Follow-up Report on Five PSL1 Substances for Which There Was Insufficient Information to Conclude Whether the Substances Constitute a Danger to the Environment

1,2-Dichlorobenzene
1,4-Dichlorobenzene
Trichlorobenzenes
Tetrachlorobenzenes
Pentachlorobenzene

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ACR	acute to chronic ratio
AET	Apparent Effect Threshold
BAF	bioaccumulation factor
BCF	bioconcentration factor
CBz	chlorobenzene
CBzs	chlorobenzenes (1,2-dichlorobenzene, 1,4-dichlorobenzene, trichlorobenzenes, tetrachlorobenzenes, pentachlorobenzene)
CEPA	*Canadian Environmental Protection Act*
CEPA 1999	*Canadian Environmental Protection Act, 1999*
CTV	Critical Toxicity Value
CTV_{SED}	Critical Toxicity Value for sediments
DCB	dichlorobenzene
1,2-DCB	1,2-dichlorobenzene
1,4-DCB	1,4-dichlorobenzene
dw	dry weight
EC_{50}	median effective concentration
EEV	Estimated Exposure Value
ENEV	Estimated No-Effects Value
$ENEV_{SED}$	Estimated No-Effects Value for sediments
$ENEV_{SOIL}$	Estimated No-Effects Value for soils
EqP	equilibrium partitioning
HC_5	hazardous concentration for 5% of exposed organisms
K_{ow}	octanol-water partition coefficient
LC_{50}	median lethal concentration
LC_{90}	lethal concentration to 90% of the test organisms
LOEC	Lowest-Observed-Effect Concentration
MDL	method detection limit
NOEC	No-Observed-Effect Concentration
NPRI	National Pollutant Release Inventory
OC	organic carbon
PCBs	polychlorinated biphenyls
PSL	Priority Substances List
PSL1	first Priority Substances List
QCB	pentachlorobenzene
STP	sewage treatment plant
TCB	trichlorobenzene
TeCBs	tetrachlorobenzenes

SYNOPSIS

1,2-Dichlorobenzene (1,2-DCB), 1,4-dichlorobenzene (1,4-DCB), trichlorobenzenes (TCBs), tetrachlorobenzenes (TeCBs) and pentachlorobenzene (QCB), which appeared on the first Priority Substances List (PSL1), were assessed to determine whether these substances should be considered "toxic" as defined under the *Canadian Environmental Protection Act* (CEPA). It was concluded in the PSL1 assessment that these compounds were not "toxic" under Paragraphs 11(b) or 11(c) of CEPA; however, there was insufficient information to conclude whether they could have immediate or long-term harmful effects on the environment, under Paragraph 11(a). Concentration data for these chlorobenzenes (CBzs) in freshwater and marine sediments and soil environments were lacking. Corresponding data reporting effects on benthic and soil-dwelling organisms were also needed to complete this assessment.

Subsequent to the completion of the PSL1 assessments, a revised CEPA, CEPA 1999, came into effect. Paragraph 64(a) of CEPA 1999 has a definition of "toxic" that is similar to that in Paragraph 11(a) under the original CEPA and addresses whether a substance has or may have an immediate or long-term harmful effect on the environment. However, in CEPA 1999, Paragraph 64(a) has been expanded to include effects on biodiversity. Research studies to address data gaps for the CBzs of interest were funded, and emphasis was placed on studies that examined effects on benthic organisms exposed to the CBzs of interest. Additionally, recent literature was reviewed for new data on concentrations in sediment and soil for each of the CBzs under consideration and for information on the effects on organisms resulting from exposure to these compounds.

Both 1,2-DCB and 1,4-DCB are produced in Canada, based on reports from the early 1990s. 1,4-DCB is used more extensively than 1,2-DCB, primarily as an air freshener/deodorizer. During the mid-1990s, 40–45 tonnes of TCBs were expected to be imported into Canada, although imports of TeCBs and QCB were not anticipated.

The primary route of entry for CBzs into Canadian surface waters and associated sediments is via effluents from industrial and sewage treatment plants. 1,2-DCB, 1,4-DCB, TCBs, TeCBs and QCB have been identified in pulp and paper mill effluents. Effluents from iron and steel manufacturing contribute to loadings of TCBs, TeCBs and QCB, while petroleum refinery effluents have been reported to contain TeCBs and QCB. The more highly chlorinated benzenes, particularly hexachlorobenzene, are subject to reductive dechlorination, which may contribute to accumulation of the lower chlorinated homologues (e.g., DCBs and TCBs) in buried sediments. The main source of CBzs to Canadian soils is accidental spillage of industrial chemicals, although CBzs may be added to agricultural soils during amendment with sewage sludge. Industrial emissions to the atmosphere represent another route of entry into the Canadian environment.

Maximum Canadian concentrations of each of the CBzs under consideration in this report were observed in sediment samples collected from the St. Clair River in Ontario. 1,4-DCB was the only CBz detected in Canadian soil samples. The CBzs of interest in this report are known to cause both chronic and acute effects in controlled tests on benthic and soil-dwelling organisms. In general, benthic organisms are more sensitive to the CBzs than soil-dwelling species, based on toxicity studies to date.

Concentrations of the CBzs of interest in the highly contaminated sediments of the St.

Clair River are elevated enough that sensitive benthic organisms could experience adverse effects.

Each of the CBzs under investigation in this report has been estimated to persist in sediment for longer than 2 years. The half-lives of 1,2-DCB, 1,4-DCB, TCBs and TeCBs in soil have been estimated to be approximately 8 months, while QCB's half-life in soil has been estimated to be 2 years. Additionally, TeCBs and QCB are subject to atmospheric transport from its source to remote areas and, therefore, are considered persistent in air. All of the CBzs of interest in this report therefore meet the criteria for persistence as defined in the Persistence and Bioaccumulation Regulations of CEPA 1999 (Government of Canada, 2000) due to the persistence of these compounds in sediment and soil. The higher chlorinated products, TeCBs and QCB also are persistent in air. The lower chlorinated benzenes (1,2-DCB, 1,4-DCB and TCBs) are not expected to be highly bioaccumulative. However, the TeCBs and QCB do have a high potential to bioaccumulate and meet the bioaccumulation criteria defined in the Persistence and Bioaccumulation Regulations of CEPA 1999 (Government of Canada, 2000).

There are special concerns about persistent and bioaccumulative substances. Persistent substances can remain in the environment for long periods of time, increasing the probability and the duration of exposure. In addition persistent substances are subject to long-range transport, which results in low-level, widespread contamination Bioaccumulative substances have the potential to biomagnify, and consequently releases of extremely low concentrations of persistent and bioaccumulative substances may - either alone or in combination with other similar substances - cause severe adverse effects.

Based on the information available, it is concluded that 1,2-DCB, 1,4-DCB and TCBs are not entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity, but TeCBs and QCB are entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity. Therefore, 1,2-DCB, 1,4-DCB and TCBs are not considered "toxic" as defined in Paragraph 64(a) of CEPA 1999. It is, however, concluded that TeCBs and QCB be considered "toxic" as defined in Paragraph 64(a) of CEPA 1999.

QCB and TeCBs are persistent, bioaccumulative, predominantly anthropogenic and are considered "toxic" under Paragraph 64(a) of CEPA 1999, and as such, meet the criteria for Track 1 substances under the Toxic Substances Management Policy. Therefore QCB and TeCB should be subject to virtual elimination of releases to the environment. Since there is currently no commercial demand for QCB and TeCBs in Canada, options to prevent their reintroduction into the Canadian market should be explored.

1.0 INTRODUCTION

1,2-Dichlorobenzene (1,2-DCB), 1,4-dichlorobenzene (1,4-DCB), trichlorobenzenes (TCBs), tetrachlorobenzenes (TeCBs) and pentachlorobenzene (QCB) appeared on the first Priority Substances List (PSL1) of the *Canadian Environmental Protection Act* (CEPA), which was published in the *Canada Gazette*, Part I, on February 11, 1989. Assessments were performed to determine whether these chlorobenzenes (CBzs) should be considered "toxic" as defined under CEPA and were completed in 1993 (Government of Canada, 1993a, 1993b, 1993c, 1993d, 1993e)[1]. It was concluded that these substances do not constitute a danger either to the environment on which human life depends or to human life or health, and, therefore, they were not found to be "toxic" under Paragraph 11(b) or 11(c) of CEPA. Additionally, during the period over which the original assessments were conducted, it was determined that concentrations of 1,2-DCB, 1,4-DCB, TCBs, TeCBs and QCB present in Canadian air and surface waters were not likely to cause adverse effects on aquatic biota or wildlife. There was, however, a lack of acceptable data on the effects of these CBzs on benthic and soil-dwelling organisms and on concentrations of CBzs in Canadian soils. Therefore, it was not possible to determine whether environmental harm was occurring due to accumulations of these substances in sediment and soil. The lack of data led to the conclusion that there was insufficient information available on sediments and soils to determine whether these substances should be considered "toxic" under Paragraph 11(a) of CEPA.

A revised CEPA, CEPA 1999, came into effect on March 31, 2000. This new legislation includes Paragraph 64(a), which is similar to Paragraph 11(a) of the original CEPA and addresses whether a substance has or may have an immediate or long-term harmful effect on the environment, although it has been expanded to include effects on biodiversity. CEPA 1999 places more emphasis on pollution prevention, gives consideration to the precautionary principle and requires special treatment of persistent and bioaccumulative substances. Substances that are shown to be both persistent and bioaccumulative, therefore, will be assessed using a more conservative approach than is used for other substances.

