	muscle				(ND)10
"	<u>Oncorhynchus kisutch</u> large whole fish				(ND)9 Niimi & Oliver 1989
	muscle				(ND)9
L. Superior/1980	lake trout <u>Salvelinus namaycush</u>	0.1	0.3	0.5	Oliver & Nicol 1982
L. Huron/1980	lake trout	0.2	1	2	Oliver & Nicol 1982
L. Erie/1980	rainbow trout <u>Oncorhynchus mykiss</u>	0.05	0.2	0.3	Oliver & Nicol 1982
L. Ontario/1980 (caught off Niagara River)	lake trout	1	5	12	Oliver & Nichol 1982
L. Ontario/1980 (caught off Point Petre)	lake trout	0.5	2	4	Oliver & Nichol 1982
L. Ontario/1981	"		4 (d.w.) 1.0 <sup>#</sup>	4.3 (d.w) 1.1 <sup>#</sup>	Fox et al 1983

Region	Species	1,2,3,5-	1,2,4,5-	1,2,3,4-	Reference	
Buffalo R./1984 (Niagara R. tributary, NY)	common carp* <u>Cyprinus carpio</u>		ND***	32-36	ND***	Jaffe & Hites 1986
Ellicott/1984 Creek (Niagara R.tributary)	common carp*		ND***	0.011	ND***	Jaffe & Hites 1986
Tonawanda/1984 Cr. (Niagara R.tributary)	common carp*		ND***	ND	ND***	Jaffe & Hites 1986
Niagara R./1984 (upper river by dumps)	common carp*		400-410***	6700-7400	400-410***	Jaffe & Hites 1986
Bergholtz/1984 Cr. (Niagara R. tributary by dumps)	common carp*		56***	470	56***	Jaffe & Hites 1986
Fort Niagara/1984 (Niagara R.)	common carp*		ND***	75-82	ND***	Jaffe & Hites 1986
12 Mile Cr./1984 (L.Ontario tributary, NY)	"		ND***	5	ND***	"
18 Mile Cr./1984 (L. Ontario tributary, NY)	goldfish <u>Carassius auratus</u> *		ND***	ND	ND***	"
	common carp*		ND***	ND	ND***	"



Region	Species	1,2,3,5-	1,2,4,5-	1,2,3,4-	Reference
Oak Orchard/1984 Cr. (L.Ontario tributary, NY)	catfish* <u>Ichthalurus</u> sp.		ND***	ND	ND*** "
Gensee R., Oswego R., Salmon R., St. Lawrence (tributaries of L.Ontario)	common carp*		ND***	ND	ND*** "
Black R. (tributaries of L.Ontario)	sucker* <u>Catostomus commersoni</u>		ND***	ND	ND*** "
Trout Lake/1990	lake trout muscle			<0.01(<0.01)6	<0.01(<0.01-0.4)6 Muir 1993
" /1991	walleye muscle			"	0.011(<0.01-0.07)6 Muir 1993
Sydney Lake/1990	lake trout muscle			<0.01(<0.01)6	<0.01(<0.01)6 Muir 1993
" /1991	walleye muscle			<0.01(<0.01)6	<0.01(<0.01)6 Muir 1993
Lake Superior/1990	lake trout muscle			<0.01(<0.01)6	0.39(<0.01-0.74)6 Muir 1993
Linge Lake/1991	walleye muscle			<0.01(<0.01)6	<0.01(<0.01)6 Muir 1993
Musclow Lake/1991	walleye muscle			<0.01(<0.01)6	0.01(<0.01-0.04)6 Muir 1993

