



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

## TETRACHLORO- ETHYLENE 1997

This fact sheet provides Canadian soil quality guidelines for tetrachloroethylene (PCE) for the protection of environmental and human health (Table 1). Supporting scientific documents are also available (Environment Canada 1996; Health Canada 1996).

### Background Information

Tetrachloroethylene ( $C_2Cl_4$ ; CAS 127-18-4) is a chlorinated hydrocarbon also known as perchloroethylene, tetrachloroethene, ethylene tetrachloride, and 1,1,2,2-tetrachloroethene. Trade names include Ankilostin, Antisal 1, Dee-Solve, Didakene, DowPer, ENT 1860, Fedal-Un, Nema, Perclene, Perscosolv, Perklone, PerSec, Tetlen,

Tetracap, Tetraleno, Tetravec, Tetroguer, and Tetropil (WHO 1984).

PCE is a nonflammable, low viscosity, chlorinated organic compound stable up to 500°C in the absence of catalysts, moisture, and oxygen. However, PCE may slowly decompose in the presence of moisture to yield trichloroacetic acid and hydrochloric acid (WHO 1984). The molecular weight of PCE is 165.83. PCE is relatively insoluble in water (150 mg·L<sup>-1</sup> at 25°C) (Verschuren 1983; Muraoka and Hirata 1988; ATSDR 1993) and is very volatile (Henry's law constant of  $17.7 \times 10^{-3}$  atm·m<sup>3</sup> at 24.8°C) (Gossett 1987). It has a moderately low octanol–water partition coefficient (log  $K_{ow}$  of 2.88) (Mackay et al. 1992), suggesting a low fat solubility and consequently low bioaccumulation potential. PCE has a

**Table 1. Soil quality guidelines for tetrachloroethylene (mg·kg<sup>-1</sup>).**

Guideline	Land use			
	Agricultural	Residential/ parkland	Commercial	Industrial
	<b>0.1<sup>a</sup></b>	<b>0.2<sup>b</sup></b>	<b>0.5<sup>b</sup></b>	<b>0.6<sup>b</sup></b>
SQG <sub>HH</sub> Limiting pathway for SQG <sub>HH</sub>	0.2 Vapour inhalation	0.2 Vapour inhalation	0.5 Vapour inhalation	0.6 Vapour inhalation
Provisional SQG <sub>HH</sub> Limiting pathway for provisional SQG <sub>HH</sub>	NC <sup>c</sup> ND	NC <sup>c</sup> ND	NC <sup>c</sup> ND	NC <sup>c</sup> ND
SQG <sub>E</sub> Limiting pathway for SQG <sub>E</sub>	NC <sup>d</sup> ND	NC <sup>d</sup> ND	NC <sup>d</sup> ND	NC <sup>d</sup> ND
Provisional SQG <sub>E</sub> Limiting pathway for provisional SQG <sub>E</sub>	3.8 Soil contact	3.8 Soil contact	34 Soil contact	34 Soil contact
Interim soil quality criterion (CCME 1991)	0.1	5	50	50

**Notes:** NC = not calculated; ND = not determined; SQG<sub>E</sub> = soil quality guideline for environmental health; SQG<sub>HH</sub> = soil quality guideline for human health.

<sup>a</sup>Data are sufficient and adequate to calculate an SQG<sub>HH</sub> and a provisional SQG<sub>E</sub>. Both are greater than the existing interim soil quality criterion (CCME 1991). Therefore, the interim soil quality criterion is retained as the soil quality guideline for this land use.

<sup>b</sup>Data are sufficient and adequate to calculate an SQG<sub>HH</sub> and a provisional SQG<sub>E</sub>. Both are less than existing interim soil quality criterion (CCME 1991). Therefore the soil quality guideline supersedes the interim soil quality criterion for this land use.

<sup>c</sup>Because data are sufficient and adequate to calculate an SQG<sub>HH</sub> for this land use, a provisional SQG<sub>HH</sub> is not calculated.

<sup>d</sup>Data are insufficient/inadequate to calculate an SQG<sub>E</sub> for this land use. However, data are sufficient and adequate to calculate a provisional SQG<sub>E</sub>.

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

boiling point of 121.4°C and a specific gravity of 1.62 g·mL<sup>-1</sup> at 20°C (Environment Canada 1996).

