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Canadian Soil Quality Guidelines for

Ethylene Glycol: Environmental

**Supporting Document — Final Draft
December 1996**

NOTICE

This final draft document provides the information supporting the derivation of environmental soil quality guidelines for ethylene glycol. Development of these soil quality guidelines was initiated through the National Contaminated Sites Remediation Program (NCSRSP) which officially ended in March 1995. Given the need for national soil quality guidelines for contaminated sites management and many other applications, development was pursued under the direction of the CCME Soil Quality Guidelines Task Group after the end of the NCSRSP.

This document is a working document that was released shortly after the publication of "A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines" (CCME 1996). The CCME recognizes that some refinements or changes to the Protocol may become necessary upon application and testing. If required, amendments to the Protocol will be made and the guidelines will be modified accordingly. For this reason guidelines are referred to in this document as CCME Recommended Guidelines. Readers who wish to comment or provide suggestions on the Protocol or on the guidelines presented in this document should send them to the following address:

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This document is a supporting technical document. It is available in English only. A French Abstract is given on page vii.

Ce document technique de soutien n'est disponible qu'en anglais avec un résumé en français présenté à la page vii.

Erratum: An error has occurred in the conversion of data from mL·L⁻¹ to mg·kg⁻¹. This error slightly affects the calculated SQG_E—provisional for Agricultural, Residential/Parkland, Commercial and Industrial land uses. Pages 11 and 12 of the document intitled “Canadian Soil Quality Guidelines for Ethylene Glycol: Environmental. Supporting Document: Final Draft, December 1996.” should be modified as follows:

Page 11, paragraph 2 should read:

From the available data based on direct soil contact experiments (Tables 5, 6, 7), the lowest reported effective concentrations come from a study by Kilroy and Gray (1992) on microbial respiration. Hence, a provisional nutrient and energy cycling check was first calculated. The concentrations reported by Kilroy and Gray (1992) to inhibit oxygen consumption by 50% were 202.36 mL·L⁻¹, 154.79 mL·L⁻¹, and 192.65 mL·L⁻¹ (see Table 5). These concentrations were converted to dry weight concentrations of **22.5 mg·kg⁻¹, 17.2 mg·kg⁻¹, and 21.5 mg·kg⁻¹** respectively, using the following equilibrium partitioning equation (CCME 1996, CCME 1997):

$$Y = C_w (K_{oc} \times f_{oc} + \theta_m)$$

where,

Y = Total contaminant concentration in solid phase at equilibrium

C_w = Aqueous phase concentration (mg/L), **calculated using a density of 1.1135 mg/mL for ethylene glycol (Budavari et al. 1989)**

K_{oc} = Organic carbon partitioning coefficient (L/kg), calculated as 0.41 x K_{ow}, where K_{ow} is the octanol-water partition coefficient (CCME 1997) (Log K_{ow} = -1.36, see Table 1)

f_{oc} = Organic fraction of dry matter (g/g), default: 0.003 (CCME 1997)

θ_m = Mass moisture content (L/kg), default: 0.1 (CCME 1996)

The Provisional nutrient and energy cycling check value was taken as the geometric mean of the above calculated dry weight concentrations. Thus:

$$\text{Provisional nutrient and energy cycling check} = (22.5 \times 17.2 \times 21.5)^{1/3} = 20 \text{ mg} \cdot \text{kg}^{-1} \text{ soil}$$

The top of page 12 should read:

cycling check was taken as the SQG_E—provisional. Hence, the SQG_E—provisional for Agricultural and Residential/Parkland land uses is:

$$[(5300 / 10) \times 20]^{1/2} = 103 \text{ mg} \cdot \text{kg}^{-1}$$

For Commercial and Industrial land uses, the geometric mean of the available EC₂₅ endpoint values listed above, which are based on direct soil contact experiments was first calculated. Then, the SQG_E—provisional was taken as equal to the geometric mean of the results from this first calculation and the Provisional nutrient and energy cycling check. Hence, the SQG_E—provisional for Commercial and Industrial land uses is:

$$[(5300 \times 7300 \times 20\ 000)^{1/3} \times 20]^{1/2} = 428 \text{ mg} \cdot \text{kg}^{-1}$$

5.3 Groundwater Check

Table 9 should read:

Table 9: Summary of environmental soil quality guidelines for ethylene glycol

Guideline	Land Use		
	Agriculture mg·kg ⁻¹	Residential/Parkland mg·kg ⁻¹	Commercial/Industrial mg·kg ⁻¹
TEC or ECL ^(a)	Insufficient data	Insufficient data	Insufficient data
Nutrient and Energy Cycling Check	Insufficient data	Insufficient data	Insufficient data
SQG _{SC}	Insufficient data	Insufficient data	Insufficient data
SQG _I	Insufficient data	Insufficient data	Insufficient data
Groundwater check for the protection of freshwater aquatic life	960	960	960
Provisional SQG _E	103	103	428

(a) As per CCME (1996) protocol, the SQG_{SC} for Agricultural and Residential/Parkland land uses corresponds to the 25th percentili of the effects and no effects data distribution when using the Weight of Evidence method, while the SQG_{SC} for Commercial/Industrial land use corresponds to the 25th percentile of the effects only data distribution.

End of corrections

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Table 9: Summary of environmental soil quality guidelines for ethylene glycol

ABSTRACT

Canadian environmental quality guidelines, developed under the auspices of the Canadian Council of Ministers of the Environment (CCME), are numerical concentrations or narrative statements recommended to support and maintain designated resource uses. CCME Canadian soil quality guidelines can be used as the basis for consistent assessment and remediation of contaminants at sites in Canada.

This report was prepared by the Guidelines Division of the Science Policy and Environmental Quality Branch (Environment Canada), which acts as Technical Secretariat for the CCME Soil Quality Guidelines Task Group. The Guidelines were derived according to the procedures described in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 1996).

Following the introduction, chapter 2 presents chemical and physical properties of ethylene glycol and a review of the sources and emissions in Canada. Chapter 3 discusses ethylene glycol's distribution and behavior in the environment while chapter 4 reports the toxicological effects of ethylene glycol on microbial processes, plants, and animals. These informations are used in chapter 5 to derive soil quality guidelines for ethylene glycol to protect environmental receptors in four types of land uses: agricultural, residential/parkland, commercial, and industrial.

The following soil quality guidelines are recommended by the CCME based on the available scientific data. For ethylene glycol, the available data were insufficient/inadequate to derive soil quality guidelines according to the CCME 1996 Protocol. Therefore, the Provisional Method, described in CCME (1997) and hereafter was used to derive provisional environmental soil quality guidelines for ethylene glycol. The provisional environmental soil quality guideline (SQG_E —provisional) for agricultural and residential/parkland land uses is $97 \text{ mg}\cdot\text{kg}^{-1}$ soil whereas for commercial and industrial land uses it is $410 \text{ mg}\cdot\text{kg}^{-1}$ soil.

RÉSUMÉ

Les recommandations canadiennes pour la qualité de l'environnement, élaborées sous les auspices du Conseil Canadien des Ministres de l'Environnement (CCME), sont des concentrations ou des énoncés décrivant les limites recommandées dans le but d'assurer le maintien et le développement durable d'utilisations désignées des ressources. Les recommandations canadiennes pour la qualité des sols proposées par le CCME peuvent être utilisées comme base pour l'uniformisation des processus d'évaluation et d'assainissement des terrains contaminés au Canada.

