

# **APPENDIX D**

## **Human Health and Deposition Model Equations**

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## D PREDICTIVE ASSESSMENT METHODS

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### D.1 Calculating Exposure Point Concentrations

The following sections present the equations used to calculate the exposure point concentrations used in the HHRA. Generally, the equations are given and the terms explained. Where site-specific values were used, rationale for these values is provided below. Where known standards or default values (as presented in US EPA, 2005) were adopted, these values are given in brackets. Unless otherwise stated, the equations presented are found in US EPA (2005).

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#### D.1.1 Air

The following equation (US EPA, 2005) calculates the air concentration of a CoPC based on the fraction in vapour phase and the fraction in particle phase.

$$C_a = Hg_{\text{factorAI}} \times Q \times [F_v \times C_{yv} + (1.0 - F_v) \times C_{yp}]$$

Where:

		<u>Units</u>
$C_a$	= air concentration	$\mu\text{g}/\text{m}^3$
$Q$	= CoPC emission rate; discussed below	g/s
$Hg_{\text{factorAI}}$	= mercury factor for air inhalation; discussed below	unitless
$F_v$	= fraction of CoPC air concentration in vapour phase; CoPC-specific	unitless
$C_{yv}$	= yearly air concentration from vapour phase	$\mu\text{g}/\text{m}^3$
$C_{yp}$	= yearly air concentration from particle phase	$\mu\text{g}/\text{m}^3$

The  $Hg_{\text{factorAI}}$  is 1.0 for all CoPCs, with the following exceptions:

0.002 for elemental mercury ( $\text{Hg}^0$ )

0.482 for divalent mercury ( $\text{Hg}^{2+}$ )

0.0 for MHg

The yearly air concentration terms ( $C_{yv}$  and  $C_{yp}$ ) and a CoPC-specific emission rate ( $Q$  in g/s) are determined by air modelling, and are site- and CoPC-specific. Note, for the purposes of this assessment,  $Q$  has been incorporated into the yearly concentration and deposition rates used in the model; therefore,  $Q$ , although presented in this equation and several that follow, was not actually used in the calculation (i.e., it was artificially set to 1.0). In addition, the data provided by the air modelers had also incorporated the  $F_v$  term. The equations are presented here to illustrate the general process; however, the actual methodology varies slightly depending on how the air data are provided.

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#### D.1.2 Soil Concentration

Chemical concentrations in soil are calculated by summing the vapour and particle phase deposition of chemicals to the soil. The US EPA (2005) has recommended three different deposition equations depending on the duration of exposure and toxic mode of action. Two of the equations deal with carcinogenic chemicals and the third deals with all non-carcinogenic chemicals. The first equation is to be used if the exposure duration is less than the operating lifetime of the emission source or time period

of combustion. The second equation should be used when the exposure duration is greater than or equal to the operating lifetime of the emission source or period of combustion. The third equation is a variation of the first carcinogenic equation, which calculates the highest 1-year annual average soil concentration; typically occurring at the end of the operating life of the emission source (US EPA, 2005).

### D.1.2.1 Carcinogen – soil concentration averaged over exposure duration

For  $T_2 \leq tD$  – (exposure duration less than or equal to the operating lifetime of the emission source):

$$C_s = \frac{D_s}{k_s \times (tD - T_1)} \times \left[ \left( tD + \frac{\exp(-k_s \times tD)}{k_s} \right) - \left( T_1 + \frac{\exp(-k_s \times T_1)}{k_s} \right) \right] + C_{s \text{ Background}}$$

For  $T_1 < tD < T_2$  – (exposure duration greater than operating lifetime of the emission source):

$$C_s = \frac{\left( \frac{D_s \times tD - C_{stD}}{k_s} \right) + \left( \frac{C_{stD}}{k_s} \right) \times \left( 1 - \exp[-k_s \times (T_2 - tD)] \right)}{(T_2 - T_1)} + C_{s \text{ Background}}$$

### D.1.2.2 Non-Carcinogens – maximum annual average soil concentration

$$C_s = \frac{D_s \times [1 - \exp(-k_s \times tD)]}{k_s}$$

Where:

		<u>Units</u>
$C_s$	= average chemical soil concentration over exposure duration	mg/kg soil
$D_s$	= deposition term; discussed below	mg chemical/kg soil/yr
$T_1$	= time period at the beginning of combustion	0 years
$k_s$	= chemical soil loss constant due to all processes; discussed below	yr <sup>-1</sup>
$tD$	= time period over which deposition occurs	35 yr
$C_{stD}$	= soil concentration at time $tD$ (equivalent to $C_s$ for non-carcinogens)	mg/kg
$T_2$	= length of exposure duration (applicable for carcinogens only)	75 yr

The deposition term ( $D_s$ ) is calculated as follows:

$$D_s = \left[ \frac{100 \times Hg_{\text{factor}} \times Q}{Z_s \times BD} \right] \times \left[ F_v \times (Dy_{dv} + Dy_{wv}) + (Dy_{dp} + Dy_{wp}) \times (1 - F_v) \right]$$

Where:		<u>Units</u>
$D_s$	= deposition term	mg CoPC/kg soil/yr
100	= units conversion factor	$\text{mg}\cdot\text{m}^2/\text{kg}\cdot\text{cm}^2$
$Hg_{\text{factorDS}}$	= mercury factor for deposition; discussed below	unitless
$Q$	= CoPC emission rate; discussed previously	g/s
$Z_s$	= soil mixing zone depth	cm
$BD$	= soil bulk density (1.5 g/cm <sup>3</sup> )	g soil/cm <sup>3</sup> soil
$F_v$	= fraction of CoPC air concentration in vapour phase, CoPC-specific	unitless
$Dy_{dv}$	= yearly average dry deposition from vapour phase; discussed below	$\text{g}/\text{m}^2\cdot\text{yr}$
$Dy_{wv}$	= yearly average wet deposition from vapour phase; discussed below	$\text{g}/\text{m}^2\cdot\text{yr}$
$Dy_{dp}$	= yearly average dry deposition from particle phase; discussed below	$\text{g}/\text{m}^2\cdot\text{yr}$
$Dy_{wp}$	= yearly average wet deposition from particle phase; discussed below	$\text{g}/\text{m}^2\cdot\text{yr}$

The  $Hg_{\text{factorDS}}$  for deposition is 1.0 for all CoPCs, with the following exceptions:

- 0.0 for  $Hg^0$  (i.e.,  $0.482 \cdot 0.0$ )
- 0.47236 for  $Hg^{2+}$  (i.e.,  $0.482 \cdot 0.98$ )
- 0.00964 for MHg (i.e.,  $0.482 \cdot 0.02$ )

A soil mixing zone depth ( $Z_s$ ) of 10 cm has been selected for this assessment, based on contaminant distribution in soils and root uptake zones.

The deposition terms ( $Dy_{dv}$ ,  $Dy_{wv}$ ,  $Dy_{dp}$ , and  $Dy_{wp}$ ) are determined by air modelling and are site- and CoPC-specific.

US EPA (2005) has outlined several processes through which chemicals may be lost from soil. These methods may or may not occur simultaneously. The total rate at which a chemical is lost from the soil is referred to as the soil loss constant ( $k_s$ ).

$$k_s = k_{sg} + k_{se} + k_{sr} + k_{sl} + k_{sv}$$

Where:		<u>Units</u>
$k_s$	= CoPC soil loss constant due to all processes	$\text{yr}^{-1}$
$k_{sg}$	= CoPC loss constant due to biotic and abiotic degradation; discussed below	$\text{yr}^{-1}$
$k_{se}$	= CoPC loss constant due to soil erosion; discussed below	$\text{yr}^{-1}$
$k_{sr}$	= CoPC loss constant due to surface runoff; discussed below	$\text{yr}^{-1}$
$k_{sl}$	= CoPC loss constant due to leaching; discussed below	$\text{yr}^{-1}$
$k_{sv}$	= CoPC loss constant due to volatilization; discussed below	$\text{yr}^{-1}$

The CoPC loss constant due to biotic and abiotic degradation reflects the loss of a CoPC from the soil by mechanisms other than leaching. Abiotic degradation includes photolysis, hydrolysis, and redox reactions. Lyman et al. (1982) states that degradation rates can be assumed to follow first order kinetics in a homogeneous media.

$$k_{se} = \frac{0.1 \times X_e \times SD \times ER}{BD \times Z_s} \times \frac{K_{d_s} \times BD}{\theta_{sw} + (K_{d_s} \times BD)}$$

Where:		<u>Units</u>
$k_{se}$	= CoPC soil loss constant due to soil erosion	unitless
0.1	= units conversion factor	$(1,000 \text{ g}\cdot\text{kg}/10,000 \text{ cm}^2\cdot\text{m}^2)$

$X_e$	=	unit soil loss; discussed below	kg/m <sup>2</sup> -yr
SD	=	sediment delivery ratio; discussed below	unitless
ER	=	soil enrichment ratio; discussed below	unitless
BD	=	soil bulk density (1.5 g/cm <sup>3</sup> )	g soil/cm <sup>3</sup> soil
$Z_s$	=	soil mixing zone depth; discussed previously	cm
$Kd_s$	=	soil/water partition coefficient; CoPC- specific	mL water/g soil
$\theta_{sw}$	=	soil volumetric water content (0.2 mL/cm <sup>3</sup> )	mL water/cm <sup>3</sup> soil

The unit soil loss equation (USLE) is as follows:

$$X_e = RF \times K \times LS \times C \times PF \times \frac{907.18}{4047}$$

Where:

		<u>Units</u>	
RF	=	USLE rainfall (or erosivity) factor, site-specific	yr <sup>-1</sup>
K	=	USLE erodibility factor	ton/acre
LS	=	USLE length-slope factor	unitless
C	=	USLE cover management factor	unitless
PF	=	USLE supporting practice factor (1)	unitless
907.18	=	units conversion factor	kg/ton
4047	=	units conversion factor	m <sup>2</sup> /acre

The sediment delivery ratio is calculated as follows:

$$SD = a(A_L)^{-b}$$

Where:

		<u>Units</u>	
a	=	empirical intercept coefficient	unitless
$A_L$	=	total watershed area receiving deposition	m <sup>2</sup>
b	=	empirical slope coefficient (0.125)	unitless

The empirical intercept coefficient (a), which varies by watershed area, and the total watershed area receiving deposition ( $A_L$ ) are watershed-specific.

Recommended values for the soil enrichment ratio (ER) were adopted from US EPA (2005); 3 for organics, 1 for inorganics.

The loss constant due to surface runoff can be estimated using the following equation, as recommended by US EPA (2005):

$$ksr = \frac{RO}{\theta_{sw} \times Z_s} \times \left( \frac{1}{1 + (Kd_s \times BD / \theta_{sw})} \right)$$

Where:

		<u>Units</u>	
ksr	=	CoPC loss constant due to runoff	yr <sup>-1</sup>

RO	=	average annual surface runoff from pervious areas; discussed below	cm/yr
$\theta_{sw}$	=	soil volumetric water content (0.2 mL/cm <sup>3</sup> )	mL water/cm <sup>3</sup> soil
$Z_s$	=	soil mixing zone depth; discussed previously	cm
$Kd_s$	=	soil/water partition coefficient; CoPC-specific	mL water/g soil
BD	=	soil bulk density (1.5 g/cm <sup>3</sup> )	g soil/cm <sup>3</sup> soil

The average annual surface runoff from pervious areas (RO) was 13.8 cm/yr, based on precipitation and evapotranspiration rates.