As a result of the publication of the PSL Assessment Reports for the CBzs, additional studies were designed and funded. Day *et al*. (1995) and Doe *et al*. (1995) reported data on the toxicity of 1,2-DCB, 1,4-DCB, TCBs and TeCBs to freshwater and marine benthic organisms. Additionally, concentrations of 1,2-DCB, 1,4-DCB, TCBs, TeCBs and QCB were determined in sediments near point sources (i.e., outfalls from sewage treatment plants [STPs] and textile manufacturing plants) in Atlantic Canada. Laboratory studies included toxicity testing to determine effects of exposure to sediments from point source locations (Rutherford *et al*., 1995). Concentrations of 1,2-DCB and 1,4-DCB were determined in sediment collected by the Ontario Ministry of the Environment near outfalls from chemical manufacturing plants and an STP on the St. Clair River, near Sarnia (DeLuca and Fox, 1995).

A literature search for new data on the CBz substances of interest was performed in 1995 and repeated in 1999. The National Pollutant Release Inventory (NPRI) and Accelerated Reduction/Elimination of Toxics databases supported by Environment Canada were also reviewed for CBz data.

Federal and Ontario government scientists were also requested to provide unpublished data relevant to the assessment of 1,2-DCB, 1,4-DCB, TCBs, TeCBs and QCB under Paragraph 11(a) of CEPA or Paragraph 64(a) of the revised CEPA, CEPA 1999.[1]

Recent data confirmed the previous conclusion, which found that environmental harm is not likely to result from the presence of 1,2-DCB, 1,4-DCB, TCBs, TeCBs or QCB in Canadian air and water. The focus of this report, therefore, is the determination of whether accumulations of the specific CBzs in aquatic sediments or soils would harm exposed benthic or soil-dwelling organisms.

2.0 ENTRY CHARACTERIZATION

2.1 Anthropogenic releases in Canada

There are no known natural sources of 1,2-DCB, 1,4-DCB, TCBs, TeCBs or QCB. 1,2-DCB and 1,4-DCB are the only CBzs under examination that are produced in Canada (Table 1). Based on reports from the mid-1990s, 1,4-DCB is used to the greatest extent in Canada (1000 tonnes), primarily as an air freshener/deodorizer (Kovrig, 1996). Survey results projected imports of TCBs to range from 40 to 45 tonnes during the mid-1990s (Camford Information Services, 1991). Imports of TeCBs and QCB into Canada were not anticipated based on survey results (Camford Information Services, 1991).

Both 1,2-DCB and 1,4-DCB releases were reported to the NPRI for 1994–1998. Releases of 1,2-DCB ranged from 0.4 to 0.5 tonnes, while 1,4-DCB releases ranged between 8.1 and 10.4 tonnes (NPRI, 1994, 1995, 1996, 1997, 1998). Releases to air were reported for both compounds. Disposal by incineration was reported to range between 8 and 23 tonnes for 1,2-DCB and between 0.4 and 0.5 tonnes for 1,4-DCB (NPRI, 1994, 1995, 1996, 1997, 1998). Total 1,4-DCB emissions were reported to be 55 tonnes by members of the Canadian Chemical Producers' Association in 1997, down from 116 tonnes in 1993 (Canadian Chemical Producers' Association, 1999). Releases of the other CBzs of interest in this report (TCBs, TeCBs and QCB) have not been reported to the NPRI.

CBzs enter Canadian surface waters and associated sediments primarily via effluents from industrial treatment plants and STPs. The major industrial sectors include chemical manufacturing and textile plants. CBzs have also been observed in effluents from pulp and paper mills (Government of Canada, 1993a, 1993b, 1993c, 1993d, 1993e). Effluents from iron and steel manufacturing contribute to loadings of the TCBs, TeCBs and QCB, while petroleum refinery effluents have been reported to contain TeCBs and QCB (Government of Canada, 1993c, 1993d, 1993e). Reductive dechlorination of the more highly chlorinated benzenes, particularly hexachlorobenzene, may lead to the accumulation of the lower chlorinated homologues (e.g., DCBs and TCBs) in buried sediments (Beurskens *et al.*, 1993a, 1993b).

The main reported source of CBzs to Canadian soils is accidental spillage of industrial chemicals, including dielectric fluids containing polychlorinated biphenyls (PCBs) (Government of Canada, 1993a, 1993b, 1993c, 1993d). Other possible sources include industrial emissions to

[1] The PSL 1 Assessment Report for the chlorobenzenes is available on the following websites: www.hc-sc.ca/hecs-sesc/exsd/psl1.htm or www.ec.gc.ca/substances/ese/eng/psap/PSL1_IIC.cfm.

the atmosphere (Ding *et al.*, 1992) and application of sewage sludge to agricultural soils (Webber and Nichols, 1995).

A few studies have been performed in which CBz concentrations have been reported in sewage sludge. In a study of sewage sludge samples collected from 12 municipalities across Canada, levels of 1,2-DCB and 1,4-DCB were reported (Table 2). Levels of TCBs were below detection limits in sludge from all municipalities. TeCBs and QCB were not included in this survey (Webber and Nichols, 1995). DCB concentrations observed in Canadian sludge samples were lower than concentrations reported in the United States during the 1980s and below levels currently reported in the United Kingdom (Table 2).

3.0 EXPOSURE CHARACTERIZATION

3.1 Environmental fate

3.1.1 Sediment

Under anaerobic laboratory conditions, dechlorination by both biotic and abiotic processes has been observed for all CBzs (Bosma *et al*., 1988; Peijnenburg *et al*., 1992; Beurskens *et al.*, 1993b, 1994; Yonezawa *et al.*, 1994). Reported dechlorination half-lives range from only a few days to over 1 year, depending upon the CBz studied and the nature of the sediment used. Mackay *et al*. (1992) estimated average half-lives in surface sediment of approximately 2 years for all of the CBzs considered in this report. CBzs entering the water column generally partition to particulate matter and accumulate in bottom sediments, based on results of fugacity modelling (Mackay *et al.*, 1992) and empirical studies (Oliver and Carey, 1986). CBzs have been shown to persist in sediments for long periods. Oliver and Nicol (1982, 1983) compared the relative proportions of different CBz congeners in surface and subsurface sediments and found little evidence of either microbial oxidation or anaerobic dechlorination of higher chlorinated benzene congeners in Lake Ontario sediments. CBzs have been detected in sediment cores dating back to the early 1900s (Eisenreich *et al*., 1989; Muir *et al*., 1995, 1996; Rawn *et al*., 2000a, 2000b).

Although a large fraction of the di- through pentachlorinated benzenes partition to organic matter, there will be some fraction present in sediment pore waters, either complexed as colloids with dissolved organic matter or as freely dissolved molecules (Di Toro *et al.*, 1991). The uncomplexed molecules may pass through cell membranes, entering organisms during exposure to sediment pore waters. Additionally, direct ingestion of organic carbon (OC) contaminated with CBzs may be an important route of exposure for some benthic organisms.

Desorption studies have suggested that irreversible adsorption occurs in some sediments, and, therefore, equilibrium is not always achieved. Irreversibility in binding of organic compounds is expected to increase with exposure time, although this theory has been questioned by some authors (Kan *et al*., 1994).

3.1.2 Soil

CBzs may enter surface soil as a result of spills, from sewage sludge additions and via atmospheric deposition from both local and distant industrial sources. Similar to observations in sediments, CBzs partition between particulate and liquid phases. Due to the hydrophobic nature of the di- through penta-CBzs, they are considered to be relatively immobile in soils,

particularly in soils with a high OC content. Volatilization and biodegradation are the main routes of loss for these compounds from soils. Mean half-lives in soil have been estimated to be approximately 8 months for 1,2-DCB, 1,4-DCB, TCBs and TeCBs and 2 years for QCB (Mackay *et al*., 1992).

Although the bioavailability of these compounds may be reduced in aged soils (Gas Research Institute, 1995), uptake by soil-dwelling organisms can also occur by exposure to freely dissolved forms in pore waters. Another route of exposure for soil-dwelling organisms is ingestion of soil organic matter. In plants, absorption of CBzs may occur via direct uptake by roots or through foliage after volatilization from the soil surface (Trapp *et al*., 1990; Scheunert *et al*., 1994; Wang and Jones, 1994).

3.1.3 Biota

Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) for CBzs have generally been reported on a whole-body basis. BCFs ranging between 270 and 560 were reported for 1,2-DCB in rainbow trout (*Oncorhynchus mykiss*) in laboratory studies (Government of Canada, 1993a). Reported BCFs for 1,4-DCB in rainbow trout ranged between 370 and 1400 (Government of Canada, 1993b). BCFs for TCBs were reported to be between 100 and 4000 in a variety of aquatic biota (Government of Canada, 1993c).

