Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health

POLYCHLORINATED BIPHENYLS (TOTAL) 1999

This fact sheet provides Canadian soil quality guidelines for polychlorinated biphenyls (PCBs) for the protection of environmental health (Table 1). A supporting scientific document is also available (Environment Canada 1998). The CCME recognizes that present and future management of persistent bioaccumulative substances such as PCBs is aimed at the virtual elimination of releases to the environment. Nevertheless, the CCME also recognizes the need for remediation guidelines as interim management objectives for persistent bioaccumulative substances in soils.

Background Information

The term PCB refers to a group of 209 compounds consisting of chlorine atoms substituted on a biphenyl moiety ($C_{12}H_{10-n}Cl_n$ where n is greater than two; CAS 1336-36-3). These 209 compounds can be categorized into 10 PCB congener groups according to the degree of chlorination of the biphenyl moiety, with a number of positional isomers possible within each group (Eisler 1986). The identity of an individual PCB compound is determined by the number and location of the chlorine atoms substituted on the biphenyl moiety. PCB

Table 1. Soil quality guidelines for polychlorinated biphenyls (total) ($mg \cdot kg^{-1}$).

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Guideline	**0.5**[a]	**1.3**[b]	**33**[b,c]	**33**[b,c]
SQG_{HH}	NC[d]	NC[d]	NC[d]	NC[d]
Limiting pathway for SQG_{HH}	ND	ND	ND	ND
Provisional SQG_{HH}	NC[e]	NC[e]	NC[e]	NC[e]
Limiting pathway for provisional SQG_{HH}	ND	ND	ND	ND
SQG_E	1.3	1.3	33	33
Limiting pathway for SQG_E	Soil and food ingestion	Soil and food ingestion	Soil contact	Soil contact
Provisional SQG_E	NC[f]	NC[f]	NC[f]	NC[f]
Limiting pathway for provisional SQG_E	ND	ND	ND	ND
Interim soil quality criterion (CCME 1991)	0.5	5	50	50

Notes: NC = not calculated; ND = not determined; SQG_E = soil quality guideline for environmental health; SQG_{HH} = soil quality guideline for human health.

[a] Data are sufficient and adequate to calculate only an SQE_E, which is greater than the interim soil quality criterion (CCME 1991) for this land use. Therefore, the interim soil quality criterion is retained as the soil quality guideline for this land use.

[b] Data are sufficient and adequate to calculate only an SQG_E, which is less than the existing interim soil quality criterion (CCME 1991) for this land use. Therefore, the SQG_E becomes the soil quality guideline and supersedes the interim soil quality criterion for this land use.

[c] In site-specific situations where the size and/or the location of commercial and industrial land uses may impact higher level consumers, the soil and food ingestion guideline is recommended as the SQG_E.

[d] There is no SQG_{HH} at this time.

[e] The is no provisional SQG_{HH} at this time.

[f] Because data are sufficient and adequate to calculate an SQG_E for this land use, a provisional SQG_E is not calculated.

congeners with chlorine atoms in non-ortho positions only (i.e., positions 3, 3', 4, 4', 5, and 5') are defined as coplanar.

PCBs were first prepared in 1881 and began to be used in industry in 1929 (Tanabe 1988). All PCBs manufactured in North America were produced by Monsanto Co. under the trade name Aroclor. Aroclor mixtures are designated by a four-digit code, with the first two numbers representing the type of compound (12 = chlorinated biphenyl) and the last two numbers representing the percent chlorine by weight (Hutzinger et al. 1974; Kalmaz and Kalmaz 1979). Aroclor 1016 is an exception to this code and is a redistilled version of Aroclor 1242 with a chlorine composition of 41% (Safe 1994). The low chlorine mixtures appear as clear mobile oils, and high chlorine mixtures as sticky yellow resins and waxy white solids (Hutzinger et al. 1974; Pal et al. 1980; Addison 1986).

PCBs are characterized by high thermal and chemical stabilities, low vapour pressures, high dielectric constants, high electric resistivities, high densities, hydrophobicity, and high lipophilicity (Hutzinger et al. 1974; Pal et al. 1980). These properties are accentuated with increasing chlorination (Pal et al. 1980; Mackay et al. 1992). Non-coplanar PCBs are slightly more reactive than coplanar PCBs (Strachan 1988). The melting points of PCBs range from 34 to 198°C and boiling point is approximately 267°C (Pal et al. 1980). PCBs are extremely resistant to oxidation, reduction, addition, elimination, electrophilic substitution, and hydrolysis (Pal et al. 1980; Moore and Walker 1991).