Losses of soil CoPCs due to leaching (ksl) depend on the amount of water available to generate leachate and soil properties. The recommended equation for calculating ksl (US EPA, 2005) is as follows:

$$ksl = \frac{P + I - RO - E_v}{\theta_{sw} \times Z_s \times [1.0 + (BD \times Kd_s / \theta_w)]}$$

Where:

		<u>Units</u>	
ksl	=	CoPC loss constant due to leaching	yr <sup>-1</sup>
P	=	average annual precipitation	cm/yr
I	=	average annual irrigation	cm/yr
RO	=	average annual surface runoff from pervious areas	cm/yr
$E_v$	=	average annual evapotranspiration	cm/yr
$\theta_{sw}$	=	soil volumetric water content (0.2 mL/cm <sup>3</sup> )	mL/cm <sup>3</sup>
$Z_s$	=	soil mixing zone depth; discussed previously	cm
BD	=	soil bulk density (1.5 g/cm <sup>3</sup> )	g soil/cm <sup>3</sup> soil
$Kd_s$	=	soil/water partition; CoPC-specific	cm <sup>3</sup> water/g soil

The following climatological data was used in the assessment:

<u>Variable</u>	<u>Hypothetical Lake</u>	<u>Reference</u>
P	88	Environment Canada Climate Normals – 1971 – 2000 - Oshawa
I	0	No irrigation
RO	13.8	Calculated based on Precipitation and Evapotranspiration
$E_v$	61	National Atlas of Canada – evapotranspiration mapping

Semi-volatile and volatile CoPCs emitted in high concentrations may become adsorbed to soil particles and exhibit volatilization losses from soil. The loss of a CoPC from the soil by volatilization depends on the rate of movement of the CoPC to the soil surface, the chemical vapour concentration at the soil surface, and the rate at which vapour is carried away by the atmosphere (Jury, 1986). The following equation is recommended by US EPA (2005) for calculating CoPC loss constant due to volatilization:

$$k_{sv} = \left( \frac{3.1536 \times 10^7 \times H}{Z_s \times K_{d_s} \times R \times T_a \times BD} \right) \cdot \left( \frac{D_a}{Z_s} \right) \cdot \left[ 1 - \frac{BD}{\rho_{soil}} - \theta_{sw} \right]$$

Where:

		<u>Units</u>
k <sub>sv</sub>	= CoPC loss constant due to volatilization	yr <sup>-1</sup>
3.1536 × 10 <sup>7</sup>	= units conversion factor	s/yr
H	= Henry's Law constant; CoPC-specific	atm-m <sup>3</sup> /mol
Z <sub>s</sub>	= soil mixing zone depth; discussed previously	cm
K <sub>D<sub>s</sub></sub>	= soil/water partition coefficient; CoPC-specific	mL/mol
R	= universal gas constant (8.205 × 10 <sup>-5</sup> )	atm-m <sup>3</sup> /mol-K
T <sub>a</sub>	= ambient air temperature	K
BD	= soil bulk density (1.5 g/cm <sup>3</sup> )	g soil/cm <sup>3</sup> soil
D <sub>a</sub>	= diffusivity of CoPC in air	cm <sup>2</sup> /s
ρ <sub>soil</sub>	= solids particle density (2.7 g/cm <sup>3</sup> )	g/cm <sup>3</sup>
θ <sub>sw</sub>	= soil volumetric water content (0.2 mL/cm <sup>3</sup> )	mL/cm <sup>3</sup>

The ambient air temperature (T<sub>a</sub>) is equal to the annual average temperature (7.7°C) in Oshawa (Canadian Climate Normals, Environment Canada, 1971-2000).

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### D.1.3 Vegetation

Indirect exposure from the ingestion of homegrown produce depends on the total concentration of chemical in the leafy, fruit and root portions of the plant. Due to general differences in contaminant uptake, ingestion of produce is separated into two categories – above-ground and below ground produce. Above-ground produce is further subdivided into exposed and protected categories.

Chemical concentrations in above-ground exposed produce were calculated by taking the sum of contamination through direct deposition of particles (wet and dry), vapour transfer, and root uptake. Above-ground protected produce such as peas, beans, and corn are covered by a protective coating and therefore are not exposed to direct deposition or vapour transfer. Root uptake is the primary mechanism of exposure for above-ground protected produce. As well, below ground produce is not exposed to direct deposition or vapour transfer and root uptake was the only pathway of exposure evaluated.

Concentrations in fruit and vegetables were calculated separately in the model. Fruit was considered to be exposed to the same contamination pathways as above-ground exposed produce. The difference was that the US EPA (2005) provides fruit and produce specific values for the calculation of contamination due to direct deposition.

Calculation of CoPC concentration in traditional plants and wild fruit was also completed using the equations below.

### D.1.3.1 Above-ground Produce Concentration Due to Direct Deposition

$$P_d = \frac{1000 \times Hg_{\text{factor}} \times Q \times (1 - F_v) \times [Dy_{dp} + (F_w \times Dy_{wp})] \times R_p \times [1.0 - \exp(-k_p \times T_p)]}{Y_p \times k_p}$$

Where:		<u>Units</u>
$P_d$	= plant (above-ground produce) concentration due to direct (wet and dry) deposition	mg CoPC/kg DW
1,000	= units conversion factor	mg/g
$Hg_{\text{factorAG}}$	= mercury factor for above-ground plants; discussed below	unitless
$Q$	= CoPC emission rate; discussed previously	g/s
$F_v$	= fraction of chemical air concentration in vapour phase; discussed previously	unitless
$Dy_{dp}$	= yearly average dry deposition from particle phase; discussed previously	g/m <sup>2</sup>
$F_w$	= fraction of chemical wet deposition that adheres to plant surfaces; discussed below	unitless
$Dy_{wp}$	= yearly wet deposition from particle phase; discussed previously	g/m <sup>2</sup>
$R_p$	= interception fraction of the edible portion of the plant; discussed below	unitless
$k_p$	= plant surface loss coefficient; discussed below	yr <sup>-1</sup>
$T_p$	= length of plant exposure to deposition per harvest of the edible portion of the $i$ th plant group; discussed below	yr
$Y_p$	= yield or standing crop biomass of the edible portion of the plant (productivity), discussed below	kg DW/m <sup>2</sup>

The  $Hg_{\text{factorAG}}$  for above-ground plants is 1.0 for all CoPCs, with the following exceptions:

- 0.0 for  $Hg^0$  (i.e.,  $0.482 \times 0.0$ )
- 0.37596 for  $Hg^{2+}$  (i.e.,  $482 \times 0.78$ )
- 0.106044 for MHg (i.e.,  $0.482 \times 0.22$ )

The  $F_w$  values adopted from US EPA (2005) were as follows; 0.2 for anions, 0.6 for cations and most organics.

The values of  $F_w$ ,  $R_p$ ,  $k_t$ ,  $T_p$ , and  $Y_p$  are neither site- nor CoPC-specific. The values used in this assessment (from US EPA, 2005) differ for fruits, vegetables, silage, and forage, and are presented below.

<u>Variable</u>	<u>Vegetable</u>	<u>Fruit</u>	<u>Silage</u>	<u>Forage</u>
$R_p$	0.982	0.053	0.46	0.5
$k_p$	18	18	18	18
$T_p$	0.164	0.164	0.16	0.12
$Y_p$	5.66	0.252	0.8	0.325



### D.1.3.2 Above-ground Produce Concentration Due to Air-to-Plant Transfer

The estimation of chemical concentrations in exposed above-ground produce from air-to-plant transfer considers the limitations of chemicals to transfer from plant surfaces to the inner portions of the plant.

$$P_v = \left[ (Q \times F_v \times C_{yv}) \right] \times B_{v_{ag}} \times V_{G_{ag}} \times \frac{Hg_{factor}}{\rho_a}$$

Where:

		<u>Units</u>
$P_v$	= plant (above-ground produce) concentration due to air-to-plant transfer	$\mu\text{g CoPC/g DW}$
$Q$	= CoPC emission rate; discussed previously	$\text{g/s}$
$F_v$	= fraction of chemical air concentration in vapour phase; CoPC-specific	unitless
$C_{yv}$	= yearly average air concentration from vapour phase; discussed previously	$\mu\text{g/m}^3$
$B_{v_{ag}}$	= air-to-plant biotransfer factor; CoPC-specific ( $[\text{mg CoPC/g DW plant}]/[\text{mg CoPC/g air}]$ )	unitless
$V_{G_{ag}}$	= empirical correction factor for above-ground produce; discussed below	unitless
$Hg_{factorAG}$	= mercury factor for above-ground plants; discussed previously	unitless
$\rho_a$	= density of air (1,200)	$\text{g/m}^3$

$V_{G_{ag}}$  was included to address potential overestimation of transfer of lipophilic compounds (Log  $K_{ow}$  greater than 4) to the inner portions of bulky produce, such as apples. US EPA (2005) recommends using an empirical constant of 0.01 for compounds considered lipophilic and a constant of 1.0 for those with a Log  $K_{ow}$  less than 4 as those chemicals are assumed to pass more easily through the skin of produce. These values have been adopted in this assessment.

For forage and silage, the  $V_{G_{ag}}$  factor is different. To use the above factors to estimate CoPC concentrations specifically for forage and silage assumes that there is insignificant translocation of CoPCs deposited on the surface of bulky silage to the inner parts of the vegetation. Forage and silage are considered vegetative plant parts, and grains are considered reproductive plant parts. US EPA (2005) recommends using  $V_{G_{ag}}$  values of 1.0 for forage and 0.5 for silage. These values have been adopted in this assessment.

### D.1.3.3 Produce Concentration Due to Root Uptake

Root uptake contributes to chemical concentrations in both above-ground and below ground produce. The US EPA (2005) has provided two separate equations to estimate chemical concentrations in the edible portions of above and below ground produce.

Above-ground produce (exposed and protected):

$$Pr = C_s \times Br_{ag}$$

Below ground produce:

$$Pr = \frac{Cs \times RCF \times VG_{\text{rootveg}}}{Kd_s \times 1 \text{ kg/L}}$$

Where:		<u>Units</u>
Pr	= concentration of chemical in produce due to root uptake	mg/kg
Br <sub>ag</sub>	= plant-soil bioconcentration factor for above-ground produce; CoPC-specific	unitless
VG <sub>rootveg</sub>	= empirical correction factor for belowground produce (0.01 or 1.0, see discussion above)	unitless
Kd <sub>s</sub>	= soil-water partition coefficient (K <sub>oc</sub> × f <sub>oc</sub> )	L/kg
Cs	= average soil concentration over exposure duration (mg CoPC/kg soil)	mg/kg
RCF	= root concentration factor	unitless

The above-ground produce equation is based on the approach developed by Travis and Arms (1988). This equation is appropriate for estimating chemical concentrations in exposed and protected above-ground produce but not below ground produce. The equation for estimating concentrations in below ground produce includes a root concentration factor that was developed by Briggs et al. (1982). The root concentration factor is the ratio of chemical in the root to the chemical in the soil water.