BAFs reported for TeCBs were between 1180 and 135 000 in fathead minnow (*Pimephales promelas*), rainbow trout, guppy (*Poecilia reticulata*) and earthworms (*Eisenia andrei*) (Government of Canada, 1993d). BAFs of 810 and 20 000 were reported for QCB in mussel (*Mytilis edulis*) and rainbow trout, respectively, but a much higher BAF for earthworms (*E. andrei*) (401 000) has also been reported (Government of Canada, 1993e). More recently, Burkhard *et al*. (1997) reported BAFs based on freely dissolved, lipid-normalized concentrations for TCBs, TeCBs and QCB in a number of species. When considered on a whole-body wet weight basis, the BAFs reported by Burkhard *et al*. (1997) were between 427 and 630, between 871 and 1905, and between 6310 and 12 883 for TCBs, TeCBs and QCB, respectively. Bioaccumulation of CBzs generally increases with degree of chlorination.

The estimated log octanol-water partition coefficient (log K_{ow}) for both 1,2-DCB and 1,4-DCB is 3.4. The log K_{ow} estimates for TCB, TeCBs and QCB are 3.85–4.30, 4.5 and 5.0, respectively (Mackay *et al*., 1992).

3.2 Environmental concentrations

3.2.1 Sediment near point sources

The CBzs, similar to other non-ionic hydrophobic compounds, partition into the organic matter in sediment. Additionally, the bioavailability of these compounds is inversely proportional to the OC content of the sediment. Therefore, CBz concentrations have been OC normalized in Table 3 using the relationship:

$$\text{OC-normalized concentration (mg/kg dw)} = \frac{C_{CBz}}{f_{oc}}$$

where C_{CBz} represents the CBz concentration in whole sediment (mg/kg dw) and f_{oc} represents the OC fraction in the sediment.

The highest reported CBz concentrations in Canadian sediment were observed near industrial sites on the St. Clair River at Sarnia, Ontario, during the 1980s (ΣDCBs: <MDL–31 µg/g dw, or <MDL–2070 µg/g OC) (Oliver and Pugsley, 1986). In general, the highest concentrations of the CBzs of interest were measured in samples collected near the Dow Chemical Canada 1st Street Sewer. Sampling stations were located upstream and downstream of chemical manufacturing sites. Fox *et al*. (1983) reported high CBz concentrations (maximum 1,4-DCB concentration = 1.3 µg/g dw, or 37 µg/g OC) in surficial sediment in Lake Ontario near the Niagara River mouth (Table 3).

More recently, 1,4-DCB was detected in sediment samples collected near municipal wastewater treatment plant effluents (<10–90 ng/g dw, or <0.1–16 µg/g OC) in Nova Scotia and New Brunswick (Rutherford *et al.*, 1995). In another recent study, elevated levels of 1,4-DCB (1.7 µg/g dw, or 40 µg/g OC) were reported in sediment near outfalls from municipal wastewater treatment plants near Victoria, British Columbia (EVS, 1992, 1996). The highest CBz concentrations in Canadian sediment remain in the St. Clair River, adjacent to organic chemical and petrochemical plants near Sarnia (DeLuca and Fox, 1995; Kauss, 1995). Median concentrations of the CBzs of interest in the most contaminated stretch of the river (1–2 km) fell by as much as an order of magnitude between 1984 and 1994 (Oliver and Pugsley, 1986; Bedard and Petro, 1992; Kauss, 1995). However, direct comparisons between the older sampling and more recent work are not possible due to differences in sampling locations and sample collection and analysis techniques.

No recent concentration data for CBzs in sediment from the Niagara River delta were identified. Results of ongoing monitoring of Niagara River water, however, indicate that concentrations of CBzs in river water and suspended sediments have decreased by as much as 10-fold since the early 1980s (Kuntz, 1993), similar to observations in sediments from the St. Clair River. It is, therefore, expected that current CBz concentrations in surface sediment in the Niagara River delta are lower than previously reported for this region (Table 3).

Although 1,4-DCB concentrations were elevated in sediment samples collected near the outfalls of primary STPs at Sarnia, Ontario (DeLuca and Fox, 1995; Kauss, 1995), Halifax, Nova Scotia (Rutherford *et al.*, 1995), and Victoria, British Columbia (EVS, 1992; Chapman *et al*., 1996), levels were below detection (approximately 0.01 µg/g dw, or 2.2 µg/g OC) near a secondary STP at Fredericton, New Brunswick, and a lagoon STP at Berwick, Nova Scotia (Rutherford *et al*., 1995). These results indicate that 1,4-DCB levels are not enriched in sediments near all the Canadian STPs (Rutherford *et al.*, 1995). The CBzs of interest were also below detection limits (approximately 0.01 µg/g dw, or 2.4 µg/g OC) in sediment collected near the outfalls from textile plants in Caraquet, New Brunswick, Bridgetown, Nova Scotia, and Magog, Quebec (Rutherford *et al.*, 1995).

3.2.2 Long-range transport

Some of the CBzs of interest (TeCBs and QCB) have been reported in lake sediments from both temperate regions and the Canadian Arctic (Eisenreich *et al*., 1989; Muir *et al*., 1995, 1996; Allen-Gil *et al*., 1997; Rawn *et al*., 2000a, 2000b). Movement of organic compounds to Arctic regions via long-range transport and deposition has been the focus of much study in recent

years. Muir *et al*. (1996) reported that maximum CBz (represented by Σ[QCB + hexachlorobenzene]) concentrations were observed in lake sediments dated to the late 1970s and 1980s, approximately 5–10 years later than maximum concentrations in Lake Ontario. These results are consistent with the cold condensation hypothesis, which explains the movement of organics to remote northern regions (Wania and Mackay, 1993). Allen-Gil *et al*. (1997) reported TeCBs (Σ[1,2,3,4-TeCB + 1,2,4,5-TeCB]) and QCB levels in surface slices of sediment cores collected in Arctic U.S. lakes (mean concentrations: 0.41 ng/g dw and 0.10 ng/g dw, respectively). Total TeCBs (Σ[1,2,3,4-TeCB + 1,2,4,5-TeCB]) concentrations detected in Yukon lake sediments ranged from below the MDL (<0.03 ng/g dw) to 0.54 ng/g dw, and QCB levels ranged from below detection levels (<0.03 ng/g dw) to 1.55 ng/g dw (Rawn *et al*., 2000b).

3.2.3 Soil

CBzs are expected to partition to solid organic matter (Kenaga and Goring, 1980), although the most bioavailable fraction exists in soil pore waters. The freely dissolved, uncomplexed fraction is inversely proportional to the OC content of the soil (van Gestel and Ma, 1988; Trapp *et al*., 1990; Hulzebos *et al*., 1993; CEU, 1995). Therefore, concentrations have been summarized on an OC-normalized basis (Table 4).

CBz concentrations in agricultural soils from 14 sites across Canada were generally below detection limits (approximately 0.05 µg/g dw, or 3.5 µg/g OC) (Webber, 1994). 1,4-DCB, the only CBz detected in the study, had a detection frequency of approximately 20%, and the maximum reported concentration was 0.14 µg/g dw (4.5 µg/g OC).

The CBzs of interest in this report (di- to pentachloro-) have not been measured in sludge-amended soils in Canada. 1,2-DCB and 1,4-DCB concentrations in sludge-amended soils can be estimated using the Ontario Ministry of Environment regulations (OMEE, 1994), in which 40 000 kg/ha was taken to be the maximum addition of sludge to soil (Webber and Nichols, 1995) and 2×10^6 kg/ha was taken to be the mass of soil in the plough layer. Mean concentrations of 1,2- and 1,4-DCB in Canadian sludge were observed to be 0.42 mg/kg dw and 0.87 mg/kg dw, respectively (Webber and Nichols, 1995). This indicates that soil concentrations following sludge treatment would be 0.008 µg/g dw (0.4 µg/g OC) and 0.017 µg/g dw (0.9 µg/g OC), respectively, assuming an OC content of 2%, based on the following relationship using 1,2-DCB as an example:

$$\text{soil concentration following sludge treatment} = \frac{0.42 \text{ mg/kg dw} \times 40\,000 \text{ kg}}{2 \times 10^6 \text{ kg}}$$

$$= 0.008 \text{ mg/kg dw soil (or µg/g dw soil)}$$

CBz contamination in Canadian soils as a result of atmospheric fallout from nearby industrial activity has not been studied. Elevated concentrations were, however, observed in soils downwind of a highly industrialized area near Niagara Falls, New York (Ding *et al.*, 1992) (Table 4). The Niagara Falls soils have been considered representative of "worst-case" exposure conditions for industrial areas in Canada for the TCBs, TeCBs and QCB.

4.0 EFFECTS CHARACTERIZATION

4.1 Benthic organisms

Effects of 1,2,4-TCB on benthic organisms were reported in two studies during the 1980s. A significant effect on marine macrobenthic community structures was observed in a number of taxa exposed to 1,2,4-TCB at nominal concentrations of 100 and 1000 µg/g dw in sediments (Tagatz *et al.*, 1985). Throughout the study, measured concentrations in sediments ranged between 2.1 and 97 µg/g dw and between 519 and 790 µg/g dw, respectively. Due to the extremely low (<0.02%) OC level in the sediment, conversion to OC-normalized results was not possible for these data (Di Toro *et al.*, 1991).

Clark *et al.* (1987) conducted 10-day bioassays with two marine species using sediment containing approximately 0.3–0.6% OC, spiked with 1,2,4-TCB. No lethality was observed in grass shrimp (*Palaemonetes pugio*) or amphioxus (*Branchiostoma caribaeum*) at nominal concentrations of 10 µg/g dw (approximately 2000 µg/g OC) and 75 µg/g dw (approximately 15 000 µg/g OC).