Region	Species	1,2,3,5-	1,2,4,5-	1,2,3,4-	Reference
Lake Nipigon/1991	walleye muscle			<0.01(<0.01)6	<0.01(<0.01)6 Muir 1993
Orange Lake/1991	walleye muscle			<0.01(<0.01)6	<0.01(<0.01-0.01)6 Muir 1993
NW Ont./1987	lichen			0.31(0.21-0.41)2	0.55(0.44-0.65)2 Muir 1993
Dorset, Ont./1987	lichen			<0.01(<0.01)2	0.11(<0.01-0.22)2 Muir 1993
St. Lawrence River/1985	mussels		(<0.01)17	(<0.01)17	(<0.01)17 Metcalfe and Charlton 1990
Ottawa River/1985	"		(<0.01)3	(<0.01)3	(<0.01)3 "

d.w.-dry weight

ND - not detectable

\*\*\*-combined values for 1,2,3,5-/1,2,3,4-tetrachlorobenznes

\*- on a lipid basis

#-estimated wet weight

Table 9-1: Effects of Tetrachlorobenzene isomers on algae and bacteria

Species	Static/ flow-through <sup>a</sup>	Temp. °C	pH	Response	Concentration, µg/L			Nominal or Measured <sup>b</sup>	Reference
					1234-TeCB	1235-TeCB	1245-TeCB		
ALGAE									
<i>Ankistrodesmus falcatus</i>	stat closed	-	-	4hr-EC50 (growth reduction)	4100	3020	4970 <sup>f</sup>	n	Wong <i>et al.</i> 1984
<i>Cyclotella meneghiniana</i>	-	15	-	48h-EC50 (DNA reduction)	1390	1370	270	n	Figueroa and Simmons 1991
<i>Selenastrum capricornutum</i>				96h-EC50 (Chlorophyll a)	---	17200 <sup>f</sup>	52900 <sup>f</sup>	n	US EPA 1978
				96h-EC50 (cell numbers)	---	17700 <sup>f</sup>	46800 <sup>f</sup>		
<i>Skeletonema costatum</i>				96h-EC50 (Chlorophyll a)	---	830	7100 <sup>f</sup>	n	US EPA 1978
				96h-EC50 (cell numbers)	---	700	7320 <sup>f</sup>		
Green algae	stat closed	19	6.5	3h-EC50 (photosynthetic inhibition)	---	2504	---	n	Hutchinson <i>et al.</i> 1980
<i>Chlorella vulgaris</i>	stat	28	-	5d-EC50 (growth inhibition)	> 63691	---	---	n	Ikemoto <i>et al.</i> 1992
<i>Chlamydomonas angulosa</i>	stat closed	19	6.5	3h-EC50 (photosynthetic inhibition)	---	1576	---	n	Hutchinson <i>et al.</i> 1980
BACTERIA									
<i>Photobacterium phosphorum</i>	-	15	-	(reduction of emitted light): 5 min-EC50	2261	3268	10100 <sup>f</sup>	n	Ribo and Kaiser 1983
				15 min-EC50	3344	3501	6520 <sup>f</sup>		
				30 min-EC50	4020	2480	4511 <sup>f</sup>		
	-	15	-	15 min-EC50	1880	---	---	n	Hermens <i>et al.</i> 1985
methanogens (anaerobic)	stat closed	35	7	48h-EC50 (inhibition of gas production)	20000 <sup>f</sup>	---	---	n	Blum and Speece 1991
<i>Nitrosomonas</i>	stat closed	25	6.5-8.0	24h-EC50 (inhibition of ammonia consumption)	20000 <sup>f</sup>	---	9800 <sup>f</sup>	n	Blum and Speece 1991

<sup>a</sup> flow = flow-through ren = renewal stat = static<sup>b</sup> n = nominal concentration m = measured concentration<sup>f</sup> above solubility

