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Canadian Soil Quality Guidelines for

Toluene, Ethylbenzene and Xylene (TEX): Environmental

Supporting Document — Final Draft
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NOTICE

This final draft document provides the information supporting the derivation of environmental soil quality guidelines for Toluene, Ethylbenzene and Xylene (TEX). Development of these soil quality guidelines was initiated through the National Contaminated Sites Remediation Program (NCSRP) 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 NCRSP.

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.

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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 toluene, ethylbenzene and xylene (TEX) and a review of the sources and emissions in Canada. Chapter 3 discusses the distribution and behavior of these compounds in the environment while chapter 4 reports their toxicological effects on microbial processes, plants, and animals. These informations are used in chapter 5 to derive soil quality guidelines for toluene, ethylbenzene and xylene 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 toluene, ethylbenzene and xylene, 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 (SQG_E—provisional). The SQG_E—provisional regarding agricultural and residential/parkland land uses is 1.4 $mg \cdot kg^{-1}$ soil for toluene, 1.2 $mg \cdot kg^{-1}$ soil for ethylbenzene, and 1 $mg \cdot kg^{-1}$ soil for xylene whereas regarding commercial and industrial land uses the SQG_E—provisional is 25 $mg \cdot kg^{-1}$ soil for toluene, 20 $mg \cdot kg^{-1}$ soil for ethylbenzene, and 21 $mg \cdot kg^{-1}$ soil for xylene.

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 du toluène, de l'éthylbenzène et du xylène (TEX) de même qu'un survol des sources et des émissions au Canada. Le chapitre 3 discute du devenir et du comportement de ces substances dans l'environnement alors que le chapitre 4 rapporte leurs 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 au toluène, à l'éthylbenzène et au xylène 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 le toluène, l'éthylbenzène et le xylène, 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, à été utilisée pour élaborer des recommandations provisoires pour la qualité des sols en vue de la protection de l'environnement (RQS_E—provisoire). La RQS_E—provisoire visant les terrains à vocation agricole et résidentielle/parc est de 1.4 $mg \cdot kg^{-1}$ de sol pour le toluène, de 1.2 $mg \cdot kg^{-1}$ de sol pour l'éthylbenzène et de 1 $mg \cdot kg^{-1}$ de sol pour le xylène, alors que pour les terrains à vocation commerciale et industrielle la RQS_E—provisoire est de 25 $mg \cdot kg^{-1}$ de sol pour le toluène, de 20 $mg \cdot kg^{-1}$ de sol pour l'éthylbenzène et de 21 $mg \cdot kg^{-1}$ de sol pour le xylène.

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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 1991a). Many of the CCME interim soil remediation criteria do not have a complete supporting scientific rationale and are being updated based on current scientific information.

This report reviews the sources and emissions of toluene, ethylbenzene and xylene (TEX), their distribution and behaviour in the environment, and their toxicological effects on terrestrial mammals, plants and soil organisms. This information is used to derive guidelines for TEX to protect ecological receptors according to the processes outlined in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 1995) 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

Benzene, toluene, ethylbenzene and the three xylene isomers are monoaromatic hydrocarbons that are often studied togheter, beeing refered to as BTEX, since they are all present in gasoline and comprise more than 60% of the mass that goes into solution when gasoline contacts water (Brookman et al. 1985 as cited by Barbaro et al. 1992). Soil quality guidelines have already been derived for benzene and the data will not be reiterated here. Thus, the present document will focus on toluene, ethylbenzene and the three isomers of xylene, these isomers beeing o-, m-, and p-xylene, depending on the position of the methyl group on the benzene ring (1,2-; 1,3- and 1,4- respectively).

Toluene, ethylbenzene and the three xylene isomers (TEX) fall into the broad category of volatile organic compounds that are monoaromatic hydrocarbons composed of an alkyl-substituted benzene ring. All TEX compounds have significantly high vapour pressures and Henry's law constants. Hence, they are subject to rapid volatilization. They also have a high air saturation potential. These characteristics combined to their low flashpoint makes them highly flammable. The solubility of TEX in water is low, ranging from 122 to 707 $mg \cdot L^{-1}$, but is high enough to be of environmental concern. TEX have a low octanol/water partition coefficient ($\log K_{ow} < 4.0$), suggesting a low fat solubility and

consequently low bioaccumulation potential. Physical and chemical properties of TEX compounds are presented in Table 1.

2.2 Analytical Methods

There are a number of analytical methods available for measuring TEX compounds in soils. The recommended methods, presented in Table 2, are US EPA Method 8240B, Packed Column Technique and US EPA Method 8260A, Capillary Column technique both of which utilize Gas Chromatography/Mass Spectrometry (CCME 1993). Both techniques are applicable to nearly all sample types and can be adapted to measure either low or high concentrations.
The detection limit in soil for method 8240B is 5 $\mu g \cdot kg^{-1}$ for all three TEX compounds.

2.3 Production and Uses in Canada

Total production capacity and supply of toluene and xylene compounds in Canada are presented in Table 3.

TEX compounds are produced as products or by-products in petroleum and coal refining. Toluene and xylene are produced as an aromatic mixture with benzene, primarily from catalytic reformate in refineries and secondarily, as by-products of olefin manufacture during the cracking of hydrocarbons. Ethylbenzene is primarily produced by the alkylation of benzene with ethylene.

TEX compounds are widely used as solvents in paints, lacquers, adhesives, inks, cleaning and degreasing agents and in the production of dyes, perfumes, plastics, pharmaceuticals and pesticides. TEX compounds also comprise a significant fraction of crude petroleum. The typical fraction of TEX in the gasolines used in Ontario are 6.7, 1.4 and 6.9% in regular unleaded, and 11.3, 1.7 and 8.0% in premium unleaded for toluene, ethylbenzene and xylenes respectively (OMOE 1993). Based on an average toluene content of 8.3% by weight, the gasolines sold annually in Canada contain some 2,000 kt of toluene, most of it beeing burned during normal engine operation (Madé 1991). The total yearly consumption of toluene in Canada, including both isolated toluene and gasoline toluene, is estimated to be 2,263 kt.

The introduction of TEX into the atmosphere is due largely to incomplete combustion of TEX-containing petroleum fuels from motor vehicles, and volatilization of TEX based solvents and thinners. Other natural sources include volcanic gases, forest fires and vegetation (Isidorov *et al.* 1990).

TEX compounds are released to soil and water mainly from leaking of underground petroleum storage tanks and landfill sites, accidents and spills during transportation, pesticide applications, and discharges of industrial and municipal wastes (Bobra 1991; DGAIS 1992, Johnson et al. 1989, Lesage *et al.* 1990 and 1991).

2.4 Levels in the Canadian Environment

The concentrations of TEX compounds found in the Canadian environment are presented in Table 4.

Soil

Data on concentration of TEX compounds in soils and sediments are scarce for the Canadian environment. In Ontario, soil samples from undisturbed old urban and rural parklands not impacted by local point sources were analyzed by the Ontario Ministry of Environment and Energy for a variety of chemicals to determine average background concentrations known as "Ontario typical range" (OTR). The 98th percentile of this data distribution (OTR_{98}) may be considered as the background level, and corresponds, for samples taken from rural parkland, to 0,0013, 0.00046, and 0.00092 $mg \cdot kg^{-1}$ soil for toluene, ethylbenzene and total xylenes respectively (OMEE 1993).

Atmosphere

Concentrations of TEX compounds in ambient air vary widely depending on the source and the sampling season. Toluene concentrations ranging from 1.1 $\mu g \cdot m^{-3}$ in rural areas (Dann *et al.* 1989) to 2600 $\mu g \cdot m^{-3}$ near gas stations in summer (PACE 1987, 1989) have been reported. Similarly, xylene concentrations ranging from 0.3 $\mu g \cdot m^{-3}$ in rural areas (Dann and Wang 1992) to 22000 $\mu g \cdot m^{-3}$ (Dann and Gonthier 1986) above landfill sites have been reported. Dann and Gonthier (1986) reported toluene concentrations in air columns of three drill holes to range from less than 2 $\mu g \cdot m^{-3}$ (detection limit) to 31 $mg \cdot m^{-3}$ in areas that received hazardous wastes in Quebec.

Water

In water, the reported toluene concentrations vary from 0.1 $\mu g \cdot L^{-1}$ (NAQUADAT 1992) to 0·5 $\mu g \cdot L^{-1}$ in Great Lakes (Otson 1987). Lesage *et al.* (1990) reported 3900 $\mu g \cdot L^{-1}$ of toluene in a shallow aquifer near a chemical waste disposal site at Elmira, Ontario. Xylene concentrations in water vary from 0.32 to 1.72 $\mu g \cdot L^{-1}$ across Canada (NAQUADAT 1992) and in sludge, 52 $\mu g \cdot L^{-1}$ for o-xylene and 1417 $\mu g \cdot L^{-1}$ for m- and p-xylene were reported (OMOE 1992).

2.5 Existing Criteria and Guidelines

Existing criteria and guidelines for the assessment and remediation of TEX contaminated soils are presented in Table 5.