PCBs had many industrial applications. Their dielectric properties, chemical stability at high temperatures, and low vapour pressures made them ideal for use as electric insulators, plasticizers for adhesives, lubricants, hydraulic fluids, liquid seals, cutting oils, heat transfer agents, flame retardants, ink solvents in carbonless copying paper, waterproofing materials, and vacuum diffusion pump oils (Kalmaz and Kalmaz 1979; Pal et al. 1980; Addison 1986; CCREM 1986; Barrie et al. 1992). After 1971, PCBs were primarily used as insulating and cooling agents in closed electrical systems such as capacitors and transformers (Eisler 1986; Strachan 1988).

The manufacturing and processing of PCBs were discontinued in North America in 1979 as a result of environmental and human health concerns (Eisler 1986; WHO 1993). Tanabe (1988) reported that an estimated 31% (370 000 t) of the total world production of PCBs had been released to the environment prior to restrictions on use. At that time, roughly 65% of produced PCBs was still in use or storage, while 4% had been destroyed in incineration plants. Concerted government and industry actions over the past two decades have practically eliminated the inventory of in-use and stored PCBs in Canada, while work continues on identification and management of PCBs released to soils. In Canada today, thermal destruction of PCBs is confined to two specifically designed high-temperature units in Alberta and Quebec.

Historical sources of PCBs to the soil environment have included leakage from electrical transformers, application of wastes to land, emissions from waste incinerators, spills during transport, volatilization and deposition from surface waters, and leakage from inappropriate disposal in landfills. Significant improvements in the management of PCB wastes in Canada over the past few years have practically eliminated direct releases to soil such that present additions to soil occur principally at low levels from diffuse and indirect sources. Atmospheric deposition—either in particulate form or gaseous absorption—is now thought to be the principal release mechanism to soil (UNECE 1994). Recent information (e.g., Webber and Wang 1995) indicates that sporadic, low-level PCB additions to soil may occur from land application of municipal sewage sludges contaminated at trace levels. Small residual consumer devices such as capacitors and electrical ballasts may also contribute minor quantities of PCBs to soil via landfill disposal or incomplete combustion in some municipal solid waste incinerators. However, the contribution is constantly decreasing as the number of municipal incinerators in Canada is declining and landfill siting and construction standards prevalent in the country would make the release of even small amounts of PCBs very unlikely.

Soil samples from 30 agricultural fields in eight Canadian provinces and eight sludge-treated fields in Ontario were analyzed for total PCB concentration (Webber and Wang 1995). PCBs were observed in all of the agricultural soils in concentrations ranging from 0.15 to 0.235 $mg \cdot kg^{-1}$, but were detected in only two of the eight sludge-treated soils; the highest level recorded was 0.514 $mg \cdot kg^{-1}$ at the Brantford landfill site (Webber and Wang 1995).

Soil samples from old urban and rural parkland sites in Ontario were analyzed to determine the Ontario typical range background concentrations of organic and inorganic compounds. Ninety-eight percent of soil samples from rural parkland had total PCB concentrations of 0.015 $mg \cdot kg^{-1}$ or lower, while 98% of old urban parkland sites had total PCB concentrations of 0.032 $mg \cdot kg^{-1}$ or

lower (OMEE 1993). Although PCBs originate solely from anthropogenic sources, acceptable soil background concentrations have been defined for Ontario soils. The recommended acceptable background concentration that applies to agricultural and residential/parkland land uses was defined as 0.3 $mg \cdot kg^{-1}$ for total PCBs (OMEE 1994) in consideration of practical analytical detection limits.

Environment Canada has developed a comprehensive procedure for analyzing PCBs in support of the various regulations that govern PCB use and disposal (Environment Canada 1997). The procedure consists of two parts: a fast and economical screening method that uses high resolution gas chromatography/electron capture detection to determine if PCBs are present in a sample and to provide an estimate of their concentration; and a confirmative method that uses gas chromatography/mass spectrometry to identify and quantify total PCBs. PCBs are quantified on a total homologue basis, as opposed to individual congeners or Aroclors. The detection limit in soils is ≥ 2.5 $ng \cdot g^{-1}$ per congener peak or ≥ 50 $ng \cdot g^{-1}$ per Aroclor.