Le présent document a été préparé par la Division des Recommandations de la Direction de la Qualité de l'Environnement et de la Politique Scientifique (Environnement Canada), qui agit comme secrétaire technique pour le Groupe de Travail du CCME sur les Recommandation pour la Qualité des Sols. Les Recommandations ont été élaborées selon les procédures décrites dans le *Protocole d'élaboration de recommandations pour la qualité des sols en fonction de l'environnement et de la santé humaine* (CCME 1996).

Faisant suite à une brève introduction, le chapitre 2 présente les propriétés physiques et chimiques de l'éthylène glycol de même qu'un survol des sources et des émissions au Canada. Le chapitre 3 discute du devenir et du comportement de cette substance dans l'environnement alors que le chapitre 4 rapporte ses effets toxicologique sur les processus microbiens, les plantes et les animaux. Ces informations sont utilisées au chapitre 5 afin d'élaborer des recommandations pour la qualité des sols relatives à l'éthylène glycol en vue de la protection de l'environnement dans le cadre de quatre types d'utilisations de terrains: agricole, résidentiel/parc, commercial et industriel.

Les recommandation pour la qualité des sols suivantes, proposées par le CCME, sont fondées sur les données scientifiques disponibles. Pour l'éthylène glycol, les données disponibles sont insuffisantes/inadéquates pour permettre l'élaboration de recommandations selon les procédures décrites dans le Protocole du CCME (1996). Ainsi, la Méthode provisoire, décrite dans un document du CCME (1997) et ci-après, a été utilisée pour élaborer des recommandations provisoires pour la qualité des sols relatives à l'éthylène glycol en vue de la protection de l'environnement. La recommandation provisoire pour la qualité des sols en vue de la protection de l'environnement (RQS_E —provisoire) visant les terrains à vocation agricole et résidentielle/parc est de $97 \text{ mg} \cdot \text{kg}^{-1}$ de sol, alors que pour les terrains à vocation commerciale et industrielle, elle est de $410 \text{ mg} \cdot \text{kg}^{-1}$ de sol.

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1. INTRODUCTION

The Canadian Council of Ministers of the Environment's (CCME) Canadian Environmental Quality Guidelines are numerical limits for contaminants intended to maintain, improve, or protect environmental quality and human health. CCME Canadian Soil Quality Guidelines can be used as the basis for consistent assessment and remediation of contaminants at sites in Canada, along with CCME guidelines issued for the protection of water quality, sediment quality and tissue quality. In response to the urgent need to begin remediation of high priority "orphan" contaminated sites, an interim set of criteria was adopted from values currently in use in various jurisdictions across Canada (CCME 1991). Many of the interim soil remediation criteria do not have complete supporting scientific rationale and are being updated based on current scientific information.

This report reviews the sources and emissions of ethylene glycol, its distribution and behaviour in the environment, and its toxicological effects on microbial processes, plants, and animals. This information is used to derive criteria for ethylene glycol to protect ecological receptors according to the processes outlined in CCME (1996) for agricultural, residential/parkland, commercial and industrial land uses.

The values derived herein are environmental soil quality guidelines and are intended as general guidance. Site specific conditions should be considered in the application of these values. The values may be applied differently in various jurisdictions, therefore, the reader should consult the appropriate jurisdiction for application of the values.

2. BACKGROUND INFORMATION

2.1 Physical and Chemical Properties

Ethylene glycol belongs to a group of organic chemicals named dihydric or aliphatic alcohols, which are characterized by two hydroxyl (OH^-) functional groups attached to methyl subunits in an aliphatic chain. The physical and chemical properties of ethylene glycol are presented in Table 1.

Ethylene glycol is a clear colourless, odourless, relatively non-volatile, viscous liquid with a melting point of -13°C , a boiling point of 197.6°C and a flash point of 111 to 115°C (Nielsen *et al.* 1993). It has a sweet taste and imparts a warming sensation to the tongue when swallowed (Beasley and Buck 1980). Ethylene glycol has a low vapour pressure of 6.7 Pa (0.05 mm Hg) at 20°C and a low Henry's law constant of $6 \times 10^{-8} \text{ atm}\cdot\text{m}^3\cdot\text{mole}^{-1}$, hence it is relatively non-volatile. It is miscible in water and solvents such as acetone, formaldehyde, glycerol, and acetic acid. It is sparingly soluble in ether, and insoluble in benzene, chlorinated hydrocarbons, and oils (Budavari *et al.* 1989; ENVIRO TIPS 1985). It is very hygroscopic and will absorb up to 200% its weight in water at 100% relative humidity (Budavari *et al.* 1989). In the atmosphere it reacts with hydroxyl radicals (Howard 1990).

The octanol/water partition coefficient of ethylene glycol is very low *ie.* -1.36 and hence, bioaccumulation is not expected to be significant (Verschuere 1983; Budavari *et al.* 1989; Howard 1990).

2.2 Analytical Methods

Both colorimetric and chromatographic methods are available for measuring ethylene glycol in the environmental media. In colorimetric methods, ethylene glycol is oxidized to aldehydes and quantified colorimetrically. Colorimetric methods are considered relatively imprecise and do not differentiate between different types of glycols. Gas chromatography (GC) and high performance liquid chromatography (HPLC) are the most commonly used techniques. Using the HPLC method, Wu *et al.* (1985) reported a 98.8% recovery with samples containing 12 to 100 mg·L⁻¹. The preferred method for the determination of ethylene glycol in soils is the extraction with water and analysis using gas chromatography in combination with flame ionization detection (GC/FID).

2.3 Production and Uses in Canada

Information on ethylene glycol production, importation and consumption in Canada is presented in Table 2. In Canada, ethylene glycol is produced by Dow Chemical Canada Inc., Union Carbide Inc., and Alberta & Orient Glycol with a production capacity of 825 ktons (CPI 1994). In 1993, total consumption of ethylene glycol in Canada was 147.7 ktons glycol (CPI 1994). The major use of ethylene glycol in Canada is for antifreeze purposes, accounting 65% of total consumption (SRI 1993). Other uses include polyester fibres and films, polyethylene terephthalate, oil and gas processing, explosives and resins (CPI 1994).

2.4 Levels in Canadian Environment

A summary of ethylene glycol concentrations in the Canadian environment is presented in Table 3. Very little information is available regarding ethylene glycol levels in the Canadian terrestrial environment.

Ethylene glycol is used at airports for de-icing and anti-icing, and hence, high environmental concentrations are expected in and around airports. Most of the glycol used at airports is released to the environment via stormwater, and some to groundwater through leaching. An average ethylene glycol concentration of 1814 mg·L⁻¹ was reported in stormwater at Ottawa International Airport and the maximum recorded concentration was 19 800 mg·L⁻¹ in 1985 (Transport Canada 1985a). The maximum concentration reported in groundwater at Ottawa International Airport was 415 mg·L⁻¹ in 1985 and 1986 and was reported to be highly variable with season (Transport Canada 1985b; 1987). At Pearson International Airport, concentrations ranging from 75 to 3200 mg·L⁻¹ were reported in stormwater drains leading to nearby creeks in 1986-87 (Transport Canada 1989b). At

Halifax International Airport, total glycol concentrations from < 10 to $16\,400\text{ mg}\cdot\text{L}^{-1}$ were reported in stormwater drains at airport boundaries in 1989-90 (Transport Canada 1990).