The plant-soil bioconcentration factor (Br<sub>ag</sub>) differed depending on the type of plant (vegetable, root vegetable (applicable only for metals), fruit, forage, or grain). In general, for all but the inorganics, the Br<sub>ag</sub> for all plant types was the same, that is Br<sub>ag(veg)</sub> = Br<sub>ag(fruit)</sub> = Br<sub>ag(forage)</sub> = Br<sub>ag(grain)</sub>. For metals, a Br<sub>rootveg</sub> value was calculated by dividing RCF by Kd<sub>s</sub>, Br<sub>ag</sub> value was calculated using methodology and data from Baes, et al. (1984): The Br value for nonvegetative growth (reproductive) in Baes, et al. (1984) was used for Br<sub>ag(fruit)</sub>. A Br value for nonvegetative (reproductive) growth and Bv values (equal to Br<sub>ag(forage)</sub>) for vegetative growth weighted as 75% (reproductive) and 25% vegetative were used for Br<sub>ag(veg)</sub>. The Br<sub>ag</sub> was calculated as a weighted average of (1) Br<sub>ag(fruit)</sub> combined with a human consumption rate of fruits of 1.44 × 10<sup>-03</sup> kg/kg/day, and (2) Br<sub>ag(veg)</sub> combined with a human consumption rate of vegetables of 1.49 × 10<sup>-03</sup> kg/kg/day. Br<sub>ag(grain)</sub> is equal to Br<sub>ag(fruit)</sub>. All Br<sub>ag</sub> values for elemental mercury were set to zero, as it is assumed that elemental mercury does not deposit onto soils; therefore, there would be no plant uptake through the soil.

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#### D.1.4 Animal Tissue

Chemical concentrations in an animal are estimated on the basis of the amount of chemical that the animal is assumed to consume through their diet. Additional contamination may occur through the incidental ingestion of soil.

The total concentration of chemicals in forage is calculated using the same formulae as were used for the homegrown produce estimates. Forage is assumed to be above-ground exposed produce. US EPA (2005) recommends that 100 percent of plant material eaten by wild game is assumed to have been grown on soil contaminated by emission sources.

US EPA (2005) recommends using the equation presented in D.1.3.1 to calculate forage concentrations due to direct deposition. As previously discussed, the recommended value for Rp (interception fraction of the edible portion of the plant) for forage is 0.5, the recommended value for Tp

(plant exposure length to deposition per harvest of the edible portion of the plant) for forage is 0.12, while the recommended value of  $T_p$  (standing crop biomass (productivity)) for forage is .24 kg DW/m<sup>2</sup>. In addition, the recommended value for  $V_{G_{ag}}$  (empirical correction factor) for forage is 1.0.

#### D.1.4.1 Wild Game

The following equation calculates the CoPC concentration in wild game through the ingestion of contaminated plants and soil. The diet of wild game is assumed to consist of forage. The equation includes a biotransfer and metabolism factors to transform the daily animal intake of a CoPC into an animal CoPC tissue concentration (mg CoPC/kg tissue).

$$C_{wildgame} = \left( \left( F_{forage} \times Q_{p_{forage}} \times P_{forage} \right) + Q_s \times C_s \times B_s + Q_w \times C_{wtot} \right) \times Ba_{wildgame} \times MF$$

Where:

		<u>Units</u>
$C_{game}$	= concentration of chemical in wild game	mg/kg FW
$F_{forage}$	= fraction of forage grown on contaminated soil and ingested by wild game (1.0)	unitless
$Q_{p_{forage}}$	= quantity of forage eaten by wild game per day; discussed below	kg DW/day
$P_{forage}$	= concentration of chemical in forage eaten by wild game	mg/kg DW
$Q_s$	= quantity of soil eaten by wild game each day	kg/day
$C_s$	= average soil concentration over exposure duration; see section A.4.4.1.1	mg/kg
$B_s$	= soil bioavailability factor	unitless
$Ba_{game}$	= chemical-specific biotransfer factor for wild game	day/kg FW
$Q_w$	= quantity of water consumed by wild game per day	L/day
$C_{wtot}$	= total CoPC concentration in the water column	mg/L
MF	= metabolism factor	unitless

The quantity of forage eaten by wild game per day ( $Q_{p_{forage}}$ ) was estimated to be 0.972 kg DW plant/day.

The CoPC-specific biotransfer factors for wild game ( $Ba_{game}$ ) were calculated as follows:

$$Ba_{game} = Ba_{beef} \times \frac{0.10}{0.19}$$

Where 0.10 (10%) is the assumed fat content of game and 0.19 (19%) is the assumed fat content of beef.

$Ba_{beef}$  is calculated as follows:

$$Ba_{beef} = 10^{\log Ba_{fat}} \times 0.19$$

Where  $Ba_{fat}$  is calculated as follows:

$$\log Ba_{fat} = -0.099(\log K_{ow})^2 + 1.07\log K_{ow} - 3.56$$

The above equation is only suitable for  $K_{ow}$  values between -0.67 and 8.2. Where  $K_{ow}$  values fell above or below this range, the  $K_{ow}$  was assigned the cap values at the high or low end of the range; respectively.

The metabolism factor (MF) estimates the amount of CoPC that remains in fat and muscle. Based on a study by Ikeda et al. (1980), US EPA (1995) used a CoPC-specific MF to account for metabolism in animals and humans. Evidence indicates that bis(2-ethylexyl)phthalate (BEHP) is more readily metabolized and excreted by mammalian species than other contaminants (ATSDR, 1987), therefore, US EPA (2005) recommends a MF of 0.01 for BEHP. Lacking data to support derivation of other chemical-specific MFs, they recommend using a MF of 1.0 for all CoPCs other than BEHP. A value of 1.0 has been adopted for all CoPCs in this assessment, with the exception of polycyclic aromatic hydrocarbons, which have been assigned a MF of 0.01 based on a study (Hoefelt, 2001) that showed a 1,000 fold decrease in the retention of PAHs with respect to other chemicals. A 10% factor of safety was applied, resulting in a MF of 0.01 for all PAHs.

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## D.1.5 Drinking Water and Fish Tissue

The model calculates CoPC concentrations in surface water for all waterbodies that were selected for evaluation. Calculations for rivers and lakes (surface waterbodies) are completed separately. Chemical loading to the water column was calculated through direct deposition, runoff from pervious and impervious surfaces in the watershed, soil erosion, direct diffusion of vapour phase CoPCs into surface water, and internal transformation of compounds chemically or biologically. Consideration of other potential mechanisms may be appropriate, due to site-specific conditions (e.g., tidal influences); however, it is typically assumed that contributions from other potential mechanisms are negligible compared to those evaluated below.

### D.1.5.1 Total CoPC Load to Waterbody

The total CoPC load to the Waterbody by all mechanisms discussed above is calculated as follows (US EPA, 2005):

$$L_T = L_{DEP} + L_{dif} + L_{RI} + L_R + L_E + L_I$$

Where:

		<u>Units</u>	
$L_T$	=	total CoPC load to the waterbody (including deposition, runoff, and erosion)	g/yr
$L_{DEP}$	=	total (wet and dry) particle phase and vapour phase CoPC direct deposition load to water body; discussed below	g/yr
$L_{dif}$	=	vapour phase CoPC diffusion load to waterbody; discussed below	g/yr

$L_{RI}$	=	runoff load from impervious surfaces; discussed below	g/yr
$L_R$	=	runoff load from pervious surfaces; discussed below	g/yr
$L_E$	=	soil erosion load; discussed below	g/yr
$L_I$	=	internal transfer; (0) discussed below	g/yr

Due to the limited data and uncertainty associated with the chemical or biological internal transfer,  $L_I$ , of compounds into degradation products, US EPA (2005) generally recommends that a default value for this variable of zero be adopted. A value of zero has been adopted for this assessment.

### D.1.5.2 Total Particle Phase and Vapour Phase Direct Deposition Load to Waterbody

$$L_{DEP} = Hg_{factorWL} \times Q \times [F_v \times Dytwv + (1 - F_v) \times Dytwp] \times A_w$$

Where:		<u>Units</u>
$L_{DEP}$	= total (wet and dry) particle phase and vapour phase CoPC direct deposition load to waterbody	g/yr
$Hg_{factorWL}$	= mercury factor for water loading; discussed below	unitless
$Q$	= CoPC emission rate; discussed previously	g/s
$F_v$	= fraction of CoPC air concentration in vapour phase; discussed previously	unitless
$Dytwv$	= yearly (waterbody or watershed) average total (wet and dry) deposition from vapour phase; discussed below	g/m <sup>2</sup> -yr
$Dytwp$	= yearly (waterbody or watershed) average total (wet and dry) deposition from particle phase; discussed below	g/m <sup>2</sup> -yr
$A_w$	= waterbody surface area	m <sup>2</sup>

The  $Hg_{factorWL}$  for water loading is 1.0 for all CoPCs, with the following exceptions:

- 0.0 for Hg<sup>0</sup>
- 0.482 for Hg<sup>2+</sup>
- 0.0 for MHg

The deposition terms ( $Dytwv$  and  $Dytwp$ ) are a result of the air modelling. The area of the waterbody was assumed to be one square kilometre.

### D.1.5.3 Vapour Phase CoPC Diffusion Load to Waterbody

$$L_{\text{dif}} = \frac{K_v \times Hg_{\text{factorWL}} \times Q \times F_v \times Cy_{\text{wv}} \times A_w \times 1 \times 10^{-6}}{H \times R \times T_{\text{wk}}}$$

Where:		<u>Units</u>
$L_{\text{dif}}$	= vapour phase CoPC diffusion load to waterbody	g/yr
$K_v$	= overall CoPC transfer rate coefficient; discussed below	m/yr
$Hg_{\text{factorWL}}$	= mercury factor for water loading; discussed previously	unitless
$Q$	= CoPC emission rate; discussed previously	g/s
$F_v$	= fraction of CoPC air concentration in vapour phase; discussed previously	unitless
$Cy_{\text{wv}}$	= yearly (waterbody or watershed) average air concentration from vapour phase discussed previously	$\mu\text{g}/\text{m}^3$
$A_w$	= waterbody surface area; discussed previously	$\text{m}^2$
$10^{-6}$	= units conversion factor	g/ $\mu\text{g}$
$H$	= Henry's Law constant; CoPC-specific	$\text{atm}\cdot\text{m}^3/\text{mol}$
$R$	= Universal gas constant ( $8.205 \times 10^{-5}$ )	$\text{atm}\cdot\text{m}^3/\text{mol}\cdot\text{K}$
$T_{\text{wk}}$	= waterbody temperature, waterbody-specific	K

The overall CoPC transfer rate coefficient ( $K_v$ ) was calculated using the following equation:

$$K_v = \left[ K_L^{-1} + \left( K_G \times \frac{H}{RT_{\text{wk}}} \right)^{-1} \right]^{-1} \times \theta^{T_{\text{wk}} - 293}$$

Where:		<u>Units</u>
$K_v$	= overall CoPC transfer rate coefficient	m/yr
$K_L$	= liquid phase transfer coefficient; discussed below	m/yr
$K_G$	= gas phase liquid transfer coefficient; discussed below	m/yr
$H$	= Henry's Law constant; CoPC-specific	$\text{atm}\cdot\text{m}^3/\text{mol}$
$R$	= Universal gas constant ( $8.205 \times 10^{-5}$ at $20^\circ\text{C}$ )	$\text{atm}\cdot\text{m}^3/\text{mol}\cdot\text{K}$
$T_{\text{wk}}$	= waterbody temperature	K
$\theta$	= temperature correction factor (1.026)	unitless

Volatile organic chemicals can move between the water column and the overlying air. The overall - transfer rate,  $K_v$ , or conductivity, is determined by a two-layer resistance model that assumes that two "stagnant films" are bounded on either side by well-mixed compartments. Concentration differences serve as the driving force for the water layer diffusion. Pressure differences drive the diffusion for the air layer. From balance considerations, the same mass must pass through both films; the two resistances thereby combine in series, so that the conductivity is the reciprocal of the total resistance. The value of the conductivity  $K_v$  depends on the intensity of turbulence in the waterbody and the overlying

atmosphere. This equation assumes that volatilization occurs much less readily in lakes and reservoirs than in moving waterbodies.