Another analytical method recommended for PCBs by the CCME is USEPA Method 8080B, revision 2, which is described in CCME (1993). This method is used to determine the concentration of PCBs in extracts prepared from water, groundwater, soils, and sediments. This gas chromatography/electron capture method is relatively inexpensive and suitable for monitoring analyses. Analytes covered by this method include Aroclors 1016, 1221, 1232, 1242, 1248, 1254, and 1260. Following corrections for a 30-g soil sample, digested, with final extract being brought to 10 mL, a detection limit of 2.17×10^{-5} mg $PCB \cdot kg^{-1}$ soil would be calculated for Aroclor 1242. Detection limits for other Aroclor mixtures for this method are not reported.

Environmental Fate and Behaviour in Soil

PCBs in soil originate primarily from particulate deposition, wet deposition, and releases from electrical transformers (WHO 1993). Soil is an important environmental sink for PCBs due to both their strong sorption to soil colloids and resistance to physicochemical degradation and biodegradation.

Sorption of PCBs onto soil particles depends on the degree of chlorination of individual congeners, soil type, organic matter content, soil pH, and soil moisture content. The adsorption of PCBs to soil particles is thought to be hydrophobic sorption, which is the partitioning of a nonpolar solute from the polar aqueous phase onto the hydrophobic surfaces of the earth materials (Gan and Berthouex 1994). In general, higher chlorinated congeners adsorb more readily onto soil particles than lower chlorinated species (Cortes et al. 1991; Gan and Berthouex 1994). Soil adsorption is also stronger for coplanar PCBs than non-coplanar congeners with the same degree of chlorination (Cortes et al. 1991; Paya-Perez et al. 1991).

The movement of PCBs in soil profiles is directly proportional to the solubility of PCBs in the leaching solvent and inversely proportional to the organic matter content of the soil. PCBs are nonpolar and sparingly soluble compounds in water; therefore, the penetration of PCBs into the soil profile by water flow is limited. However, PCBs are highly mobile when leached with organic solvents; thus, PCBs and organic solvents should not be disposed of in the same landfill location (Chou and Griffin 1986).

PCBs can be biodegraded under both aerobic and anaerobic conditions. The biochemical pathway for aerobic degradation of PCBs involves initial addition of O_2 at the 2, 3 position by a dioxygenase enzyme, with subsequent metabolism to chlorobenzoic acid. Aerobic biodegradation generally metabolizes the less chlorinated congeners (Gan and Berthouex 1994). Microbial reductive dechlorination occurs under anaerobic conditions. The dechlorination process leaves the biphenyl nucleus untouched and forms less chlorinated PCBs. The rate of microbial decomposition of PCBs depends on the degree of chlorination and the positions of chlorine atoms (Eisler 1986). In general, the microbial degradation rate of PCBs in soils generally decreases as chlorine substitution increases (Furukawa 1982).

The volatilization of PCBs from soil depends on the vapour pressures and solubilities of individual congeners, soil concentration, soil adsorption reactions, the water and organic matter solubility of individual congeners, temperature, wind velocity, depth of incorporation, photodegradation, and soil water content (Fairbanks et al. 1987; Gan and Berthouex 1994). In general, lower chlorinated PCBs tend to be more volatile than higher chlorinated PCBs (Fairbanks et al. 1987). Vapour pressures of PCBs are reduced by their interaction with soil, mainly as the result of adsorption (Chou and Griffin 1986; Fairbanks et al. 1987).

Behaviour and Effects in Biota

Commercial PCB Formulations

The complexity of commercial PCB mixtures presents immense analytical and toxicological problems as a result of the varying levels of individual congeners and impurities present within them. Toxicological problems are further aggravated by the fact that some of the trace impurities (e.g., polychlorinated dibenzofurans [PCDFs]) in the mixtures may be more toxicologically significant than the PCBs themselves (Addison 1986; Tanabe 1988). The composition of most PCB extracts from environmental samples does not resemble that of commercial PCB mixtures as a result of environmental redistribution of individual congeners with varying volatilization and degradation rates (WHO 1993; Safe 1994).