More recently, Day *et al.* (1995) reported chronic whole-sediment toxicity of 1,2-DCB, 1,4-DCB, 1,2,3-TCB and 1,2,4,5-TeCB to two species of freshwater benthic invertebrates, mayfly (*Hexagenia* spp.) and oligochaete worms (*Tubifex tubifex)*, in sediment systems under open static conditions over 21 and 28 days, respectively. Nominal concentrations of 0.5, 5, 50 and 500 µg/g dw were used for 1,2-DCB, 1,4-DCB and 1,2,3-TCB exposures, while 1,2,4,5-TeCB concentrations of 0.5, 5, 50 and 150 µg/g dw were used. Concentrations were measured at the beginning and termination of individual studies (Day *et al*., 1995). For these studies, a mixture of natural sediment, kaolin and fine silica sand, with an average OC content of 3.93% (3.38–4.45%), was used. Survival and biomass and survival and reproduction were taken to be the endpoints for *Hexagenia* and *T. tubifex* studies, respectively. Survival was not affected by exposure to CBzs in either species, although reduction in growth of *Hexagenia* spp. was observed (18–34%) in the 500 µg/g dw exposures with 1,4-DCB and 1,2,3-TCB and in the 150 µg/g dw exposure with 1,2,4,5-TeCB (Table 5). Reproduction of *T. tubifex* was impaired (64–72%) in the 500 µg/g dw exposure trials with 1,2-DCB, 1,4-DCB and 1,2,3-TCB (Table 5). Because effects on growth and reproduction were observed at only the highest concentration level of each exposure series tested (Table 5) — with the exception of 1,2-DCB and 1,2,4,5-TeCB for *Hexagenia* spp. and *Tubifex tubifex*, respectively, where no effect was observed following exposure to spiked sediments — estimates of traditional endpoint values (e.g., LC_{50}, EC_{50}, LOEC, etc.) were not possible.

Doe *et al*. (1995) reported acute toxicity of 1,2-DCB, 1,4-DCB, 1,2,3-TCB and 1,2,4,5-TeCB based on 10-day exposures of the infaunal amphipod *Rhepoxynius abronius* in marine sediments. The sediment used in this series was a mixture of two natural sediments, resulting in an OC content of 0.55% (Doe *et al.*, 1995). Nominal concentrations of 4, 20, 100 and 500 µg/g dw were used in the 1,2-DCB, 1,4-DCB and 1,2,3-TCB exposure studies. For 1,2,4,5-TeCB, nominal concentrations were 1.2, 6.0, 30 and 150 µg/g dw. Concentrations of each exposure system were measured at the beginning of each study, although measurements at the end of the study were restricted to the highest treatment level only (Doe *et al*., 1995). Mortality of *R. abronius* was significant at the 100 µg/g dw nominal exposure for 1,2-DCB and 1,2,3-TCB, while significant mortality was reported in the 500 µg 1,4-DCB/g dw and 30 µg 1,2,4,5-TeCB/g

dw nominal exposure systems (Table 6). Doe *et al*. (1995) reported LOEC and NOEC values on a ng/g dw basis for the DCBs, 1,2,3-TCB and 1,2,4,5-TeCB, which have been converted to OC-normalized values in Table 6.

The mode of action of the CBzs is considered non-specific or narcosis (van Wezel *et al*., 1996a, 1996b). Effect levels for individual CBzs are, therefore, expected to be approximately equal, for a given species, based on molar concentrations (McCarty *et al.*, 1992). Because Day *et al.* (1995) and Doe *et al.* (1995) did not conduct toxicity tests for QCB, estimates of its effect levels were made based on the results of the four CBzs tested, on a molar basis. For example, for 1,2,4,5-TeCB, which has a molecular weight of 215.9 g/mol, the LOEC (8.7 µg/g dw, or 1582 µg/g OC) reported by Doe *et al*. (1995) on a molar basis would be:

$$\text{LOEC} = \frac{1582\ \mu g/g\ OC}{215.9\ g/mol}$$

$$= 7.33\ \mu g \cdot mol/g^2$$

The molar LOEC for QCB, therefore, was estimated to be:

$$\text{LOEC} = 7.33\ \mu g \cdot mol/g^2 \times 250.3\ g/mol$$

$$= 1835\ \mu g/g\ OC$$

based on the TeCB result.

This calculation was repeated for 1,2-DCB, 1,4-DCB and 1,2,3-TCB, and the results for each congener were used to determine a range where effects would be expected due to QCB exposure, for each organism. The range of QCB concentrations over which the lowest effect level would be expected, based on individual congener calculations for *T. tubifex*, was 2750–9010 µg/g OC. The range of lowest QCB concentrations expected to cause effects in *Hexagenia* spp. was estimated to be between 400 and 9510 µg/g OC. LOEC values for *R. abronius* were estimated to range between 1840 and 10 410 µg/g OC. Calculations of LOEC values for *R. abronius* were based solely on initial concentrations.

Additional techniques may be used as part of a weight-of-evidence approach to determine the toxicity of organic compounds to benthic organisms. Di Toro *et al*. (1991) proposed a method for estimating toxicity based on the assumption that equilibrium exists between non-ionic compounds bound to sediment OC and those freely dissolved in pore waters. Concentrations of the freely dissolved compounds in pore waters are considered to be proportional to OC-normalized values in sediment, and, therefore, effects of dissolved compounds on pelagic organisms may be used as a surrogate for effects on benthic organisms exposed to contaminated sediments (Di Toro *et al*., 1991). Estimates of OC-normalized concentrations in sediment resulting in effects on freshwater and marine organisms were made using the equilibrium partitioning (EqP) method (Table 7). Concentrations were calculated using the relationship:

$$C_{sed}\ (\mu g/g\ OC) = \frac{C_{diss}\ (\mu g/L) \times K_{ow}\ (L/kg)}{1000}$$

where C_{sed} represents the OC-normalized concentration in sediment that is likely to cause an effect in benthic biota, K_{ow} is the octanol-water partition coefficient, C_{diss} represents the corresponding concentration in the freely dissolved state and 1000 is the factor used to convert µg/kg OC to µg/g OC.

By using the lowest effect concentrations (e.g., LC_{50} and EC_{50} [16–28 days] data) for pelagic organisms reported in the literature, benthic effects estimates were determined using the EqP method (Table 7). Toxicity data for all the CBzs of interest were available in the literature, although a larger data set exists for freshwater organisms than for marine organisms (Government of Canada, 1993f, 1993g, 1993h, 1993i; Environment Canada, 1994).

4.2 Soil-dwelling biota

CBzs have been shown to affect soil microbial populations. Marinucci and Bartha (1979) reported a 24-hour EC_{50} (respiration) for soil microorganisms at approximately 50 µg 1,2,4-TCB/g dw based on nominal concentrations. In another study, microbial respiration was depressed by addition of 1000 µg 1,2-DCB/g dw (67 114 µg/g OC) initially, although no effect on respiration was observed by the final day of the 6-day experiment (Walton *et al*., 1989). Fourteen-day LC_{50} values reported for several earthworm species exposed to 1,4-DCB, 1,2,3-TCB and 1,2,4-TCB ranged from 115 to 563 µg/g dw soil (2592 to 6500 µg/g OC) (Table 8) (Neuhauser *et al*., 1986; van Gestel and Ma, 1990; van Gestel *et al.*, 1991).

Hulzebos *et al.* (1993) reported 7- to 14-day EC_{50} values (growth) for lettuce (*Lactuca sativa*) exposed to DCBs, TCBs and TeCBs. Measurements using 1,2-DCB were not performed in the study, and no similar data were found in the literature for 1,2-DCB; therefore, the effect concentration for 1,4-DCB was taken to represent that for 1,2-DCB (Table 8). Lettuce was found to be more sensitive to 1,2,3-TCB (5.8 µg/g dw) and 1,2,4,5-TeCB (4.2 µg/g dw) than 1,4-DCB, for which the EC_{50} was estimated to be 213 µg/g dw (19 722 µg/g OC). EC_{50} values for individual TeCBs and TCB isomers varied by one and two orders of magnitude, respectively (Table 8).

5.0 ASSESSMENT OF "TOXIC" UNDER CEPA 1999

5.1 CEPA 64(a): Environment

The environmental risk assessment of a PSL substance is based on the procedures outlined in Environment Canada (1997). Analysis of exposure pathways and subsequent identification of sensitive receptors are used to select environmental assessment endpoints (e.g., adverse reproductive effects on sensitive fish species in a community). For each endpoint, a conservative Estimated Exposure Value (EEV) is selected and an Estimated No-Effects Value (ENEV) is determined by dividing a Critical Toxicity Value (CTV) by an application factor. A conservative (or hyperconservative) quotient (EEV/ENEV) is calculated for each of the assessment endpoints in order to determine whether there is potential for ecological harm in Canada. If these quotients are less than one, it can be concluded that the substance poses no significant risk to the environment, and the risk assessment is completed. If, however, the quotient is greater than one for a particular assessment endpoint, then the risk assessment for that endpoint proceeds to an analysis where more realistic assumptions are used and the probability and magnitude of effects are considered. This latter approach involves a more thorough consideration of sources of

variability and uncertainty in the risk analysis.