Formulated ethylene glycol, used as aircraft de-icing fluid, is applied using high pressure equipment, which results in the formation of fine mist in the vicinity of the de-icing operation. Percy (1992) reported air concentrations of 3.2 to $4.1\text{ mg}\cdot\text{m}^{-3}$ at Thunder Bay Airport during de-icing operations.

No data is available on levels of ethylene glycol in Canadian soils and sediments. Based on its physical and chemical properties (high solubility and low K_{OW} and K_{OC}), it is unlikely that significant quantities of ethylene glycol are retained in soils (Howard 1990).

Additional sources of entry into the environment may include glycol production, use and disposal of glycol products such as antifreeze, and manufacturing processes using glycols (Miller 1979). Ethylene glycol is released in to the environment during manufacturing via evaporation (at high temperatures), drying and distillation towers and columns, and also via fugitive emissions at valves, seals and vents due to accidental leaks and spills (Nielsen *et al.* 1993). At low temperatures, as the volatility of ethylene glycol is low, it will not be released to the atmosphere in large quantities. Releases in wastewater stream will be more significant.

2.5 Existing Criteria and Guidelines

Existing criteria and guidelines for ethylene glycol in soils are presented in Table 4.

3. ENVIRONMENTAL FATE AND BEHAVIOUR

The soil factors that determine the fate and behaviour of ethylene glycol in the terrestrial environment are pH, organic matter, clay content, cation exchange capacity, aeration and texture. The major processes that determine the mobility and distribution of ethylene glycol in the terrestrial environment are leaching, biodegradation and photolysis, where as volatilization and sorption are relatively minor fate processes.

Ethylene glycol has a low vapour pressure (0.05 mm at 20°C) which indicates that volatilization is not an important fate process under most conditions (MacDonald *et al.* 1992). Also, it's relatively low Henry's law constant of 6×10^{-8} suggests that ethylene glycol will not evaporate rapidly from soils (Howard 1990, Nielsen *et al.* 1993). In the atmosphere, ethylene glycol reacts with hydroxyl radicals and a hydroxyl radical rate constant of $7.7\times 10^{-12}\text{ cm}^3\cdot\text{mol}^{-1}\cdot\text{sec}^{-1}$ has been reported (Howard 1990). A half-life of one day in the atmosphere was reported for ethylene glycol by Howard (1990) and Nielsen *et al.* (1993)

Ethylene glycol has a low K_{OW} ($\log K_{\text{OW}} = -1.36$) and a high water solubility, hence it will not bioconcentrate (Howard 1990; Sills and Blakeslee 1992) and has very low potential for soil and sediment adsorption (Abdelghani *et al.* 1990; Howard 1990, Nielsen *et al.* 1993; Lokke 1984;

MacDonald *et al.* 1992). Soil adsorption coefficients of 0 to 0.62 have been reported by Lokke (1984). But since it is miscible in water, it has high potential for leaching to groundwater (Nielsen *et al.* 1993; Lokke 1984). Field studies showed that a 10% ethylene glycol solution moved through silt sand at an average rate of $0.6 \text{ m} \cdot \text{day}^{-1}$ (Transport Canada 1987). Ethylene glycol is also prone to surface transport with surface and stormwater.

Ethylene glycol has no hydrolysable groups and is thus not subjected to hydrolysis (Lyman *et al.* 1982; SRC 1989). On the other hand, photodegradation of ethylene glycol has been reported in several studies (Freitag *et al.* 1985; Atkinson 1985). When ethylene glycol, absorbed on silica gel, was irradiated with light (wavelength $> 290 \text{ nm}$) for 17 hours, 12% of ethylene glycol applied was degraded (Freitag *et al.* 1985). Photo-oxidation was reported to be directly proportional to light intensity (Cunningham *et al.* 1985). A photo-oxidation half-life for ethylene glycol between 0.35 and 3.5 days has been reported by SRC (1989).

Ethylene glycol is biodegraded both in aerobic (Means and Anderson 1981; Willetts 1981; Haines and Alexander 1975) and anaerobic conditions (Howard 1990; Dwyer and Tiedje 1983; Gaston and Stadtman 1963) in soils, sediments and sewage sludge. Degradation under methanogenic conditions has also been reported (Dwyer and Tiedje 1983; Battersby and Wilson 1989). Under aerobic conditions, ethylene glycol is degraded by species such as *Pseudomonas sp* and *Flavobacterium sp*. to glycolate and eventually to CO_2 (Haines and Alexander 1975; Willetts 1981). Under anaerobic conditions, it is degraded by anaerobic bacteria such as *Clostridium glycolicum* and converted to ethanoic acid and ethanol (Gaston and Stadtman 1963). Under methanogenic conditions, it is degraded by bacteria species such as *Methanobacterium sp* and *Desulfovibrio sp*. to methane, ethanol and acetate (Dwyer and Tiedje 1983; Battersby and Wilson 1989).

Sewage microorganisms are capable of degrading up to $1000 \text{ mg ethylene glycol} \cdot \text{kg}^{-1}$ and pure cultures of microorganisms up to $300 \text{ mg} \cdot \text{L}^{-1}$ (Daugherty 1980). Micronutrient availability may be a limiting factor in the degradation of glycols (Jerger and Flathman 1990; McGahey and Bouwer 1992). A biodegradation rate, as measured by chemical oxygen demand, of $41.7 \text{ mg} \cdot \text{COD} \cdot \text{g}^{-1} \cdot \text{hour}^{-1}$ was reported by Pitter (1976). Some workers reported a lag period of up to 3 days (Boatman *et al.* 1986; Means and Anderson 1981; McGahey and Bouwer 1992), whereas others reported no such lag period (Pitter 1976; Zahn and Wellens 1980). Half-lives ranging from 6 h to 22 h have been reported by McGahey and Bouwer (1992), where as Howard *et al.* (1991) reported soil half lives of 2 to 12 days for ethylene glycol.

4. BEHAVIOUR AND EFFECTS IN BIOTA

4.1 Soil Microbial Processes

The available information on the toxicity of ethylene glycol to terrestrial microorganisms and microbial processes is presented in Table 5.

Very few studies on the effects of ethylene glycol on terrestrial microorganisms and microbial processes are available. These studies report inhibitory effects from ethylene glycol concentrations varying between a few $\text{mL}\cdot\text{L}^{-1}$ to $20000 \text{ mg}\cdot\text{L}^{-1}$, depending on the type of microorganism and the medium (Daugherty 1980; Stahl and Pessen 1953). Kilroy and Gray (1992) reported an EC_{50} of $202.36 \text{ mL}\cdot\text{L}^{-1}$ on respiration inhibition in a mixture of municipal sludge and synthetic sewage. The EC_{50} values for respiration inhibition for factory sludge/synthetic sewage and factory sludge/factory feed were 154.79 and $192.65 \text{ mL}\cdot\text{L}^{-1}$, respectively. The tests were conducted following the procedure of ISO activated sludge respiration inhibition test. Whereas, Klecka and Landi (1985) reported an IC_{50} of $> 1000 \text{ mg}\cdot\text{L}^{-1}$ on microbial respiration in a 3 h incubated activated sludge using OECD activated sludge respiration inhibition test. IC_{50} is the concentration of the chemical in the test substance at which the respiration rate is 50% of that observed in untreated controls.

