HAMILTON WATERFRONT TRUST

Pier 8 Hamilton, ON – Risk Assessment

APPENDIX C: Worked Example and Equations

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INTRODUCTION

The purpose of this appendix is to provide a worked example outlining how exposure and human health risk estimates were calculated for COCs in soil and groundwater.

The following is a worked example for a subsurface worker (construction/remediation worker) on the Site while potentially being exposed to cadmium in soil and soil particulates, exposed to vanadium in groundwater and exposed to benzene in trench air. Similar methods were used for evaluation of exposure to residents, indoor and outdoor workers. In addition, exposure of the toddler resident receptor to benzene in indoor air is described below.

Exposure Averaging Factor

The TRVs developed by regulatory agencies are averaged daily exposure values and represent daily exposures that can occur over a lifetime without resulting in adverse human health effects or unacceptable increases in lifetime cancer risks. The human receptor exposures to chemicals in soil and groundwater on the Site are considered intermittent exposures, because exposures are assumed to only occur on the days when the receptors are on-site. Before these intermittent exposures can be compared to the appropriate toxicity values, the intermittent exposures must be adjusted to account for the differences in the exposure duration between the intermittent exposures at the Site and the continuous exposures that were assumed in the development of the toxicity values. The difference in exposure duration is calculated as an exposure averaging factor. This is also sometimes referred to as a pro-rating factor.

The calculation of averaging factors depends on the type of exposure being considered. For example, inhalation occurs on a continuous 24-hour basis regardless of whether a person is on-site or off-Site. Therefore, the inhalation exposure experienced by people on a site is a function of both the time spent on-site in a given day and the number of days spent on-site in a given year. Exposures of this nature are considered Time Driven. Exposures such as the incidental ingestion of groundwater or dermal contact with groundwater can only occur when a person is present on-site. These exposures are considered Event Driven. A discussion of the calculation of exposure averaging factors is provided below.

Time Driven Exposure Averaging Factors

The calculation of Time Driven averaging factors is a function of the time spent in the study area in a given day and the number of days spent in the study area in a given year. The averaging factor values for Time Driven exposures are calculated on the basis of hours per year over which exposures can occur and are calculated as shown in Equation C-1.

Equation C-1: Calculation of Exposure Averaging Factor for Time Driven Exposures

$$AF = \frac{(ET \times EFa \times EFb)}{\left(24\ {}^{hours}/_{day} \times 365\ {}^{days}/_{year}\right)}$$

Where:	AF	= Exposure averaging factor	unitless
	ET	= Exposure time	hours/day
	EF_a	= Exposure frequency	days/week
	EF_b	= Weeks per year	weeks/year

Event Driven Exposure Averaging Factors

The calculation of Event Driven averaging factors is a function of the number of days spent on a site in a given year. As scientific information relating to the apportionment of exposures between on-site and off-Site sources is limited, the risk assessment process conservatively assumes that on the days that a person is on-site, all of the daily incidental ingestion of groundwater, or other direct contact exposures, occurs while on-site. The calculation of the averaging factor for Event Driven exposures is based on the number of days exposures are assumed to occur compared with the number of days in a given year. The averaging factor for Event Driven exposures is calculated as shown in Equation C-2.

Equation C-2: Calculation of Exposure Averaging Factor for Event Driven Exposures

$$AF = \frac{(EFa \times EFb)}{\left(365\ {}^{days}/_{year}\right)}$$

Where:	AF	= Exposure averaging factor	unitless
	EF_a	= Exposure frequency	days/week
	EF_b	= Weeks per year	weeks/year

In all cases, the exposure assumptions (i.e., EF_a, EF_b, and ET) were set to the values indicated in Section 4.0 of the RA (see Section 4.2.1 and Table 4-3).

Exposure to Cadmium via Incidental Ingestion of Soil (Subsurface Worker)

$$ADD = \frac{(C_{soil} \times IR \times RAF_{oral} \times AF \times ED)}{BW \times AT}$$

Where:

ADD	= Average daily dose - incidental ingestion of soil (mg/kg/day)
C_{soil}	= Chemical concentration in soil (15.8 µg/g)
IR	= Daily soil ingestion rate (0.1 g/day)
RAF_{oral}	= Relative absorption factor (1.0)
AF	= Exposure averaging factor [(5 d/w x 44 w/y)/365 = 0.603]
ED	= Exposure Duration (1.5 years)
BW	= Receptor body weight (70.7 kg)
AT	= Averaging Time (1.5 years)

Therefore, the total exposure to cadmium for a construction worker via incidental ingestion of soil was estimated to be 1.3×10^{-5} mg/kg/day.