Table 9-2: Effects of Tetrachlorobenzene isomers on freshwater invertebrates

Species	Size / age	Static / flow-through <sup>a</sup>	Temp. °C/ pH	Hardness mg/L	Response	Concentration, µg/L			Nominal or measured <sup>b</sup>	Reference
						1234-TeCB	1235-TeCB	1245-TeCB		
Water flea <i>Daphnia magna</i>	<48 h	stat	22/-	ca 100	48h-EC50 immobilization	542	358 <sup>c</sup>	358 <sup>c</sup>	n	Hermens <i>et al.</i> 1984
	<24 h	stat ren	19/-	ca 100	16d-EC50 reproduction 16d-NOEC reproduction	43 10	— —	67 <sup>c</sup> —	n	Hermens <i>et al.</i> 1984
	<24 h	stat ren	19/-	ca 100	16d-LC50 16d-NOEC	320 100	— —	278 <sup>c</sup> —	n	Hermens <i>et al.</i> 1984
	<24 h	stat ren	19/-	ca 100	16d-EC50 growth 16d-NOEC growth	160 (98 <sup>d</sup> ) 56 (34 <sup>d</sup> )	— —	— —	n <sup>d</sup>	Hermens <i>et al.</i> 1985
	<24 h	stat ren	19/-	ca 100	16d-EC50 reproduction 16d-NOEC reproduction 16d-NOEC growth	90 55 55	— — —	— — —	m	De Wolf <i>et al.</i> 1988
	1.5 mm/ 4-6 day	stat closed	23/6-7	-	48h-EC50 (immobilization)	—	863	—	n <sup>e</sup>	Bobra <i>et al.</i> 1983
	1.5 mm/ 4-6 day	stat closed	23/6-7	-	48h-EC50 (immobilization)	—	863	—	n <sup>e</sup>	Bobra <i>et al.</i> 1985
	1.5 mm/ 4-6 day	stat closed	23/6-7	-	48h-EC50 (immobilization)	—	863	—	n <sup>e</sup>	Abernathy <i>et al.</i> 1986
	≤24 day	stat	22/8.0	173	24h-LC50 48h-LC50	— —	18000 <sup>f</sup> 9700 <sup>f</sup>	> 530000 <sup>f</sup> > 530000 <sup>f</sup>	n	LeBlanc 1980
<i>Daphnia pulex</i>	<24h	stat	20/-	-	96h-LC50	184	—	—	n	Ikemoto <i>et al.</i> 1992
Mysid shrimp <i>Mysidopsis bahia</i>		stat		salt water	96h-LC50	—	340	1480 <sup>f</sup>	n	US EPA 1980a

<sup>a</sup> flow = flow-through    ren = renewal    stat = static<sup>b</sup> n = nominal concentration    m = measured concentration<sup>c</sup> QSARS: quantitative structure-activity relationships were used to determine the toxicity thresholds from selected experimental results<sup>d</sup> Adjusted to reflect measured concentration of 61% of nominal assay<sup>e</sup> Based on dilution of a saturated solution<sup>f</sup> Above water solubility of compound

Table 9-3: Acute effects of Tetrachlorobenzenes on fish

Species	Size / age	Static / flow-through <sup>a</sup>	Temp. °C/ pH	Hardness mg/L	Response	Concentration, µg/L			Nominal or measured <sup>b</sup>	Reference
						1234-TeCB	1235-TeCB	1245-TeCB		
Fathead minnow <i>Pimaphales promelas</i>	30 d	stat	25/7.3-7.6	44-46	96h-LC50	1100	---	---	n	Carlson and Kosian 1987
	4-12 hr	stat	25/7.3-7.6	44-46	33d-NOEC 33d-MATC	250 320	---	---	n	Carlson and Kosian 1987
	30-35 d	flow	25/7.4	45	96h-LC50	1070	---	---	m	Ahmad <i>et al.</i> 1984
	30-35 d	flow	25/7.4	45	32d MATC	245-412	---	---	m	Ahmad <i>et al.</i> 1984
	30 d/0.12 g	flow	25/7.5	56	96h-LC50	1080	---	---	m	Veith <i>et al.</i> 1983
	30-35d	flow	25/-	43-49	96h-LC50	802	---	305	m?	Hall <i>et al.</i> 1984
Guppy <i>Poecilia reticulata</i>	2-3 mo	stat ren	22/-	25	14d-LC50	802	802	305	n?	Könemann 1981
	1 yr/ 90-130 mg	flow	20/-	-	96h-LC50 192h-LC50	365 244	---	---	m	van Hoogen and Opperhuizen 1988
Zebra fish <i>Brachydanio rerio</i>	egg < 6 h	stat ren	24/8.0-8.2	210	28d-LC50	410	---	---	m	van Leeuwen <i>et al.</i> 1990
					28d-NOLC (no mortalities)	310	---	---		
					28d-NOEC (growth)	100	---	---		
Brook trout <i>Salvelinus fontinalis</i>	early life stages	flow	5/7	48	10-14d-MATC (hatch)	---	---	347-455	m	ARTG 1987
					100d-MATC (survival and growth)	---	---	<243		
American flagfish <i>Jordanella floridae</i>	juvenile	stat	25/7	48	96h-LC50	---	---	2080 <sup>f</sup> (380 <sup>g</sup> )	m	Smith <i>et al.</i> 1991
		flow	25/7	48	96h-LC50	---	---	1950 <sup>f</sup>		
	early life stages	flow	25/7	48	10d-MATC (hatch)	---	---	>238	m	Smith <i>et al.</i> 1991
					28d-MATC (fry growth)	---	---	69-104		
					28d-CV (fry growth)	---	---	85		
					28d-MATC (fry survival)	---	---	104-182		
					28d-CV (fry survival)	---	---	138		