3. ENVIRONMENTAL FATE AND BEHAVIOUR

The major processes that determine the behaviour of TEX in the terrestrial environment are volatilization, sorption, biodegradation and leaching. TEX compounds do not have hydrolysable groups and therefore, hydrolysis is not an important transformation pathway (Howard 1990).

Likewise, TEX are not degraded directly by photolysis (Howard 1990; Mackay *et al.* 1992). In the atmosphere, however, TEX are degraded by reacting with photochemically produced hydroxyl radicals with a half-life of 3 h to 1 day.

Volatilization is the dominant process determining the fate of TEX in the terrestrial environment (Anderson et al. 1991, HSDB 1992, Jin and O'Connor 1990, Parker and Jenkins 1986). Volatilization depends on temperature, humidity, sorption and biodegradation processes in soils (Ashworth 1988, Aurelius and Brown 1987). The relatively high vapour pressures and Henry's Law Constants ($>10^{-3}$ $atm \cdot m^{-3}$/ mole) of TEX make them subject to rapid volatilization from soils with half-lives ranging from 2.2 to 28 d (Howard 1990, Anderson et al. 1991).

Adsorption reduces the mobility of TEX in soils and affects their biotransformation rate. Soil organic matter, especially humic acids, strongly sorb TEX compounds (Jin and O'Connor 1990, Jury et al. 1987, Schwarzenbach and Westall 1981, HSDB 1992, El-Dib et al. 1978). TEX compounds are also adsorbed on clay minerals such as bentonite, illite, and kaolinite. They follow Freundlich's adsorption isotherm (Kango and Quinn 1989, WHO 1985, Nielsen and Howe 1991, Crooks *et al.* 1993). Adsorption in soil increases with increasing TEX concentrations, with decreasing pH, and with decreasing moisture content (English and Loehr 1991, Chiou *et al.* 1981, Rutherford and Chiou 1992, HSDB 1992, El-Dib et al. 1978). Sorption is low in light textured soils with low organic matter (English and Loehr 1991, Garbarini and Lion 1986).

A variety of soil microorganisms are able to utilize TEX as source of carbon, and degrade them to CO_2 and water. *Pseudomonas* species are the main degrading bacteria in soils but other species such as *Arthobacter* have also been reported to degrade TEX compounds (Utkin *et al.* 1992). Intermediate degradation products for toluene are benzoic acid and 3-methylcatechol, while degradation of xylene results in *m*-toluic, *p*-toluic and 2,3-dihydroxy-*p*-toluic acids (Nielsen and Howe 1991, Crooks *et al.* 1993). *O*-xylene was reported to be degraded at a significantly lower rate than the m- and p-isomers (Thomas *et al.* 1990). Degradation half-lives usually range from 5 to 10 days and are typically < 20 days (Mackay *et al.* 1992, Chiang *et al.* 1989, Evans *et al.* 1991a,b, Grabic-Galic and Vogel 1987, Haag *et al.* 1991). Degradation may occur in aerobic or anaerobic conditions. In aerobic conditions, the oxygen supply in soil is the major controlling factor (Allen 1991, Barker *et al.* 1989, Chiang *et al.* 1989). The availability of nutrients, especially nitrogen, also affects the degradation rate. This rate is higher in soil upper horizons and in unsaturated zones due to greater oxygen supply (Haag *et al.* 1991, Miller *et al.* 1990, Kampbell *et al.* 1987, Edwards *et al.* 1992). Anaerobic degradation is much slower and may be increased by adding nitrates and sulphates to the soil (Evans *et al.* 1991a,b, Edwards *et al.* 1992, Hutchins 1991, Beller *et al.* 1992).

TEX compounds are moderately soluble in water. Hence, they may move with percolating waters, either in solution or sorbed to dissolved organic mater. Thus, TEX compounds are moderately to highly mobile in soils (log K_{oc} 1.89 to 2.58 for toluene, 1.98 to 3.04 for ethylbenzene and 1.63 to 3.13 for xylene, depending on soil) (Howard 1990, Mackay *et al.* 1992). In organic soils, TEX leaching is highest in low organic matter and light texture situations whereas in mineral soils, it depends on the type of clay and the soil moisture content. Sorption and biodegradation processes reduce TEX mobility in soils.

Bioconcentration

Herman *et al.* (1991) examined the relationship between K_{ow}, bioconcentration, and toxicity of toluene, ethylbenzene, *m*-xylene, *o*-xylene, and *p*-xylene in algae (*Selenastum capricornutum*). A strong positive linear relationship was reported between bioconcentration and K_{ow} (r^2= 0.98), and between bioconcentration and toxicity (EC_{50}) (r^2 = 0.99). The sorption rate of these aromatic hydrocarbons by algae was initially rapid and then relatively constant. The 12 hours bioconcentration factors, expressed as logarithms to the base 10 were 1.99 for toluene, 2.31 for ethylbenzene, and 2.41, 2.40, and 2.34 for *m*-, *o*-, and *p*-xylene respectively. The 8 days EC_{50}'s reported were 9.4 $mg \cdot L^{-1}$ for toluene, 4.8 $mg \cdot L^{-1}$ for ethylbenzene, and 4.4, 3.9, and 4.2 $mg \cdot L^{-1}$ for *m*-, *o*-, and *p*-xylene respectively (Herman et al. 1991). Casserly *et al.* (1983) reported a higher BCF *i.e.* 3.81 for toluene with *S. Capricornutum*, where as Geyer *et al.* (1984) reported 2.69 using *Chlorella fusca*.

Although TEX may accumulate in algae (Howard 1990), the relatively low log K_{ow} (< 4.0) of TEX compounds indicates that the bioconcentration potential is generally low (WHO 1985; Nielsen and Howe 1991).

4. BEHAVIOUR AND EFFECTS IN BIOTA

4.1 Soil Microbes

Anderson *et al.* (1991) reported that 100 $mg \cdot kg^{-1}$ soil dw of toluene or p-xylene was not toxic to soil microorganisms. Walton *et al.* (1989) observed depressed soil microbial activity, as measured by $C0_2$ production, at 1000 mg toluene$\cdot kg^{-1}$ soil dw. However, the effect disappeared 6 days after application suggesting low potential for long term impacts. Hutchins *et al.* (1991) reported that m-xylene inhibited the rate of denitrification in soils in a Michigan aquifer.

Vonk *et al.* (1986) measured short-term (5 h) oxygen consumption, and nitrification in two soils (loam and humic sand), treated with toluene at 0, 300, 1000 and 10,000 $mg \cdot kg^{-1}$ soil ww. The NOEC values for respiration and nitrification were 300 to 1000, and <20 $mg \cdot kg^{-1}$ soil ww respectively and did not differ with the soil type. Sloof and Blokzijl (1988) reported that the NOEC for toluene on soil microbial respiration and ammonification ranged from 100 to 1300 $mg \cdot kg^{-1}$ while for nitrification, the NOEC was < 26 $mg \cdot kg^{-1}$.

Eisman *et al.* (1991) studied the toxicity of a fuel mixture containing toluene, o-xylene, n-octane, cyclohexane, cyclohexene, benzene, and naphthalene using the Microtox Assay (*Photobacterium phosphorium*). The concentrations at which bioluminescence was decreased by 50% after an exposure of 5 min were 200 and 456 $\mu g \cdot L^{-1}$ for *o*-xylene and toluene, respectively. For the water soluble fraction, the 5-min EC_{50} for *o*-xylene and toluene were 21 and 66 $\mu g \cdot L^{-1}$ respectively. Short-term volatility was not a factor as EC_{50}'s were consistent for test periods that ranged from 2.5 to 15 min.

4.2 Terrestrial Plants

Summaries of the available toxicological studies on the effects of toluene, ethylbenzene, and xylene on terrestrial plants are presented in tables 6, 7, and 8 respectively.

Very little data was available on the uptake and toxicity of TEX to plants. Early work by a number of researchers indicated that concentrations of aromatic hydrocarbons in oils correlated positively with phytotoxicity (Havis 1950; Ivens 1952).

Ivens (1952) exposed detached leaves of runner bean and parsnip to toluene, ethylbenzene, *p*-xylene, and *m*-xylene vapour in a Bell-jar for one hour and determined the degree of damage to the leaves. Phytotoxicity was found to be correlated with oils that had higher aromatic hydrocarbon content. This suggests that the volatile compounds could have a greater phytotoxic potential.

Toluene can enter the plant through the stomata and cuticle and thus damage the plasma membrane. Plant chlorosis and growth inhibition were induced at levels > 6 $mg \cdot L^{-1}$ of air, 500 $mg \cdot L^{-1}$ of aqueous medium, and 1000 $mg \cdot kg^{-1}$ soil ww (Slooff and Blokzijl 1988).

Keymeulen *et al.* 1991 measured TEX concentrations in one and two year old needles of six different Franco trees (*Pseudotsuga menziesii* Mirb.). Concentrations were greater in the two year old needles. The same authors also measured TEX concentrations in leaves of six different "Skogholm" shrubs (*Cotoneaster dammeri* Schn.), concluding that the partitioning of monocyclic aromatic hydrocarbons into the plant cuticle depends on plant species, individual plant variation, amount of cuticle, and age of the leaves. Miller *et al.* (1976) sustain that there is no evidence that toluene is bioaccumulated in plant tissues in any quantity. No toxicological measurements were recorded in these studies.

