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

PENTACHLOROPHENOL 1997

This fact sheet provides Canadian soil quality guidelines for pentachlorophenol (PCP) for the protection of environmental and human health (Table 1). A supporting scientific document is also available (CCME 1997).

Background Information

Pentachlorophenol (C_6HCl_5O; CAS 87-86-5) and its salt, sodium pentachlorophenate ($C_6Cl_5O^-Na^+$; CAS 113-52-2), are the most common forms of pentachlorophenol used in Canada. Synonyms for PCP include chlorophen, pentachlorol, penta, pentachlorofenol, and 2,3,4,5,6-PCP. It has a molecular weight of 266.35, a specific gravity of 1.987 (at 25°C), a log K_{ow} of 5.05 (at pH of 5.1), vapour pressure of 2.0×10^{-6} kPa (at 20°C), and a pH-dependant water solubility ranging from 14.0 to 15 000 $mg \cdot L^{-1}$ (CCME 1997). PCP is an anthropogenic chemical that is ubiquitous in the Canadian environment as a result of extensive historical use in the wood preservation and wood protection industries. The only current uses of the chemical are restricted to heavy-duty wood preservation and ground line remedial treatment of utility poles; both uses are subject to re-evaluation under the Pest Control Products Regulations.

PCP has been detected in a wide range of environmental media sampled from across Canada. In particular, PCP has been found in association with wood preservation and protection facilities, sewage effluents, and in soils, waters, and sediments contiguous to these sources. PCP has also been detected in groundwater, surface waters, indoor and ambient air, housedust, and food (CCME 1997).

The majority of samples (98th percentile of determinations) from old urban parklands and rural parklands in Ontario

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

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Guideline	**7.6**[a]	**7.6**[a]	**7.6**[a]	**7.6**[a]
SQG_{HH}	7.6	7.6	7.6	7.6
Limiting pathway for SQG_{HH}	Groundwater check (drinking water)	Groundwater check (drinking water)	Groundwater check (drinking water)	Groundwater check (drinking water)
Provisional SQG_{HH}	NC[b]	NC[b]	NC[b]	NC[b]
Limiting pathway for provisional SQG_{HH}	ND	ND	ND	ND
SQG_E	11	11	28	28
Limiting pathway for SQG_E	Soil contact	Soil contact	Soil contact	Soil contact
Provisional SQG_E	NC[c]	NC[c]	NC[c]	NC[c]
Limiting pathway for provisional SQG_E	ND	ND	ND	ND
Interim soil quality criterion (CCME 1991)	0.05	0.5	5	5

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 an SQG_{HH} and an SQG_E. Therefore the soil quality guideline is the lower of the two and represents a fully integrated de novo guideline for this land use, derived in accordance with the soil protocol (CCME 1996a). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

[b]Because data are sufficient and adequate to calculate an SQG_{HH} for this land use, a provisional SQG_{HH} is not calculated.

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

The guidelines in this fact sheet are for general guidance only. Site-specific conditions should be considered in the application of these values. The values may be applied differently in various jurisdictions. The reader should consult the appropriate jurisdiction before application of the values.

not impacted by a local source of pollution contained PCP concentrations below the detection limit of 14 $ng \cdot g^{-1}$, with a maximum value of 21.5 $ng \cdot g^{-1}$ determined in rural parklands (OMEE 1993). At Canadian wood treatment sites, PCP concentrations in soil ranged from 0.049 to 16 000 $mg \cdot kg^{-1}$ (CCME 1997).

Impurities in technical grade PCP, which may include tetrachlorophenol, trichlorophenols, hexachlorobenzene, polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzo-furans (PCDFs), and chlorinated phenoxyphenols, are contributors to the compound's toxicity. Chronic toxicity studies indicate that technical grade PCP can be up to 10 times more potent than purified PCP due to the presence of these impurities (CCME 1997).

Environmental Fate and Behaviour in Soil

Laboratory studies indicate that the major physical and chemical processes that determine the transport and distribution of PCP and its derivatives in soil, water, and air are volatilization, adsorption, and leaching. At low concentrations, persistence in soil is generally low (<10 d), but may be modified by a number of factors (Bellin and O'Connor 1990).

Volatilization of PCP can occur from treated materials at a significant rate. A 30–80% evaporative loss of applied PCP was observed from treated wood within 1 year of application (Morgan and Purslow 1973).

Adsorption of PCP to soil is influenced by soil pH and organic carbon content (Choi and Aomine 1974). In general, adsorption was found to increase as soil pH decreased. As adsorption increases, PCP is less bioavailable and the rate of biodegradation tends to be reduced (van Gestel and Ma 1988).