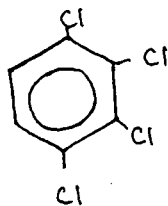
<sup>a</sup> flow = flowthrough; ren = renewal; stat = static <sup>b</sup> n = nominal concentration; m = measured concentration <sup>c</sup> precipitate formed, nominal concentration was 10X solubility <sup>d</sup> no mortality when 96h-LC50 test initiated at 0 h, 24 h, 14 d, 28 d and 42 day. <sup>e</sup> units are µg/kg fish. <sup>f</sup> may be artificially high due to insoluble component still present in water samples <sup>g</sup> water filtered through 0.22 µm filter to remove particulate TeCB.

Table 9.3 (concluded)

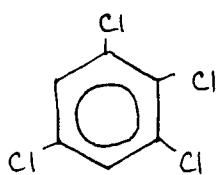
Species	Size / age	Static / flow-through <sup>a</sup>	Temp. °C/ pH	Hardness mg/L	Response	Concentration, µg/L			Nominal or measured <sup>b</sup>	Reference
						1234-TeCB	1235-TeCB	1245-TeCB		
Bluegill sunfish <i>Lepomis macrochirus</i>	0.3-1.2 g	stat	22/6.7-7.8	32-48	24h-LC50 96h-LC50	--- ---	59000 <sup>c</sup> 6400 <sup>c</sup>	5700 <sup>c</sup> 1600 <sup>c</sup>	n	Buccafusco <i>et al.</i> 1981
Rainbow trout <i>Salmo gairdneri</i>	77d early fry <sup>d</sup>	stat ren	10/7.2	50	96h-LC50	---	---	1200	n	van Leeuwen <i>et al.</i> 1985
	35 g	ip injection	15/7.6	135	96h-EC50 (loss of equilibrium & buoyancy)	---	---	2280 <sup>e</sup>	-	Smith and Craig 1981
	20-30 g	ip injection	15/7.6	135	96h-LD50	1060 <sup>f</sup>	1680 <sup>e</sup>	>4720 <sup>f</sup>	-	Ribo and Kaiser 1983
	1.2-3.8 g	flow	15/7.6-8.19	-	96h-LC50	497	1533	---	m	Hodson <i>et al.</i> 1988
Killifish <i>Oryzias latipes</i>	0.2 g	stat ren	20/-	-	24h-LC50	1924	---	---	m	Ikemoto <i>et al.</i> 1992
Sheepshead minnow <i>Cyprinodon variegatus</i>	14-28d/ 8-15 mm	stat	25-31/-	10-31‰	24h-LC50	---	>7500 <sup>c</sup>	>1800 <sup>c</sup>	n	Heitmüller <i>et al.</i> 1981
					48h-LC50	---	5600 <sup>c</sup>	900		
					72h-LC50	---	4700 <sup>c</sup>	800		
					96h-LC50	---	3700 <sup>c</sup>	800		
					96h-NOEC	---	1000	300		

<sup>a</sup> flow = flowthrough; ren = renewal; stat = static <sup>b</sup> n = nominal concentration; m = measured concentration <sup>c</sup> precipitate formed, nominal concentration was 10X solubility <sup>d</sup> no mortality when 96h-LC50 test initiated at 0 h, 24 h, 14 d, 28 d and 42 day. <sup>e</sup> units are µg/kg fish. <sup>f</sup> may be artificially high due to insoluble component still present in water samples <sup>g</sup> water filtered through 0.22 µm filter to remove particulate TeCB.