Xylene is a selective herbicide used in carrot crops. It is also used for the control of submersed aquatic weeds. Bruns and Kelly (1974) applied xylene to several field crops (alfalfa, tomatoes, dwarf corn, squash, potatoes, and field beans) in irrigation water to assess injury to crops. The emulsified xylene was applied at 370, 740 and 1480 $mg \cdot L^{-1}$ using an oscillating, half-circle sprinkler. No detectable symptoms of injury or reduction in yield were observed.

Environment Canada (1995) studied the effects of TEX on seedling emergence of radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*) in an artificial soil. For toluene, the NOEC, LOEC, EC_{25} and EC_{50} concentrations on seedling emergence were, for radish, 6, 12, 7, and 84 $mg \cdot kg^{-1}$, respectively, and, for lettuce, 7, 17, 9 and 12 $mg \cdot kg^{-1}$ respectively. For ethylbenzene, the corresponding toxicity values were 9, 20, 12 and 16 $mg \cdot kg^{-1}$ for radish and 5, 9, 5 and 9 $mg \cdot kg^{-1}$ for lettuce, respectively. For xylene, they were 1.4, 33, 32 and 97 $mg \cdot kg^{-1}$ for radish, and 0.6, 19, 5 and 13 $mg \cdot kg^{-1}$ for lettuce, respectively.

Root elongation studies for radish and lettuce were conducted for TEX using nutrient solutions (Environment Canada 1995). The LOEC values for radish were 15 $mg \cdot L^{-1}$ for toluene, 34 $mg \cdot L^{-1}$ for ethylbenzene, and 0.76 $mg \cdot L^{-1}$ for xylene, respectively. For lettuce, in the same order, the LOEC values were 7 $mg \cdot L^{-1}$, 25 $mg \cdot L^{-1}$ and 0.52 $mg \cdot L^{-1}$.

Currier (1951) exposed tomato, carrot and barley seedlings to 12 $mg \cdot L^{-1}$ of toluene for 30 to 120 minutes at 25 °C. Inhibition of root formation was found to be 0 to 75, 50 to 100, and 0 to 25 % for tomato, carrot and barley respectively. Hung (1992) reported erratic responses in seed mortality, germination and seedling vigour when seeds of corn were soaked in xylene for up to 8 h.

4.3 Terrestrial Invertebrates

Summaries of the available toxicological studies of the effects of toluene, ethylbenzene, and xylene on soil invertebrates are presented in tables 6, 7, and 8 respectively.

Environment Canada (1995) determined NOEC, LOEC, LC_{25} and LC_{50} values for survival of earthworms (*Eisenia foetida*) exposed to toluene, ethylbenzene and xylene in artificial soil. The reported NOEC, LOEC, LC_{25} and LC_{50} values were 34, 71, 44, and 126 $mg \cdot kg^{-1}$ soil, respectively for toluene; 73, 192, 113 and 155 $mg \cdot kg^{-1}$ soil, respectively for ethylbenzene; and 33, 124, 56, and 79 $mg \cdot kg^{-1}$ soil, respectively for xylene.

The toxicity of toluene to *E. foetida* was also evaluated by Hartenstein (1982). Mortality and growth, measured as weight gain, were assessed at 2, 4, and 6 weeks after exposure to concentrations of toluene ranging between 0 and 4000 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$. Toluene caused 100% mortality at 2000 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$ and a reduced growth rate at < 50 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$.

Neuhauser *et al.* (1985) exposed *E. foetida* to toluene and ethylbenzene on filter paper and reported 48-h LC_{50} values of 75 and 47 $\mu g \cdot cm^{-2}$, respectively. Slooff and Blokzijl (1988) reported a NOEC value of 15-50 mg $toluene \cdot kg^{-1}$ soil dw for *E. foetida*.

Vonk *et al.* (1986) exposed *Eisenia foetida* to 0, 32, 100, 180 and 320 mg $toluene \cdot kg^{-1}$ artificial soil. The 14-day and 28-day LC_{50} for mortality were reported between 100 and 180 $mg \cdot kg^{-1}$ soil ww. The 28-day NOEC for mortality was also reported in the same range. The 28-day NOEC for worms appearance and for cocoon production were reported at concentrations between 10 to 32 and 32 to 100 mg $toluene \cdot kg^{-1}$ soil, respectively. The change in appearance was believed to be related to the ability of toluene to dissolve fat and damage cell membranes.

4.4 Mammals and Birds

4.4.1 Uptake, Metabolism and Elimination

The uptake of TEX compounds in animals may occur via many routes including oral, inhalation, subcutaneous, and dermal (percutaneous) absorption. Skowronski *et al.* (1989) found percutaneous absorption of toluene to be a major route of exposure in male rats. The high dermal bioavailability is a significant factor to be considered for terrestrial organisms, especially in spill situations. Skowronski *et al.* (1989) also reported that soil type had little effect on the bioavailability of toluene to the rat.

TEX compounds are absorbed and rapidly distributed throughout the animal's body. They are preferentially stored in adipose tissue but also accumulated in the kidneys, liver and brain. Excretion through urine is the major route of elimination from the body and hippuric acid appears to be the main metabolite (Chin *et al.* 1980a; Mattia *et al.* 1991; Skowronski *et* al. 1989; Turkall *et al.* 1991).

Toluene

Following exposure via inhalation, Gospe Jr. and Calaban (1988) found toluene in the brain, as well as in the blood and liver. Distribution of toluene in the brain was found to be uneven (Ameno *et al.*, 1992; Gospe Jr. and Calaban 1988) and not affected by methods of administration and blood concentration (Ameno *et al.* 1992). Toluene distribution in the brain was found to be correlated with local lipid concentrations (Ameno *et al.* 1992; Gospe Jr. and Calaban 1988). Lipid-rich areas of the brain, such as the medulla, are more likely to retain toluene. Intoxication of the medulla with toluene will affect certain functions, such as respiration (Guyton 1981).

Toluene administration has been shown to increase liver cytochrome P_{450} levels in rats (Pyykkö *et al.* 1987) as well as free fatty acid (FFA) and triglyceride levels (Takahashi *et al.* 1988). An increase in FFA is a good indicator of stress in an organism. Increases in triglycerides may have an adverse effect on heart function. Long term toluene exposure may result in increased liver fat due to the constant increases in systemic FFA and triglycerides (Takahashi *et al.* 1988).

Toluene is metabolized to benzyl alcohol via the cytochrome P_{450} mixed function oxidase system and is, in turn, oxidized to benzaldehyde. Benzaldehyde is subsequently oxidized to benzoic acid which is conjugated to form the major urinary metabolite, hippuric acid (Mattia *et al.* 1991; Skowronski *et al.* 1989). Small amounts of benzyl alcohol and ortho- and para-cresol can also be recovered from the urine of rats exposed to toluene (Skowronski *et al.* 1989). Reactive metabolites, formed in the liver of rats, bind irreversibly and covalently to microsomal detoxification components inactivating them permanently (Pathiratne *et al.* 1986). Inactivation may lead to increased toxicity of other xenobiotics.

Turkall *et al.* (1991) administered toluene, directly and mixed with soil, by gavage to rats. The soil types used were sandy (2% clay) and clay (22% clay). Toluene absorbtion in the stomach was reduced when administered with clay soil. However, metabolism and tissue distribution were unaffected by soil type.

Ethylbenzene

Chin *et al.* (1980a) reported that 44% of inhaled ethylbenzene was retained in the rat. Excretion was virtually complete within 42 h after exposure, with 82.6% in urine and 8.2% in expired gasses. The main metabolites of ethylbenzene in the urine are hippuric acid (Chin *et al.* 1980b) and mandelic acid (Drummond *et al.* 1989).

Xylene

Acute exposure to xylene affects the cytochrome P_{450} system. Simmons et al. (1991) found that the concentration of rat hepatic cytochrome P_{450} increased significantly during acute (6 h) and short-term (3 d, 6 $h \cdot d^{-1}$) exposure to mixed xylene up to 2000 ppm. Rat liver weight and size increased concurrently with the increase in cytochrome P_{450} and all increases were found to be readily reversible upon cessation of exposure (Simmons et al. 1991).

Elovaara (1982) found similar effects on the liver and kidney of the rat when exposed to m-xylene. A dose-dependent relationship was reported between xylene concentration and changes in microsomal enzyme (cytochrome P_{450}) activity. Xylene was found to be an effective inducer of rat liver oxidative metabolism even at low concentrations and with intermittent modes of inhalation exposure (Liira *et al.* 1991).

4.4.2 Toxicity

Summaries of the available toxicological studies on toluene, ethylbenzene, and xylene are found in tables 9, 10 and 11 respectively.