Leaching of PCP tends to increase with high PCP input, high soil moisture, alkaline soil conditions, and low organic matter content in the soil (Kaufman 1976). Over a range of environmentally significant temperatures and pH, the solubility of PCP was found to vary from 5 to 8000 $mg \cdot L^{-1}$.

Biodegradation is an important process particularly under aerobic conditions. Biodegradation processes reported include reduction, dechlorination, methylation, demethylation, acetylation, and hydroxylation. Products include lower chlorinated phenols, methyl ethers, and pentachloroanisole. The rate of biodegradation in soil is affected by temperature, pH, moisture, adsorption, and cation exchange capacity. Microbial species known to biodegrade PCP include *Pseudomonas*, *Flavobacterium*, and *Arthrobacter*. Several species of fungi are also known to be capable of PCP degradation (CCME 1997).

Behaviour and Effects in Biota

Soil Microbial Processes

Very few data are available on the effects of PCP on soil microbial processes including nitrification, ammonification, and respiration. Respiration has been shown to be unaffected by an application of 2 $mg \cdot kg^{-1}$ and inhibited by 10–20% by an application of 20 mg $PCP \cdot kg^{-1}$ (Zelles et al. 1985). In a comparison of the effects of PCP on nitrification, ammonification, and respiration in soils, a study has shown that nitrification is the most sensitive process (NOEC between ≥10 and <100 $mg \cdot kg^{-1}$ ww), respiration less sensitive (NOEC between ≥100 and <1000 $mg \cdot kg^{-1}$ ww), and ammonification the least sensitive of the three processes (NOEC ≥ 1000 $mg \cdot kg^{-1}$ ww) (Vonk et al. 1986).

Terrestrial Plants

PCP is metabolized rapidly in plants, so that while PCP products may be detected in plants, little intact PCP is found in plant tissues. Corn plants *(Zea mays)* exposed to soil spiked with 1.25 $mg \cdot kg^{-1}$ dry soil for 14 d accumulated 6.30 mg $^{14}C\text{-}PCP \cdot kg^{-1}$. Of the accumulated PCP, 16% was parent PCP, 40% unknown, and 44% PCP conjugates (Lu et al. 1978).

Scheunert et al. (1986) tested the uptake of 1 $mg \cdot kg^{-1}$ applied ^{14}C-PCP in carrots during one growing season. The authors determined that 57.6% was recovered in soil, 42% was lost to the atmosphere, and only very low amounts were leached to groundwater (0.1%) or taken up by carrots (0.1%). The weight of evidence from uptake, metabolism, and elimination studies suggests that bioaccumulation from PCP in soil would not be a major occurrence in plants.

The lowest soil PCP concentrations at which phytotoxic effects have been observed are 3.2 $mg \cdot kg^{-1}$, resulting in 25% reduction in lettuce growth and 4.8 $mg \cdot kg^{-1}$ resulting in a 50% growth reduction (Vonk et al. 1986). The next most sensitive measurements were a 23% reduction in seedling emergence for lettuce at 11 $mg \cdot kg^{-1}$ (CCME 1997) and a 50% reduction in turnip growth at 11.32 $mg \cdot kg^{-1}$ (Gunter and Pestemer 1990).

Terrestrial Invertebrates

Van Gestel and Ma (1988) reported soil BCFs of 8.0 and 3.4 for the earthworms *Lumbricus rubellus* and *Eisenia foetida andrei*, respectively. A change in organic matter content of soil did not influence the BCF. In a study by Haque and Ebing (1988), whole body BCFs of the earthworm *Allolobophora caliginosa* exposed to 2.2 and 11.2 mg Na-PCP·kg^{-1} for 14 d were 37 and 50, respectively. In the first of two food chain studies by Gruttke et al. (1986), springtails *(Folsomia candida)* accumulated up to 370 mg·kg^{-1} fresh weight (fw) after a 10-d diet of baker's yeast containing 870 mg ^{14}C-Na-PCP·kg^{-1} dw. Carabid beetles *(Nebria brevicollis)* showed a body burden of approximately 4.5 mg PCP·kg^{-1} fw in the steady state (days 4–12) after feeding on contaminated springtails. After 4 d of feeding on uncontaminated springtails, the body burden had dropped to 0.4 mg·kg^{-1} fw. Similar results of low bioaccumulation tendency were reported in a PCP-contaminated soil system consisting of poplar leaves, isopods *(Oniscus asellus)* as a primary consumer, and staphylinid beetle *(Ocypus olens)* predators (Gruttke et al. 1986).