There are, however, special concerns about persistent and bioaccumulative substances. Persistent substances can remain in the environment for long periods of time, increasing the probability and the duration of potential exposure. Releases of extremely low concentrations of persistent and bioaccumulative substances may lead to accumulations in organisms which can eventually cause adverse effects. Substances that, because of their persistence are subject to long-range transport, are of particular concern because they can result in low-level, widespread contamination. Remote and cold regions, such as the Canadian Arctic, can act as a sink for these compounds. Bioaccumulative substances have the potential to biomagnify through the food chain. Although current science is unable to accurately predict the cumulative effects of exposure to low levels of persistent and bioaccumulative substances on the environment, the potential exists for extensive, irreversible impacts. Assessments of such substances must be performed using a proactive, preventative approach to ensure that widespread cumulative effects do not occur. Therefore, environmental assessments of persistent and bioaccumulative substances require a more conservative approach than that used for other substances, even in situations where a substance is released in a small area and effects appear to be localized.

Conservative methodologies are used for both the exposure and effects characterizations for persistent and bioaccumulative substances. If exposure monitoring data are available, the maximum reported/estimated field concentration is used as the EEV. An additional application factor of 10 was to be used in the effects characterization to calculate the ENEV for persistent and bioaccumulative substances.

5.2 Persistence and bioaccumulation criteria as defined in the Persistence and Bioaccumulation Regulations of CEPA 1999

The persistence criteria as defined under the Persistence and Bioaccumulation Regulations of CEPA 1999 (Government of Canada, 2000) are available in Appendix 1.

5.2.1 Persistence

5.2.1.1 Sediment

Mackay *et al*. (1992) estimated average half-lives in surface sediment of approximately 2 years for all of the CBzs considered in this report. Additionally, the tetra- and pentachlorinated congeners have been identified in sediments from lakes in both temperate regions and northern Canadian environments (Eisenreich *et al*., 1989; Muir *et al*., 1995; Rawn *et al*., 2000b). The detection of the TeCBs and QCB in northern lake sediments in the absence of nearby sources indicates that these residues are a result of long-range transport, and these CBzs, therefore, meet the criteria for persistence in air. CBzs have been reported in sediments dated to the early 1900s, although maximum concentrations were reported to occur between the 1970s and 1980s. These data are consistent with half-life estimates exceeding 1 year in a variety of sediments.

5.2.1.2 Soil

Mean half-lives in soil have been estimated by Mackay *et al*. (1992) to be approximately 8 months for 1,2-DCB, 1,4-DCB, TCBs and TeCBs and 2 years for QCB. All of the CBzs considered in this report are, therefore, likely to persist in soils under aerobic conditions

(Government of Canada, 1993a, 1993b, 1993c, 1993d, 1993e).

5.2.1.3 Air

TeCBs and QCB have been identified in sediments from lakes in both temperate regions and northern Canadian environments (Eisenreich *et al*., 1989; Muir *et al*., 1995; Rawn *et al*., 2000b). The detection of the TeCBs and QCB in northern lake sediments in the absence of nearby sources indicates that these residues are a result of long-range atmospheric transport, and these CBzs, therefore, meet the criteria for persistence in air.

On the basis of the available information, it can be concluded that all of the CBzs of interest are persistent in soil and sediment according to the criteria stipulated in the Persistence and Bioaccumulation Regulations of CEPA 1999, and TeCBs and QCB are also persistent in air.

5.2.2 Bioaccumulation

BCFs reported on a whole-body basis for 1,2-DCB in rainbow trout (*Oncorhynchus mykiss*) ranged between 270 and 560 in laboratory studies (Government of Canada, 1993a). BCFs for 1,4-DCB in rainbow trout ranged between 370 and 1400 (Government of Canada, 1993b), and BCFs between 100 and 4000 have been reported for TCBs. Reported BAFs for TeCBs range between 1180 and 135 000 (Government of Canada, 1993c, 1993d). BAFs of 810 and 20 000 were reported for QCB in mussel (*Mytilis edulis*) and rainbow trout, respectively, although the BAF determined for earthworms (*Eisenia andrei*) was much higher (401 000) (Government of Canada, 1993e). Both 1,2-DCB and 1,4-DCB have an estimated log K_{ow} of 3.4. The log K_{ow} estimates for TCBs, TeCBs and QCB were 3.85–4.30, 4.5 and 5.0, respectively (Mackay *et al*., 1992).

On the basis of the available information, it is concluded that the TeCBs and QCB are bioaccumulative substances according to the criteria stipulated in the Persistence and Bioaccumulation Regulations of CEPA 1999.

5.3 Assessment endpoints

The CBzs under investigation in this report (1,2-DCB, 1,4-DCB, TCBs, TeCBs and QCB) were assessed during the PSL1. At that time, it was determined that concentrations of these compounds in Canadian air and surface waters were not likely to cause adverse effects on aquatic biota or wildlife. The assessment endpoints of interest in this report, therefore, are adverse effects on populations of benthic and soil-dwelling species.

5.4 Environmental risk characterization

5.4.1 Sediment

Effects on growth and reproduction were observed in two freshwater species, *Hexagenia* spp. and *Tubifex tubifex*, respectively, following exposure to sediment spiked with 1,2-DCB, 1,4-DCB, 1,2,3-TCB and 1,2,4,5-TeCB (Day *et al*., 1995). The TCB and TeCB isomers studied were assumed to represent all members of each homologue group. Effects on growth and reproduction were observed at the highest concentration level of each exposure series tested (Table 5), with

the exception of 1,2-DCB and 1,2,4,5-TeCB for *Hexagenia* spp. and *Tubifex tubifex*, respectively. In these studies, no effect was observed following exposure to spiked sediments. Based on these data limitations, estimates of traditional endpoint values (e.g., LC_{50}, EC_{50}, LOEC, etc.) were not possible. For QCB, where no measurements were made, effect concentrations were extrapolated using the measured molar effect concentrations determined for each of the other CBzs. The EqP estimates for benthic organisms were within the range reported for *Hexagenia* spp. and *Tubifex tubifex* by Day *et al*. (1995) for 1,4-DCB and 1,2,4,5-TeCB (Table 5). Measured effects concentrations for 1,2-DCB and 1,2,3-TCB were higher than the EqP estimates. Based on these results, the EqP results were taken to be the conservative CTV_{SED} for 1,2-DCB (1382 µg/g OC), 1,4-DCB (1005 µg/g OC), TCBs (1637 µg/g OC), TeCBs (2846 µg/g OC) and QCB (2500 µg/g OC) for freshwater benthos (Table 9).

Doe *et al*. (1995) reported LOECs for marine organisms exposed to sediment spiked with 1,2-DCB, 1,4-DCB, 1,2,3-TCB and 1,2,4,5-TeCB. The LOEC for QCB was estimated by extrapolating the molar-based values measured for the DCBs, 1,2,3-TCB and 1,2,4,5-TeCB. EqP values were also determined for marine benthic organisms, and comparisons between measured and calculated values were made. The more conservative estimate was taken to be the CTV for marine benthic organisms. The measured LOECs reported by Doe *et al*. (1995) for marine benthos were taken to be the CTV_{SED}s for 1,2-DCB (1127 µg/g OC) and TeCBs (1582 µg/g OC). The median LOEC for QCB, based on the molar estimates reported by Doe *et al*. (1995), was taken to be the CTV_{SED} (3080 µg/g OC) (Table 9). The EqP value was used as the CTV_{SED} for 1,4-DCB (4999 µg/g OC) and TCBs (504 µg/g OC) (Table 9) in marine systems.

5.4.1.1 Determination of Estimated No-Effects Values ($ENEV_{SED}$s)

The CTV_{SED}s determined for each of the CBzs under consideration in this report, in both freshwater and marine sediments, were divided by an application factor, resulting in an $ENEV_{SED}$ to convert chronic lowest-reported-effect levels to no-effect concentrations and to account for extrapolation from laboratory to field conditions and inter- and intraspecies variability (Environment Canada, 1997) (Table 10). An acute to chronic ratio (ACR) of 3:1 (Carlson and Kosian, 1987) was applied to the marine CTV_{SED} for 1,2-DCB, 1,4-DCB, TeCBs and QCB because these CTV_{SED}s were based on acute studies. Although the freshwater CTV_{SED} for TCB was based on an acute endpoint (LC_{90}) (Lay *et al*., 1985), the test was performed over a 21-day period using daphnids; therefore, it may be considered a chronic study, and an ACR was thus not deemed necessary. An additional application factor of 10 was used for TeCBs and QCB since these have been shown to be persistent and bioaccumulative compounds according to the Persistence and Bioaccumulation Regulations of CEPA 1999 (Government of Canada, 2000) and since there are special concerns about the long-term cumulative effects of these types of substances. Freshwater $ENEV_{SED}$s ranged from 25 µg/g OC for QCB to 164 µg/g OC for TCBs. Marine $ENEV_{SED}$s ranged from 5 µg/g OC for TeCBs to 167 µg/g OC for 1,4-DCB.