The acute toxicity of toluene to terrestrial animals via the oral, inhaled and dermal routes, is relatively low (OMOE 1989). Acute oral LD_{50} for toluene to young adult rats ranged from 5.55 to 6.6 $g \cdot kg^{-1}$ bw (Kimura *et al.* 1971; Smyth Jr. *et al.* 1969). Four hour inhalation studies using rats gave an LC_{50} in the order of 8800 ppm in air (35mg/L) (Carpenter *et al.* 1976), while a dermal toxicity test on rabbits resulted in an LD_{50} of 14,000 $mg \cdot kg^{-1}$ bw (Union Carbide 1976). Although dose levels are used as indicators of toxicity, biological effects of toluene exposure are reported to be more closely related to blood or tissue concentration (Moser and Balster 1985; Kishi *et al.* 1988).

One of the major effects of TEX compounds appears to be on the cytochrome P_{450} enzyme system, which is responsible for the metabolic detoxification of xenobiotics. Toluene has been shown to inhibit the cytochrome P_{450} mixed function oxidase in the lungs of rats (Pyykkö *et al.* 1987). The detoxification of benzo[a]pyrene (BaP), a known carcinogen, is significantly reduced following acute p-xylene exposure (Roberts *et al.* 1986; 1988) and acute m-xylene exposure (Stickney *et al.* 1989). This inhibition of BaP metabolism is directly related to the reduction in cytochrome P_{450} (Stickney *et al.* 1989; Roberts *et al.* 1986; 1988) and possibly to an alteration in the phospholipid microenvironment of the cytochrome P_{450} (Roberts *et al.* 1988). Stickney *et al.* (1989) suggested that the inhibition of detoxification of xenobiotics, which also occurs in the presence of xylene, is due to irreversible binding of cytochrome P_{450}. Roberts *et al.* (1986) found that inhibition of xenobiotic metabolism by xylene was directly dose and time-dependent. The reduction of cytochrome P_{450} metabolizing enzymes may result in increased toxicity of other xenobiotics (Furman *et al.* 1991). For example, in the case of BaP, the longer it stays in the body, the higher the probability that carcinogenic events will occur. Thus the presence of toluene may exacerbate the carcinogenic effects of BaP (Furman *et al.* 1991). Toluene and BaP may co-occur in the environment.

TEX compounds have been reported to affect the central nervous system of organisms. Acute toluene exposure may result in respiratory failure due to severe depression of the central nervous system (Moser and Balster 1985). Kishi *et al.* (1988) reported that the neurobehavioural effects of acute toluene inhalation depend on exposure concentrations. Rats showed a decrease in effective avoidance response rate of electric shock as the toluene concentration increased from 125 to 1000 ppm. At 2000 ppm, rats showed extreme excitation. At 4000 ppm, rats displayed a drastic increase in response rate which gradually decreased to a light ataxia (failure or irregularity in muscle action/ coordination). Kishi *et al.* (1988) confirmed the central nervous system as the organ most sensitive to toluene exposure and concluded that blood toluene levels are a reasonable index of the behavioral effects of toluene in experimental mammals.

Toluene

Subacute toxicity studies have shown that inhalation exposure to toluene affects locomotor function in rats and mice. Von Euler *et al.* (1991) exposed rats to 30 to 80 ppm toluene for 3 days, 6 hours per day, and found changes in locomotor behaviour in the case of rats with previously activated or sensitized dopamine receptors, hence suggesting that, at low concentrations, toluene is not the direct affector, but does have neural effects if receptors have been previously induced. Wood and Colotla (1990) exposed mice to toluene at different concentrations in 1 hour sessions twice a week for three weeks. At 300 ppm, no altered activity was noted. Motor activity increased at toluene concentrations of 560 to 1780 ppm and then decreased at exposure levels of 1780 to 3000 ppm.

Chronic inhalation exposure to toluene resulted in decreased body and brain weights of rats exposed to 320 $mg \cdot kg^{-1}$ bw (1400 $mg \cdot m^3$) continuously for 30 days (Kyrklund *et al.* 1987). Phospholipid content in the cerebral cortex decreased, and general brain atrophy was noted, especially in the cerebral cortex. A distinct loss of grey matter suggests specific neurotoxic properties of toluene. Gospe Jr. and Calaban (1988) reported that toluene exposure leads to chronic neurological effects which may result in irreversible disfunction of certain CNS regions. Ladefoged *et al.* (1991) reported no central nervous system-neurotoxicity and no adverse effects on the liver or kidneys in rats when they were exposed to 0, 500 and 1500 ppm toluene for 6 hours/day, five days/week for 6 months. However, minor changes in the size of the cerebral cortex and amine content indicated certain irreversible effects of toluene.

Huff (1990) reported a LOEL of 375 $mg \cdot m^{-3}$, which induced a decrease in body weight (7.5 and 12 % in males and females, respectively), in a 14-week toluene inhalation study on mice and rats. In subchronic studies, a NOEL of 100 $mg \cdot kg^{-1}$(375 $mg \cdot m^{-3}$) was reported for rats and in chronic toxicity studies, a LOEL of 600 $mg \cdot kg^{-1}$ (2250 $mg \cdot m^{-3}$) was observed, at with histopathological changes occured in the female rats. Fetotoxic effects due to continuous inhalation exposure of toluene at 133 to 2000 $mg \cdot kg^{-1}$ (7500 $mg \cdot m^{-3}$) have also been observed (Donald et al. 1991).

Ethylbenzene

Acute toxicological studies of the effects of ethylbenzene on rats, by Pyykkö *et al.* (1987) showed a fifty percent increase in cytochrome P_{450} in the liver and a sixty percent decrease in cytochrome P_{450}

in the lungs. Despite the significant P_{450} changes, no alterations in liver or lung weights were noted. Ethylbenzene has also been shown to reduce brain dopamine levels in both striatal and tuberoinfundibular regions (Romanelli *et al.* 1986). The changes in brain dopamine levels were not found to result from any type of solvent effect on membranes but rather, resulted from metabolic interferences of ethylbenzene metabolites on the catabolism of dopamine.

Ethylbenzene is a relatively non-toxic compound with the oral LD_{50} for rats ranging from 3.5 to 4.7 $g \cdot kg^{-1}$ (Wolf *et al.*, 1956; Smyth Jr. et al. 1962). Dermal application of ethylbenzene resulted in an LD_{50} of 15400 $mg \cdot kg^{-1}$ (Smyth Jr. *et al.*, 1962). The effects of ethylbenzene inhalation vary from nasal and eye irritation to vertigo, ataxia, and lung edema at concentrations from 1000 to 10000 ppm.

Chronic exposure of rats to ethylbenzene showed sporadic incidence of salivation and lacrimation, increase in liver weight, increases in liver to body weight ratios and liver to brain weight ratios, and increases in platelet counts (Cragg *et al.* 1989). The authors suggest that the liver weight and ratio changes are due to an adaptive ability of the microsomal enzymes rather than to direct toxic effects. Cragg *et al.* (1989) observed no effects on rabbits exposed to ethylbenzene up to 1610 ppm at which point the animals exhibited a reduced body weight. The results of this study showed that ethylbenzene did not accumulate when chronically inhaled. The results of Elovaara *et al.* (1985) support the Cragg *et al.* (1989) view that the increase in liver and kidney cytochrome P-450, and the dose related increase in microsomal hepatic protein (with no indication of liver injury), provide no indication as to whether the organs are undergoing an adaptive or toxic response.

Xylene

Acute exposure to xylene has been reported to damage the central nervous system. Carpenter *et al.* (1975) reported a time dependent pattern of salivation, ataxia and spasms followed by death within two hours when rats were exposed to 9500 ppm of mixed xylene (ethylbenzene comprised approximately 20% of the xylene mixture). In a concurrent study with rats exposed to 11000 ppm xylene, toxic effects progressed from eye irritation to prostration, tremors, and death. Rats exposed to 9900 ppm xylene have suffered from haemorrhage and interlobular edema of the lungs (Carpenter *et al.* 1975). Most of the damage has been attributed to the inactivation/reduction of cytochrome P_{450} in the lungs (Stickney *et al.* 1989; Roberts *et al.* 1986, 1988; Elovaara *et al.* 1987). Condie *et al.* (1988) reported the lowest NOAEL (on body and liver weights) at 250 $mg \cdot kg^{-1}$ $bw \cdot day^{-1}$ in short-term studies with rats.

Xylene has a relatively low toxicity in the rat, with acute oral LD_{50} ranging from 4300 to 5800 $mg \cdot kg^{-1}$ (Wolf *et al.* 1956; Ungvary 1979). LC_{50}'s ranging from 6350 to 6700 ppm have been reported with rat inhalation studies (Hine *et al.* 1970; Carpenter *et al.* 1975). The toxicity of xylene mixtures will depend on the relative proportions of its constituent isomers. Gerarde (1959), in an acute oral toxicity study with rats found an LD_{70} of 4401 $mg \cdot kg^{-1}$ for o-xylene, an LD_{30} of 4421 $mg \cdot kg^{-1}$ for m-xylene and an LD_{60} of 4306 $mg \cdot kg^{-1}$ for p-xylene.

With subacute/chronic studies, xylenes have been shown in rats to induce the cytochrome P_{450} in liver (Raunio *et al.* 1990) and kidney (Elovaara 1982), but to destroy the cytochrome P_{450} of the lungs,

even at low exposure levels (Elovaara *et al.* 1987). Additional effects of chronic xylene exposure include changes in body weight, liver, kidney, heart, spleen, brain and thymus weights as well as aggressiveness and alterations in white blood cells (Condie *et al.* 1988). In the chronic toxicity and carcinogenic studies with male rats, the NOEL and LOEL (5 to 8% decrease in body weight and survival) were observed at 250 and 500 $mg \cdot kg^{-1}$ $bw \cdot day^{-1}$ (NTP 1986).