Individual PCB Congeners

The persistence and toxicity of individual PCB congeners is determined by the structure and positions of the chlorine atoms on the molecule as well as the number of chlorine atoms present (Lech and Peterson 1983). Coplanar PCBs, congeners with four or more chlorines at both the para and meta positions, but none at the ortho positions, have higher toxicities than other congeners. The toxicities of coplanar halogenated hydrocarbons relative to that of 2,3,7,8-tetrachloro dibenzo-*p*-dioxin, the most potent compound in this class of chemicals, are compared through a calculated toxic equivalency factor (TEF). TEFs for coplanar PCB congeners range from 1×10^{-5} for PCB 180 to 0.1 for PCB 126 (Safe 1994; Eisler and Belisle 1996; Hoffman et al. 1996). However, application of the TEFs for individual congeners must be performed with caution, as it has been suggested that PCB mixtures show both additive and nonadditive (antagonistic) interactions (Safe 1994).

Bioaccumulation is a critical aspect of the environmental fate and behaviour of PCBs. PCBs accumulate in almost all organisms as a result of their high lipid solubility and slow rates of metabolism and elimination (WHO 1993). These characteristics permit PCBs to accumulate to relatively high levels in biota, even at low exposure rates. Thus, sustained low levels of PCBs in the abiotic environment may result in adverse chronic effects in the biota exposed to them (UNECE 1994). Higher chlorinated PCBs and coplanar PCBs are more likely to be bioaccumulated than lower chlorinated congeners as a result of their lower water solubilities, lower volatilities, and greater resistance to biodegradation (Moore and Walker 1991).

Soil Microbial Processes

A long-term field study conducted in the vicinity of a municipal incinerator indicated that very low soil concentrations of PCBs can influence microbial processes. A plot directly impacted by emissions from the incinerator showed soil PCB levels of 0.014 $mg \cdot kg^{-1}$. Microbes taken from this contaminated plot showed significant reductions in nitrification rates, biomass content, and respiration rates when compared to a control plot with PCB concentrations of 0.0044 $mg \cdot kg^{-1}$ (considered to be a background level of contamination for the area). Levels of other contaminants, such as polycyclic aromatic hydrocarbons, polychlorinated dibenzo-*p*-dioxins, PCDFs, DDT, and heavy metals, were either at or below normal background concentrations in both plots, and the authors concluded that the observed effects were the result of PCB contamination (Dusek 1995; Dusek and Tesarova 1996).

Terrestrial Plants

Accumulations of PCBs in plant tissues may be the result of direct root uptake from contaminated soils, localized movement of PCBs from contaminated soils in particle-bound or vapour form to plant foliage, or long-range atmospheric deposition to plant foliage (Buckley 1982). Roots tend to accumulate PCBs more than stems or foliage, and much of this contamination consists of adsorption on the surface of the root rather than translocation within the root (Wallnöfer et al. 1975; Strek and Weber 1982). Lower chlorinated congeners are more readily taken up by plants as a result of their greater mobility in soils (Strek and Weber 1982; WHO 1993). Several studies have shown that the primary source of PCBs to leaves and stems is surface deposition from the atmosphere to the plant (Buckley 1982).

Soybean *(Glycine max)* height and fresh top weight were significantly inhibited by 15 and 22%, respectively, at soil concentrations of 1000 $mg \cdot kg^{-1}$ Aroclor 1254. Malformation of newly developing leaves, inhibited root growth, and decreased water uptake were also observed at this dose. The fresh top weight of fescue *(Fescue arundinacea)* was significantly inhibited by 16% at soil concentrations of 1000 $mg \cdot kg^{-1}$ Aroclor 1254, but no other adverse effects were observed (Weber and Mrozek 1979).