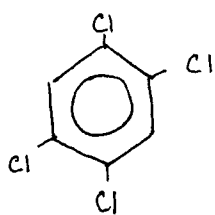
FIGURES



1,2,3,4-



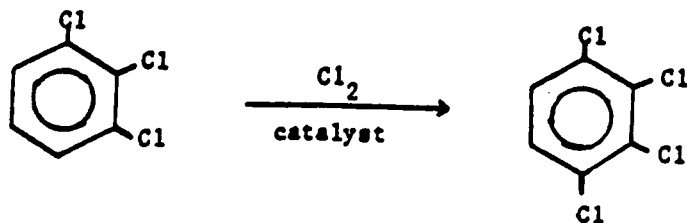
1,2,3,5-



1,2,4,5-

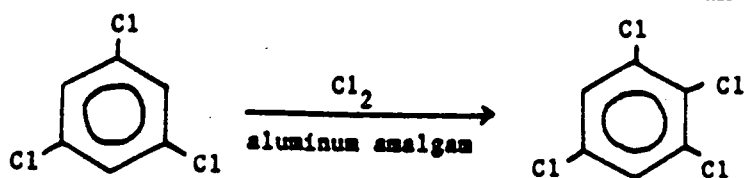
Figure 1-1: Molecular structure of tetrachlorobenzenes