Khoury *et al.* (1990) reported an average toxic endpoint, IC_{50} , of $114,300 \text{ mg}\cdot\text{L}^{-1}$ on heterotrophic soil microorganisms. The toxicity was measured using oxygen uptake and growth by turbidity test (Alsop assay). The Bauer assay, where short term oxygen depletion is used as a measure of toxicity, was also studied. The T_{50} values (time required for 50% depletion in dissolved oxygen) were estimated at 44.5, 64.5, 68.9, and 96.5 minutes for levels of 0, 10, 20, and 30%, ethylene glycol (v/v) in the test medium, respectively. Activity coefficient ($\text{T-50 control/T-50 test}$) showed that ethylene glycol was moderately toxic at 20%, and extremely toxic at 30% of the test medium.

Daugherty (1980) reported that the *Pseudomonas aeruginosa* is capable of degrading ethylene glycol up to $1000 \text{ mg}\cdot\text{L}^{-1}$ while concentrations greater than $2000 \text{ mg}\cdot\text{L}^{-1}$ were found to be inhibitory. Tests were conducted in culture medium incubated for 10 days at 25°C . Stahl and Pessen (1953) reported the inhibitory effect for the same organism at $20\,000 \text{ mg}\cdot\text{L}^{-1}$.

4.2 Terrestrial Plants

The available information on the toxicity of ethylene glycol to terrestrial plants is presented in Table 6.

Environment Canada (1995) studied the toxicity of ethylene glycol on seedling emergence and root elongation in radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*). Seedling emergence studies were conducted in artificial soil (pH 4 to 4.2, sand 72 to 75%, clay 16 to 19%, silt 8 to 9%, organic matter 4.7 to 6.3% and moisture 80% water holding capacity). The radish and lettuce seeds were exposed to ethylene glycol soil concentrations of 0 to 26100 and 0 to $52000 \text{ mg}\cdot\text{kg}^{-1}$, respectively. Tests were conducted according to the Protocol for Short Term Toxicity Screening of Hazardous Waste Sites, EPA 600/3-88-029 (Greene *et al.* 1989). All the reported values are based on measured concentrations. The NOEC, LOEC, EC_{25} and EC_{50} for seedling emergence were 3500, 7400, 5300, and $7300 \text{ mg}\cdot\text{kg}^{-1}$ for radish (72 h) and 6000, 13000, 9000, and $12000 \text{ mg}\cdot\text{kg}^{-1}$ for lettuce (120 h), respectively (Table 6). The LOEC for seedling emergence corresponded to 41 and 64% for radish and lettuce, respectively. Root elongation studies were conducted with nutrient solutions using petri dishes. NOEC, LOEC, EC_{25} , and EC_{50} toxicity values of 11000, 25000, 17000, and $25000 \text{ mg}\cdot\text{L}^{-1}$

for radish, and 18000, 31000, 32000, and 42000 mg·L⁻¹ for lettuce, respectively, have been reported. LOECs corresponded to 47% and 24% reduction in root growth in radish and lettuce, respectively.

Reynolds (1977) reported an LC₅₀ of 55 mg·L⁻¹ for germination of lettuce (*Lactuca sativa* L. cv.) seeds exposed to ethylene glycol. Germination tests were conducted for 72 h at 30 °C with nutrient solution. Lipophilicity was reported to be the major factor regulating the inhibitory activity, even though other factors such as low osmotic potential and metabolic acceptability play a role. The passage of the chemical inhibitor across the various cell membranes of the seed to the site of action depends on lipophilicity of the molecule. Compounds with a hydroxyl (OH) group were reported to inhibit lettuce seed germination in direct proportion to the lipophilicity of the molecule (Reynolds 1974).

4.3 Terrestrial Invertebrates

The available information on the ethylene glycol toxicity to terrestrial invertebrates is presented in Table 7. Very little information is available on the toxicity of ethylene glycol to terrestrial invertebrates.

Environment Canada (1995) determined 14 day NOEC, LOEC, LC₂₅ and LC₅₀ values for earthworms (*Eisenia fetida*) exposed to ethylene glycol in artificial soils (pH 4 to 4.2, sand 72 to 75%, clay 16 to 19%, silt 8 to 9%, organic matter 4.7 to 6.3%, and moisture 80% of water holding capacity). The worms were exposed to ethylene glycol concentrations ranging from 0 to 94,000 mg·kg⁻¹. Tests were conducted according to the Protocol for Short Term Toxicity Screening of Hazardous Waste Sites, EPA 600/3-88-029 (Greene *et al.* 1989). The reported NOEC, LOEC, LC₂₅ and LC₅₀ were 16000, 36000, 20000 and 25000 mg·kg⁻¹ soil, respectively, based on measured concentrations (Table 7).

4.4 Mammals and Birds

Uptake, Metabolism and Excretion

Ethylene glycol imparts a sweet or semi-sweet taste to fluids such as antifreeze and apparently attracts animals to consume it. Ethylene glycol poisoning is common among domestic animals and has been reported in cats, pigs, poultry, wildlife, and calves (Amstrup *et al.* 1989; Black 1983; Kersting and Nielsen 1965; Riddell *et al.* 1967).

In the absence of food, ethylene glycol is rapidly absorbed from the gastro-intestinal tract and the initial toxic effects are seen within an hour (Paton 1989). Levels of ethylene glycol in serum and urine peak at three and six hours, respectively (Paton 1989).

According to Black (1983), ethylene glycol itself is not toxic, however, its intermediary oxidation products are the active toxicants. Ethylene glycol is metabolized by alcohol and aldehyde

dehydrogenases in the liver and the main metabolites are glycoaldehyde, glycolic acid, glyoxylic acid, and glycolate. Glycolic acid was reported to be more toxic than ethylene glycol (Beasley and Buck 1980). Chou and Richardson (1978) observed a direct correlation between urinary glycolate levels and mortality and reported that the glycolate is the primary toxic metabolite of ethylene glycol. These metabolites produce severe metabolic acidosis causing death. Glyoxylate is further oxidized to formic acid, glycine, CO_2 , and oxalate. Oxalic acid forms salts with Ca, and accumulates in several tissues causing epithelial destruction. Calcium oxalate crystal formation due to ethylene glycol has been reported by several workers (Black 1983; Schiefer and Moffatt 1974).

The relative toxicity of the intermediates in ethylene glycol metabolism is : glyoxylate > glycoaldehyde > glycolate > ethylene glycol (Beasley and Buck 1980; Bove 1966; Richardson 1973). Glycine may be converted to serine and other amino acids or added to benzoic acid to form hippuric acid (Chou and Richardson 1978; Beasley and Buck 1980).