The liquid phase transfer coefficient ( $K_L$ ) is calculated differently, depending on the body of water, as detailed below:

For flowing streams or rivers (transfer coefficient controlled by flow-induced turbulence):

$$K_L = \sqrt{\frac{(1 \times 10^{-4}) \times D_w \times u}{d_z}} \times 3.1536 \times 10^7$$

For quiescent lakes or ponds (transfer coefficient controlled by wind-induced turbulence):

$$K_L = (C_d^{0.5} \times W) \times \left(\frac{\rho_a}{\rho_w}\right)^{0.5} \times \frac{k^{0.33}}{\lambda_z} \times \left(\frac{\mu_w}{\rho_w \times D_w}\right)^{-0.67} \times 3.1526 \times 10^7$$

Where:

		<u>Units</u>
$K_L$	= liquid phase transfer coefficient	m/yr
$D_w$	= diffusivity of CoPC in water; CoPC-specific	$\text{cm}^2/\text{s}$
$\mu$	= current velocity; waterbody specific	m/s
$1 \times 10^{-4}$	= units conversion factor	$\text{m}^2/\text{cm}^2$
$d_z$	= total waterbody depth; waterbody specific	m
$C_d$	= drag coefficient (0.0011)	unitless
$W$	= average annual wind speed (1.4)	m/s
$\rho_a$	= density of air (0.0012 at standard conditions)	$\text{g}/\text{cm}^3$
$\rho_w$	= density of water (1)	$\text{g}/\text{cm}^3$
$k$	= von Karman's constant (0.4)	unitless
$\lambda_z$	= dimensionless viscous sublayer thickness (4)	unitless
$\mu_w$	= viscosity of water corresponding to water temperature (0.0169)	$\text{g}/\text{cm}\cdot\text{s}$
$3.1536 \times 10^7$	= units conversion factor	s/yr

The following equation is recommended (US EPA, 2005) to calculate the gas phase transfer coefficient:

For quiescent lakes or ponds:

$$K_G = (C_d^{0.5} \times W) \times \frac{k^{0.33}}{\lambda_z} \times \left(\frac{\mu_a}{\rho_a \times D_a}\right)^{-0.67} \times 3.1536 \times 10^7$$

Where:		<u>Units</u>
$K_G$	= gas phase transfer coefficient	m/yr
$C_d$	= drag coefficient; discussed previously	unitless
$W$	= average annual wind speed	m/s
$k$	= von Karman's constant; discussed previously	unitless
$\lambda_z$	= dimensionless viscous sublayer thickness; discussed previously	unitless
$\mu_a$	= viscosity of air corresponding to water temperature ( $1.81 \times 10^{-4}$ )	g/cm-s
$\rho_a$	= density of air; discussed previously	g/cm <sup>3</sup>
$D_a$	= diffusivity of CoPC in air; CoPC-specific	cm <sup>2</sup> /s
$3.1536 \times 10^7$	= units conversion factor	s/yr

For flowing streams or rivers, US EPA (2005) recommends using a value of  $K_G = 36,500$  m/yr., because the rate of transfer of CoPC from the gas phase for a flowing stream or river is assumed to be constant.

#### D.1.5.4 Runoff Load from Impervious Surfaces

$$L_{RI} = Hg_{\text{factorWL}} \times Q \times [F_v \times \text{Dytwv} + (1.0 - F_v) \times \text{Dytwp}] \times A_I$$

Where:		<u>Units</u>
$L_{RI}$	= runoff load from impervious surfaces	g/yr
$Hg_{\text{factorWL}}$	= mercury factor for water loading; discussed previously	unitless
$Q$	= CoPC emission rate; discussed previously	g/s
$F_v$	= fraction of CoPC air concentration in vapour phase; discussed previously	unitless
$\text{Dytwv}$	= yearly (waterbody or watershed) average total (wet and dry) deposition from vapour phase; discussed previously	g/m <sup>2</sup> -yr
$\text{Dytwp}$	= yearly (waterbody or watershed) average total (wet and dry) deposition from particle phase; discussed previously	g/m <sup>2</sup> -yr
$A_I$	= impervious watershed area receiving CoPC deposition	m <sup>2</sup>

The impervious watershed area receiving CoPC deposition ( $A_I$ ) is the portion of the total effective watershed area that is impervious to rainfall (such as roofs, driveways, streets, and parking lots) and drains to the waterbody. This value is watershed-specific.

#### D.1.5.5 Runoff Load from Pervious Surfaces

$$L_R = RO \times (A_L - A_I) \times \frac{Cs \times BD}{\theta_{sw} + Kd_s \times BD} \times 0.01 \times Hg_{\text{factorRL}}$$



Where:		<u>Units</u>
$L_R$	= runoff load from pervious surfaces	g/yr
RO	= average annual surface runoff from pervious areas; discussed previously	cm/yr
$A_L$	= total watershed area receiving CoPC deposition; waterbody-specific	$m^2$
$A_I$	= impervious watershed area receiving CoPC deposition; waterbody specific	$m^2$
Cs	= average soil concentration over exposure duration (in watershed soils)	mg CoPC/kg soil
BD	= soil bulk density (1.5 g/cm <sup>3</sup> )	g soil/cm <sup>3</sup> soil
$\theta_{sw}$	= soil volumetric water content (0.2 mL/cm <sup>3</sup> )	mL water/cm <sup>3</sup> soil
$Kd_s$	= soil-water partition coefficient, CoPC-specific	cm <sup>3</sup> water/g soil
0.01	= units conversion factor	kg-cm <sup>2</sup> /mg-m <sup>2</sup>

#### D.1.5.6 Soil Erosion Load

$$L_E = X_e \times (A_L - A_I) \times SD \times ER \times \frac{Cs \times Kd_s \times BD}{\theta_{sw} + Kd_s \times BD} \times 0.001$$

Where:		<u>Units</u>
$L_E$	= soil erosion load	g/yr
$X_e$	= unit soil loss; discussed previously	kg/m <sup>2</sup> -yr
$A_L$	= total watershed area receiving CoPC deposition; previously discussed	$m^2$
$A_I$	= impervious watershed area receiving CoPC deposition; previously discussed	$m^2$
SD	= sediment delivery ratio (watershed); discussed previously	unitless
ER	= soil enrichment ratio; discussed previously	unitless
Cs	= average soil concentration over exposure duration (in watershed soils); see section A.4.4.1.1	mg CoPC/kg soil
BD	= soil bulk density (1.5 g/cm <sup>3</sup> )	g soil/cm <sup>3</sup> soil
$\theta_{sw}$	= soil volumetric water content (0.2 mL/cm <sup>3</sup> )	mL water/cm <sup>3</sup> soil
$Kd_s$	= soil-water partition coefficient; CoPC-specific	cm <sup>3</sup> water/g soil
0.001	= units conversion factor	k-cm <sup>2</sup> /mg-m <sup>2</sup>

#### D.1.5.7 Drinking Water Concentration

US EPA recommends using the following equation to calculate the total waterbody CoPC concentration, which includes both the water column and the bed sediment.

To be conservative it was assumed that receptors would consume water directly from the water column of the waterbody without any prior filtering.

$$C_{wtot} = \frac{L_T}{V f_x \times f_{wc} + k_{wt} \times A_W \times (d_{wc} + d_{bs})}$$

Where:		<u>Units</u>
$C_{wtot}$	= total waterbody CoPC concentration (including water column and bed sediment)	g CoPC/m <sup>3</sup> waterbody
$L_T$	= total CoPC load to the waterbody (including deposition, runoff, and erosion); presented previously	g/yr
$Vf_x$	= average volumetric flow rate through waterbody; discussed below	m <sup>3</sup> /yr
$f_{wc}$	= fraction of total waterbody CoPC concentration in the water column; discussed below	unitless
$k_{wt}$	= overall total waterbody CoPC dissipation rate constant; discussed below	yr <sup>-1</sup>
$A_W$	= waterbody surface area; waterbody-specific	m <sup>2</sup>
$d_{wc}$	= depth of water column; waterbody-specific	m
$d_{bs}$	= depth of upper benthic sediment layer (0.03m)	m

The average volumetric flow rate through the waterbody ( $Vf_x$ ) was estimated for the lake based on the equation presented in US EPA (2005) [Watershed Area x (1/2) average annual RO].

The depth of the upper benthic layer ( $d_{bs}$ ), which represents the portion of the bed that is in equilibrium with the water column, cannot be precisely specified; however, the US EPA (2005) recommends values from 0.01 to 0.05 and a default value of 0.03, which represents the midpoint of the specified range. This value has been adopted for use in this assessment.

US EPA (2005) recommends using the following equation to calculate  $f_{wc}$  (the fraction of total waterbody CoPC concentration in the water column). In addition, the equation for  $f_{bs}$  is presented.

$$f_{wc} = \frac{(1 + Kd_{sw} \times TSS \times 1 \times 10^{-6}) \times d_{wc} / d_z}{(1 + Kd_{sw} \times TSS \times 1 \times 10^{-6}) \times d_{wc} / d_z + (\theta_{bs} + Kd_{bs} \times C_{BS}) \times d_{bs} / d_z}$$

$$f_{bs} = 1 - f_{wc}$$

Where:		<u>Units</u>
$f_{wc}$	= fraction of total waterbody CoPC concentration in the water column	unitless
$f_{bs}$	= fraction of total waterbody CoPC concentration in benthic sediment	unitless
$Kd_{sw}$	= suspended sediments/surface water partition coefficient; CoPC-specific	L water/kg suspended sediment
TSS	= total suspended solids concentrations; discussed below	mg/L
$1 \times 10^{-6}$	= units conversion factor	kg/mg
$d_z$	= total waterbody depth; discussed below	m
$\theta_{bs}$	= bed sediment porosity; discussed below	L <sub>water</sub> /L <sub>sediment</sub>
$Kd_{bs}$	= bed sediment/sediment pore water partition coefficient; CoPC-specific	L water/kg bottom sediment
$C_{BS}$	= bed sediment concentration; discussed below	g/cm <sup>3</sup> [equivalent to kg/L]
$d_{wc}$	= depth of water column; water-body specific	m
$d_{bs}$	= depth of upper benthic sediment layer; discussed previously	m

The total waterbody depth ( $d_z$ ) is calculated by adding the depth of the water column to the depth of the upper benthic layer ( $d_{wc}+d_{bs}$ ).

US EPA (2005) recommends using waterbody-specific measured TSS values representative of long-term average annual values. Average annual values for TSS are generally expected to be in the range of 2 to 300 mg/L. If measured data are not available, or of unacceptable quality, US EPA (2005) recommends the following equation be used to calculate the TSS for non-flowing bodies of water:

$$TSS = \frac{X_e \times (A_L - A_I) \times SD \times 1 \times 10^3}{Vf_x + D_{ss} \times A_W}$$

Where:		<u>Units</u>
TSS	= total suspended solids concentration	mg/L
$X_e$	= unit soil loss; discussed previously	kg/m <sup>2</sup> -yr
$A_L$	= total watershed area (evaluated) receiving CoPC deposition; discussed previously	m <sup>2</sup>
$A_I$	= impervious watershed area receiving CoPC deposition; discussed previously	m <sup>2</sup>
SD	= sediment delivery ratio (watershed); discussed previously	unitless
$1 \times 10^3$	= units conversion factor	
$Vf_x$	= average volumetric flow rate through waterbody; discussed previously	m <sup>3</sup> /yr
$D_{ss}$	= suspended solids deposition rate (1,825)	m/yr
$A_W$	= waterbody surface area	m <sup>2</sup>

For the purpose of this assessment, TSS values were calculated.