5.4.1.2 Determination of risk quotients for sediments

The maximum reported CBz concentrations observed in Canadian sediments were from the St. Clair River (Table 3). These levels were taken to represent the EEVs (EEV_{SED}s) for freshwater benthic organisms because they are suitable representatives of conservative estimates for freshwater Canadian sediments. Risk quotients were calculated for each CBz of interest in this report using the following relationship, with 1,2-DCB as an example:

$$\text{Quotient} = \frac{\text{EEV}}{\text{ENEV}}$$

$$= \frac{52\ \mu g/g\ OC}{138\ \mu g/g\ OC}$$

$$= 0.4$$

1,2-DCB was found to have a risk quotient less than 1 (Table 11), indicating that 1,2-DCB concentrations are below a level for concern in Canadian freshwater sediments. Risk quotients of greater than 1 were found for 1,4-DCB in approximately 25% of the samples from St. Clair River, while risk quotients of greater than 1 for TCBs were found in 18% of the St. Clair River samples. Risk quotients for TeCBs and QCB exceeded a value of 1 in 28% (11 of 39) and 23% (9 of 39) of samples collected from the St. Clair River, respectively. In general, the highest risk quotients were determined for sediment samples collected within 0.5 km of the Dow Chemical Canada 1st Street Sewer.

Based on the results of the risk analysis for freshwater benthic organisms using conservative EEV data, 1,2-DCB is present in Canadian sediments at concentrations not expected to result in effects on freshwater benthic organisms. 1,4-DCB, TCBs, TeCBs and QCB are present at concentrations in Canadian sediments such that effects on freshwater benthic organisms are possible. The very high concentrations used as freshwater EEV_{SED}s have been reported at only one site in Canada, the St. Clair River, which indicates that these concentrations do not represent the majority of Canadian sediments.

The lower chlorinated CBzs (e.g., 1,2-DCB, 1,4-DCB and TCBs) have not been reported in sediments from remote areas and do not meet the criteria for both persistence and bioaccumulation in the Persistence and Bioaccumulation Regulations of CEPA 1999 (Government of Canada, 2000). A less conservative approach to determining EEV_{SED}s for 1,4-DCB and TCBs in freshwater sediments was, therefore, employed, which takes into account the distribution of concentrations in Canada. Examination of data in Table 3, which summarizes the highest concentrations of 1,4-DCB and TCBs reported in Canadian sediment,[2] indicates that maximum concentrations in freshwater sediment from other locations in Canada are consistently below ENEVs (i.e., risk quotients <1.0). Furthermore, concentrations of 1,4-DCB and TCBs are less than the ENEVs in approximately 75% of the samples collected from the most highly contaminated 2-km stretch of the St. Clair River. For example, risk quotients calculated using median concentrations for 1,4-DCB and TCBs for this 2-km stretch are 0.4 and 0.5, respectively. This indicates that, in the vast majority of cases, the presence of 1,4-DCB and TCBs in Canadian freshwater sediments will not likely result in adverse effects on freshwater benthic organisms.

The higher chlorinated CBzs, TeCBs and QCB, however, have been reported in freshwater sediments from northern regions of Canada, indicating that they are subject to long-range transport and deposition. TeCBs and QCB also meet the persistence and bioaccumulation requirements of the Persistence and Bioaccumulation Regulations of CEPA 1999 (Government of Canada, 2000). These factors necessitate the use of a conservative approach in the assessment of TeCBs and QCB.

[2] Additional data on concentrations in sediment from less contaminated sites elsewhere in Canada are presented in Government of Canada (1993a, 1993b, 1993c, 1993d, 1993e).

Risk quotients for all CBzs of interest in marine systems were less than 1, and, therefore, effects on marine benthic organisms would not be anticipated based on current CBz concentrations in marine sediments.

5.4.2 Soil

Limited effects data for soil-dwelling organisms exist, and no new data were produced during this review of the CBzs. The lowest concentrations causing an effect were, therefore, taken to be the CTV_{SOIL} estimates for each CBz under examination in this report (Table 12).

5.4.2.1 Determination of Estimated No-Effects Values ($ENEV_{SOIL}$s)

The CTV_{SOIL}s determined for 1,2-DCB, 1,4-DCB, TCBs, TeCBs and QCB in soils were divided by an application factor of 10 to convert chronic lowest-reported-effect levels to no-effect concentrations and to account for extrapolation from laboratory to field conditions and inter- and intraspecies variability (Environment Canada, 1997). An additional factor of 3 was used for all CBzs to account for the limited data on effects on terrestrial organisms. For the TeCBs and QCB, an additional application factor of 10 was used because these compounds are persistent and bioaccumulative. The resulting $ENEV_{SOIL}$s range from 0.6 µg/g OC for 1,2,4,5-TeCB to 157 µg/g OC for 1,2- and 1,4-DCB (Table 12).

5.4.2.2 Determination of risk quotients for soils

The maximum 1,2-DCB and 1,4-DCB concentrations estimated for Canadian sludge-amended soil, based on sludge concentrations reported in Webber and Nichols (1995), were taken to be the EEV for Canadian soil. Individual isomer concentrations reported by Ding *et al*. (1992) (Table 4) were taken to be the EEV_{SOIL}s for TCBs and TeCBs. This enabled the calculation of $ENEV_{SOIL}$ values for individual isomers (Table 12). Risk quotients, therefore, were calculated using EEV_{SOIL} and $ENEV_{SOIL}$ determinations for the individual isomers where data were available (Table 13).

The concentrations used to calculate risk quotients for TCBs, TeCBs and QCB are representative of a highly industrialized area in the United States and, therefore, are expected to overestimate the majority of Canadian soil concentrations. These data were selected to represent worst-case conditions that may be observed near highly industrialized areas in Canada. The risk quotients for all CBzs under consideration were below 1, despite these extreme conditions. This indicates that CBz concentrations would not result in effects on Canadian soil-dwelling organisms.

5.5 Sources of uncertainty

During the freshwater sediment exposure studies with 1,2-DCB, 1,4-DCB, TCBs and TeCBs, effects were observed at the highest exposure level only; therefore, the EqP method was used as an additional line of evidence to estimate effect concentrations for freshwater benthic organisms. Effects on benthic organisms as a result of exposure to QCB in sediment, in both freshwater and marine systems, were not reported; therefore, QCB effect levels were estimated by relating effect concentrations of all the other CBzs tested to that of QCB, on a molar basis.

There are a number of sources of uncertainty in this environmental risk assessment. Soil concentration data for the Canadian environment were limited to one study in which highly industrialized areas were not emphasized. Representative data, therefore, were taken from a highly industrialized region in the United States, where such data were available. Additionally, there are limited data in the literature for effects of CBzs on soil-dwelling organisms. An additional application factor was applied to the effects data to account for the small data set in the literature for effects on soil-dwelling organisms.

Although current scientific methods are unable to accurately predict the effects of persistent and bioaccumulative substances on the environment, these substances have been dealt with in a conservative manner in this assessment. Persistent substances can remain in the environment for long periods of time, thereby increasing the probability and duration of exposure relative to compounds that do not persist in the environment. Additionally, substances that are subject to long-range transport are of particular concern, because remote and/or cold regions, such as the Canadian Arctic, can act as a sink for such contaminants. Bioaccumulative substances have the potential to biomagnify through the food chain. Even releases of extremely low concentrations of persistent and bioaccumulative substances can lead to accumulations in organisms having the potential – either alone or in combination with other similar substances - to cause adverse effects on organisms that are continually exposed to them over long periods; therefore, an additional application factor of 10 was applied to the TeCBs and QCB, which are persistent and bioaccumulative substances.

Non-polar halogenated organic compounds occur together in sediments near industrial effluents (Bedard and Petro, 1997). Narcosis is the mode of action of many of these compounds, including CBzs. As a result, a cumulative effect on exposed organisms would be anticipated (McCarty *et al*., 1992). Toxicity studies using St. Clair River sediments confirmed that exposure to multiple narcotic substances, including QCB, was correlated with increased lethality of mayfly (*Hexagenia limbata*) and midge (*Chironomus tentans*) (Bedard and Petro, 1997). Sediments near the Dow Chemical sewer outfall, where multiple non-polar chlorinated organic compounds were detected, are characterized by low abundance and poor benthic invertebrate diversity (Bedard and Petro, 1997).

Losses of the volatile compounds, such as TCBs, were observed in toxicity studies relative to field samples (Bedard and Petro, 1997), indicating that many toxicity studies may result in an underestimation of toxicity.

$ENEV_{SED}$s determined in this assessment were compared with hazard-based assessments and effect threshold studies. Quantitative structure–activity relationships and EqP models were used by van Leeuwen *et al.* (1992) to estimate concentrations of CBzs that would not be expected to affect 95% of the species in benthic communities (marine or freshwater). These concentrations, known as HC_5s because they are expected to be hazardous concentrations for 5% of the exposed species, were estimated to be approximately 107 µg/g OC for both 1,2- and 1,4-DCB and 115 µg/g OC for TCBs. These values are within an order of magnitude of the freshwater and marine $ENEV_{SED}$s developed in this analysis. The HC_5 for TCBs (115 µg/g OC) compares extremely well with the $ENEV_{SED}$s developed for TCBs in the present assessment (164 µg/g OC [freshwater] and 50 µg/g OC [marine]) (Table 10). The HC_5s estimated for TeCBs and QCB (119 µg/g OC and 120 µg/g OC, respectively), however, were 1–2 orders of magnitude higher than the freshwater and marine $ENEV_{SED}$s determined in this analysis (Table 10). The lower $ENEV_{SED}$ values for the TeCBs and QCB determined in this assessment are a result of the

conservative approach taken with persistent and bioaccumulative substances. Using another approach, marine Apparent Effect Thresholds (AETs) were developed in the Puget Sound area of Washington State, using data from paired sediment chemistry–effects measurements performed with field sediment samples (Barrick *et al.*, 1988). AET estimates for 1,2-DCB, 1,4-DCB and TCBs (2 µg/g OC, 16 µg/g OC and 3 µg/g OC, respectively) were lower by an order of magnitude or more than marine $ENEV_{SED}$s developed in this assessment. The AET method has, however, been criticized because the results may be strongly influenced by the presence of unmeasured contaminants (Chapman, 1989).