Major biotransformation products include trichloroacetic acid, trichloroacetyl chloride, and carbon monoxide. All products of PCE biotransformation, whether the result of biotic or abiotic processes, can pose a greater risk to wildlife and the environment than PCE itself. The transformation products are generally more water soluble, more mobile, and more toxic, and have been shown to increase the toxicity of each other (Kefalas and Stacey 1991).

The major uses of PCE in Canada include dry cleaning, feedstock for the production of fluorocarbons, metal degreasing/cleaning, and textile cleaning (CIS 1990). Other uses include formulation of adhesives, aerosols, dye carriers, specialized electric circuit cleaning fluids, paints, solvents, and caulking (Wakeham et al. 1980; Government of Canada 1993). Consumer wastes from these products, which ultimately form a complex mixture with PCE, also include vinyl chloride, 1,1,1-trichloroethane, 1,1,2-trichlorotrifluoroethane, trichloroethylene, and carbon tetrachloride (Sack and Steele 1992).

PCE is found in all Canadian environmental media. Nearly all of the nationwide usage of PCE is dispersive, thus the potential release of PCE to the Canadian environment can be estimated as being at least equal to the Canadian net domestic production (e.g., 19.5 kt in 1989, 17.1 kt in 1988, and 22.5 kt in 1987) (Environment Canada 1996).

Concentrations of PCE in air over remote regions are generally in the nanogram per cubic metre range, with higher levels occurring over urban areas. Ambient air concentrations tend to be subject to marked variation over relatively short periods of time depending on the strength of emission sources, variations in wind direction and velocity, rain scavenging, and photodecomposition (Ohta et al. 1977; Figge 1990; Frank et al. 1991).

PCE has been identified at atmospheric concentrations to a maximum of 50.4 µg·m<sup>-3</sup> in Hamilton, Ontario. Ambient air was surveyed in the same study on Walpole Island, Ontario, in 1989 and 1990. The mean PCE concentrations were 0.3 µg·m<sup>-3</sup> and 0.2 µg·m<sup>-3</sup>, respectively (Dann and Wang 1992).

The Ontario Ministry of Environment and Energy has reported that the 98th percentiles of PCE concentrations in rural and old urban parkland soils not impacted by local point sources of pollution are 1.1 µg·kg<sup>-1</sup> and 0.87 µg·kg<sup>-1</sup>, respectively (OMEE 1993).

One of the major sources of concern for PCE is the potential for contamination of groundwater.

Contaminated aquifers can pose a risk to human populations as well as to the environment. PCE concentrations of 0.79–1.7 µg·L<sup>-1</sup> were detected at depths of 19.6 to 25.6 m near a landfill site in Woolwich Township, Ontario. At a Gloucester, Ontario, landfill site, PCE was detected at the special waste compound in 27% of the samples, with concentrations ranging from 2 to 105 µg·L<sup>-1</sup> (Jackson et al. 1991). The improper disposal of used commercial dry-cleaning solvents in Manotick, Ontario, resulted in PCE levels ranging from below detection limit (2.0 µg·L<sup>-1</sup>) to 80 000 µg·L<sup>-1</sup> in groundwater (Government of Canada 1993).

PCE was identified in two out of five sediment samples taken near Sarnia, Ontario. Concentrations of PCE at these sites ranged from 0.006 to 0.029 mg·kg<sup>-1</sup> and were attributable to industrial operations (Marsalek 1986). Sediment samples taken from the St. Clair River, Ontario, were also found to contain PCE at levels of 0.0004 to 2.8 mg·kg<sup>-1</sup> (OMOE 1987).

### **Environmental Fate and Behaviour in Soil**

Primary sources of PCE pollution in soil include seepage from unlined lagoons and other surface impoundments, improper land filling, improper surface and subsurface disposal practices, and leaks in pipes, storage tanks, and other processing or transport equipment associated with dry-cleaning operations.

Relatively small releases of chlorinated hydrocarbons, such as PCE, have been shown to produce substantial and long-lasting sources of groundwater contamination in Canada (Jackson et al. 1991). Since chlorinated hydrocarbons are characterized as having high densities, high vapour pressures, and low water solubilities, these chemicals will undergo density-induced sinking into the soil matrix (Anderson et al. 1992a). Depending on soil water content, soil porosity, and soil organic carbon content, some of the liquid will be left behind in pores, some will continue to move downward, and some will evaporate (Anderson et al. 1992a).