Significant quantities of ethylene glycol are excreted in first 24 hours after exposure and especially during the first 4 hours in Rhesus monkey (Beasley and Buck 1980). At 24 hours after dosing, virtually no ethylene glycol was detected in the urine or tissues of monkeys (McChesney *et al.* 1971). Ethylene glycol is also metabolized and excreted as CO_2 especially during the first 24 hours of poisoning (Gessner *et al.* 1961; McChesney *et al.* 1971).

Toxicity

The available information on the toxicity of ethylene glycol to mammals and birds is presented in Table 8.

Ethylene glycol is a slow-acting poison. Even after massive dose, an animal will be unaffected for 0.5 to 2 h post exposure (Beasley 1985; Grauer and Thrall 1986; Lakshmipaty and Oehme 1975; Oehme 1983). The toxicity of ethylene glycol varies among species. Cats were reported to be the most susceptible to poisoning (Osweiler *et al.* 1985). The reported lethal dose for cats is only $1.5 \text{ mL} \cdot \text{kg}^{-1}$ (Black 1983), whereas for dogs it is 4.2 to $6.6 \text{ mL} \cdot \text{kg}^{-1}$ bw (Beasley and Buck 1980; Grauer and Thrall 1986; Oehme 1983). Osweiler *et al.* (1985) reported a lethal dose of 2 to $4 \text{ mL} \cdot \text{kg}^{-1}$ bw in cats, 4 to $5 \text{ mL} \cdot \text{kg}^{-1}$ bw in dogs and 7 to $8 \text{ mL} \cdot \text{kg}^{-1}$ bw in poultry.

Ingestion of small doses of ethylene glycol may affect the central nervous system within 1 to 6 h, resulting in weakness, depression, vomiting, and muscular incoordination. Ingestion of large dose causes severe depression, metabolic acidosis, coma, cardiopulmonary collapse and death within 12 hours. Production of coffee-coloured urine may occur during the acute stage (Beasley and Buck 1980), followed by progressive incoordination, depression, loss of reflexes and coma during the first 24 hours (Penumarthy and Oehme 1975). Formation of oxalate crystals and lesions in kidneys due to ethylene glycol poisoning has been reported in swine, cattle, sheep, cats and dogs (Boermans *et al.* 1988; Beasley 1985; Crowell *et al.* 1979; Osweiler and Eness 1972; Osweiler *et al.* 1985). In poultry, Riddell *et al.* (1967) reported drowsiness, ataxia, dyspnea, and torticollis followed by ruffled feathers, watery droppings, recumbency and death due to ethylene glycol poisoning.

In cattle, ethylene glycol poisoning has been reported by Crowell *et al.* (1979). Calves and cows ranging from 0.8 to 48 months old and weighing 26 to 493 kg were exposed orally to ethylene glycol at 0 to 10 mL·kg⁻¹ bw. The toxic dose was reported at 2 mL·kg⁻¹ bw and the symptoms were increased respiration, staggering gait, paraparesis, depression and later, recumbency and death. Of the 10 animals tested, 7 died due to ethylene glycol poisoning at doses from 2 to 10 mL·kg⁻¹ bw.

Birds such as chickens and ducks are also susceptible to ethylene glycol poisoning (Riddell *et al.* 1967; Freytag and Tettenborn 1963; Schwarzmaier 1941). Riddell *et al.* (1967) exposed 6 month old chickens to ethylene glycol concentration of 0, 6, 13, 25, 42, 59, 76 and 93 mL·L⁻¹ in drinking water (corresponding to 0, 0.7, 1.5, 2.8, 4.8, 6.7, 8.6, and 10.6 mL·kg⁻¹ bw, respectively). In acute studies, the chickens were exposed for 24 h at high doses (2.8 to 10.6 mL·kg⁻¹ bw) and in chronic studies for 14 days at low doses (< 2.8 mL·kg⁻¹ bw). The reported LD₅₀ on mortality, in acute studies, was 67.5 mL·L⁻¹ drinking water corresponding to 7.7 mL·kg⁻¹ bw. Clinical signs (renal oxalosis) were observed at doses >2.8 mL·kg⁻¹ bw. The birds in chronic studies on continuous lower doses were not affected clinically. Calcium oxalate crystals in renal tubules were found consistently in chickens treated with ethylene glycol and are suggested as a diagnostic symptom for ethylene glycol poisoning. Schwarzmaier (1941) also reported an LD₅₀ at 7.5 mL·kg⁻¹ bw in hens. The hens died within 16 to 38 h after treatment. Swollen kidneys containing oxalate crystals due to ethylene glycol poisoning have been reported by Freytag and Tettenborn (1963).

Stowe *et al.* (1981) treated mallard ducks with ethylene glycol orally at 0, 1.1, 2.3, 4.5, 8.9, 13.3, and 17.8 mL·kg⁻¹ bw and reported NOED and LOED values of 1.1 and 2.3 mL·kg⁻¹ bw, respectively. As the dosage was increased, blood and tissue concentrations of ethylene glycol increased and time to death decreased. Signs of intoxication, consisting of depression and ataxia, developed within 2 to 4 hours and all ducks treated with 2.3 mL·kg⁻¹ bw and above died within 21 to 76 hours of the initial exposure.

Ethylene glycol poisoning in polar bear has been reported by Amstrup *et al.* (1989). Soil, snow and urine, sampled under the dead animal, contained high quantities of ethylene glycol (200 mg·kg⁻¹ soil) and rhodamine B, a mixture commonly used to mark roads and runways during snow and ice periods. It was concluded that there was enough ethylene glycol in the body to cause the bear's death.

Blood (1965) reported NOED value of 0.2% of ethylene glycol in the diet on mortality of male rats but the effects on females were not clear. The rats were fed with 0 to 4% of ethylene glycol in the diet for 2 years. The results also showed increased calcification of kidneys and oxalate-containing crystals at 0.5, 1 and 4% of ethylene glycol in diet in male rats.

When guinea pig, rabbit, rat, monkey and dog were exposed by inhalation to 10 and 57 mg·m⁻³ ethylene glycol for 8 hours per day, 5 days a week, no toxic effects were observed (Coon *et al.* 1970). When exposed continuously for 90 days at 12 mg·m⁻³, 20, 33 and 7% mortality was observed in guinea pigs, rabbits and rats, respectively.

Laug *et al.* (1939) administered ethylene glycol by gavage to guinea pigs, rats and mice and reported LD₅₀ values of 7.35, 5.5 and 13.1 mL·kg⁻¹ bw, respectively. The experiments were conducted over

a 10 month period and lethal doses reported were the composite results of mortality studies throughout the extent of experimental period.

Robinson *et al.* (1990) reported that the toxicity of ethylene glycol to rats varied with the period of exposure and sex. Ethylene glycol was administered in drinking water to male and female rats at 554, 1108, 2216 and 4432 mg·kg⁻¹ bw·day⁻¹ in subacute (10 day) studies, and in subchronic studies (90 day), same doses were given to females but for males, doses of 227, 554, 1108 and 2216 mg·kg⁻¹ bw·day⁻¹ were administered. No mortality occurred in the 10-day study, where as in the 90 day study, 8/10 females and 2/10 males died in the high dose group. Body weights were suppressed in a dose response fashion for males and females. Male rats were more adversely affected with exposure to ethylene glycol than were female rats. Similar effects were reported by several researchers (DePass *et al.* 1986; Melnick 1984; Richardson 1965).