Strek et al. (1981) continued the work reported in Weber and Mrozek (1979) by evaluating the second and third plantings of soybeans in the same contaminated soils in an effort to examine the longevity of effects of soil-applied PCBs. Significant reductions in height (22 and 18%), fresh top weight (24 and 37%), and cumulative water use (47 and 32%) were observed at a dose rate of 1000 $mg \cdot kg^{-1}$ for the second and third soybean crops, respectively. Significant reductions in the height of the third soybean crop were observed at all application rates. The toxicity of Aroclor 1254 was also evaluated for beets *(Beta vulgaris)*, corn *(Zea mays)*, and sorghum *(Sorghum bicolor)* in this study. The height, fresh top weight, and cumulative water uptake were dramatically reduced in beets at the 1000 $mg \cdot kg^{-1}$ dose (100, 100, and 96%, respectively, after 56 d). The applied doses of PCBs had no effect on the corn or sorghum plants, except for a reduction in corn height during the first 5 d of growth at the 100 $mg \cdot kg^{-1}$ and 1000 $mg \cdot kg^{-1}$ levels. The corn plants appeared to recover after this period.

Terrestrial Invertebrates

Uptake of PCBs from soil to invertebrates may occur through direct dermal absorption, through soil contact, and by ingestion of contaminated soil.

Earthworm uptake of PCBs was studied in nine confined disposal facilities bordering the Great Lakes. Earthworm species included in the study were *Lumbricus rubellus*, *Dendrodrilus rubidus*, *Eiseniella tetraedra*, *Aporrectodea trapezoides*, *Aporrectodea tuberculata*, *Lumbricus terrestris*, and *Allolobophora chlorotica*. The purpose of this study was to determine if the concentrations of contaminants in the earthworms were hazardous to predators; therefore, reported concentrations of contaminants in the worms refer to the whole animal, including ingested soil. Soil PCB concentrations, estimated as Aroclor 1254, ranged from below the detection limit of 0.1 to 1.0 $mg \cdot kg^{-1}$ dw, while earthworm concentrations ranged from below the detection limit of 0.4 to 1.8 $mg \cdot kg^{-1}$ dw. PCB concentrations in earthworms tended to be several times that of the surrounding soil, with an average BCF (based on sites where PCBs were detected in earthworms) of approximately 3. Based on the results of reported laboratory toxicity studies, an earthworm concentration of 5 $mg \cdot kg^{-1}$, corresponding to a soil concentration of 1.7 $mg \cdot kg^{-1}$, was suggested to be hazardous to PCB-sensitive predators (Beyer and Stafford 1993).

The acute toxicity of soil contaminated with Aroclor 1254 was evaluated for soil fauna, including nematodes and microarthropods (Parmelee et al. 1997). Soil collected from an oak–beech forest (pH = 3.8) was contaminated at levels of 25, 250, 500, and 2500 $mg \cdot kg^{-1}$. After an exposure period of 7 d, there were no observed effects on total nematode abundance or nematode trophic groups at any concentration. Total microarthropod numbers were significantly decreased (87%) at the highest level of contamination. The authors suggest that the LC_{50} for arthropods is likely to be similar to that reported for crickets by Paine et al. (1993). Although the soil pH reported in this study was slightly less than 4, it was included as a selected study because so few data were available for terrestrial invertebrates.

Paine et al. (1993) evaluated the toxicity of soil contaminated with Aroclor 1254 to house crickets *(Acheta domesticus)*. The 14-d LC_{50} for 21-d-old nymphs was 1200 $mg \cdot kg^{-1}$, corresponding to a body concentration of approximately 150 $mg \cdot kg^{-1}$. The authors suggest a benchmark whole body concentration for mortality of 100–300 $mg \cdot kg^{-1}$ for terrestrial insects.

Birds

PCBs may be taken up by birds from contaminated food or water and stored in fatty tissues. Higher chlorinated PCBs accumulate to a greater extent than lower chlorinated congeners. Egg-laying females can transfer substantial amounts of PCBs to their eggs. When birds undergo starvation, the PCB body burden is redistributed such that concentration in the brain increases and may become lethal without further intake of PCBs (WHO 1993). Laboratory studies indicate that lower chlorinated PCBs can be dechlorinated and metabolized by some species of birds (Hamdy and Gooch 1986).