A study on the teratogenic effects indicates that xylenes are subjected to transplacental passage in the mouse (Marks *et al.* 1982). Xylene administered via gavage at 2.4 $mL \cdot kg \cdot d^{-1}$ on days 6 to 15 of gestation resulted in a greater than average number of malformed fetuses. Abnormalities included cleft palate and/or open eye, which are indicators of delayed development, and decreased average fetal weight. The study concluded that at these doses, mixed xylenes were teratogenic as well as embryotoxic to mouses.

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 toluene, ethylbenzene and xylene. Results are presented in Table 12.

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, litterature 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 additionnal 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, professionnal jugement 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 12 presents a summary of the results of the Provisional derivation procedures and a comparison with the CCME (1991) interim remediation criteria.

The available data was insufficient to meet the minimum data requirements for the derivation of a guideline based on soil contact. However, the available data based on direct soil contact was used in the following manner to derive a SQG_E—provisional. Only the reported EC_{25} endpoints based on direct soil contact experiments, and for these endpoints, only the recovered (measured) concentrations were considered.

5.2.1 Toluene

For Agricultural and Residential/Parkland land uses, the lowest of the considered values was divided by an uncertainty factor of 5 and the result was taken as the SQG_E—provisional. Thus, from Table 6 the available EC_{25} endpoints based on direct soil contact experiments are: 7 $mg \cdot kg^{-1}$ for radish seedling emergence, 9 $mg \cdot kg^{-1}$ for lettuce seedling emergence, and 44 $mg \cdot kg^{-1}$ for earthworm survival. Hence, the SQG_E—provisional for Agricultural and Residential/Parkland land uses is:

$7 / 5 = 1.4\ mg \cdot kg^{-1}$

For Commercial and Industrial land uses, the SQG_E—provisional was taken as equal to the geometric mean of the available EC_{25} endpoint values listed above, which are based on direct soil contact experiments. Hence, the SQG_E—provisional for Commercial and Industrial land uses is:

$(7 \times 9 \times 44)^{1/3} = 24.5 = 25\ mg \cdot kg^{-1}$

5.2.2 Ethylbenzene

For Agricultural and Residential/Parkland land uses, the lowest of the considered values was divided by an uncertainty factor of 5 and the result was taken as the SQG_E—provisional. Thus, from Table 7, the available EC_{25} endpoints based on direct soil contact experiments are: 12 $mg \cdot kg^{-1}$ for radish seedling emergence, 6 $mg \cdot kg^{-1}$ for lettuce seedling emergence, and 113 $mg \cdot kg^{-1}$ for earthworm survival. Hence, the SQG_E—provisional for Agricultural and Residential/Parkland land uses is:

$6 / 5 = 1.2\ mg \cdot kg^{-1}$

For Commercial and Industrial land uses, the SQG_E—provisional was taken as equal to the geometric mean of the available EC_{25} endpoint values listed above, which are based on direct soil contact experiments. Hence, the SQG_E—provisional for Commercial and Industrial land uses is:

$(12 \times 6 \times 113)^{1/3} = 20\ mg \cdot kg^{-1}$

5.2.3 Xylene

For Agricultural and Residential/Parkland land uses, the lowest of the considered values was divided by an uncertainty factor of 5 and the result was taken as the SQG_E—provisional. Thus, from Table 8 the available EC_{25} endpoints based on direct soil contact experiments are: 32 $mg \cdot kg^{-1}$ for radish seedling emergence, 5 $mg \cdot kg^{-1}$ for lettuce seedling emergence, and 56 $mg \cdot kg^{-1}$ for earthworm survival. Hence, the SQG_E—provisional for Agricultural and Residential/Parkland land uses is:

$5 / 5 = 1\ mg \cdot kg^{-1}$

For Commercial and Industrial land uses, the SQG_E—provisional was taken as equal to the geometric mean of the available EC_{25} endpoint values listed above, which are based on direct soil contact experiments. Hence, the SQG_E—provisional for Commercial and Industrial land uses is:

$(32 \times 5 \times 56)^{1/3} = 20.7 = 21\ mg \cdot kg^{-1}$

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 toluene, ethylbenzene and xylene, the following equation is used:

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

where
Y = concentration of contaminant in soil (mg substance$\cdot kg^{-1}$ dry soil)
DF = dilution factor = 50 (default)
C_{wa} = water protection value
K_d = distribution coefficient
θ_m = soil moisture content = 0.1 (default)

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 1995) while, for consistency, the sorption partition coefficient should be evaluated using the octanol-water partition coefficient based on the following equation (Mackay et al. 1992):

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

5.3.1. Toluene

For toluene, log K_{ow} has been evaluated at 2.69 (Mackay et al. 1992) and the recommended Canadian value established for the protection of freshwater aquatic life is 0.3 $mg \cdot L^{-1}$ (CCREM 1987).

Therefore,

$K_{ow} = 489.78$
$K_{oc} = 200.81$
$K_d = 0.60$

For the protection of freshwater aquatic life:

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

$Y = 50 \times 0.3 (0.60 + 0.1)$
$Y = 10.5$ mg toluene$\cdot kg^{-1}$ dry soil

5.3.2. Ethylbenzene

For ethylbenzene, log K_{ow} has been evaluated at 3.13 (Mackay et al. 1992) and the recommended Canadian value established for the protection of freshwater aquatic life is 0.7 $mg \cdot L^{-1}$ (CCREM 1987).

Therefore,

$K_{ow} = 1348.96$
$K_{oc} = 553.07$
$K_d = 1.66$

For the protection of freshwater aquatic life:

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

$Y = 50 \times 0.7 (1.66 + 0.1)$
$Y = 61.6$ mg ethylbenzene·kg^{-1} dry soil

5.3.3. Xylene

For xylene, log K_{ow} has been evaluated at 3.20 (Mackay et al. 1992) and, since the CCREM (1987) has not yet established a Canadian value for the protection of freshwater aquatic life, the lowest available concentration known to affect freshwater aquatic life will be used after application of a safety factor if necessary. According to Environment Canada and Health Canada (1993), the freshwater organism shown to be the most sensitive to xylenes is *Daphnia magna* for which Galassi et al. (1988) reported 24-hour LC_{50} values of 1.0 mg·L^{-1} for *o*-xylene, 3.6 mg·L^{-1} for *p*-xylene, and 4.7 mg·L^{-1} for *m*-xylene. Thus, the lowest concentration known to affect freshwater aquatic life is 1.0 mg·L^{-1}. A safety factor of 2 is applied since this concentration is an LC_{50}. Hence, the value protective of freshwater aquatic life used in the calculations below is 0.5 mg·L^{-1}.

Therefore,

$K_{ow} = 1584.89$
$K_{oc} = 649.80$
$K_d = 1.95$

For the protection of freshwater aquatic life:

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

$Y = 50 \times 0.5 (1.95 + 0.1)$
$Y = 51.25$ mg xylene·kg^{-1} dry soil

6. DATA GAPS

Generally, very little information on the toxicity of toluene, ethylbenzene, and xylene to soil organisms (microbes, invertebrates and plants) in direct soil contact was found.

Attempts to generate toxicological data by Environment Canada (1995) for use in the derivation of soil quality criteria have demonstrated the unresolved problems associated with testing volatile organic compounds. Two tests were run for each VOC yet sampling and handling problems persisted. Generally the amount of VOC applied and the amount actually measured in the soil differed by an order of magnitude, which was considered unacceptable.
Additional research on the toxicity, bioaccumulation, and biomagnification in terrestrial organisms is required.

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TABLES

Table 1. Physical and Chemical Properties of TEX Compounds

Property	Toluene	Ethylbenzene	Xylene		
			o-xylene	m-xylene	p-xylene
Synonyms	Toluol phenylmethane methylbenzene methylbenzol antasal-1a	Ethylbenzol phenylethane	Xylol, ortho-xylene, 1,2-dimethyl-benzene	Xylol, meta-xylene, 1,3-dimethyl-benzene	Xylol, para-xylene, 1,4-dimethyl-benzene
CAS registry number	108-88-3	100-41-4	95-47-6	108-38-3	106-42-3
Molecular formula	$C_6H_5CH_3$	$C_2H_5C_6H_5$	$C_6H_4(CH_3)_2$	$C_6H_4(CH_3)_2$	$C_6H_4(CH_3)_2$
Molecular weight	92.5	106.17	106.2	106.2	106.2
Physical state (20°C)	liquid	liquid	liquid	liquid	liquid
Melting point (°C)	- 95.0	-94.97	- 25.18	- 47.87	13.26
Boiling point (°C, 1 Atm)	110.6	136.25	144.4	139.1	138.5
Density ($g \cdot cm^{-1}$@ 20 °C)	0.8669	0.867	0.8802	0.8642	0.8611
Flash point (°C)	4.4	18.0	17.0	25.0	25.0
Vapour pressure (kPa @ 25°C)	3.74-4.0	1.276	8.80-8.92	11.00-11.66	11.60-11.80
Henry's law constant ($Pa \cdot m^3 . mole^{-1}$)	518-682	669-1001	436-594	506-1115	506-879
Solubility ($mg \cdot L^{-1}$ at 25 °C)	347-707	150	170-221	122-223	150-215
Half-life (h) in					
Air	17	17	17	17	17
Water	550	550	550	550	550
Soil	1700	1700	1700	1700	1700
Log K_{oc}	1.89-2.58	1.98-3.04	1.63-2.73	2.04-3.13	2.05-3.08
Log K_{ow}	2.11-3.0	3.13-3.43	3.08-3.29	3.20-3.29	3.09-3.18
Log BCF*	0.22-3.28	0.67-2.67	0.79-2.34	0.78-2.40	1.17-2.41

* BCF: bioconcentration factor
Table source: Mackay et. al. (1992).