A number of variables influence the movement rate of PCE into groundwater. These include the size of the spill, the depth of groundwater, the maximum pore volume available to take up PCE in the vadose zone, and soil absorption capabilities (Anderson et al. 1992a, 1992b). The risk of PCE contamination of groundwater is highest when large spills occur on coarse-grained soils during periods of high rainfall or flooding (Environment Canada 1996).

PCE concentrations, normally regarded as labile in the environment because of their volatility and weak

equilibrium sorption tendencies, actually persist as nonreversible sorbed residues (Pavlostathis and Mathavan 1992). A PCE-contaminated soil matrix can act as a long-term reservoir for PCE contamination (Lawrence et al. 1990).

Inhalation or dermal exposure to PCE-contaminated vapour may be considered a plausible uptake route for soil-dwelling biota. PCE has a low boiling point and a low water solubility, therefore, volatilization has been considered the dominant fate process of PCE, with the atmosphere being the primary PCE sink (Wakeham et al. 1983). Even where volatilization may be limited, PCE vapour has been detected in soil pore air of contaminated sites. Significant differences in PCE vapour flux during soil infiltration can be observed from site to site depending on soil porosity, degree of saturation, and infiltration rates. Gas-phase diffusion dominates transport (mass flux) in the near surface unsaturated zones. Diffusion of PCE from pore water controls upward soil transport of PCE within the saturated zone (Cho and Jaffe 1990).

### **Behaviour and Effects in Biota**

PCE has been declared toxic according to the Canadian Environmental Protection Act (Government of Canada 1993). PCE was found to enter the Canadian environment in significant quantities, cause adverse effects in terrestrial plants due to high atmospheric concentrations, and have significant potential for contamination of groundwater and groundwater recharged surface water.

### **Microbial Processes**

Data on the effect of PCE to microbial processes are limited. Vonk et al. (1986) reported a no effect concentration ranging from 0.1 to 40 mg·kg<sup>-1</sup> for nitrification and <2000 mg·kg<sup>-1</sup> for respiration. Nitrification was reduced by 50% (EC<sub>50</sub>) at 0.8 mg PCE·kg<sup>-1</sup> soil, and microbial oxygen consumption was reduced by 30% at 2000 mg PCE·kg<sup>-1</sup> soil.

### **Terrestrial Plants**

In an attempt to establish phytotoxic levels of PCE in soil, Environment Canada conducted seedling emergence tests for both radishes (*Raphanus sativa*) and lettuce (*Lactuca sativa*). The lowest soil concentrations at which adverse effects occurred were 172 and 226 mg PCE·kg<sup>-1</sup>, resulting in a 25% reduction in seedling emergence for radishes and lettuce, respectively (Environment Canada 1995). Unresolved problems associated with the recovery of PCE from soil and the volatility of the compound allow these

results to be used for calculating provisional soil quality guidelines only. Other studies on the phytotoxic effects of PCE have examined the effects of atmospheric PCE on plants.

In field experiments, Frank and Frank (1985) exposed spruce and hornbeam shrubs to 0.45 µg PCE·m<sup>-3</sup> induced by evaporating PCE through a 5-mm-thick layer of water. This atmospheric level, similar to those in rural regions of industrial countries (Frank et al. 1991), resulted in severe chlorosis of the plants (Frank and Frank 1985). These results suggest plants can develop lesions from epoxide intermediates formed during metabolism of PCE absorbed from air. Further studies by the same authors reported chlorophyll reduction in spruce needles of 50% and 64%, as compared to the control, following a 5-h exposure to 0.013 µg·m<sup>-3</sup> and 1.24 µg·m<sup>-3</sup> PCE, respectively (Frank and Frank 1986), with ultraviolet light activating PCE toxicity.

Since PCE and trichloroethylene are known to undergo photolytic transformations to trichloroacetic acid (TCA), the phytotoxicity of PCE may be partially related to this known herbicide. In Europe, for instance, TCA is suspected to be an important cause of forest decline (Frank et al. 1991). Further observations also indicate a correlation between high loss of conifer needles and elevated atmospheric PCE concentrations (Frank 1990; Frank et al. 1991).