Some of the studies have shown no toxic effects of ethylene glycol on animals even when high doses were administered for prolonged periods. DePass *et al.* (1986) reported no adverse effects on mortality, reproduction, weight gain or food consumption in rats receiving ethylene glycol in their diet up to 1 000 mg·kg⁻¹ bw·day⁻¹, for three generations.

5. DERIVATION OF ENVIRONMENTAL SOIL QUALITY GUIDELINES

5.1 Introduction

Canadian soil quality guidelines are designed to protect four different land uses: agricultural, residential/parkland, commercial and industrial. The derivation procedures are described in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 1996).

There were insufficient data available to meet the minimum data requirements described in the Protocol (CCME 1996), for the derivation of soil quality guidelines based on soil contact (SQG_{sc}), soil and food ingestion (SQG_i) or the nutrient and energy cycling check for any of the categories of land use. Studies were excluded from use because of one or more of the following reasons:

- soil pH was not recorded;
- soil pH was below 4 (as this is considered outside the normal pH range of most soils in Canada)
- no indication of soil texture was provided;
- inappropriate statistical analysis was used;
- test was not conducted using soil or artificial soil;
- test soil was amended with sewage sludge or a mixture of toxicants;
- test did not use controls.

Therefore, the Provisional Method, described in CCME (1997) and hereafter was used to derive Provisional Canadian Soil Quality Guidelines for ethylene glycol. Results are presented in Table 9.

5.2 Provisional Soil Quality Guidelines

Provisional Soil Quality Guidelines Derivation Method

Limitations in the availability of quality soil toxicity data hinder the derivation of soil quality guidelines since the methods described in the Protocol (CCME 1996) are all limited by minimum data requirements. However, literature searches often yield data which do not meet the requirements of the 1996 Protocol, but still provide some toxicity information. Also, toxicity tests using standard methodologies may produce data that do not meet the regular quality standards defined by toxicologists, due to difficulties in handling and evaluating certain substances such as volatile organic chemicals in the context of a soil contact test for example.

While acknowledging the need for toxicity data of the highest quality, it is the opinion of the Subcommittee that guidelines based on limited toxicity information are still more practical and scientifically defensible than the absence of guidelines or than guidelines that are not risk based. Thus, a provisional method for deriving environmental soil quality guidelines was proposed (CCME 1997). The guidelines derived using this method are called "provisional" to clearly indicate that the underlying data do not meet the requirements of the Protocol (CCME 1996) and that there is an urgent need for additional research. Also, given the increased uncertainty surrounding the provisional soil quality guidelines, such provisional guidelines may not be used to raise an existing criteria or guideline, such as the 1991 interim criteria, but only to lower it if the provisional value indicates that the existing criteria or guideline is not adequately protective.

The guiding principles described in the Protocol (CCME 1996) are to be followed while applying relaxed data requirements in order to allow the derivation of provisional soil quality guidelines. When the data requirements of one of the derivation methods described in the Protocol (CCME 1996) are met, regular soil quality guidelines must be derived. However, when the available data do not meet those requirements, professional judgement is used to evaluate the available information and to recommend a provisional soil quality guideline. The derivation of provisional soil quality guidelines is directed by the following landmarks:

- be precautionary: use higher safety factors where degree of uncertainty is high;
- use soil contact data for plants and invertebrates preferentially over mammalian data, equilibrium partitioning data or other data;
- rely on equilibrium partitioning data only to justify additional safety factors and to assist in professional judgement;
- use microbial data as a check mechanism, follow the method described in the protocol (use geometric mean of soil contact number and microbial value where microbial value is lower);
- keep in mind that provisional soil quality guidelines for agricultural and residential/parkland land uses are intended to approximate no appreciable effect levels where those for commercial/industrial land use allow for a low level of effects;
- be consistent with the spirit of the 1996 Protocol.

Derivation of Provisional Soil Quality Guidelines

Table 9 presents a summary of the results of the Provisional derivation procedures and a comparison with the CCME (1991) interim remediation criteria.

From the available data based on direct soil contact experiments (Tables 5, 6, 7), the lowest reported effective concentrations come from a study by Kilroy and Gray (1992) on microbial respiration. Hence, a provisional nutrient and energy cycling check was first calculated. The concentrations reported by Kilroy and Gray (1992) to inhibit oxygen consumption by 50% were 202.36 mL·L⁻¹, 154.79 mL·L⁻¹, and 192.65 mL·L⁻¹ (see Table 5). These concentrations were converted to dry weight concentrations of 20.2 mg·kg⁻¹, 15.5 mg·kg⁻¹, and 19.2 mg·kg⁻¹ respectively, using the following equilibrium partitioning equation (CCME 1996, CCME 1997):

$$Y = C_w (K_{oc} \times f_{oc} + \theta_m)$$

where,

Y = Total contaminant concentration in solid phase at equilibrium

C_w = Aqueous phase concentration

K_{oc} = Organic carbon partitioning coefficient (L/kg), calculated as 0.41 × K_{ow}, where K_{ow} is the octanol-water partition coefficient (CCME 1997) (Log K_{ow} = -1.36, see Table 1)

f_{oc} = Organic fraction of dry matter (g/g), default: 0.003 (CCME 1997)

θ_m = Mass moisture content (L/kg), default: 0.1 (CCME 1996)

The Provisional nutrient and energy cycling check value was taken as the geometric mean of the above calculated dry weight concentrations. Thus:

$$\text{Provisional nutrient and energy cycling check} = (20.2 \times 15.5 \times 19.2)^{1/3} = 18 \text{ mg} \cdot \text{kg}^{-1} \text{ soil}$$

However, according to the Protocol (CCME 1996), guidelines should not be based uniquely on microbial data. Hence, the available direct soil contact data was used in combination with the above calculated provisional nutrient and energy cycling check value to derive a SQG_E—provisional. Only the reported EC₂₅ endpoints based on direct soil contact experiments were considered. From Tables 6 and 7, the available EC₂₅ endpoints based on direct soil contact experiments are: 5300 mg·kg⁻¹ for radish seedling emergence, 7300 mg·kg⁻¹ for lettuce seedling emergence, and 20 000 mg·kg⁻¹ for earthworm survival.

For Agricultural and Residential/Parkland land uses, the lowest of the considered values was divided by an uncertainty factor of 10 (an uncertainty factor of 5 because minimum data requirements were not met, and an additional uncertainty factor of 2 because of the considerable difference in magnitude between the considered values and the calculated Provisional nutrient and energy cycling check). The geometric mean between the result of this division and the calculated Provisional nutrient and energy

cycling check was taken as the SQG_E—provisional. Hence, the SQG_E—provisional for Agricultural and Residential/Parkland land uses is:

$$[(5300 / 10) \times 18]^{1/2} = 97 \text{ mg} \cdot \text{kg}^{-1}$$

For Commercial and Industrial land uses, the geometric mean of the available EC₂₅ endpoint values listed above, which are based on direct soil contact experiments was first calculated. Then, the SQG_E—provisional was taken as equal to the geometric mean of the results from this first calculation and the Provisional nutrient and energy cycling check. Hence, the SQG_E—provisional for Commercial and Industrial land uses is:

$$[(5300 \times 7300 \times 20\,000)^{1/3} \times 18]^{1/2} = 406 = 410 \text{ mg} \cdot \text{kg}^{-1}$$

5.3 Groundwater Check

Soils are hydrologically linked to groundwater systems. A major concern with soil contamination is that it can and does lead to groundwater contamination. This check is designed to prevent unacceptable transfers of contaminants to groundwater to protect aquatic life. Thus, the lowest value between the Provisional guideline and the values derived using this check should be used in areas with underlying groundwater systems.