Table 2. Detection Limits and Accuracy of Analytical Methods 8240B and 8260A for TEX in Soils

	Method 8240B			Method 8260A		
TEX	Detection limit $\mu g \cdot kg^{-1}$	Range $\mu g \cdot kg^{-1}$	Accuracy $\mu g \cdot kg^{-1}$	Detection limit $\mu g \cdot L^{-1}$	Range $\mu g \cdot L^{-1}$	Mean Accuracy (% of true value)
Toluene	5	5 to 600	0.98C+2.03	0.5	0.5 to 10	102
Ethylbenzene	5	5 to 600	0.98C+2.48	0.1	01 to 10	99
o-xylene	—	—	—	0.1	0 to 31	103
m-xylene	—	—	—	0.1	0.1 to 10	97
p-xylene	—	—	—	0.5	0.5 to 10	104
Xylene (Total)	5	5 to 600	—	—	—	—

Source: CCME 1993

Table 3. Production Capacity and Supply of Toluene and Xylene in Canada

TEX		1986	1987	1988	1989	1990	1993[1]
Toluene	Capacity	580	630	630	630	630	595
	Supply	426.6	446	490.7	483	NA	540
Xylene	Capacity	460	495	495	495	790	790
	Total supply	376.5	351	405	439.5	518.5	623

All values are in ktons
NA = not available
Source = CIS 1991
[1] forecast from Corpus Information Service (CIS 1989, 1991)

Table 4. Concentrations of TEX Compounds in the Canadian Environment

Environment	Toluene	Ethyl-benzene	Xylene	Remarks	Reference
Soil ($mg \cdot kg^{-1}$)	0.0013 0.00092	0.00046 0.00040	0.00092 0.00080	rural parkland old urban parkland	OMEE 1993
Air ($\mu g \cdot m^{3}$)	202 in 1985 535 in 1986 1900 (winter) 2600 (summer)	— —	221 (winter) 85 (summer) 716 (winter) 973 (summer)	gas stations across Canada self-service gas stations	PACE 1987, 1989
	5 to 44 (urban) 1.1 (rural)	—	—	Ontario, 1983 to 1989	Dann *et al.* 1989
	—	—	0.4 to 34 0.3 to 2.5	urban Ontario rural Ontario	Dann and Wang 1992
	—	—	2 to 22000	Quebec, landfill	Dann and Gonthier 1986
Water ($\mu g \cdot L^{-1}$)	0.1 to 131 (sewage)	0.38 to 1.09	0.32 to 1.72	across Canada	NAQUADAT 1992
	0.5 (spring) 0.3 (summer) 0.1 (winter)	—	—	Great Lakes, Ontario, 1982 to 1983,	Otson 1987
	0.4	—	—	St.Clair River, 1985	Comba and Kaiser 1987
	0.59 2.08 (max)	—	—	refinery effluents, Ontario	OMOE 1989
	<0.2 to 730	<0.2 to 74	<0.2 to 191 (p- and m-) <0.2 to 123 (o-)	groundwater (landfills), Ontario	Baeker 1987
	295	—	—	groundwater, Ontario	Slaine and Barker 1990
	3900	—	—	shallow aquifer chemical waste disposal site	Lesage *et al.* 1990
	2800	—	—	liquid waste disposal site, Quebec groundwater	Pakdel *et al.* 1992
	— —	—	52 o-xylene 110 m-and p-xylene 37 o-xylene, 1417 m-and p- xylene	pulp effluent, Ontario sludge, Ontario	OMOE 1992
	—	5 to 10	—	treated water, across Canada	Otson *et al.* 1982
	—	0.1 14 to 480	—	background concentration Ontario landfill	Reinhard *et al.* 1984

Table 5. Existing Guidelines and Criteria for TEX in Canada, USA and Netherlands

Jurisdiction	Guideline/Criterion	Toluene $mg \cdot kg^{-1}$	Ethyl-benzene $mg \cdot kg^{-1}$	Xylene $mg \cdot kg^{-1}$	Reference
Canada (CCME)	Interim Assessment Criteria	0.1	0.1	0.1	CCME 1991a
	Interim Remediation Criteria: Agricultural Residential/Park Land Commercial/Industrial	 0.1 3.0 30	 0.1 5.0 50	 0.1 5.0 50	
Alberta	Assessment Criteria: Tier I Tier II: Site Specific	 1.0	 0.5	 1.0	CCME 1991b
	Level I (High Sensitive Site) Level II (Medium Sensitive Site) Level III (low Sensitive Site)	1.0 10 100	0.5 5.0 100	1.0 5.0 50	Alberta MUST 1991 (under revision)
British Columbia	Level A (Background Level) Level B (Remediation Criteria, Agricultural, Residential/Parklands) Level C (Commercia/Industrial Lands)	0.1 3.0 30	0.1 5.0 50	0.1 5.0 50	BCMOE 1989
Manitoba	High risk (High Sensitive Site) Medium risk (Medium Sensitive Site) Low risk (low Sensitive Site)	0.1 3.0 30	0.1 5.0 50	0.1 5.0 50	Manitoba Environment 1992
New Brunswick	Level I (Potential to contaminate water) Level II (Not covered in Level I)	3.0 30	5.0 50	5.0 50	New Brunswick DOE 1992
Nova Scotia	Level I - Total BTEX[1] Level II - Total BTEX Level III - Total BTEX	1.0 2.0 200	1.0 2.0 200	1.0 2.0 200	CCME, 1991b
Ontario (proposed clean-up guidelines)	Surface soil with potable groundwater situation (pH 5 to 9): Agricultural Residential/Park Land Commercial/Industrial	 1 1 1	 0.5 0.5 0.5	 1 1 1	OMEE 1994
	Surface soil with non-potable groundwater situation (pH 5 to 9): Residential/Park Land Commercial/Industrial	 1 10	 0.5 5.0	 1 5	
	Sub-surface soil with potable groundwater situation (pH 5 to 11): Residential/Park Land Commercial/Industrial	 1 1	 0.5 0.5	 1 1	
	Sub-surface soil with non-potable groundwater situation (pH 5 to 11): Residential/Park Land Commercial/Industrial	 10 100	 5 100	 5 50	

Jurisdiction	Guideline/Criterion	Toluene $mg \cdot kg^{-1}$	Ethyl-benzene $mg \cdot kg^{-1}$	Xylene $mg \cdot kg^{-1}$	Reference
Prince Edward Island	Level I - Total BTEX Level II - Total BTEX	ND 2.0	ND 2.0	ND 2.0	CCME 1991b
Quebec	Level A (Background Level) Level B (Remediation Criteria) Level C (Immediate Clean-up)	0.1 3.0 30	0.1 5.0 50	0.1 5.0 50	MENVIQ 1988
Saskatchewan	Level I (Agricultural/ Residential lands) Level II (Commercial/Industrial lands)	1.0 10	0.5 5.0	1.0 5.0	SEPS 1990
California	Maximum Allowable Limits	0.3-50	1-50	1-50	OMOE 1992
Illinois	Soil Objective (BTEX)	11.7	11.7	11.7	CCME 1991b
Kansas	Remediation Level (BTEX)	100	100	100	CCME 1991b
Massachussets[2]	Soil Standard for S-1 (accessible soil used for growing fruits or vegetables for humans, or high frequency or intensity of use by children or adults) GW-1 GW-2 GW-3	100 8 8 8	100 80 100 100	100 100 100 100	MDEP 1993
	Soil Standard for S-2 (accessible soil of low use and intensity of activity) GW-1 GW-2 GW-3	2500 90 510 2500	2500 80 2500 500	2500 830 460 2500	
	Soil Standard for S-3 (accessible soil which children are unlikely to visit) GW-1 GW-2 GW-3	5000 90 510 4300	5000 80 3300 500	5000 830 460 4100	
Michigan	Soil level	0:8	0.6	0.4	CCME 1991b
New Hampshire	Soil level (BTEX)	1.0	1.0	1.0	CCME 1991b
New York	Soil Guidance Value	0.375	0.15	0.03	CCME 1991b
Washington	Soil Action Level	0.04	0.02	0.02	CCME 1991b
The Netherlands	Target value Intervention value	0.05 130	0.05 50	0.05 25	MHSPE 1994

[1] BTEX : benzene, toluene, ethylbenzene, xylene.
[2] GW-1 : groundwater is a current or potential source of drinking water
GW-2 : oil or hazardous material in groundwater may likely act as a source of vapour infiltration to occupied buildings
GW-3 : groundwater discharges to surface water.