### **Terrestrial Invertebrates**

Environment Canada reported 25% mortality in the earthworm *Eisenia foetida* at 95 mg PCE·kg<sup>-1</sup> soil (Environment Canada 1995). The same unresolved problems associated with the phytotoxicity tests were encountered, and the results are used for deriving a provisional soil quality guideline.

Vonk et al. (1986) studied the response of mortality, appearance, and cocoon production in earthworms (*E. foetida*) following a 4-week exposure to tetrachloroethylene in a fine sand soil. The NOEC for mortality was determined to be between 32 and 100 mg·kg<sup>-1</sup>, while the LC<sub>50</sub> occurred between 32 and 320 mg·kg<sup>-1</sup>. For cocoon production and worm appearance, the authors reported NOEC values with results of ≤18 and between 18 and 32 mg·kg<sup>-1</sup>, respectively.

### **Livestock and Wildlife**

PCE may be taken up by wildlife by three main routes: dermal absorption of contaminated air and/or soil; oral ingestion of contaminated soils; and inhalation of

contaminated air. Inhalation is expected to be a minor route of exposure for wildlife, however, subsurface areas contaminated by high concentrations of PCE (e.g., in the case of industrial discharges and/or accidental spills) may act as a localized source of high inhalation and dermal exposure for certain wildlife, especially burrowing mammals, reptiles, and amphibians. There are no available direct soil contact exposure or toxicity data for wildlife or livestock.

In general, aliphatic hydrocarbons are metabolized in the mammalian liver by the cytochrome P<sub>450</sub> system to produce reactive intermediates and radicals. It is these epoxy intermediates and oxygen radicals that attack polyunsaturated fatty acids, ultimately causing lipid peroxidation of hepatocyte membranes (Berger et al. 1986; Dogterom et al. 1988).

Chlorinated hydrocarbons have also been found to inhibit membrane ATPases (Rufeger and Frimmer 1976). Often in contaminated sites, PCE co-occurs with other chlorinated aliphatic hydrocarbons. Preliminary research has shown that combined treatments of different chlorinated aliphatics can result in synergistic toxicity. Kefalas and Stacey (1991) reported membrane permeability increases and ATPase function decreases when carbon tetrachloride and PCE, or carbon tetrachloride and TCE, were co-administered to male Sprague-Dawley rats. The only specific report of PCE and carbon tetrachloride co-occurrence in the environment comes from Frieria-Gandara et al. (1990), stating that these two chemicals were most frequently detected in the drinking water at 233 locations sampled evenly among four provinces of Spain. In the province of La Coruna, the mean carbon tetrachloride and PCE concentrations were 16 and 13 µg·L<sup>-1</sup>, respectively (n > 50) (Frieria-Gandara et al. 1990). Vinyl chloride and dichloroethene, the more toxic degradation products of PCE, may also increase the toxicity of each other to terrestrial wildlife (Kefalas and Stacey 1991).

### Human and Experimental Animal Health Effects

Quantitative data on the absorption of PCE in humans are limited. PCE is readily taken up by the lungs, is likely completely absorbed during ingestion, and is only slightly absorbed through the skin. Symptoms of PCE exposure in humans have been reported and include hepatotoxic and nephrotoxic effects and death from acute exposure and mild eye and nasal irritation, anesthesia, light-headedness, speech difficulties, nausea, and eye and throat irritation from short-term exposure.

Epidemiological studies concerning the carcinogenicity of PCE in humans are limited principally to investigations of workers employed in the dry-cleaning and laundry industries, who were likely exposed to several substances in addition to PCE and for whom quantitative data on cumulative exposure were not available. Experimental animals have shown increased incidence of renal tubular cell adenomas and adenocarcinomas in rats, mononuclear cell leukemias in mice, and hepatocellular adenomas and carcinomas in mice following inhalation exposure to PCE in an NTP carcinogenesis bioassay (NTP 1986).

The most pertinent result in assessing the weight of evidence for carcinogenicity to humans is the small increase in spontaneously occurring mononuclear cell leukemias in mice.