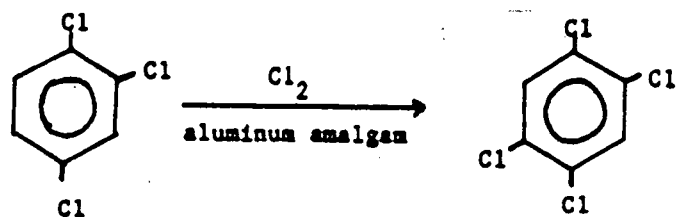
1,2,3-trichlorobenzene

1,2,3,4-tetrachlorobenzene



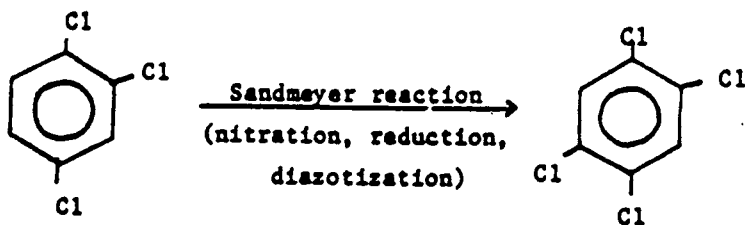
1,3,5-trichlorobenzene

1,2,3,5-tetrachlorobenzene



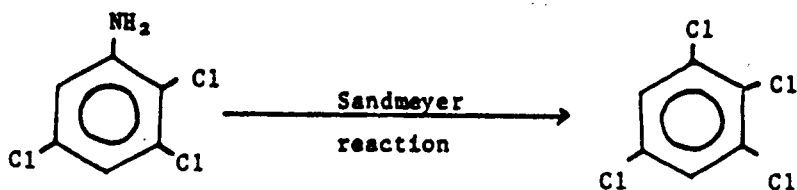
1,2,4-trichlorobenzene

1,2,4,5-tetrachlorobenzene



1,2,4-trichlorobenzene

1,2,4,5-tetrachlorobenzene



2,3,5-trichloroaniline

1,2,3,5-tetrachlorobenzene

Figure 3-1: Manufacturing processes of tetrachlorobenzenes

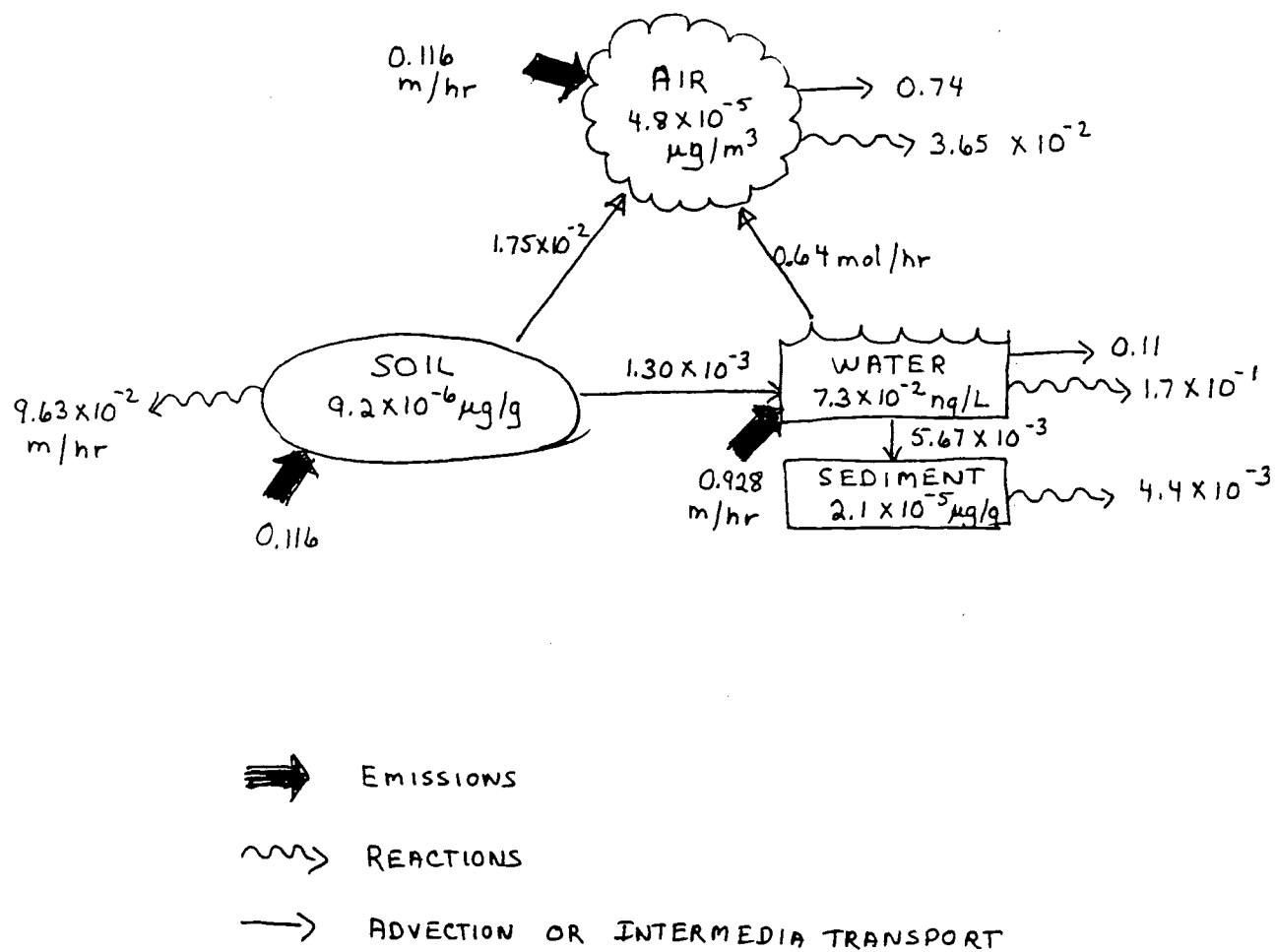


Figure 4-1: Mass balance diagram for tetrachlorobenzenes in Southern Ontario