5.6 Conclusions

Concentrations of 1,2-DCB, 1,4-DCB, TCBs, TeCBs and QCB in Canadian soil are unlikely to be causing harm to populations of soil-dwelling organisms. However, it is possible that concentrations of 1,4-DCB, TCBs, TeCBs and QCB in sediment from the St. Clair River near Sarnia may be harming benthic organisms.

Of the CBzs under consideration, only TeCBs and QCB meet the criteria for both persistence and bioaccumulation specified in the Persistence and Bioaccumulation Regulations of CEPA 1999 (Government of Canada, 2000). There are special concerns about persistent and bioaccumulative substances. Persistent substances can remain in the environment for long periods of time, increasing the probability and the duration of exposure. In addition persistent substances are subject to long-range transport, which results in low-level, widespread contamination Bioaccumulative substances have the potential to biomagnify, and consequently releases of extremely low concentrations of persistent and bioaccumulative substances may - either alone or in combination with other similar substances - cause severe adverse effects.

CEPA 64(a): Based on available data, it is concluded that 1,2-dichlorobenzene, 1,4-dichlorobenzene and the trichlorobenzenes are not entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity. Therefore 1,2-dichlorobenzene, 1,4-dichlorobenzene and the trichlorobenzenes are not considered "toxic" as defined under Paragraph 64(a) of CEPA 1999.

Based on available data, tetrachlorobenzenes and pentachlorobenzene are entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity and that the tetrachlorobenzenes and pentachlorobenzene are considered "toxic," as defined under Paragraph 64(a) of CEPA 1999.

6.0 CONSIDERATIONS FOR FOLLOW-UP

It is recommended that both TeCBs and QCB be added to the List of Toxic Substances (Schedule I) of CEPA 1999.

QCB and TeCBs are persistent, bioaccumulative, predominantly anthropogenic and are considered "toxic" under Paragraph 64(a) of CEPA 1999, and as such, meet the criteria for Track 1 substances under the Toxic Substances Management Policy. Therefore QCB and TeCB should be subject to virtual elimination of releases to the environment. Since there is currently no commercial demand for QCB and TeCBs in Canada, options to prevent their reintroduction into the Canadian market should be explored.

7.0 REFERENCES

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Table 1. Summary of information on production and uses of CBzs in Canada[1]

CBz	Produced in Canada	Primary applications
1,2-DCB	yes	Industrial cleaning solvents
1,4-DCB	yes	Air fresheners/deodorizers Moth and bird repellents
TCBs	no	Solvents in textile industry Chemical manufacturing Transformer maintenance
TeCBs	no	Transformer maintenance
QCB	no	Laboratory reagent

[1] Based on data reported by Camford Information Services (1991); data applicable to 1995.

Table 2. Concentration of CBzs in sewage sludge

Country	Reference	Median concentration (µg/kg dw)				
		1,2-DCB	1,4-DCB	ΣTCBs	ΣTeCBs	QCB
Canada	Webber and Nichols (1995)	<MDL[1] – 451[2]	1–810[2]	ND[3]	NA[4]	NA[4]
United States	Jacobs *et al*. (1987)	6455	20205	4045	ND[3]	Not reported
United Kingdom	Rogers *et al*. (1989)	7900	9800	780	80	<MDL[1]
United Kingdom	Wang and Jones (1994)	2310	1120	558	67	47

[1] Below method detection limit.
[2] Range of median values was determined for each of 12 sludge treatment plants.
[3] Not detected.
[4] Not analysed.
[5] Data reported as means rather than medians.

Table 3. Recent OC-normalized CBz concentrations, reported as median values, in Canadian sediments near point sources

	Median concentration (range) (µg/g)					Year collected	Reference
	1,2-DCB	**1,4-DCB**	**ΣTCBs**	**ΣTeCBs**	QCB		
Industrial, particularly chemical manufacturing							
St. Clair River near Sarnia, Ontario[1]	1.5 (0.2–52)	37 (2–522)	25 (1–539)	3.5 (0.1–320)	12 (0.3–601)	1994	DeLuca and Fox (1995); Kauss (1995)
Niagara River delta, Lake Ontario[2]	0.64 (0.51–1.5)	5.2 (<2.2–37)	3.4 (2.5–9.8)	2.9 (2.0–9.1)	1.1 (0.7–3.4)	1981	Fox *et al.* (1983)
Textile mills							
Atlantic Canada (3 sites)[1]	<2.4 (<2.4)	<2.4 (<2.4)	<2.4 (<2.4)	<2.4 (<2.4)	<2.4 (<2.4)	1994	Rutherford *et al.* (1995)
STPs							
Victoria, B.C.[1]	0.06 (0.01–0.30)	1.0 (0.1–40)	0.02 (0.01–0.3)	–	–	1991	EVS (1992)
Sarnia, Ontario[1]	0.34 (0.13–0.83)	2.0 (0.40–7.5)	2.0 (0.20–4.9)	0.09 (0.07–0.42)	0.09 (0.07–0.42)	1994	Kauss (1995)
Halifax, Nova Scotia[1]	<2.2 (<2.2)	0.4 (<0.1–16)	<2.2 (<2.2)	<2.2 (<2.2)	<2.2 (<2.2)	1994	Rutherford *et al.* (1995)
Other Atlantic sites, 1994[3]	<2.2 (<2.2)	<2.2 (<2.2)	<2.2 (<2.2)	<2.2 (<2.2)	<2.2 (<2.2)	1994	Rutherford *et al.* (1995)

[1] OC content ranged between 0.2% and 10.1%.
[2] OC content assumed to be 3.5%, based on analyses of delta samples (Mudroch, 1983).
[3] Fredericton, New Brunswick, and Berwick, Nova Scotia.

Table 4. Median OC-normalized CBz concentrations in soils

	Median concentration (range) (µg/g)								**Year collected**	**Reference**
	1,2-DCB	**1,4-DCB**	**1,3,5-TCB**	**1,2,4-TCB**	**1,2,3-TCB**	**1,2,3,5-/1,2,4,5-TeCB**	**1,2,3,4-TeCB**	**QCB**		
Near agricultural source (Canada)[1]	<3.5 (<3.5)	<3.5 (<3.5–4.5)	Not measured	<3.5 (<3.5)	Not measured	Not measured	Not measured	Not measured	early 1990s	Webber (1994)
Near industrial source (Niagara Falls, NY)[2]	Not measured	Not measured	Not measured	0.127 (0.060–0.255)	0.027 (0.012–0.050)	0.231 (0.120–0.400)	0.156 (0.065–0.325)	0.052 (0.024–0.085)	late 1980s	Ding *et al*. (1992)

[1] OC-normalized (OC content ranged between 0.1% and 3.8%).
[2] Normalized assuming 2% OC content.

Table 5. Percentage of freshwater test populations (*Hexagenia* spp. and *Tubifex tubifex*) affected by CBz exposure (µg/g OC normalized[1]) after 21-day and 28-day exposures, respectively (Day *et al.*, 1995)

CBz	***Hexagenia* spp.**				***Tubifex tubifex***			
	Reduction in growth observed (% of affected organisms)[2]	**Concentration**			**Reduction in number of young produced (% of affected organisms)[2]**	**Concentration**		
		Nominal (µg/g dw)	**Initial (µg/g OC)**	**Final (µg/g OC)**		**Nominal (µg/g dw)**	**Initial (µg/g OC)**	**Final (µg/g OC)**
1,2-DCB[3]	none	500	3789	218	67	500	4448	1871
1,4-DCB	25	500	3677	234	64	500	3187	1573
1,2,3-TCB	34	500	6845	1444	72	500	6556	5947
1,2,4,5-TeCB[4]	18	150	3128	2012	none	150	3981	3266

[1] % OC = 3.93% ± 0.56%.

[2] Statistical significance ($P < 0.05$) of effects, relative to solvent controls, demonstrated using Dunnett's test.

[3] No effect on growth of *Hexagenia* spp. was observed at the highest exposure concentration of 1,2-DCB, initial = 3789 µg/g OC, final = 218 µg/g OC.

[4] No effect on growth of *T. tubifex* was observed at the highest exposure concentration of 1,2,4,5-TeCB, initial = 3981 µg/g OC, final = 3266 µg/g OC.

Table 6. Lowest concentrations of CBzs causing effects on the marine amphipod *Rhepoxynius abronius* (Doe *et al.*, 1995)

CBz	**Observed % mortality[1]**	**Concentration**			**NOEC[3] (µg/g OC[2])**	**LOEC[3] (µg/g OC[2])**
		Nominal (µg/g dw)	**Initial (µg/g OC[2])**	**Final (µg/g OC[2])**		
1,2-DCB	23	100	1127	Not measured	289	1127
1,4-DCB	31	500	6121	9273	1345	6121
1,2,3-TCB	60	100	3455	Not measured	898	3455
1,2,4,5-TeCB	25	30	1582	Not measured	254	1582

[1] The lowest exposure concentration associated with mortality that is significantly different from acetone controls at 95% confidence level**.**

[2] % OC = 0.55%.