Exposure to Cadmium via Dermal Contact with Soil (Subsurface Worker)

$$ADD = \frac{(C_{soil} \times SA \times SAF \times RAF \times AF \times ED\ )}{BW \times AT}$$

Where:

ADD	= Average daily dose - dermal contact with soil (mg/kg/day)
C_{soil}	= Chemical concentration in soil (15.8 µg/g)
SA	= Surface area of exposed skin (3,400 cm^2)
SAF	= Soil adhesion factor (2×10^{-4} g/cm^2/day)
RAF	= Relative absorption factor (0.01)
AF	= Exposure averaging factor [(5 d/w x 44 w/y)/365 = 0.603]
ED	= Exposure Duration (1.5 years)
BW	= Receptor body weight (70.7 kg)
AT	= Averaging Time (1.5 years)

Therefore, the total exposure to cadmium for a construction worker via dermal contact with soil was estimated to be 9.2×10^{-7} mg/kg/day.

The total direct contact exposure (i.e., incidental ingestion and dermal contact) to cadmium for a construction worker was estimated to be 1.4×10^{-5}.

Exposure to Cadmium via Inhalation of Soil Particulate (Subsurface Worker)

$$C_{air} = C_{soil} \times PA \times FPM_{inh} \times AF$$

Where: C_{air} = Chemical concentration in air (mg/m^3)
C_{soil} = Chemical concentration in soil (15.8 µg/g)
PA = Particulate Concentration in Air ($1.0x10^{-7}$ kg/m^3)
FPM_{inh} = Fraction of PM_{10} deposited (0.6)
AF = Exposure averaging factor [(9.8 hr./d x 5 d/w x 44 w/y)/(24x365) = 0.246]

Therefore, the exposure concentration for non-carcinogenic effects related to cadmium for a subsurface worker via soil particulate inhalation was estimated to be $2.3x10^{-7}$ mg/m^3. The exposure concentration for carcinogenic effects was calculated after applying an adjustment factor of 0.027 to account for the longer averaging time (i.e., 1.5/56); and therefore, the exposure concentration for carcinogenic effects was estimated to be $6.2x10^{-9}$ mg/m^3.

Exposure to Vanadium via Dermal Contact with Groundwater (Subsurface worker)

$$ADD = \frac{(C_{GW} \times SA \times Kp \times AF \times ED)}{BW \times AT}$$

Where: ADD = Average daily dose - dermal contact with groundwater (mg/kg/day)
C_{GW} = Chemical concentration in groundwater (107.8 µg/L)
SA = Skin surface area (3,988 cm^2 – development toxicant)
K_p = Dermal permeability constant (0.001 cm/hr.)
AF = Exposure averaging factor (1.0 - development toxicant)
ED = Exposure Duration (1.5 years)
BW = Body Weight (63.1 kg - development toxicant)
AT = Averaging Time (1.5 years)

Dermal permeability constants for inorganic COCs were obtained from US EPA (2004). For organic chemicals, the US EPA (2004) recommends the use of their predicted values of dermal permeability constant in water calculated as follows:

$$\log Kp = -2.80 + 0.66 logKow - 0.0056 MW$$

Where: K_p = Chemical-specific skin permeability constant in water (cm/hr.)
K_{ow} = Octanol/water partition coefficient of the non-ionized particles (unitless)
MW = Molar mass of chemical (g/mol)

Table C-1 provides dermal permeability constants (K_p) values used in the RA.