PCE has been classified as a Group III (possibly carcinogenic to humans) carcinogen according to the classification scheme developed for use in the derivation of the guidelines for Canadian drinking water quality (Environmental Health Directorate 1989). Substances classified as “possibly carcinogenic to humans” are generally assessed by Health Canada in a manner similar to threshold toxicants.

The available data derived from epidemiological and clinical studies in humans are considered inadequate to serve as a basis for development of a TDI. Inhalation is considered to be the most important route of exposure to PCE for the general population. A TDI has been derived on the basis of results from the longest-term study of adequate design in which PCE was administered by inhalation to laboratory animals (NTP 1986; Government of Canada 1993). Based on a LOAEL of 100 ppm (678 mg·m<sup>-3</sup>) reported for reduced survival, hepatotoxic effects, lung congestion, and nephrotoxic effects in mice (NTP 1986), and using an uncertainty factor of 5000 (10 each for intra- and interspecies variation, 10 for use of a LOAEL, and 5 for limited evidence of carcinogenicity), a TDI of 34 µg·kg<sup>-1</sup> bw per day was established (Government of Canada 1993) and is adopted for the derivation of human health soil quality guidelines for PCE.

### Guideline Derivation

Canadian soil quality guidelines are derived for different land uses following the process outlined in CCME (1996a) using different receptors and exposure scenarios for each land use (Table 1). Detailed derivations for PCE soil quality guidelines are provided in Environment Canada (1996) and Health Canada (1996).

### *Soil Quality Guidelines for Environmental Health*

Environmental soil quality guidelines ( $SQG_{ES}$ ) are based on soil contact using data from toxicity studies on plants and invertebrates. In the case of agricultural land use, soil and food ingestion toxicity data for mammalian and avian species are included. To provide a broader scope of protection, a nutrient and energy cycling check is calculated. For industrial land use, an off-site migration check is also calculated.

In the case of PCE, there are insufficient data to derive any of the environmental health guidelines or check values. However, there are sufficient data to derive a provisional  $SQG_E$  based on soil contact of plants and invertebrates (Table 2).

The environmental groundwater check has been used to derive a PCE soil concentration that is intended to protect freshwater aquatic life associated with groundwater recharge to surface water. This groundwater check value is not applied in the determination of an  $SQG_E$ , but should be applied on a site-specific basis (Table 2).

### *Soil Quality Guidelines for Human Health*

Human health soil quality guidelines ( $SQG_{HH}$ ) for threshold contaminants require a TDI for the most sensitive receptor designated for a land use. For volatile organic compounds like PCE, ingestion is deemed to be an inappropriate exposure route because volatile contaminants will not remain in surface soil. Therefore the relevant exposure route is via migration into indoor air, and the TDIs for inhalation are the basis of guideline development.

The CCME recommends the application of various check mechanisms, when relevant, in order to provide a broader scope of protection (Table 2). For PCE, the lower of the inhalation of indoor air check, the off-site migration check, and the groundwater (drinking water) check is recommended as the  $SQG_{HH}$ . The  $SQG_{HH}$  is therefore based on the inhalation of indoor air check for all land uses (Table 1).

### **Soil Quality Guidelines for PCE**

The soil quality guidelines are intended to be protective of both environmental and human health. Where sufficient and adequate data exist for both, the interim soil quality criteria (CCME 1991) can be superseded.

### *Agricultural Land*

The  $SQG_{HH}$  and the provisional  $SQG_E$  for agricultural land use are greater than the existing interim soil quality criterion (CCME 1991). Therefore, due to lack of information on human health effects and certain ecological receptors, the interim soil quality criterion is retained as the soil quality guideline for this land use.

### *Residential/Parkland, Commercial, and Industrial Lands*

The  $SQG_{HH}$  and the provisional  $SQG_E$  for residential/parkland, commercial, and industrial land uses are less than the existing interim soil quality criteria (CCME 1991). Therefore, the soil quality guidelines supersede the interim soil quality criteria for these land uses.

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

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Table 2. Soil quality guidelines and check values for tetrachloroethylene (mg·kg<sup>-1</sup>).