Prudent assumptions are that an aquifer underlying a remediated site may have the potential to enter surface water bodies. Therefore, the following equations are used to calculate the concentration in soil which will not cause an exceedence of groundwater concentrations above existing water quality guidelines for the protection of freshwater aquatic life. The groundwater check follows the rationale and calculation procedure recommended in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 1996). It is based on equilibrium partitioning between solid and aqueous phases. For most nonionic organics, including ethylene glycol, the following equation is used:

$$Y = DF \times C_{wa} (K_d + \theta_m)$$

where,

- Y = concentration of contaminant in soil (mg substance·kg⁻¹ dry soil)
- DF = dilution factor = 50
- C_{wa} = water protection value = 192 mg·L⁻¹ (CCREM 1987)
- K_d = distribution coefficient
- θ_m = soil moisture content = 0.1

The distribution coefficient (K_d) is directly related to the organic matter content and can be derived using the sorption partition coefficient (K_{oc}) and the organic fraction of dry soil (F_{oc}) as described by the following equation:

$$K_d = K_{oc} \times f_{oc}$$

A default value of 0.3% (or 0.003) is used for f_{oc} (CCME 1996) while, for consistency, the sorption partition coefficient should be evaluated using the octanol-water partition coefficient based on the following equation (Mackay et al. 1993):

$$K_{oc} = 0.41 \times K_{ow}$$

For ethylene glycol, $\log K_{ow}$ has been evaluated at -1.36 (Howard 1990) and a value of $192 \text{ mg}\cdot\text{L}^{-1}$ has been established for the protection of freshwater aquatic life (CCREM 1987).

Since,

$$K_{ow} = 0.0436$$

$$K_{oc} = 0.0179$$

$$K_d = 5.37 \times 10^{-5}$$

For the protection of freshwater aquatic life:

$$Y = 50 \times 192 (5.37 \times 10^{-5} + 0.1) = 960 \text{ mg}\cdot\text{kg}^{-1} \text{ dry soil}$$

For ethylene glycol, the groundwater check indicates that for the protection of freshwater aquatic life, the level of ethylene glycol in soil should not exceed $960 \text{ mg}\cdot\text{kg}^{-1}$ soil.

6. DATA GAPS

A review of literature showed that there is a lack of acceptable data on toxicity of ethylene glycol to mammals, birds and terrestrial microorganisms. It is recommended that research be conducted in these areas. Also, while the minimum data are available on ethylene glycol toxicity to terrestrial plants and invertebrates, additional experiments on the toxic effects of soil-incorporated ethylene glycol on the emergence of seedlings, root elongation and early stages of growth of different terrestrial plants is recommended. Further research on toxicity of ethylene glycol with well defined concentrations to earthworms in an artificial soil is desirable. Additional data on levels of ethylene glycol compounds in the vicinity of Canadian point sources are also needed.

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TABLES

Table 1: Physical and chemical properties of ethylene glycol

Property	Parameter
Empirical formula	$C_2H_6O_2$
Molecular weight	62.07
CAS registry number	107-21-1
Common synonyms	glycol, glycol alcohol, ethylene alcohol, ethylene dihydrate, monoethylene glycol, 1,2-dihydroxyethane and 1,2-ethanediol
Physical state (25°C)	colourless liquid
Melting point (°C)	-13
Boiling point (°C)	197.6
Flash point (°C)	111 to 115
Density (g/mL)	1.1135 (20° C)
Vapour pressure (Pa at ° C) (mm Hg at ° C)	6.7 (20° C); 11.7 (25° C) 0.05 (20° C); 0.0878 (25° C)
Henry's law constant ($atm \cdot m^3 \cdot mole^{-1}$)	6×10^{-4}
Log K_{oc}	-2.14
Log K_{ow}	-1.36
Solubility in water	miscible
Solubility in ethanol, acetone, acetic acid, aldehydes and pyridine	miscible
Solubility in ether	slightly soluble
Solubility in benzene, chlorinated hydrocarbons, petroleum ethers and oils	insoluble
Sources: Howard 1990; Budavari <i>et al.</i> 1989; Nielsen <i>et al.</i> 1993; Verschueren 1983	

Table 2: Production, importation and consumption of ethylene glycol in Canada

Year	Capacity ktons	Production ktons	Importation ktons	Exportation ktons	consumption (ktons)			
					antifreeze	PET	other	total
1986	502	474	6	322	93	19	45	157
1987	497	490	2	330	96	19	47	162
1988	497	488	4	332	85	20	47	152
1989	517	485	3	317	87	20	50	157
1990	547	520	1305	392	85	16	45	146
1991	547	500	8	367	80	15	40	135
1992	524	533.5	7.9	387.7	92.6	46.2	15.8	153.7
1993	605	513.2	18.7	384.2	91.7	38.7	16.4	147.7
1996 forecast	825	713.6	22.6	575.0	96.4	47.5	17.3	161.2

NA: not available

PET: polyethylene terephthalate fibres

Sources: SRI 1993; CPI 1994

Table 3: Concentrations of ethylene glycol in the Canadian environment.

Environment	Concentration	Remarks	Reference
Water (mg·L ⁻¹)	1814	Ottawa airport stormwater	Transport Canada 1985a, b
	73 (1 to 552)	Dorval (Montreal) airport stormwater	Transport Canada 1988
	75 to 3200	Pearson (Toronto) airport stormwater	Transport Canada 1989b
	14.7 (<0.1 to 110)	Calgary airport stormwater	Transport Canada 1989c
	<2 to 415	groundwater at Ottawa airport stormwater	Transport Canada 1985a, 1987
	< 10 to 16400	Halifax airport receiving waters	Transport Canada 1990
	1 to 13200	Dorval airport receiving waters	Transport Canada 1988
	10 to 475	Mirabel airport receiving waters	Transport Canada 1989a
	upto 70	Pearson Toronto airport receiving waters	Transport Canada 1989b
Air (mg·m ⁻³)	3.2 to 4.1	Thunder bay airport during deicing operations	Percy 1992

Table 4: Existing soil and water quality criteria and guidelines for ethylene glycol

Jurisdiction	Category	Concentration	Reference
Canada	Fresh water aquatic life (mg·L ⁻¹)	192	CCREM 1987
Michigan, USA	State guideline for freshwater aquatic life (mg·L ⁻¹)	68	As cited in CCREM 1987
USEPA	Preliminary remediation goals (health based): Residential soil (mg·kg ⁻¹) Industrial soil (mg·kg ⁻¹) Tap water (mg·L ⁻¹)	78000 100000 73	USEPA 1993