The default value of 1,825 m/yr provided for  $D_{ss}$  is characteristic of Stoke's settling velocity for an intermediate (fine to medium) silt.

US EPA (2005) recommends the following default values (which have been adopted for bed sediment porosity ( $\theta_{bs}$ ), adapted from NC DEHNR (1997):

$$\theta_{bs} = 0.6 L_{water}/L_{sediment}$$

assuming

$$\rho_s = 2.65 \text{ kg/L [bed sediment density]}$$

and

$$C_{BS} = 1.0 \text{ kg/L [bed sediment concentration]}$$

US EPA (2005) recommends the following equation to calculate the overall dissipation rate of CoPCs in surface water, resulting from volatilization and benthic burial:

$$k_{wt} = f_{wc} \times k_v + f_{bs} \times k_b$$

Where:		<u>Units</u>
$k_{wt}$	= overall total waterbody dissipation rate constant	$yr^{-1}$
$f_{wc}$	= fraction of total waterbody CoPC concentration in the water column; discussed above	unitless
$k_v$	= water column volatilization rate constant	$yr^{-1}$
$f_{bs}$	= fraction of total waterbody CoPC concentration in benthic sediment; discussed above	unitless
$k_b$	= benthic burial rate constant; discussed below	$yr^{-1}$

The water column volatilization rate constant ( $k_v$ ) is calculated as follows:

$$k_v = \frac{K_v}{d_z \times (1 + K_{d_{sw}} \times TSS \times 1 \times 10^{-6})}$$

Where:		<u>Units</u>
$k_v$	= water column volatilization rate constant	$yr^{-1}$
$K_v$	= overall CoPC transfer rate coefficient; discussed previously	m/yr
$d_z$	= total waterbody depth; discussed previously	m
$K_{d_{sw}}$	= suspended sediments/surface water partition coefficient	L water/kg suspended sediments
TSS	= total suspended solids concentration	mg/L
$1 \times 10^{-6}$	= units conversion factor	kg/mg

The recommended equation (US EPA. 2005) for benthic burial rate constant ( $k_b$ ) is presented below:

$$k_b = \left( \frac{X_e \times A_L \times SD \times 1 \times 10^3 - VF_x \times TSS}{A_w \times TSS} \right) \times \left( \frac{TSS \times 1 \times 10^{-6}}{C_{BS} \times d_{bs}} \right)$$

Where:		<u>Units</u>
$k_b$	= benthic burial rate constant	$yr^{-1}$
$X_e$	= unit soil loss; discussed previously	$kg/m^2\text{-yr}$
$A_L$	= total watershed area (evaluated) receiving deposition; discussed previously	$m^2$
SD	= sediment delivery ratio (watershed); discussed previously	unitless
$VF_x$	= average volumetric flow rate through waterbody; discussed previously	$m^3/yr$
TSS	= total suspended solids concentration; discussed previously	mg/L
$A_w$	= waterbody surface area; waterbody-specific	$m^2$
$C_{BS}$	= bed sediment concentration; discussed previously	$g/cm^3$
$d_{bs}$	= depth of upper benthic sediment layer; discussed previously	m
$1 \times 10^{-6}$	= units conversion factor	kg/mg
$1 \times 10^3$	= units conversion factor	g/kg

The US EPA (2005) recommends using the following equation to calculate the total CoPC concentration in the water column ( $C_{wctot}$ ):

$$C_{wctot} = f_{wc} \times C_{wtot} \times \frac{d_{wc} + d_{bs}}{d_{wc}}$$

Where:

Units

$C_{wctot}$	=	total CoPC concentration in water column; discussed previously	mg CoPC/L water column
$f_{wc}$	=	fraction of total waterbody CoPC concentration in the water column; discussed previously	unitless
$C_{wtot}$	=	total waterbody CoPC concentration, including water column and bed sediment; discussed previously	mg CoPC/L waterbody
$d_{wc}$	=	depth of water column; discussed previously	m
$d_{bs}$	=	depth of upper benthic sediment layer; discussed previously	m

The recommended equation for calculating the concentration of CoPC dissolved in the water column ( $C_{dw}$ ) is as follows (US EPA, 2005):

$$C_{dw} = \frac{C_{wctot}}{1 + Kd_{sw} \times TSS \times 1 \times 10^{-6}} \times Hg_{factorC_{dw}}$$

Where:

Units

$C_{dw}$	=	dissolved phase water concentration	mg CoPC/L water
$C_{wctot}$	=	total CoPC concentration in water column; discussed previously	mg CoPC/L water column
$Kd_{sw}$	=	suspended sediments/surface water partition coefficient; CoPC-specific	L water/kg suspended sediment
TSS	=	total suspended solids; discussed previously	mg/L
$1 \times 10^{-6}$	=	units conversion factor	kg/mg
$Hg_{factorC_{dw}}$	=	mercury factor for dissolved water concentration; discussed below	unitless

The  $Hg_{factorC_{dw}}$  for dissolved water concentration is 1.0 for all CoPCs, with the following exceptions:

0.968 for  $Hg^{2+}$  (96.8% is the ratio of Inorganic Mercury ( $Hg^{+2}$ ) to Total Mercury)

0.032 for MHg (3.2% is the ratio of Methyl Mercury (MHg) to Total Mercury)

The following equation is recommended for the calculation of CoPC concentration sorbed to bed sediment ( $C_{sb}$ ):

$$C_{sb} = f_{bs} \times C_{wtot} \times \left( \frac{Kd_{bs}}{\theta_{bs} + Kd_{bs} \times C_{BS}} \right) \times \frac{d_{wc} + d_{bs}}{d_{bs}}$$

Where:		<u>Units</u>
$C_{sb}$	= CoPC concentration sorbed to bed sediment	mg CoPC/kg sediment
$f_{bs}$	= fraction of total waterbody CoPC concentration in benthic sediment; discussed previously	unitless
$C_{wtot}$	= total waterbody CoPC concentration, including water column and bed sediment; discussed previously	mg CoPC/L waterbody
$Kd_{bs}$	= bed sediment/sediment pore water partition coefficient; CoPC-specific	L CoPC/kg waterbody
$\theta_{bs}$	= bed sediment porosity; discussed previously	$L_{\text{pore water}}/L_{\text{sediment}}$
$C_{BS}$	= bed sediment concentration; discussed previously	$g/cm^3$
$d_{wc}$	= depth of water column; discussed previously	m
$d_{bs}$	= depth of upper benthic sediment layer; discussed previously	m

### D.1.5.8 Fish Concentrations

Chemical concentrations in fish were calculated using either a CoPC-specific bioconcentration factor (BCF), bioaccumulation factor (BAF), or biota-sediment accumulation factor (BSAF). In accordance with US EPA (2005) guidance, extremely hydrophobic chemicals such as dioxins, furans, and PCBs are assumed to have a high tendency to bioaccumulate in bed sediments and therefore a BSAF was used to assess fish uptake for these chemicals. All other CoPC were evaluated using BCF/BAFs.

BCFs and BAFs are generally based on dissolved water concentrations. Therefore, it's appropriate to calculate the CoPC concentration in fish using dissolved water concentrations. BSAF values are based on benthic sediment concentrations; therefore, when using BSAF values, US EPA (2005) recommend calculating CoPC concentrations in fish using benthic sediment concentrations. The appropriate equations are presented below:

#### Fish concentration using BCFs or BAFs

$$C_{\text{fish}} = Hg_{\text{factorFC}} \times C_{\text{dw}} \times \left( BCF_{\text{fish}} \text{ or } BAF_{\text{fish}} \right) \times MF$$

Where:		<u>Units</u>
$C_{\text{fish}}$	= concentration of chemical in fish	mg CoPC/kg FW tissue
$Hg_{\text{factorFC}}$	= mercury factor for fish concentration; discussed below	unitless
$C_{\text{dw}}$	= concentration in water dissolved phase; previously discussed	mg CoPC/L
$BCF_{\text{fish}}$	= chemical specific bioconcentration factor for fish; CoPC-specific	L/kg
$BAF_{\text{fish}}$	= chemical specific bioaccumulation factor for fish; CoPC-specific	L/kg FW tissue
MF	= metabolism factor; discussed previously	unitless

The  $Hg_{\text{factorFC}}$  is 1.0 for all CoPCs, with the following exceptions:

- 0.0 for elemental mercury ( $Hg^0$ )
- 0.0 for divalent mercury ( $Hg^{2+}$ )
- 1.0 for MHg

## Fish concentration using BSAFs

$$C_{\text{fish}} = \frac{C_{\text{sb}} \times f_{\text{lipid}} \times \text{BSAF}}{\text{OC}_{\text{sed}}} \times \text{MF}$$

Where:

		<u>Units</u>
$C_{\text{fish}}$	= concentration of chemical in fish	mg CoPC/kg FW tissue
$C_{\text{sb}}$	= concentration sorbed to bed sediment; previously discussed	mg CoPC/kg bed sediment
$f_{\text{lipid}}$	= fish lipid content; site-specific and dependent on type of fish consumed	unitless
BSAF	= CoPC-specific biota-to-sediment accumulation factor	unitless
$\text{OC}_{\text{sed}}$	= fraction of organic carbon in bottom sediment; discussed below	unitless
MF	= metabolism factor; discussed previously	unitless

The fraction of organic carbon in bottom sediment ( $\text{OC}_{\text{sed}}$ ) is waterbody specific. A value of 0.05 was assumed for the lake. The US EPA (2005) default is 0.04; however, values can range between 0.01 and 0.25.

## Mercury Modelling

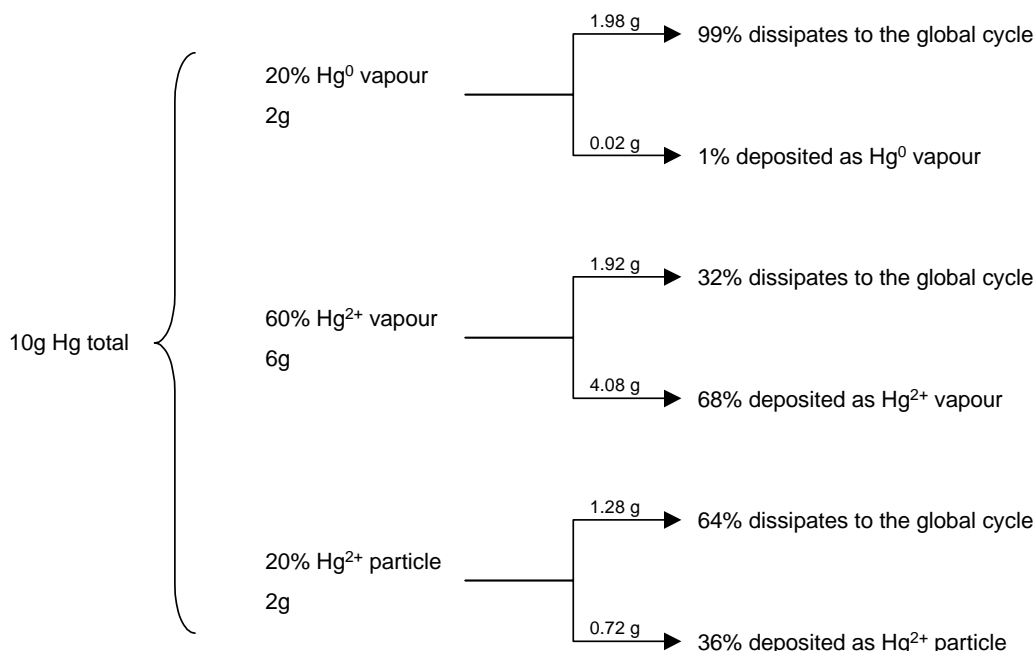
The US EPA HHRAP constitutes a series of numerical models designed to estimate the environmental fate, transport, and uptake of airborne contaminants. Each model includes default assumptions and, like any other generic guidance, is constructed in a conservative manner. In the case of mercury modelling, the HHRAP includes a series of conservative default assumptions that multiply together to lead to predictions that are higher than could reasonably be expected and that are often in disagreement with empirical data (Zemba et al., 2001).