In contrast to mammals, the acute toxicity of Aroclor mixtures to birds increases with increasing chlorination (Hill et al. 1975; Hill and Camardese 1986). Sudden heavy intake of PCBs leads to high brain residues that correlate with mortality; brain residues of 300–400 $mg \cdot kg^{-1}$ are considered to be diagnostic of acute poisoning and death (Stickel et al. 1984; WHO 1993). Chronic PCB exposure does not result in brain residues as high; death in these cases appears to be due to edema and related symptoms (WHO 1993). Sublethal effects of PCBs on birds are varied and include decreased growth of dosed animals and their progeny, changes in

organs, reproductive effects (decreased egg production and hatchability), thyroid and pituitary changes, porphyria, and changes in behaviour (Hoffman et al. 1996).

Aroclors 1232, 1242, 1248, and 1254 fed to white leghorn hens *(Gallus domesticus)* at 20 $mg \cdot kg^{-1}$ significantly reduced egg production, the hatchability of fertile eggs, and progeny growth, with Aroclor 1248 showing the most marked effects (Lillie et al. 1974). Aroclor 1248 also significantly increased the rate of progeny mortality. Aroclors 1232, 1242, and 1248 significantly decreased the hatchability of eggs at concentrations of 10 $mg \cdot kg^{-1}$ during an 8-week exposure period, and Aroclors 1242 and 1248 slightly reduced progeny growth at levels of 10 $mg \cdot kg^{-1}$ (Lillie et al. 1975). In another study, white leghorn hens exposed to dietary levels of 5 $mg \cdot kg^{-1}$ Aroclor 1254 for 28 weeks showed a 20% reduction in egg production during their second fortnight of exposure (Platonow and Reinhart 1973).

Few data were available on the effects of PCBs to secondary avian consumers. American kestrels *(Falco sparverius)* fed diets containing 3 $mg \cdot kg^{-1}$ Aroclor 1248 for 6 months showed small but significant reductions in eggshell thickness and shell weight (Lowe and Stendell 1991). Dietary exposure to Aroclor 1254 at concentrations of 33 $mg \cdot kg^{-1}$ over 2 months resulted in significant decreases in the number of sperm per ejaculate for American kestrels. No effect was observed on sperm motility. A highly significant interaction effect between Aroclor 1254 and Mirex was noted in this study, and the semen collected from birds exposed to both chemicals was of poor quality by the end of the study (Bird et al. 1983).

Mammals

In general, PCBs are rapidly absorbed, particularly by the gastrointestinal tract after oral exposure, and are transported by the blood to the liver and adipose tissue of various organs (Matthews 1983; WHO 1993). There is also evidence of placental transport, fetal accumulation, and distribution to milk (Ringer 1983; WHO 1993).

The major sites of PCB pathology in mammals are the skin and liver, but the gastrointestinal tract, immune system, and nervous system may also be affected (WHO 1993). Common manifestations of PCB exposure include hepatoxicity, immunotoxicity, neurotoxicity, reproductive effects, gastrointestinal ulceration and necrosis, bronchitis, dermal effects, weak mutagenicity at high doses, and preneoplastic changes at low doses (Eisler and Belisle 1996). PCB-induced toxicity patterns vary greatly between species as a result of differing abilities to metabolize PCBs and differing primary sites of action. The toxicity of PCBs to mammals may also depend on the age, growth rate, mass, and lipid content of the animal; dose rate; route and duration of exposure; the presence of specific congeners within the administered dose; and interactions with other compounds (Eisler and Belisle 1996).

A substantial part of the toxicity of commercial PCB mixtures results from the presence of coplanar congeners. These compounds have been demonstrated to cause toxic effects similar to those of 2,3,7,8-TCDD, including edema, weight loss, hepatic and thymus changes, embryotoxicity, teratogenicity, and immunotoxicity, in both mammals and birds (Eisler and Belisle 1996; Hoffman et al. 1996).

Acute oral LD_{50} values for PCBs in rats range from 1010 $mg \cdot kg^{-1}$ bw for Aroclor 1254 to 4250 $mg \cdot kg^{-1}$ bw for Aroclor 1242 (Indian and Northern Affairs Canada 1997), while LD_{50} values for mink range from 750 to 4000 $mg \cdot kg^{-1}$ bw (Aulerich and Ringer 1977). Single-dose mortality data have not been reported for other mammalian species. In contrast to birds, the acute lethality of Aroclor mixtures to mammals is inversely related to chlorine content (WHO 1993). Variation in LD_{50} values may be related to the species, age, and/or sex of the animal tested, as well as the purity of the PCB formulation (ATSDR 1995). The principal signs of acute toxicity in rats include diarrhea, respiratory depression, and dehydration (ATSDR 1995).