Table 5: Consulted microbial toxicological studies for ethylene glycol

Species	Effect	Endpoint	Concentration	pH	Test substrate	Reference
Microbial respiration	inhibition (O ₂ consumption) (ISO activated sludge respiration inhibition test)	EC ₅₀	202.36 mL·L ⁻¹	NA	mixture of activated sludge , synthetic sewage and water	Kilroy and Gray 1992
		EC ₅₀	154.79 mL·L ⁻¹		factory sludge/synthetic sewage	
		EC ₅₀	192.65 mL·L ⁻¹		factory sludge/factory feed	
Microbial respiration	inhibition (O ₂ consumption) (OECD activated sludge respiration inhibition test)	IC ₅₀	> 1000 mg·L ⁻¹	7.4 to 8	activated sludge	Klecka and Landi 1985
Microbial growth	inhibition of O ₂ uptake	IC ₅₀	114,300 mg·L ⁻¹	NA	culture medium	Khoury <i>et al.</i> 1990
<i>Pseudomonas aeruginosa</i>	growth inhibition (plate count)	NOEC LOEC	2000 mg·L ⁻¹ > 2000 mg·L ⁻¹	NA	culture medium	Daugherty 1980
<i>Pseudomonas aeruginosa</i>	growth inhibition	LOEC	20000 mg·L ⁻¹	NA	culture medium	Stahl and Pessen 1953

NA: not available

WHC : water holding capacity

Table 6: Consulted plant toxicological studies for ethylene glycol

Species	Effect	Endpoint	Concentration mg·kg ⁻¹	Soil pH	Test substrate	Reference
<i>Raphanus sativa</i> (radish)	seedling emergence	NOEC LOEC (41% reduction) EC ₂₅ EC ₅₀	3500 7400 5300 7300	4 to 4.2	Artificial soil: sand 72 to 75%; clay 16 to 19%;silt 8 to 9%; moisture 80% WHC; OM 4.7 to 6.3%	Environment Canada 1995*
	root elongation	NOEC LOEC (47% reduction) EC ₂₅ EC ₅₀	11000 mg·L ⁻¹ 25000 mg·L ⁻¹ 17000 mg·L ⁻¹ 25000 mg·L ⁻¹	NA	nutrient solution	
<i>Lactuca sativa</i> (lettuce)	seedling emergence	NOEC LOEC (64% reduction) EC ₂₅ EC ₅₀	5700** 11700** 7300** 10000**	4 to 4.2	Artificial soil: sand 72 to 75%; clay 16 to 19%;silt 8 to 9%; moisture 80% WHC; OM 4.7 to 6.3%	
	root elongation	NOEC LOEC (24% reduction) EC ₂₅ EC ₅₀	18000 mg·L ⁻¹ 31000 mg·L ⁻¹ 32000 mg·L ⁻¹ 42000 mg·L ⁻¹	NA	nutrient solution	
<i>Lactuca sativa</i> L. (lettuce)	inhibition of germination	EC ₅₀	55 mg·L ⁻¹	NA	nutrient solution	Reynolds 1977

* Reported values are measured concentrations.

** Nominal concentrations

NA : not available

WHC : water holding capacity

Table 7: Consulted invertebrate toxicological studies for ethylene glycol

Species	Effect	Endpoint	Concentration mg·kg ⁻¹	Soil pH	Test substrate	Reference
<i>Eisenia fetida</i> (earthworm)	mortality (14 days)	NOEC LOEC LC ₂₅ LC ₅₀	16000 36000 20000 25000	4 to 4.2	Artificial soil: sand 72 to 75%; clay 16 to 19%; silt 8 to 9%; moisture 80% WHC; OM 4.7 to 6.3%	Environment Canada 1995*

* Reported values are measured concentrations.

WHC : water holding capacity

Table 8: Consulted mammalian and avian toxicological studies for ethylene glycol

Species	Exposure period	Exposure route	Endpoint	Effect concentration	Reference
Cattle (7 calves and 3 cows)	NA	oral	toxic dose (increased respiration, staggering gait, paraparesis, depression and later recumbency and death)	2 mL·kg ⁻¹ bw	Crowell <i>et al.</i> 1979
Chicken	24 h	oral	LD ₅₀ (mortality)	6.7 mL·kg ⁻¹ bw	Riddell <i>et al.</i> 1967
	14 d	oral	clinical signs (renal oxalosis) no clinical effects in chronic studies	2.8 mL·kg ⁻¹ bw 1.5 mL·kg ⁻¹ bw / day	
Hen	NA	oral	LD ₅₀ (mortality)	7.5 mL·kg ⁻¹ bw	Schwarzmaier 1941
Mallard duck	76 h	oral	NOED (mortality) LOED	1.1 mL·kg ⁻¹ bw 2.3 mL·kg ⁻¹ bw	Stowe <i>et al.</i> 1981
Guinea pig, Rabbit, Dog, Rat and Monkey	6 w (8 h/d, 5 d/w) 90 d (continuous)	inhalation inhalation	NOED mortality : (20% in guinea pigs, 33% in rabbits, 7% in rats, 0% in dogs, 0% in monkeys)	57 mg·m ⁻³ 12 mg·m ⁻³	Coon <i>et al.</i> 1970
Male rat	2 y	oral	NOED (mortality)	0.2% in diet	Blood 1965
Rat	subacute (10 day) subchronic (90 day)	oral oral	NOED (mortality) LD ₈₀ (female) (mortality) LD ₂₀ (male)	4432 mg·kg ⁻¹ bw / day 4432 mL·kg ⁻¹ bw / day 2216 mL·kg ⁻¹ bw / day	Robinson <i>et al.</i> 1990
Guinea pig	single dose	oral	LD ₅₀ (mortality)	7.35 mL·kg ⁻¹ bw	Laug <i>et al.</i> 1939
Rat		oral	LD ₅₀ (mortality)	5.5 mL·kg ⁻¹ bw	
Mice		oral	LD ₅₀ (mortality)	13.1 mL·kg ⁻¹ bw	
Cat	NA	NA	lethal dose	1.5 mL·kg ⁻¹ bw	Black 1983

NA: not available

Table 9: Summary of environmental soil quality guidelines for ethylene glycol

Guideline	Land Use		
	Agriculture mg·kg ⁻¹	Residential/Parkland mg·kg ⁻¹	Commercial/Industrial mg·kg ⁻¹
TEC or ECL ^(a)	Insufficient data	Insufficient data	Insufficient data
Nutrient and Energy Cycling Check	Insufficient data	Insufficient data	Insufficient data
SQG _{sc}	Insufficient data	Insufficient data	Insufficient data
SQG _i	Insufficient data	Insufficient data	Insufficient data
Groundwater check for the protection of freshwater aquatic life	960	960	960
Provisional SQG _E	97	97	410

(a) As per CCME (1996) protocol, the SQG_{sc} for Agricultural and Residential/Parkland land uses corresponds to the 25th percentili of the effects and no effects data distribution when using the Weight of Evidence method, while the SQG_{sc} for Commercial/Industrial land use corresponds to the 25th percentile of the effects only data distribution.

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GUIDELINES FOR ETHYLENE
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