## Speciation of Mercury Emissions

The US EPA HHRAP is a risk assessment protocol designed specifically for the evaluation of hazardous waste combustion facilities. However, its use has been commonly extrapolated to assess other situations. Stack emissions are speciated into both divalent ( $\text{Hg}^{2+}$ ) and elemental ( $\text{Hg}^0$ ) mercury, and include both vapour and particle-bound forms. Divalent mercury emitted either in the vapour phase or particle-bound is subject to much faster atmospheric removal than elemental mercury (Lindberg et al., 1992; Peterson et al., 1995; Shannon and Volder, 1994) and therefore has a much more significant impact on near-field deposition. The vast majority of elemental mercury dissipates into the global mercury cycle.

Percentages of  $\text{Hg}^{2+}$  and  $\text{Hg}^0$ , vapour and particle-bound, vary widely depending on the source. The HHRAP made the following default assumptions for the phase allocation and speciation of mercury in air:

### Phase Allocation and Speciation of Mercury Emissions - US EPA HHRAP Default Assumptions



**Figure D.1 Phase Allocation and Speciation of Mercury Emissions – US EPA HHRAP Default Assumptions**

Based on the above, 48.2% (0.02g + 4.08g + 0.72g) of mercury emissions are assumed to deposit locally. This default allocation in the HHRAP is based on the following:

- Consistency with emissions speciation data for hazardous waste combustion sources; and
- High degree of protection, since it results in the highest percentage of total mercury being deposited near the source and, therefore, is indicative of the maximum risk.

The phase allocation in the HHRAP is based on data for municipal waste incinerators presented in the Mercury Report to Congress (US EPA, 1997b).

### Mercury Methylation in Waterbodies

The great majority of mercury deposited on land is assumed to be inorganic. A portion of the total mercury deposited into a waterbody is then assumed to be converted into the organic form – methyl mercury – in the water. The HHRAP recommends a default methylation of mercury in the waterbody of 15% methyl mercury and 85% inorganic mercury. Both forms of mercury are accumulated into fish at different rates and then all of the fish tissue mercury is assumed to be converted to methyl mercury in the fish.

The 15% portion of total dissolved mercury that is assumed to be present as methyl mercury references the Report to Congress. In fact, a range of studies is referenced in the Report to Congress (Volume 3, Appendix D) which provide a range of methyl mercury fractions. The default value adopted in the



HHRAP of 15% is the single maximum value from any of the quoted studies and is likely to overestimate the rate of methylation. The range of values presented from the other studies is from 4.6% up to 9.2% methyl mercury in the water. The point estimate for %methyl mercury given in the Report to Congress is 7.8%. This value is the median of all the studies presented.

Subsequently, the US EPA published the Water Quality Criterion for the Protection of Human Health: Methylmercury Final (US EPA, 2001). This criteria document provides discussion of mercury methylation in waterbodies and provides the following methyl mercury fractions:

- Lakes - 3.2%
- Rivers - 1.4%

## D.2 Calculating Human Exposure Rates

The EPCs were carried forward into calculating human exposure rates. The following equations were used to evaluate all receptors, scenarios, and chemicals of potential concern. Tables of Receptor Characteristics, Site Input Parameters, and Chemistry Parameters are found Appendices A and C.

### D.2.1 Exposure from Vapour

#### D.2.1.1 Direct Inhalation (Vapour and Particulate)

These equations are used to assess the potential risk resulting from direct inhalation of or dermal contact with vapour and particulate emissions.

$$\text{Intake}_{\text{INHc or nc}} = \frac{\text{IR}_{\text{inh}} \times \text{AF}_{\text{inh}} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times (\text{AT}_{\text{c}} \text{ or } \text{AT}_{\text{nc}})}$$

Where:

	<u>Units</u>
$\text{Intake}_{\text{INHc or nc}}$ = intake factor from direct inhalation (carcinogenic or non-carcinogenic)	$\text{m}^3/\text{kg}\cdot\text{day}$
$\text{IR}_{\text{inh}}$ = air inhalation rate	$\text{m}^3/\text{day}$
$\text{AF}_{\text{inh}}$ = inhalation absorption factor	unitless
ET = exposure time (hours per day divided by 24)	unitless
EF = exposure frequency	days/year
ED = exposure duration	years
BW = body weight of receptor	kg
$\text{AT}_{\text{c}}$ = averaging time carcinogen (365 days/year x 75 years*)	days
$\text{AT}_{\text{nc}}$ = averaging time non-carcinogen (365 days/year x ED)	days

All the inputs (with the exception of the inhalation absorption factor,  $\text{AF}_{\text{inh}}$ ) are receptor-specific. Tables of receptor characteristics (including references) for the six receptors evaluated are found in Appendix A. In general, the averaging time for carcinogens was based on a 75 year lifespan (with the exception of the commercial adult receptor, who was assumed to be exposed to CoPCs his place of work over a

56-year adult lifetime). For assessment of inhalation exposures, the exposure time for all receptors was equal to 24 hours a day (or 24/24 = 1) and the exposure frequency was 365 days per year.

The intake factors were used to calculate chronic daily intakes (to assess non-carcinogenic endpoints) and lifetime average daily doses (to assess carcinogenic endpoints), using the equations presented below:

$$CDI_{INH} = Intake_{INHnc} \times C_a$$

$$LADD_{INH} = Intake_{INHc} \times C_a$$

Where:

		Units
$CDI_{INH}$	= chronic daily intake from direct inhalation	mg/kg-day
$LADD_{INH}$	= lifetime average daily dose from direct inhalation	mg/kg-day
$Intake_{INHnc}$	= intake factor from direct inhalation (non-carcinogenic)	$m^3/kg\text{-day}$
$Intake_{INHc}$	= intake factor from direct inhalation (carcinogenic)	$m^3/kg\text{-day}$
$C_a$	= concentration of chemical in air	$mg/m^3$

### D.2.1.2 Direct Dermal Exposure (Vapour and Particulate) - Summer

$$Intake_{DDERMS\ c\ or\ nc} = \frac{Kp \times (SA_{hand} + SA_{body}) \times ET \times EF \times ED \times CF}{BW \times (AT_c\ or\ AT_{nc})}$$

Where:

		<u>Units</u>
$Intake_{DDERMS\ c\ or\ nc}$	= daily intake from direct dermal contact - summer	$m^3/kg\text{-day}$
$Kp$	= dermal permeability coefficient	cm/d
$SA_{hand}$	= exposed surface area - hand	$cm^2$
$SA_{body}$	= exposed surface area - body (summer)	$cm^2$
$ET$	= exposure time	unitless
$EF$	= exposure frequency	days/year
$ED$	= exposure duration	years
$CF$	= conversion factor ( $1 \times 10^{-6}$ )	$m^3/cm^3$
$BW$	= body weight of receptor	kg
$AT_c$	= averaging time carcinogen	days
$AT_{nc}$	= averaging time non-carcinogen	days

$$CDI_{DDERMS} = Intake_{DDERMSnc} \times C_a$$

$$LADD_{DDERMS} = Intake_{DDERMSc} \times C_a$$

Where:

		<u>Units</u>
$CDI_{DDERMS}$	= chronic daily intake from direct dermal contact - winter	mg/kg-day
$LADD_{DDERMS}$	= lifetime average daily dose from direct dermal contact - winter	mg/kg-day
$Intake_{DDERMSnc}$	= intake factor from direct inhalation (non-carcinogenic)	$m^3/kg\text{-day}$
$Intake_{DDERMSc}$	= intake factor from direct inhalation (carcinogenic)	$m^3/kg\text{-day}$
$C_a$	= concentration of chemical in air	mg/ $m^3$

### D.2.1.3 Direct Dermal Exposure (Vapour and Particulate) - Winter

$$Intake_{DDERMWc \text{ or } nc} = \frac{Kp \times (SA_{hand} + SA_{body}) \times ET \times EF \times ED \times CF}{BW \times (AT_c \text{ or } AT_{nc})}$$

Where:

		<u>Units</u>
$Intake_{DDERMWc \text{ or } nc}$	= daily intake from direct dermal contact - winter	$m^3/kg\text{-day}$
$Kp$	= dermal permeability coefficient	cm/d
$SA_{hand}$	= exposed surface area - hand	$cm^2$
$SA_{body}$	= exposed surface area - body (winter)	$cm^2$
$ET$	= exposure time	unitless
$EF$	= exposure frequency	days/year
$ED$	= exposure duration	years
$CF$	= conversion factor ( $1 \times 10^{-6}$ )	$m^3/cm^3$
$BW$	= body weight of receptor	kg
$AT_c$	= averaging time carcinogen	days
$AT_{nc}$	= averaging time non-carcinogen	days

$$CDI_{DDERMW} = Intake_{DDERMWnc} \times C_a$$

$$LADD_{DDERMW} = Intake_{DDERMWc} \times C_a$$

Where:

		<u>Units</u>
$CDI_{DDERMW}$	= chronic daily intake from direct dermal contact - winter	mg/kg-day
$LADD_{DDERMW}$	= lifetime average daily dose from direct dermal contact - winter	mg/kg-day
$Intake_{DDERMWnc}$	= intake factor from direct inhalation (non-carcinogenic)	$m^3/kg\text{-day}$
$Intake_{DDERMWc}$	= intake factor from direct inhalation (carcinogenic)	$m^3/kg\text{-day}$
$C_a$	= concentration of chemical in air	mg/ $m^3$

## D.2.2 Inhalation of Soil Vapours

The following equations are used to assess the potential risk resulting from inhalation of or dermal contact with vapours re-volatilizing from soil.

$$\text{Intake}_{\text{INH SVc or nc}} = \frac{\text{IR}_{\text{inh}} \times \text{AF}_{\text{inh}} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times (\text{AT}_{\text{c or nc}})}$$

Where:

	<u>Units</u>
$\text{Intake}_{\text{INH SV}}$ = daily intake from inhalation of soil vapours	$\text{m}^3/\text{kg}\text{-day}$
$\text{IR}_{\text{inh}}$ = air inhalation rate	$\text{m}^3/\text{day}$
$\text{AF}_{\text{inh}}$ = inhalation absorption factor	unitless
ET = exposure time	unitless
EF = exposure frequency	days/year
ED = exposure duration	years
BW = body weight of receptor	kg
$\text{AT}_{\text{c}}$ = averaging time carcinogen	days
$\text{AT}_{\text{nc}}$ = averaging time non-carcinogen	days

$$\text{CDI}_{\text{INH SV}} = \text{Intake}_{\text{INH SVnc}} \times C_v$$

$$\text{LADD}_{\text{INH SV}} = \text{Intake}_{\text{INH SVc}} \times C_v$$

Where:

	<u>Units</u>
$\text{CDI}_{\text{INH SV}}$ = chronic daily intake from inhalation of soil vapours	$\text{mg}/\text{kg}\text{-day}$
$\text{LADD}_{\text{INH SV}}$ = chronic daily intake from inhalation of soil vapours	$\text{mg}/\text{kg}\text{-day}$
$\text{Intake}_{\text{INH SVc}}$ = daily intake from inhalation of soil vapours	$\text{m}^3/\text{kg}\text{-day}$
$\text{Intake}_{\text{INH SVnc}}$ = daily intake from inhalation of soil vapours	$\text{m}^3/\text{kg}\text{-day}$
$C_v$ = concentration of chemical in vapour (see below)	$\text{mg}/\text{m}^3$

$$C_v = \left( \frac{C_s \times W \times \rho_s \times d}{U_{\text{air}} \times \delta_{\text{air}} \times \tau} \right) \times \text{CF}$$

Where:

	<u>Units</u>
$C_v$ = concentration of chemical in soil vapour	$\text{mg}/\text{m}^3$
$C_s$ = concentration of chemical in soil	$\text{mg}/\text{kg}$
W = width of source area parallel to wind	cm
$\rho_s$ = soil bulk density	$\text{g}/\text{cm}^3$
d = lower depth of surficial soil zone	cm
$U_{\text{air}}$ = windspeed above-ground surface in ambient mixing zone	cm/s
$\delta_{\text{air}}$ = height of mixing zone	cm
$\tau$ = averaging time for vapour flux	s
CF = conversion factor (1,000)	$\text{cm}^3/\text{m}^3 \times \text{kg}/\text{g}$

### D.2.2.1 Dermal Exposure from Soil Vapour - Summer

$$\text{Intake}_{\text{VDERMS}_{c \text{ or } nc}} = \frac{Kp \times (SA_{\text{hand}} + SA_{\text{body}}) \times ET \times EF \times ED \times CF}{BW \times (AT_c \text{ or } AT_{nc})}$$

Where:

	<u>Units</u>
$\text{Intake}_{\text{VDERMS}_{c \text{ or } nc}}$ =	daily intake from dermal contact with soil vapours summer m <sup>3</sup> /kg-day
$Kp$ =	dermal permeability coefficient cm/d
$SA_{\text{hand}}$ =	exposed surface area - hand cm <sup>2</sup>
$SA_{\text{body}}$ =	exposed surface area - body (summer) cm <sup>2</sup>
$ET$ =	exposure time unitless
$EF$ =	exposure frequency days/year
$ED$ =	exposure duration years
$CF$ =	conversion factor (1 x 10 <sup>-6</sup> ) m <sup>3</sup> /cm <sup>3</sup>
$BW$ =	body weight of receptor kg
$AT_c$ =	averaging time carcinogen days
$AT_{nc}$ =	averaging time non-carcinogen days

$$CDI_{\text{VDERMS}} = \text{Intake}_{\text{VDERMS}_{nc}} \times C_v$$

$$LADD_{\text{VDERMS}} = \text{Intake}_{\text{VDERMS}_c} \times C_v$$

Where:

	<u>Units</u>
$CDI_{\text{VDERMS}}$ =	chronic daily intake from inhalation of soil vapours mg/kg-day
$LADD_{\text{VDERMS}}$ =	chronic daily intake from inhalation of soil vapours mg/kg-day
$\text{Intake}_{\text{VDERMS}_c}$ =	daily intake from inhalation of soil vapours m <sup>3</sup> /kg-day
$\text{Intake}_{\text{VDERMS}_{nc}}$ =	daily intake from inhalation of soil vapours m <sup>3</sup> /kg-day
$C_v$ =	concentration of chemical in vapour (see below) mg/m <sup>3</sup>

### D.2.2.2 Dermal Exposure from Soil Vapour - Winter

$$\text{Intake}_{\text{VDERMW}_{c \text{ or } nc}} = \frac{Kp \times (SA_{\text{hand}} + SA_{\text{body}}) \times ET \times EF \times ED \times CF}{BW \times (AT_c \text{ or } AT_{nc})}$$

Where:

	<u>Units</u>
$\text{Intake}_{\text{VDERMW}_{c \text{ or } nc}}$ =	daily intake from dermal contact with soil vapours summer m <sup>3</sup> /kg-day
$Kp$ =	dermal permeability coefficient cm/d
$SA_{\text{hand}}$ =	exposed surface area - hand cm <sup>2</sup>
$SA_{\text{body}}$ =	exposed surface area - body (summer) cm <sup>2</sup>
$ET$ =	exposure time unitless

EF	= exposure frequency	days/year
ED	= exposure duration	years
CF	= conversion factor (1 x 10 <sup>-6</sup> )	m <sup>3</sup> /cm <sup>3</sup>
BW	= body weight of receptor	kg
AT <sub>c</sub>	= averaging time carcinogen	days
AT <sub>nc</sub>	= averaging time non-carcinogen	days

$$CDI_{VDERMW} = Intake_{VDERMW_{nc}} \times C_v$$

$$LADD_{VDERMW} = Intake_{VDERMW_c} \times C_v$$

Where:		<u>Units</u>
CDI <sub>VDERMW</sub>	= chronic daily intake from inhalation of soil vapours	mg/kg-day
LADD <sub>VDERMW</sub>	= chronic daily intake from inhalation of soil vapours	mg/kg-day
Intake <sub>VDERMW_c</sub>	= daily intake from inhalation of soil vapours	m <sup>3</sup> /kg-day
Intake <sub>VDERMW_nc</sub>	= daily intake from inhalation of soil vapours	m <sup>3</sup> /kg-day
C <sub>v</sub>	= concentration of chemical in vapour (see below)	mg/m <sup>3</sup>

## D.2.3 Exposure from Soil/Dust

The following equations are used to assess the potential risk resulting from inhalation and ingestion of resuspended soil/dust in the summer and winter, indoors and outdoors.

### D.2.3.1 Inhalation of Resuspended Soil/Dust – Summer - Outdoor

$$Intake_{INHS/DSO_{c \text{ or } nc}} = \frac{IR_{inh} \times AF_{inh} \times TSP \times ET \times EF \times ED}{BW \times (AT_{c \text{ or } nc})}$$

Where:		<u>Units</u>
Intake <sub>INHS/DSO</sub>	= intake factor from inhalation of resuspended soil/dust – summer outdoor	kg/kg day
IR <sub>inh</sub>	= air inhalation rate	m <sup>3</sup> /day
AF <sub>inh</sub>	= inhalation absorption factor	unitless
TSP	= Total Suspended Particulate	kg/m <sup>3</sup>
ET	= exposure time	unitless
EF	= exposure frequency	days/year
ED	= exposure duration	years
BW	= body weight of receptor	kg
AT <sub>c</sub>	= averaging time carcinogen	days
AT <sub>nc</sub>	= averaging time non-carcinogen	days

$$CDI_{INHS/DSO} = Intake_{INHS/DSOnc} \times C_s$$

$$LADD_{INHS/DSO} = Intake_{INHS/DSOc} \times C_s$$

Where:		<u>Units</u>
$CDI_{INHS/DSO}$	= chronic daily intake from inhalation of resuspended soil/dust - summer outdoor	mg/kg-day
$LADD_{INHS/DSO}$	= lifetime average daily dose from inhalation of resuspended soil/dust - summer outdoor	mg/kg-d
$Intake_{INHS/DSOc}$	= intake factor from inhalation of resuspended soil/dust (carcinogenic)	kg/kg day
$Intake_{INHS/DSOnc}$	= intake factor from inhalation of resuspended soil/dust (non-carcinogenic)	kg/kg day
$C_s$	= concentration of chemical in soil	mg/kg

### D.2.3.2 Inhalation of Resuspended Soil/Dust – Summer - Indoor

$$Intake_{INHS/DSIc \text{ or } nc} = \frac{IR_{inh} \times AF_{inh} \times TSP \times FR_{soili} \times ET \times EF \times ED}{BW \times (AT_{c \text{ or } nc})}$$

Where:		<u>Units</u>
$Intake_{INHS/DSI}$	= intake factor from inhalation of resuspended soil/dust - summer indoor	kg/kg day
$IR_{inh}$	= air inhalation rate	m <sup>3</sup> /day
$AF_{inh}$	= inhalation absorption factor	unitless
TSP	= Total Suspended Particulate	kg/m <sup>3</sup>
$FR_{soili}$	= fraction of dust from soil - indoor	unitless
ET	= exposure time	unitless
EF	= exposure frequency	days/year
ED	= exposure duration	years
BW	= body weight of receptor	kg
$AT_c$	= averaging time carcinogen	days
$AT_{nc}$	= averaging time non-carcinogen	days

$$CDI_{INHS/DSI} = Intake_{INHS/DSInc} \times C_s$$

$$LADD_{INHS/DSI} = Intake_{INHS/DSIc} \times C_s$$

Where:		<u>Units</u>
$CDI_{INHS/DSI}$	= chronic daily intake from inhalation of resuspended soil/dust - summer indoor	mg/kg-day
$LADD_{INHS/DSI}$	= lifetime average daily dose from inhalation of resuspended soil/dust - summer indoor	mg/kg-d
$Intake_{INHS/DSIc}$	= intake factor from inhalation of resuspended soil/dust (carcinogenic)	kg/kg day
$Intake_{INHS/DSInc}$	= intake factor from inhalation of resuspended soil/dust (non-carcinogenic)	kg/kg day
$C_s$	= concentration of chemical in soil	mg/kg

### D.2.3.3 Inhalation of Resuspended Soil/Dust – Winter - Outdoor

$$\text{Intake}_{\text{INHS/DWOc or nc}} = \frac{\text{IR}_{\text{inh}} \times \text{AF}_{\text{inh}} \times \text{TSP} \times \text{FR}_{\text{snow}} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times (\text{AT}_{\text{c or nc}})}$$

Where:

	<u>Units</u>
$\text{Intake}_{\text{INHS/DWO}}$ = intake factor from inhalation of resuspended soil/dust - winter outdoor	kg/kg day
$\text{IR}_{\text{inh}}$ = air inhalation rate	$\text{m}^3/\text{day}$
$\text{AF}_{\text{inh}}$ = inhalation absorption factor	unitless
TSP = Total Suspended Particulate	$\text{kg}/\text{m}^3$
$\text{FR}_{\text{snow}}$ = fraction of winter that site is not snow covered	unitless
ET = exposure time	unitless
EF = exposure frequency	days/year
ED = exposure duration	years
BW = body weight of receptor	kg
$\text{AT}_{\text{c}}$ = averaging time carcinogen	days
$\text{AT}_{\text{nc}}$ = averaging time non-carcinogen	days

$$\text{CDI}_{\text{INHS/DWO}} = \text{Intake}_{\text{INHS/DWOn c}} \times C_s$$

$$\text{LADD}_{\text{INHS/DWO}} = \text{Intake}_{\text{INHS/DWOC}} \times C_s$$

Where:

	<u>Units</u>
$\text{CDI}_{\text{INHS/DWO}}$ = chronic daily intake from inhalation of resuspended soil/dust - winter outdoor	mg/kg-day
$\text{LADD}_{\text{INHS/DWO}}$ = lifetime average daily dose from inhalation of resuspended soil/dust - winter outdoor	mg/kg-d
$\text{Intake}_{\text{INHS/DWOC}}$ = intake factor from inhalation of resuspended soil/dust (carcinogenic)	kg/kg day
$\text{Intake}_{\text{INHS/DWOn c}}$ = intake factor from inhalation of resuspended soil/dust (non-carcinogenic)	kg/kg day
$C_s$ = concentration of chemical in soil	mg/kg