The lowest soil PCP concentration at which toxic effects have been observed in soil invertebrates is 10 mg·kg^{-1} resulting in an LC_{50} for the earthworm *E. foetida andrei*, after 28 d of exposure (van de Meent et al. 1991).

Human and Experimental Animal Health Effects

The majority of PCP exposure to humans is through contaminated food (accounting for 92–97% of estimate total daily exposure) and to a lesser extent from contaminated indoor air and house dust. The average total daily intake of PCP was estimated to range from 0.039 µg·kg^{-1} bw per day in adults to 0.16 µg·kg^{-1} bw per day in breast-fed infants (CCME 1997). Aboriginal peoples who rely on a traditional diet of fish and fish products may receive approximately twice as much dietary PCP as the average adult Canadian.

PCP is readily absorbed via the lungs, gastrointestinal tract, and skin in both humans and experimental animals. Chronic and subchronic PCP exposure of workers in high-risk, multiple-exposure environments has been extensively studied. Although various symptoms, including impairments in liver and kidney functions, have been reported in association with occupational exposure, no clear correlation between exposure and chronic/subchronic effects could be made (CCME 1997).

Experimental animal studies have shown that PCP is embryolethal and embryotoxic. In a single generation reproduction study, purified PCP (Dowicide EC-7) was given to rats at doses of 3 and 30 mg·kg^{-1} bw per day in the diet. The highest dose, administered to females prior to mating, during mating and gestation, and throughout lactation, caused a reduction in mean adult body weight and a significant decrease in neonatal survival and growth among litters of treated females (Schwetz et al. 1978). Ingestion of 3 mg·kg^{-1} bw per day had no effect on reproduction, neonatal growth, survival, or development. The same authors also studied the chronic toxicity of PCP in rats and reported mild signs of toxicity at 30 mg·kg^{-1} bw per day (decreased body weight [females], impaired liver function [both sexes] and impaired kidney function [females]). Ingestion of 3 mg·kg^{-1} bw per day or less by females and 10 mg·kg^{-1} bw per day or less by males was not associated with significant toxic effects (Schwetz et al. 1978).

Recent National Toxicology Program investigations have shown that long-term oral exposure to 100 and 200 ppm (18 and 37 mg·kg^{-1} bw per day) technical PCP and Dowicide EC-7 in mice resulted in significantly increased incidence of hemangiosarcomas (blood vessel tumours), pheochromocytoma (adrenal gland tumours), and hepatocellular adenomas and carcinomas (liver tumours) (U.S. Department of Health and Human Services 1989). PCP may be genotoxic, but the evidence is equivocal.

PCP is therefore classified in Group III, possibly carcinogenic to humans, according to the classification scheme of the Bureau of Chemical Hazards of Health Canada (Health Canada 1994). Substances classified as "possibly carcinogenic to humans" are generally assessed by Health Canada in a manner similar to threshold toxicants. Based on the NOEL of 3 mg·kg^{-1} bw per day reported in both a subchronic reproductive study and a limited chronic study (Schwetz et al. 1978), and using an uncertainty factor of 1000 (10 each for intra- and interspecies variation, and 10 for limited evidence of carcinogenicity, reproductive and teratogenic effects, and limitations of chronic studies), a provisional TDI of 3 µg·kg^{-1} bw per day was established (CCME 1997).

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 PCP soil quality guidelines are provided in CCME (1997).

Soil Quality Guidelines for Environmental Health

The environmental soil quality guidelines (SQG_Es) are 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. To provide a broader scope of protection, a nutrient and energy cycling check is calculated. For industrial land use, an off-site migration check is also calculated (Table 2).

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 becomes the soil quality guideline for soil contact.

For agricultural land use, the lower of the soil quality guideline for soil contact and the soil and food ingestion guideline is recommended as the SQG_E.

For residential/parkland and commercial land uses, the soil quality guideline for soil contact is recommended as the SQG_E.

For industrial land use, the lower of the soil quality guideline for soil contact and the off-site migration check is recommended as the SQG_E.

In the case of PCP, there are insufficient data to calculate the nutrient and energy cycling check or the soil and food ingestion check. Therefore, the soil contact guidelines are recommended as the SQG_Es for all land uses (Table 2).

The results of the groundwater check for the protection of aquatic life are reported over a range of pH; the adsorption of PCP to soil as well its solubility in soil pore water and groundwater will vary significantly with pH. Although the groundwater check value is not applied in the determination of environmental soil quality guidelines, its application should be evaluated on a site-specific basis (Table 2).