Table C-1 Dermal Permeability Constants

COC	Log K_w (unitless)	Molecular Weight (g/mol)	Dermal Permeability Constant (cm/hr)
Antimony	nv	124.8	1.0E-03[a]
Arsenic	nv	77.9	1.0E-03[a]
Barium	nv	137.3	1.0E-03[a]
Cobalt	nv	58.9	4.0E-04[a]
Molybdenum	nv	95.9	1.0E-03[a]
Selenium	nv	80.9	1.0E-03[a]
Vanadium	nv	50.9	1.0E-03[a]
Phenanthrene	4.46	178.2	1.4E-01
Fluorene	4.18	166.2	1.1E-01
Methylnaphthalene	3.86	142.2	8.9E-02
Naphthalene	3.30	128.2	4.7E-02
Acenaphthylene	3.94	152.2	8.9E-02
Acenaphthene	3.92	154.2	8.4E-02
Fluoranthene	4.95	202.3	2.2E-01
Pyrene	4.88	202.3	1.9E-01
Benzo(a)anthracene	5.66	228.3	4.7E-01
Benzo(a)pyrene	6.10	250	7.0E-01
Benzo(b)fluoranthene	6.12	252.3	7.0E-01
Benzo(ghi)perylene	6.63	276.3	1.1E+00
Benzo(k)fluoranthene	6.11	252.3	6.6E-01
Chrysene	5.66	228.3	4.7E-01
Dibenzo(a,h)anthracene	6.84	278.4	1.5E+00
Indeno(1,2,3-cd)pyrene	6.58	276.3	1.0E+00
Benzene	2.13	78.1	1.5E-02
Ethylbenzene	3.15	106.2	4.9E-02
Vinyl Chloride	1.36	62.5	5.6E-03
PHC F2 Aliphatic >C10-C12	5.4	160	7.4E-01
PHC F2 Aliphatic >C12-C16	6.7	200	3.2E+00
PHC F2 Aromatic >C10-C12	3.4	130	5.2E-02
PHC F2 Aromatic >C12-C16	6.7	150	6.1E+00
PHC F3 Aliphatic >C16-C21	8.8	270	3.1E+01
PHC F3 Aliphatic >C21-C34	nv	400	9.1E-06

COC	Log K_w (unitless)	Molecular Weight (g/mol)	Dermal Permeability Constant (cm/hr)
PHC F3 Aromatic >C16-C21	4.2	180	9.2E-02
PHC F3 Aromatic >C21-C34	5.1	250	9.1E-06
PHC F4 Aliphatic >C34	nv	500	2.5E-06
PHC F4 Aromatic >C34	nv	400	9.1E-06

Notes:
nv: No value available
[a] Dermal permeability constant for inorganic COCs were obtained from US EPA (2004).

Therefore, the total exposure to vanadium for a subsurface worker via groundwater dermal contact was estimated to be 1.6×10^{-4} mg/kg/day.

Exposure to Vanadium via Incidental Ingestion of Groundwater (Subsurface worker)

$$ADD = \frac{(C_{GW} \times IR_{GW} \times AF \times ED\ )}{BW \times AT}$$

Where: ADD = Average daily dose - incidental ingestion of groundwater (mg/kg/day)
C_{GW} = Chemical concentration in groundwater (107.8 µg/L)
IR_{GW} = Ingestion rate of groundwater (0.1 L/day)
AF = Exposure averaging factor (1.0 - development toxicant)
ED = Exposure Duration (1.5 years)
BW = Body weight (63.1 kg - development toxicant)
AT = Averaging Time (1.5 years)

Therefore, the total exposure to vanadium for a subsurface worker via incidental ingestion of groundwater was estimated to be 1.7×10^{-4} mg/kg/day.

The total direct contact exposure (i.e., incidental ingestion and dermal contact) to vanadium for a construction worker was estimated to be 3.3×10^{-4}.

Exposure to Benzene via Inhalation of Trench Air (Subsurface worker)

$$C_{air} = C_{vapour} \times VA \times AF$$

Where: C_{air} = Chemical concentration in trench air (mg/m^3)
C_{vapour} = Chemical concentration in soil vapour (799 µg/m^3)
VA = Vapour attenuation factor (0.09)
AF = Exposure averaging factor [(2 hr/d x 5 d/w x 2 w/y)/(24x365) = 0.0023]

Therefore, the exposure concentration for benzene for a subsurface worker via trench air inhalation was estimated to be 1.7×10^{-4} mg/m^3.

Exposure to Benzene via Inhalation of Indoor Air (Toddler Resident)

$$C_{air} = C_{vapour} \times VA \times AF$$

Where: C_{air} = Chemical concentration in indoor air (mg/m^3)

C_{vapour} = Chemical concentration in soil vapour (799 $\mu g/m^3$)

VA = Vapour attenuation factor (0.02)

AF = Exposure averaging factor [(24 hr/d x 7 d/w x 50 w/y)/(24x365) = 0.959]

Therefore, the exposure concentration for benzene for a toddler resident via indoor air inhalation was estimated to be 1.54×10^{-2} mg/m^3.