Table 6. Available Data on the Effects of Toluene on Terrestrial Plants and Invertebrates

Species	Effect (Exposure period)	Endpoint	Concentration. of toluene[a] $mg \cdot kg^{-1}$	Soil pH	Test substrate	Extraction method	Reference
Radish (*Raphanus sativa*)	Seedling emergence (72 hours)	NOEC LOEC EC_{25} EC_{50}	6[b] (68)[b] 12[b] (271)[b] 7[b] (406)[b] 84[b] (119)[b]	4 - 4.5	Artificial soil (20% kaolinite clay, 10% peat, 70% silica sand)	EPA SW846, 3810/8015 and 8020.	Environment Canada 1995
Lettuce (*Lactuca sativa*)	Seedling emergence (120 hours)	NOEC LOEC EC_{25} EC_{50}	7 (135) 17 (271) 9 (162) 12 (148)				
Radish (*Raphanus sativa*)	Root elongation (72 hours)	NOEC LOEC EC_{25} EC_{50}	6 (102) 15 (203) 11 (162) 22 (284)				
Lettuce (*Lactuca sativa*)	Root elongation (120 hours)	NOEC LOEC EC_{25} EC_{50}	4 (68) 7 (136) 5 (82) 7 (133)				
Earthworm (*Eisenia foetida*)	Mortality (7 days)	NOEC LOEC LC_{25} LC_{50}	34 (338) 71 (678) 44 (463) 126 (678)				
Earthworm (*Eisenia foetida*)	Mortality (14 days) (28 days) (28 days) Cocoon prod. (28 d) Worms appearance (fat dissolution and cell membrane damage) (28 d)	LC_{50} LC_{50} NOEC NOEC NOEC	(100-180) (100-180) (100-180) (32-100) (10-32)	6	Artificial soil (sand, peat and kaoline), moisture 55 %	Nominal	Vonk *et al.* 1986
Earthworm (*Eisenia foetida*)	Reduced growth Mortality (2 to 6 weeks)	EC EC (100%)	(50 $mg \cdot kg^{-1} bw \cdot d$) (2000 $mg \cdot kg^{-1} bw \cdot d$)	---	30 g sludge on 4 cm of silt loam	Nominal	Hartenstein 1982
Earthworm (*Eisenia foetida*)	Mortality Coccon production Visual conditions (2 week)	NOEC NOEC NOEC	(15 to 50) (15 to 50) (15 to 50)	---	Artificial soil	Nominal	Sloof and Blokzijl 1988
Earthworm (*Eisenia foetida*)	Mortality (48 hours)	LC_{50}	(75 $\mu g.cm^2$)	---	Filter paper	Nominal	Neuhauser *et al.* 1985

[a] Values in parenthesis are nominal concentrations [b] Value from only one replicate

Table 7. Available Data on the Effects of Ethylbenzene on Terrestrial Plants and Invertebrates

Species	Effect	Endpoint	Concentration of ethylbenzene[a] $mg \cdot kg^{-1}$	Soil pH	Test substrate	Extraction method	Reference
Radish (*Raphanus sativa*)	Seedling emergence (72 hours)	NOEC LOEC EC_{25} EC_{50}	9 (42) 20 (84) 12 (53) 16 (68)	4 - 4.5	Artificial soil (20% kaolinite clay, 10% peat, 70% silica sand)	EPA Method SW846, 3810/8015 and 8020	Environment Canada 1995
Lettuce (*Lactuca sativa*)	Seedling emergence (120 hours)	NOEC LOEC EC_{25} EC_{50}	5[b] (34)[b] 9 (42) 6 (30) 9 (43)				
Radish (*Raphanus sativa*)	Root elongation (72 hours)	NOEC LOEC EC_{25} EC_{50} n	16 (68) 34 (135) 31 (122) 71 (217)				
Lettuce (*Lactuca sativa*)	Root elongation (120 hours)	NOEC LOEC EC_{25} EC_{50}	12 (51) 25 (102) 15 (61) 23 (94)				
Earthworm (*Eisenia foetida*)	Mortality (7 days)	NOEC LOEC LC_{25} LC_{50}	73 (203) 192 (406) 113 (288) 155 (377)				
Earthworm (*Eisenia foetida*)	Mortality (48 hours)	LC_{50}	47 $\mu g \cdot cm^{-2}$	---	Filter paper (contact test)	---	Neuhauser *et al.* 1985

[a] Values in parenthesis are nominal concentrations
[b] Values from only one replicate

Table 8. Available Data on the Effects of Xylene on Terrestrial Plants and Invertebrates

Species	Effect	Endpoint	Concentration of xylene[a] $mg \cdot kg^{-1}$	Soil pH	Test substrate	Analytical method	Reference
Radish (*Raphanus sativa*)	Seedling emergence (72 hours)	NOEC LOEC EC_{25} EC_{50}	1.4 (104) 33 (206) 32 (178) 97 (291)	4 - 4.5	Artificial soil (20% kaolinite clay, 10% peat, 70% silica sand)	EPA Method SW846, 3810/8015 and 8020	Environment Canada 1995
Lettuce (*Lactuca sativa*)	Seedling emergence (120 hours)	NOEC LOEC EC_{25} EC_{50}	0.6 (69) 19 (86) 5 (81) 13 (132)				
Radish (*Raphanus sativa*)	Root elongation (72 hours)	NOEC LOEC EC_{25} EC_{50}	0.43 (21) 0.76 (43) 0.65 (36) 28 (180)				
Lettuce (*Lactuca sativa*)	Root elongation (120 hours)	NOEC LOEC EC_{25} EC_{50}	0.26 (17) 0.52 (34) 0.34 (24) 9 (66)				
Corn (*Zea mays L*)	Germination, seedling development and dry weight (8 hours)	EC (significant reduction)	Seeds soaked in pure xylene	---	---	---	Hung *et al.* 1992
Earthworm (*Eisenia foetida*)	Mortality (7 days)	NOEC LOEC LC_{25} LC_{50}	33 (206) 124 (412) 56 (258) 79 (309)	4 - 4.5	Artificial soil (20% kaolinite clay, 10% peat, 70% silica sand)	EPA Method SW846, 3810/8015 and 8020	Environment Canada 1995

[a] Values in parenthesis are nominal concentrations

Table 9. Available Data on the Effects of Toluene on Mammals

Species	Effect	Endpoint	Concentration of toluene	Dose of toluene	Exposure Period (Exposure route)	Reference
Rat	Mortality	LD_{50}	---	2.5 $g \cdot kg^{-1}$ bw	single dose (oral)	Gerarde 1959
Rat (young adult)	Mortality	LD_{50}	---	5.55 $g \cdot kg^{-1}$ bw	single dose	Kimura *et al.* 1971
Rat (young adult)	Mortality	LD_{50}	---	6.6 $g \cdot kg^{-1}$ bw	(oral)	Smyth Jr. *et al.* 1969
Rat (14 d old)	Mortality	LD_{50}	---	2.6 $g \cdot kg^{-1}$ bw	single dose (oral)	Kimura *et al.* 1971
Rat	Mortality	LC_{50}	8800 ppm	---	4 hours (inhalation)	Carpenter *et al.*1976
Rat	Decreased avoidance response Extreme excitation Slight ataxia	EC EC EC	125 ppm 2000 ppm 4000 ppm	---	4 hours (inhalation)	Kishi *et al.* 1988
Rat	Decreased lung cytochrome P-450	EC	---	1 $g \cdot kg^{-1}$ bw	single dose (i.p.)	Furman *et al.* 1991
Rabbit	Mortality	LD_{50}	---	14 $g \cdot kg^{-1}$ bw	single dose (dermal)	Union Carbide 1976
Rat (female)	---	NOAEL	---	590 $mg \cdot kg^{-1}$ bw/day	193 days (oral)	Wolf *et al.* 1956
Rat	Decreased growth, induced MFO activity	EC NOAEL	---	100 $g \cdot kg^{-1}$ bw 50 $g \cdot kg^{-1}$ bw	14 days (oral)	Komsta *et al.* 1989
Rat, guinea pig, dog, primate	Body weight, histopathological or hematologic effects	NOEC	389 mg/m^3	---	90 d, continuous (inhalation)	Jenkins *et al.* 1970
Rat, dog	Significantly different effects	NOEC	1515 ppm 6h/d	---	13 weeks (inhalation)	Carpenter *et al.* 1976
Rat	Inhibition of phagocytic activity of leucocytes	EC	390 ppm 4h/d	---	6 months (inhalation)	Bernshtein 1972
Rat (male)	Increased adrenal weight and plasma hydrocorticoids decreased eosinophiles	EC	1000 ppm 8h/d	---	4 weeks (inhalation)	Takevchi *et al.* 1979
Rat	Decreased serum albumin increased beta- and gama-globulin and lipoprotein levels	EC	6450 ppm 5h/d	---	4 months (inhalation)	Mackshanova and Omelyanchik 1977
Mouse	Motor activity increase	LOAEL NOAEL	560 ppm 300 ppm	---	1 h/d, 2 d/w for 3 weeks (inhalation)	Wood and Colotla 1990
Rat	Locomotor activity	NOAEL	80 ppm	---	6 h/d for 3 days (inhalation)	von Euler *et al.* 1991
Rat	Behaviour, kidney, liver some biochemical changes	NOAEL	1500 ppm	---	6 h/d , 5 d/w for 6 months (inhalation)	Ladefoged *et al.* 1991