The effects of chronic dietary exposure of PCBs were investigated in three generations of Oldfield mice *(Peromyscus polionotus)* maintained on a diet containing 5 $mg \cdot kg^{-1}$ Aroclor 1254. Birth and weaning weights were significantly lower in first- and second-generation offspring of PCB-exposed animals than those of controls. Second-generation offspring also exhibited a lower birth rate, longer intervals prior to the birth of the first litter, and decreased survival to weaning relative to controls. The results of this study clearly show that chronic exposure to PCBs through diet has the potential to reduce fertility, growth, and survival in *Peromyscus* and that these effects can be amplified through multigenerational exposure (McCoy et al. 1995).

Guideline Derivation

Canadian soil quality guidelines are derived for different land uses following the process outlined in CCME

(1996a) using different receptors and exposure scenarios for each land use (Table 1). Detailed derivations for PCB soil quality guidelines are provided in Environment Canada (1998).

Soil Quality Guidelines for Environmental Health

Environmental soil quality guidelines (SQG_Es) are usually based on soil contact using data from toxicity studies on plants and invertebrates. In the case of agricultural land, soil and food ingestion toxicity data for mammalian and avian species are included. However, since PCBs are persistent substances that are subject to long-range transport and have a strong tendency to bioaccumulate and biomagnify in the food chain, particularly in third-level predators, the concept of land uses as envisioned in CCME (1996a) does not provide adequate protection for ecological receptors. Therefore, soil quality guidelines for residential/ parkland and agricultural land uses are based on models designed to protect primary, secondary, and tertiary consumers from adverse effects due to ingestion of contaminated soil and food. To provide a broader scope of protection, a nutrient and energy cycling check is also calculated.

For all land uses, the preliminary soil contact value (also called threshold effects concentration [TEC] or effects concentration low [ECL], depending on the land use) is compared to the nutrient and energy cycling check. If the nutrient and energy cycling check is lower, the geometric mean of the preliminary soil contact value and the nutrient and energy cycling check is calculated as the soil quality guideline for soil contact. If the nutrient and energy cycling check is greater than the preliminary soil contact value, the preliminary soil contact value is the soil quality guideline for soil contact.

For residential/parkland and agricultural land uses, the lower of the soil quality guideline for soil contact and the soil and food ingestion guideline is recommended as the SQG_E. The soil and food ingestion guideline is based on the lower of three values: the protection of primary consumers value, the protection of secondary consumers value, and the protection of tertiary consumers value. The primary consumer value is modeled using a soil → plant → herbivore pathway; the secondary consumer model uses a soil → plant → herbivore → predator pathway; and the tertiary consumer model uses a soil → invertebrate → secondary consumer → predator pathway. All exposure scenarios incorporate bioconcentration and bioavailability factors of PCBs through the food chains to estimate the soil concentrations, which should not be exceeded in order to prevent adverse toxicological effects to ecological receptors.

For commercial and industrial land uses, the soil quality guideline for soil contact is recommended as the SQG_E. However, in site-specific situations where the size and/or the location of these land uses may impact primary, secondary, and tertiary consumers, the soil and food ingestion guideline is recommended as the SQG_E.

Toxicological data were often only available for the commercial mixture Aroclor 1254. However, Aroclor 1254 mixtures contain relatively high abundances of the PCB congeners 52, 77, 90, 95, 101, 110, 118, 138, 149, 153, and 180 (Schulz et al. 1989). These congeners are often found dominating environmental samples; relatively high abundances of these congeners were detected in soil samples (Bright et al. 1995; Hendriks et al. 1995), vascular plants (Dushenko et al. 1996), and earthworms (Hendriks et al. 1996) from areas that were not directly impacted by point sources of Aroclor 1254 contamination. Therefore, the guidelines derived from the selected toxicological data should be regarded as guidelines for total PCBs present in soil.

Soil Quality Guidelines for Human Health

There are no human health guidelines or check values available at this time (Table 2).

Soil Quality Guidelines for PCBs

The soil quality guidelines are the lower of the SQG_Es and the interim soil quality criteria (CCME 1991).