[3] NOEC = No-Observed-Effect Concentration; LOEC = Lowest-Observed-Effect Concentration.

Table 7. Lowest effect concentration estimates in sediment (µg/g OC) based on effects data for water column organisms, calculated using the EqP method

CBz	K_{ow}[1]	Freshwater				Marine			
		Endpoint	**Dissolved concentration (µg/L)**	**Reference**	**Estimated C_{sed} (µg/g OC)**	**Endpoint**	**Dissolved concentration (µg/L)**	**Reference**	**Estimated C_{sed} (µg/g OC)**
1,2-DCB	2512	14-day EC_{50} reproduction (*Daphnia*)	550	Calamari *et al*. (1983)	1382	96-hour LC_{50}[2] (mysid shrimp)	1970	U.S. EPA (1980a)	4949
1,4-DCB	2512	28-day LOEC reproduction (*Daphnia*)	400	Calamari *et al*. (1982)	1005	96-hour LC_{50}[2] (mysid shrimp)	1990	U.S. EPA (1980a)	4999
TCBs	12 589	21-day LC_{90} (*Daphnia*)	130	Lay *et al.* (1985)	1637	reduced colonization of sediment (molluscs)	40	Tagatz *et al.* (1985)	504
TeCBs	31 623	16-day EC_{50} reproduction (*Daphnia*)	90	DeWolf *et al.* (1988)	2846	96-hour LC_{50}[2] (mysid shrimp)	340	U.S. EPA (1980b)	10 752
QCB	100 000	16-day EC_{50}[2] reproduction (*Daphnia*)	25	Hermens *et al.* (1984)	2500	96-hour LC_{50}[2] (mysid shrimp)	160	US EPA (1980b)	16 000

[1] Mackay *et al.* (1992).
[2] Nominal concentration.

Table 8. Lowest effect concentrations (µg/g OC) for lettuce and earthworms

CBz	Species	Endpoint	Concentration (µg/g OC)	Source
1,2-DCB	–	no data	4712[2]	Assumed equal to 1,4-DCB
1,4-DCB	earthworm (*E. andrei*)	14-day LC_{50}	4712[2]	van Gestel *et al.* (1991)
1,2,3-TCB	lettuce (*Lactuca sativa*)	14-day EC_{50}[1] (growth)	119[3]	Hulzebos *et al.* (1993)
1,2,4-TCB	earthworm (*E. eugeniae*)	14-day LC_{50}[1]	2592[2]	Neuhauser *et al.* (1986)
1,3,5-TCB	lettuce	7-day EC_{50}[1] (growth)	10 648[4]	Hulzebos *et al.* (1993)
1,2,3,4-TeCB	lettuce	14-day EC_{50}[1] (growth)	2963[4]	Hulzebos *et al.* (1993)
1,2,4,5-TeCB	lettuce	14-day EC_{50}[1] (growth)	185[4]	Hulzebos *et al.* (1993)
QCB	earthworm (*L. rubellus*)	14-day LC_{50}	4136[2]	van Gestel *et al.* (1991)

[1] Determined using nominal concentrations.
[2] 4.9% OC.
[3] 0.84% OC.
[4] 1.08% OC.

Table 9. CTV_{SED}s selected for benthic freshwater and marine organisms

CBz	Freshwater		Marine	
	CTV_{SED} (µg/g OC)	**Data type**	**CTV_{SED} (µg/g OC)**	**Data type**
1,2-DCB	1382	EqP-based chronic EC_{50}	1127	Measured LOEC (*R. abronius*)
1,4-DCB	1005	EqP-based chronic LOEC	4999	EqP-based (acute effect)
TCBs	1637	EqP-based LC_{90}	504	EqP-based (chronic effect)
TeCBs	2846	EqP-based chronic EC_{50}	1582	Measured LOEC (*R. abronius*)
QCB	2500	EqP-based chronic EC_{50}	3080	Median of extrapolated LOEC (*R. abronius*)

Table 10. Application factors and derived $ENEV_{SED}$s for benthic organisms (freshwater and marine)

CBz	Freshwater				Marine				
	CTV_{SED} (µg/g OC)	**Factors applied**		**$ENEV_{SED}$ (µg/g OC)**	**CTV_{SED} (µg/g OC)**	**Factors applied**			**$ENEV_{SED}$ (µg/g OC)**
		chronic to no effects	**P&B[1]**			**ACR**	**chronic to no effects**	**P&B[1]**	
1,2-DCB	1382	10	–	138	1127	3	10	–	38
1,4-DCB	1005	10	–	101	4999	3	10	–	167
TCBs	1637	10	–	164	504	–	10	–	50
TeCBs	2846	10	10	29	1582	3	10	10	5
QCB	2500	10	10	25	3080	3	10	10	10

[1] P&B = persistence and bioaccumulation.

Table 11. Risk quotients for benthic organisms, based on maximum EEVs (EEV_{SED}s) for Canadian sediments

CBz	Freshwater			Marine		
	Maximum EEV (µg/g OC)	**ENEV (µg/g OC)**	**Quotient**	**Maximum EEV (µg/g OC)**	**ENEV (µg/g OC)**	**Quotient**
1,2-DCB	52	138	0.4	<2.2	38	<0.06
1,4-DCB	522	101	5.2	40	167	0.24
TCBs	539	164	3.3	<2.2	50	<0.05
TeCBs	320	29	11	<2.2	5	<0.44
QCB	601	25	24	<2.2	10	<0.22

Table 12. Determination of $ENEV_{SOIL}$s for soil-dwelling organisms

CBz	**CTV_{SOIL} (µg/g OC)**	**Factor applied**			**$ENEV_{SOIL}$ (µg/g OC)**
		Limited data	**Chronic to no effects**	**Persistence and bioaccumulation**	
1,2-DCB	4712	3	10	–	157
1,4-DCB	4712	3	10	–	157
1,2,3-TCB	119	3	10	–	4.0
1,2,4-TCB	2592	3	10	–	86
1,2,3,4-TeCB	2963	3	10	10	9.9
1,2,4,5-TeCB	185	3	10	10	0.62
QCB	4136	3	10	10	14

Table 13. Risk quotients for terrestrial organisms, based on maximum EEVs (EEV_{SOIL}s) for Canadian soils

CBz	**Maximum EEV (µg/g OC)**	**Data source for maximum EEV**	**$ENEV_{SOIL}$ (µg/g OC)**	**Quotient**
1,2-DCB	0.42	Calculated from Webber and Nicols (1995)	157	0.003
1,4-DCB	0.87	Calculated from Webber and Nicols (1995)	157	0.006
1,2,3-TCB	0.05	Ding *et al*. (1992)	4.0	0.01
1,2,4-TCB	0.25	Ding *et al*. (1992)	86	0.003
1,2,3,4-TeCB	0.33	Ding *et al*. (1992)	9.9	0.03
1,2,4,5-/1,2,3,5-TeCB	0.40	Ding *et al*. (1992)	0.62	0.65
QCB	0.09	Ding *et al*. (1992)	14	0.006

Appendix 1. Persistence and bioaccumulation criteria as defined in the Persistence and Bioaccumulation Regulations of CEPA 1999

Persistence[a]		**Bioaccumulation**[b]
Medium	Half-life	
Air	≥ 2 days or is subject to atmospheric transport from its source to a remote area	BAF[c] ≥ 5000; BCF[d] ≥ 5000; log K_{ow}[e] ≥ 5
Water	≥ 182 days	
Sediment	≥ 365 days	
Soil	≥ 182 days	

[a] A substance is persistent when at least one criterion is met in any one medium.
[b] When the BAF of a substance cannot be determined in accordance with generally recognized methods, then the BCF of a substance will be considered, however, if neither its BAF nor its BCF can be determined with recognized methods, then the log K_{ow} will be considered.
[c] Bioaccumulation factor means the ratio of the concentration of a substance in an organism to the concentration in water, based on uptake directly from the surrounding medium and food.
[d] Bioconcentration factor means the ratio of the concentration of a substance in an organism to the concentration in water, based only on uptake directly from the surrounding medium.
[e] octanol-water partition coefficient means the ratio of the concentration of a substance in an octanol phase to the concentration of the substance in the water phase of an octanol-water mixture

Appendix 2. Search Strategy - New Information for the Assessment of "Toxic" to the environment under Paragraph 64 (a) of CEPA 1999

To identify relevant information on Canadian production, importation, use, and environmental release, searches of the NPRI (National Pollutant Release Inventory, Environment Canada), the ARET (Accelerated Reduction/Elimination of Toxics, Environment Canada) were performed.

Data relevant to the assessment of whether 1,2-dichlrobenzene, 1,4-dichlorobenzene, trichlorobenzenes, tetrachlorobenzenes or pentachlorobenzene are “toxic” to the environment under paragraph 64 (a) of CEPA *1999* were identified from existing review documents, published reference checks and on-line searches of the following databases up to December, 1999. A search was conducted by name or CAS registry number in the following databases: Aquire, Registry of toxic effects of chemical substances (RTECS), Environment Abstracts, CAB abstracts, Current Contents, Poltox, Capulus Bib Abstracts, UnCover.