Soil Quality Guidelines for Human Health

The PCP soil concentration, based on direct exposure from soil ingestion, has been approved by the Standards and Guidelines Rulings Committee of the Bureau of Chemical Hazards of Health Canada as a preliminary human health soil quality guideline. However, the CCME recommends the application of various check mechanisms, when relevant, in order to provide a broader scope of protection. For PCP, the lowest of the soil ingestion guideline, the inhalation of indoor air check, the off-site migration check, and groundwater for drinking water check is recommended as the SQG_{HH}. Therefore, for PCP, the SQG_{HH} is the groundwater check for drinking water for all land uses (Table 2).

Soil Quality Guidelines for PCP

The soil quality guidelines for PCP are the lower of the SQG_{HH} and SQG_E for each land use. For all land uses, the soil quality guideline is the soil concentration calculated for the SQG_{HH}, which is based on the protection of groundwater for drinking water (Table 1).

Because there are sufficient data to calculate an SQG_{HH} and an SQG_E for each land use, the soil quality guideline represents a fully integrated de novo guideline for each land use, derived according to the soil protocol (CCME 1996a). The interim soil quality criteria (CCME 1991) for PCP are superseded by the soil quality guidelines.

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

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Table 2. Soil quality guidelines and check values for pentachlorophenol ($mg \cdot kg^{-1}$).

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Guideline	**7.6**[a]	**7.6**[a]	**7.6**[a]	**7.6**[a]
Human health guidelines/check values				
SQG_{HH}	7.6[b]	7.6[b]	7.6[b]	7.6[b]
Soil ingestion guideline	93	93	340	7500
Inhalation of indoor air check	66 000	66 000	240 000	280 000
Off-site migration check	—	—	—	1 300
Groundwater check (drinking water) pH 7.0	7.6	7.6	7.6	7.6
Produce, meat, and milk check	NC[c]	NC[c]	—	—
Provisional SQG_{HH}	NC[d]	NC[d]	NC[d]	NC[d]
Limiting pathway for provisional SQG_{HH}	ND	ND	ND	ND
Environmental health guidelines/check values				
SQG_E	11[e]	11[e]	28[e]	28[e]
Soil contact guideline	11	11	28	28
Soil and food ingestion guideline	NC[f]	—	—	—
Nutrient and energy cycling check	NC[f]	NC[f]	NC[f]	NC[f]
Off-site migration check	—	—	—	160
Groundwater check (aquatic life) pH 4.5	7.4[g]	7.4[g]	7.4[g]	7.4[g]
pH 5.0	4.0	4.0	4.0	4.0
pH 5.5	1.7	1.7	1.7	1.7
pH 6.0	0.58	0.58	0.58	0.58
pH 6.5	0.19	0.19	0.19	0.19
pH 7.0	0.063	0.063	0.063	0.063
pH 7.5	0.022	0.022	0.022	0.022
pH 8.0	0.009	0.009	0.009	0.009
Provisional SQG_{HH}	NC[h]	NC[h]	NC[h]	NC[h]
Limiting pathway for provisional SQG_{HH}	ND	ND	ND	ND
Interim soil quality criterion (CCME 1991)	0.05	0.5	5	5

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 an SQG_{HH} and an SQG_E. Therefore the soil quality guideline is the lower of the two and represents a fully integrated de novo guideline for this land use, derived in accordance with the soil protocol (CCME 1996a). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

[b]The SQG_{HH} is the lowest of the human health guidelines and check values.

[c]Calculated for nonpolar organic compounds. Because PCP is a polar organic compound in its dissociated form, the check is not calculated.

[d]Because data are sufficient and adequate to calculate an SQG_{HH} for this land use, a provisional SQG_{HH} is not calculated.

[e]The SQG_E is based on the soil contact guideline value.

[f]Data are insufficient/inadequate to calculate this value.

[g]The groundwater check (aquatic life) value has not been applied in the determination of the soil quality guideline. The applicability of the groundwater check (aquatic life) values should be determined on a site-specific basis.

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

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This fact sheet was originally published in the working document entitled “Recommended Canadian Soil Quality Guidelines” (Canadian Council of Ministers of the Environment, March 1997, Winnipeg). A revised and edited version is presented here.

Reference listing:

Canadian Council of Ministers of the Environment. 1999. Canadian soil quality guidelines for the protection of environmental and human health: Pentachlorophenol (1997). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

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