Table 10. Available Data on the Effects of Ethylbenzene on Mammals

Species	Effect	Endpoint	Concentration of ethylbenzene	Dose of ethylbenzene	Exposure Period (exposure route)	Reference
Rat	Mortality	EC (70%)	---	2.7 $g \cdot kg^{-1}$	single dose (oral)	Gerarde 1959
Rat	Mortality	LD_{50}	---	3.5 $g \cdot kg^{-1}$	single dose (oral)	Wolf, *et al.* 1956
Rat	Mortality	LD_{50}	---	4.7 $g \cdot kg^{-1}$	single dose (oral)	Smyth Jr. *et al.* 1962
Rabbit	Mortality	LD_{50}	---	15.4 $g \cdot kg^{-1}$	single dose (dermal)	Smyth Jr. *et al.* 1962
Rabbit	Mortality	LD_{50}	---	> 5 $g \cdot kg^{-1}$	single dose (dermal)	Opdyke 1975
Rat	Destructive to pulmonary cytocrhome P-450	EC	---	0.53 $g \cdot kg^{-1}$	single dose (i.p.)	Pyykkö *et al.* 1987
Rat	Increased liver & kidney weights	NOAEL NOAEL EC	---	13.5 $mg \cdot kg^{-1} \cdot d^{-1}$ 135 $mg \cdot kg^{-1} \cdot d^{-1}$ 408 & 680 $mg \cdot kg^{-1} \cdot d^{-1}$	5 days a week for 6 months (oral)	Wolf *et al.* 1956
Rabbit	Changes in blood and plasma globulins liver,kidney and muscle weights	EC	250 ppm/h/day	---	7 months (inhalation)	US EPA 1980
Rat	Growth depression increase in liver & kidney weights	EC	2200 ppm 7 $h \cdot d^{-1}$, $5d \cdot wk^{-1}$	---	144 days total 103 exposures total (inhalation)	Wolf *et al.*, 1956
Rat	Increase in liver & kidney weights	EC (slight)	1250 ppm $7h \cdot d^{-1}$, $5d \cdot wk^{-1}$	---	214 days total 138 exposure days (inhalation)	Wolf *et al.* 1956
Guinea pig	---	NOEC	1250 ppm $7h \cdot d^{-1}$, $5d \cdot wk^{-1}$	---	214 days total 138 exposure days (inhalation)	Wolf *et al.* 1956
Rat Mice	---	NOAEL LOAEL	382 ppm 782 ppm	---	6 h/d, 5 d/w for 4 weeks (inhalation)	Cragg *et al.* 1989
Rabbit	---	NOAEL LOAEL	782 ppm 1610 ppm	---	6 h/d, 5 d/w for 4 weeks (inhalation)	Cragg *et al.* 1989

Table 11. Available Data on the Effects of Xylene on Mammals

Species	Effect	Endpoint	Concentration of xylene	Dose of xylene	Form of xylene	Exposure Period (exposure route)	Reference
Rat	Mortality	LD_{50}	---	4300 mg· kg^{-1}	mixed	single dose (oral)	Wolf *et al.* 1956
Rat	Mortality	LD_{50}	---	5800 mg· kg^{-1}	mixed	single dose (oral)	Ungvary 1979
Rat	Mortality (7 of 10 died)	LD_{70}	---	4401 mg· kg^{-1}	o-xylene	single dose (oral)	Gerarde 1959
	Mortality (3 of 10 died)	LD_{30}	---	4421 mg· kg^{-1}	m-xylene	single dose (oral)	
	Mortality (6 of 10 died)	LD_{60}	---	4306 mg· kg^{-1}	p-xylene	single dose (oral)	
Rat - male	Mortality	LC_{50}	6700 ppm	---	mixed with EB 19.3%	4 hours (inhalation)	Carpenter *et al.* 1975
Rat - female	Mortality	LC_{50}	6350 ppm	---	mixed with EB 19.3%	4 hours (inhalation)	Hine *et al.* 1970
Rat	Liver damage Increased liver cytochrome P-450	NOAEL LOAEL	1600 ppm 1600 ppm	--- ---	P-xylene	6 h/d for 1-3 days (inhalation)	Simmons *et al.* 1991
Rat	Chemical changes in the liver	EC	---	864 mg·kg^{-1}	m-Xylene	once a day for 3 days (oral)	Raunio *et al.* 1990
Rat	Coordination & irritation of mucous membranes decreased white cell count 2 out of 4 died	EC	1600 ppm	---	mixed	18-20 h/d up to 4 days (inhalation)	NAS 1977
Guinea pig	Liver and lung effects	EC (slight)	1150 ppm	---	mixed	4 h/d, 6 d/w for 4 months (inhalation)	
Rabbit	Decrease red and white blood cell count	EC	1150 ppm	---	benzene free Xylene	40-55 days (inhalation)	
Rat	Mortality Mortality teratogenic effects	EC (100%) EC (31%) EC	---	4.8 mL· kg^{-1}/d 3.6 mL· kg^{-1}/d 2.4 mL· kg^{-1}/d	mixed	days 6 to 15 of gestation (oral) (gavage)	Marks *et al.* 1982
Rat & rabbit	Conjunctivic, anorexia, weight loss, drowsiness, equilibrium disturbances, some paralysis of the hind extremities	EC	1133 ppm	---	mixed	6 h/d, 6 d/w for 130 days (inhalation)	Fabre *et al.* 1960
Rabbit & rat	Peripheral blood	NOAEL	690 ppm	---	mixed	8 h/d, 6 d/w for 130 days (inhalation)	ACGIH 1980

Species	Effect	Endpoint	Concentration of xylene	Dose of xylene	Form of xylene	Exposure Period (exposure route)	Reference
Rat	Mortality	LD_{50}	11000 ppm	---	mixed	92 min (inhalation)	Carpenter *et al.* 1975
Mouse	Hematologic and immunologic changes	EC	11.5 ppm	---	mixed	4 h/d for 12 months (inhalation)	Kashin *et al.* 1968
	Hematologic and immunologic changes	EC	46.4 ppm	---	mixed	2 h/d for 12 months (inhalation)	
Rat	Decreased lung cytochrome P-450	LOAEL	75 ppm	---	m-Xylene	24 hours (inhalation)	Elovaara *et al.* 1987
Rat	Biochemical changes in the liver	EC	300 ppm	---	m-Xylene	6 hours (inhalation)	Liira *et al.* 1991
Rat	Altered function in the formation, secretion and transport of neurosecretory substances and of the hypothalmic-pituitary function	EC	---	200 $mg \cdot kg^{-1}$	mixed	4 months (subcutaneous)	Bakhtizina 1976

Table 12. Summary of Environmental Soil Quality Guidelines for Toluene, Ethylbenzene and Xylene

Guideline	Land Use		
	Agriculture $mg \cdot kg^{-1}$	Residential/Parkland $mg \cdot kg^{-1}$	Commercial/Industrial $mg \cdot kg^{-1}$
Toluene			
SQG_{SC}	Insufficient data	Insufficient data	Insufficient data
SQG_I	Insufficient data	Not applicable	Not applicable
Groundwater check (aquatic life)	10	10	10
Ontario soil background levels (OTR_{98}) (OMEE 1993)	0.0013	0.0013	No Value
CCME interim remediation criteria (CCME 1991b)	0.1	3	30
Provisional SQG_E	**1.4**	**1.4**	**25**
Ethylbenzene			
SQG_{SC}	Insufficient data	Insufficient data	Insufficient data
SQG_I	Insufficient data	Not applicable	Not applicable
Groundwater check (aquatic life)	62	62	62
Ontario soil background levels (OTR_{98}) (OMEE 1993)	0.00046	0.00046	No Value
CCME interim remediation criteria (CCME 1991b)	0.1	5	50
Provisional SQG_E	**1.2**	**1.2**	**20**
Xylene			
SQG_{SC}	Insufficient data	Insufficient data	Insufficient data
SQG_I	Insufficient data	Not applicable	Not applicable
Groundwater check (aquatic life)	51	51	51
Ontario soil background levels (OTR_{98}) (OMEE 1993)	0.00092	0.00092	No Value
CCME interim remediation criteria (CCME 1991b)	0.1	5	50
Provisional SQG_E	**1**	**1**	**21**

CANADIAN SOIL QUALITY GUIDELINES FOR TOLUENE, ETHYLBENZENE AND XYLENE (TEX): ENVIRONMENTAL

CANADIAN SOIL QUALITY GUIDELINES FOR TOLUENE, ETHYLBENZENE AND XYLENE (TEX): ENVIRONMENTAL

DATE	ISSUED TO