Guideline	Land use			
	Agricultural	Residential/ parkland	Commercial	Industrial
	0.1 <sup>a</sup>	0.2 <sup>b</sup>	0.5 <sup>b</sup>	0.6 <sup>b</sup>
Human health guidelines/check values				
SQG <sub>HH</sub>	0.2 <sup>c</sup>	0.2 <sup>c</sup>	0.5 <sup>c</sup>	0.6 <sup>c</sup>
Soil ingestion guideline	NC <sup>d</sup>	NC <sup>d</sup>	NC <sup>d</sup>	NC <sup>d</sup>
Inhalation of indoor air check	0.2	0.2	0.5	0.6
Off-site migration check	—	—	—	2.1
Groundwater check (drinking water)	1.6	1.6	1.6	1.6
Produce, meat, and milk check	NC <sup>e</sup>	NC <sup>e</sup>	—	—
Provisional SQG <sub>HH</sub>	NC <sup>f</sup>	NC <sup>f</sup>	NC <sup>f</sup>	NC <sup>f</sup>
Limiting pathway for provisional SQG <sub>HH</sub>	ND	ND	ND	ND
Environmental health guidelines/check values				
SQG <sub>E</sub>	NC <sup>g</sup>	NC <sup>g</sup>	NC <sup>g</sup>	NC <sup>g</sup>
Soil contact guideline	NC <sup>g</sup>	NC <sup>g</sup>	NC <sup>g</sup>	NC <sup>g</sup>
Soil and food ingestion guideline	NC <sup>g</sup>	—	—	—
Nutrient and energy cycling check	NC <sup>g</sup>	NC <sup>g</sup>	NC <sup>g</sup>	NC <sup>g</sup>
Off-site migration check	—	—	—	NC <sup>g</sup>
Groundwater check (aquatic life)	6 <sup>h</sup>	6 <sup>h</sup>	6 <sup>h</sup>	6 <sup>h</sup>
Provisional SQG <sub>E</sub>	3.8 <sup>i</sup>	3.8 <sup>i</sup>	34 <sup>i</sup>	34 <sup>i</sup>
Limiting pathway for provisional SQG <sub>E</sub>	Soil contact	Soil contact	Soil contact	Soil contact
Interim soil quality criterion (CCME 1991)	0.1	5	50	50

**Notes:** NC = not calculated; ND = not determined; SQG<sub>E</sub> = soil quality guideline for environmental health; SQG<sub>HH</sub> = soil quality guideline for human health. The dash indicates guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

<sup>a</sup>Data are sufficient and adequate to calculate an SQG<sub>HH</sub> and a provisional SQG<sub>E</sub>. Both are greater than the existing interim soil quality criterion (CCME 1991). Therefore the interim soil quality criterion is retained as the soil quality guideline for this land use.

<sup>b</sup>Data are sufficient and adequate to calculate an SQG<sub>HH</sub> and a provisional SQG<sub>E</sub>. Both are less than the existing interim soil quality criterion (CCME 1991). Therefore the soil quality guideline supersedes the interim soil quality criterion for this land use.

<sup>c</sup>The SQG<sub>HH</sub> is the lowest of the human health guidelines and check values. For PCE, the SQG<sub>HH</sub> is based on the inhalation of indoor air check.

<sup>d</sup>For volatile organic compounds like PCE, ingestion is deemed to be an inappropriate exposure route because volatile contaminants will not remain in surface soil. Therefore the relevant exposure route is via migration into indoor air, and the human health soil ingestion guideline is not calculated.

<sup>e</sup>PCE is a nonpolar compound, but because of its high vapour pressure (18.47 mm Hg), the most likely scenario for human exposure is by inhalation of contaminated air following migration of the contaminant from soil into buildings. Therefore the produce, meat, and milk check is not calculated.

<sup>f</sup>Because data are sufficient and adequate to calculate an SQG<sub>HH</sub> for this land use, a provisional SQG<sub>HH</sub> is not calculated.

<sup>g</sup>Data are insufficient or inadequate to calculate the value for this land use.

<sup>h</sup>The groundwater check (aquatic life) value has not been applied in the determination of the soil quality guideline. The applicability of the groundwater check (aquatic life) values should be determined on a site-specific basis.

<sup>i</sup>Data are sufficient and adequate to calculate a provisional SQG<sub>E</sub> for this land use.

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