Agricultural and Residential/Parkland Lands

For agricultural lands, the SQG_E, which is based on the soil and food ingestion guideline, is higher than the existing interim soil quality criteria (CCME 1991). Since no SQG_{HH} was calculated, the existing interim soil quality criteria is retained as the soil quality guideline for this land use (Table 1).

For residential/parkland lands, the SQG_E, which is based on the soil and food ingestion guideline, is lower than the existing interim soil quality criteria (CCME 1991). Therefore, the SQG_E becomes the soil quality guideline for this land use (Table 1).

Table 2. Soil quality guidelines and check values for polychlorinated biphenyls (total) (mg·kg^{-1}).

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Guideline	**0.5**[a]	**1.3**[b]	**33**[b, c]	**33**[b, c]
Human health guidelines/check values[d]				
SQG_{HH}	NC	NC	NC	NC
Soil ingestion guideline	NC	NC	NC	NC
Inhalation of indoor air check	NC	NC	NC	NC
Off-site migration check	—	—	—	NC
Groundwater check (drinking water)	NC	NC	NC	NC
Produce, meat, and milk check	NC	NC	—	—
Provisional SQG_{HH}	NC	NC	NC	NC
Limiting pathway for provisional SQG_{HH}	ND	ND	ND	ND
Environmental health guidelines/check values				
SQG_E	1.3[e]	1.3[e]	33[c, f]	33[c, f]
Soil contact guideline	33	33	33	33
Soil and food ingestion guideline:				
Primary consumer	25	25	—	—
Secondary consumer	1.8	1.8	—	—
Tertiary consumer	1.3	1.3		
Nutrient and energy cycling check	NC[g]	NC[g]	NC[g]	NC[g]
Off-site migration check	—	—	—	ND
Groundwater check (aquatic life)	NC	NC	NC	NC
Provisional SQG_E	NC[h]	NC[h]	NC[h]	NC[h]
Limiting pathway for provisional SQG_E	ND	ND	ND	ND
Interim soil quality criterion (CCME 1991)	0.5	5	50	50

Notes: NC = not calculated; ND = not determined; SQG_E = soil quality guideline for environmental health; SQG_{HH} = soil quality guideline for human health. The dash indicates guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

[a]Data are sufficient and adequate to calculate only an SGE_E, which is greater than the existing interim soil quality criterion (CCME 1991) for this land use. Therefore, the interim soil quality criterion is retained as the soil quality guideline for this land use.

[b]Data are sufficient and adequate to calculate only an SQG_E, which is less than the interim soil quality criterion (CCME 1991) for this land use. Therefore, the SQG_E becomes the soil quality guideline and supersedes the interim soil quality criterion for this land use.

[c]In site-specific situations where the size and/or the location of commercial and industrial land uses may impact primary, secondary or tertiary consumers, the soil and food ingestion guideline is recommended as the SQG_E.

[d]There are no values for the human health guidelines/check values at this time.

[e]Based on the soil and food ingestion guideline for the protection of tertiary consumers.

[f]Based on the soil contact guideline value.

[g]Data are insufficient/inadequate to calculate the nutrient and energy cycling check for this land use.

[h]Because data are sufficient and adequate to calculate an SQG_E for this land use, a provisional SQG_E is not calculated.

Commercial and Industrial Lands

For commercial and industrial lands, the SQG_Es, which are based on the soil contact guidelines, are lower than the interim soil quality criteria (CCME 1991). Therefore, the SQG_Es become the soil quality guidelines for these land uses (Table 1).

CCME (1996b) provides guidance on potential modifications to the recommended soil quality guideline when setting site-specific objectives.

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For further scientific information, contact:

Environment Canada
Guidelines and Standards Division
351 St. Joseph Blvd.
Hull, QC K1A 0H3
Phone: (819) 953-1550
Facsimile: (819) 953-0461
E-mail: ceqg-rcqe@ec.gc.ca
Internet: http://www.ec.gc.ca

For additional copies, contact:

CCME Documents
c/o Manitoba Statutory Publications
200 Vaughan St.
Winnipeg, MB R3C 1T5
Phone: (204) 945-4664
Facsimile: (204) 945-7172
E-mail: spccme@chc.gov.mb.ca

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