### D.2.3.4 Inhalation of Resuspended Soil/Dust – Winter - Indoor

$$\text{Intake}_{\text{INHS/DWIC or nc}} = \frac{\text{IR}_{\text{inh}} \times \text{AF}_{\text{inh}} \times \text{TSP} \times \text{FR}_{\text{soil i}} \times \text{FR}_{\text{snow}} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times (\text{AT}_{\text{c or nc}})}$$

Where:

	<u>Units</u>
$\text{Intake}_{\text{INHS/DWI}}$ = intake factor from inhalation of resuspended soil/dust - winter indoor	kg/kg day
$\text{IR}_{\text{inh}}$ = air inhalation rate	$\text{m}^3/\text{day}$
$\text{AF}_{\text{inh}}$ = inhalation absorption factor	unitless



TSP	= Total Suspended Particulate	kg/m <sup>3</sup>
FR <sub>soil</sub>	= fraction of dust from soil - indoor	unitless
FR <sub>snow</sub>	= fraction of winter that site is not snow covered	unitless
ET	= exposure time	unitless
EF	= exposure frequency	days/year
ED	= exposure duration	years
BW	= body weight of receptor	kg
AT <sub>c</sub>	= averaging time carcinogen	days
AT <sub>nc</sub>	= averaging time non-carcinogen	days

$$CDI_{INHS/DWI} = Intake_{INHS/DWIc} \times C_s$$

$$LADD_{INHS/DWI} = Intake_{INHS/DWIc} \times C_s$$

Where:		<u>Units</u>
CDI <sub>INHS/DWI</sub>	= chronic daily intake from inhalation of resuspended soil/dust - summer indoor	mg/kg-day
LADD <sub>INHS/DWI</sub>	= lifetime average daily dose from inhalation of resuspended soil/dust - summer indoor	mg/kg-d
Intake <sub>INHS/DWI c</sub>	= intake factor from inhalation of resuspended soil/dust (carcinogenic)	kg/kg day
Intake <sub>INHS/DWI nc</sub>	= intake factor from inhalation of resuspended soil/dust (non-carcinogenic)	kg/kg day
C <sub>s</sub>	= concentration of chemical in soil	mg/kg

### D.2.3.5 Soil/Dust Ingestion – Summer - Outdoor

$$Intake_{SDINGSOc \text{ or } nc} = \frac{IR_{soil} \times AF_{oral} \times ET \times EF \times ED \times CF}{BW \times (AT_c \text{ or } AT_{nc})}$$

Where:		<u>Units</u>
Intake <sub>SDINGSO</sub>	= daily intake from ingestion of soil/dust – summer outdoor	kg/kg-day
IR <sub>soil</sub>	= ingestion rate of soil	mg/day
AF <sub>oral</sub>	= oral absorption factor	unitless
ET	= exposure time	unitless
EF	= exposure frequency	days/year
ED	= exposure duration	years
CF	= conversion factor (1 x 10 <sup>-6</sup> )	kg/mg
BW	= body weight of receptor	kg
AT <sub>c</sub>	= averaging time carcinogen	days
AT <sub>nc</sub>	= averaging time non-carcinogen	days

$$CDI_{SDINGSO} = Intake_{SDINGSOnc} \times C_s$$

$$LADD_{SDINGSO} = Intake_{SDINGSOc} \times C_s$$

Where:		<u>Units</u>
$CDI_{SDINGSO}$	= chronic daily intake from ingestion of soil/dust - summer outdoor	mg/kg-day
$LADD_{SDINGSO}$	= lifetime average daily dose from ingestion of soil/dust - summer outdoor	mg/kg-day
$Intake_{SDINGSO_{nc}}$	= daily intake from ingestion of soil/dust - summer outdoor (non-carcinogenic)	kg/kg-day
$Intake_{SDINGSO_c}$	= daily intake from ingestion of soil/dust - summer outdoor (carcinogenic)	kg/kg-day
$C_s$	= concentration of chemical in soil	mg/kg

### D.2.3.6 Soil/Dust Ingestion – Summer – Indoor

$$Intake_{SDINGSI_{c \text{ or } nc}} = \frac{IR_{dust} \times AF_{oral} \times FR_{soili} \times ET \times EF \times ED \times CF}{BW \times (AT_c \text{ or } AT_{nc})}$$

Where:		<u>Units</u>
$Intake_{SDINGSI}$	= daily intake from ingestion of soil/dust - summer indoor	kg/kg-day
$IR_{dust}$	= ingestion rate of dust; discussed below	mg/day
$AF_{oral}$	= oral absorption factor	unitless
$FR_{soili}$	= fraction of dust derived from soil	unitless
$ET$	= exposure time	unitless
$EF$	= exposure frequency	days/year
$ED$	= exposure duration	years
$CF$	= conversion factor ( $1 \times 10^{-6}$ )	kg/mg
$BW$	= body weight of receptor	kg
$AT_c$	= averaging time carcinogen	days
$AT_{nc}$	= averaging time non-carcinogen	days

$$CDI_{SDINGSI} = Intake_{SDINGSI_{nc}} \times C_s$$

$$LADD_{SDINGSI} = Intake_{SDINGSI_c} \times C_s$$

Where:		<u>Units</u>
$CDI_{SDINGSI}$	= chronic daily intake from ingestion of soil/dust - summer indoor	mg/kg-day
$LADD_{SDINGSI}$	= lifetime average daily dose from ingestion of soil/dust - summer indoor	mg/kg-day
$Intake_{SDINGSI_{nc}}$	= daily intake from ingestion of soil/dust - summer indoor (non-carcinogenic)	kg/kg-day
$Intake_{SDINGSI_c}$	= daily intake from ingestion of soil/dust - summer indoor (carcinogenic)	kg/kg-day
$C_s$	= concentration of chemical in soil	mg/kg

### Soil/Dust Ingestion – Winter - Outdoor

$$\text{Intake}_{\text{SDINGWO}_{\text{c or nc}}} = \frac{\text{IR}_{\text{soil}} \times \text{AF}_{\text{oral}} \times \text{FR}_{\text{snow}} \times \text{ET} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times (\text{AT}_{\text{c}} \text{ or } \text{AT}_{\text{nc}})}$$

Where:

	<u>Units</u>
$\text{Intake}_{\text{SDINGWO}}$ = daily intake from ingestion of soil/dust - winter outdoor	kg/kg-day
$\text{IR}_{\text{soil}}$ = ingestion rate of soil	mg/day
$\text{AF}_{\text{oral}}$ = oral absorption factor	unitless
$\text{FR}_{\text{snow}}$ = Fraction of winter that site is not snow covered	unitless
$\text{ET}$ = exposure time	unitless
$\text{EF}$ = exposure frequency	days/year
$\text{ED}$ = exposure duration	years
$\text{CF}$ = conversion factor ( $1 \times 10^{-6}$ )	kg/mg
$\text{BW}$ = body weight of receptor	kg
$\text{AT}_{\text{c}}$ = averaging time carcinogen	days
$\text{AT}_{\text{nc}}$ = averaging time non-carcinogen)	days

$$\text{CDI}_{\text{SDINGWO}} = \text{Intake}_{\text{SDINGWO}_{\text{nc}}} \times \text{C}_s$$

$$\text{LADD}_{\text{SDINGWO}} = \text{Intake}_{\text{SDINGWO}_{\text{c}}} \times \text{C}_s$$

Where:

	<u>Units</u>
$\text{CDI}_{\text{SDINGWO}}$ = chronic daily intake from ingestion of soil/dust - winter outdoor	mg/kg-day
$\text{LADD}_{\text{SDINGWO}}$ = lifetime average daily dose from ingestion of soil/dust - winter outdoor	mg/kg-day
$\text{Intake}_{\text{SDINGWO}_{\text{nc}}}$ = daily intake from ingestion of soil/dust - winter outdoor (non-carcinogenic)	kg/kg-day
$\text{Intake}_{\text{SDINGWO}_{\text{c}}}$ = daily intake from ingestion of soil/dust - winter outdoor (carcinogenic)	kg/kg-day
$\text{C}_s$ = concentration of chemical in soil	mg/kg

### D.2.3.7 Soil/Dust Ingestion – Winter – Indoor

$$\text{Intake}_{\text{SDINGWI}_{\text{c or nc}}} = \frac{\text{IR}_{\text{dust}} \times \text{AF}_{\text{oral}} \times \text{FR}_{\text{soili}} \times \text{ET} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times (\text{AT}_{\text{c}} \text{ or } \text{AT}_{\text{nc}})}$$

Where:

	<u>Units</u>
$\text{Intake}_{\text{SDINGSI}}$ = daily intake from ingestion of soil/dust - winter indoor	kg/kg-day
$\text{IR}_{\text{dust}}$ = ingestion rate of dust; discussed below	mg/day
$\text{AF}_{\text{oral}}$ = oral absorption factor	unitless
$\text{FR}_{\text{soili}}$ = fraction of dust derived from soil	unitless
$\text{ET}$ = exposure time	unitless
$\text{EF}$ = exposure frequency	days/year
$\text{ED}$ = exposure duration	years
$\text{CF}$ = conversion factor ( $1 \times 10^{-6}$ )	kg/mg
$\text{BW}$ = body weight of receptor	kg

$AT_c$	= averaging time carcinogen	days
$AT_{nc}$	= averaging time non-carcinogen	days

$$CDI_{SDINGWI} = Intake_{SDINGWI_{nc}} \times C_s$$

$$LADD_{SDINGWI} = Intake_{SDINGWI_c} \times C_s$$

Where:

		<u>Units</u>
$CDI_{SDINGWI}$	= chronic daily intake from ingestion of soil/dust - winter indoor	mg/kg-day
$LADD_{SDINGWI}$	= lifetime average daily dose from ingestion of soil/dust - winter indoor	mg/kg-day
$Intake_{SDINGWI_{nc}}$	= daily intake from ingestion of soil/dust - winter indoor (non-carcinogenic)	kg/kg-day
$Intake_{SDINGWI_c}$	= daily intake from ingestion of soil/dust - winter indoor (carcinogenic)	kg/kg-day
$C_s$	= concentration of chemical in soil	mg/kg

### D.2.3.8 Dust Ingestion Rate

The dust ingestion rate calculation applies only to infant, toddler, and child receptors, as it is based on the frequency of finger mouthing events.

$$IR_{dust} = SA_{finger} \times SAF_{finger} \times FR_{soil} \times FME \times ET \times CF$$

Where:

		<u>Units</u>
$IR_{dust}$	= ingestion rate of dust	mg/hour
$SA_{finger}$	= surface area of 1/2 finger	cm <sup>2</sup> /event
$SAF_{finger}$	= soil adherence factor - finger	mg/cm <sup>2</sup>
$FR_{soil}$	= fraction of dust from soil - indoor	unitless
$FME$	= frequency of finger mouthing events	events/hour
$ET$	= exposure time	hours/day

### D.2.3.9 Soil/Dust Dermal – Summer - Outdoor

$$Intake_{SDERM} = \frac{\left( (SA_{body} \times SAF_{body}) + (SA_{hand} \times SAF_{hand}) \right) \times AF_{dermal} \times ET \times EF \times ED \times CF}{BW \times (AT_c \text{ or } AT_{nc})}$$

Where:

		<u>Units</u>
$Intake_{SDERM_{c \text{ or } nc}}$	= daily intake from dermal contact with soil/dust - summer outdoor	kg/kg-day
$SA_{body}$	= exposed surface area - body (summer)	cm <sup>2</sup>
$SAF_{body}$	= soil adherence factor - body	mg-soil/cm <sup>2</sup>

SA <sub>hand</sub>	= exposed surface area - hand	cm <sup>2</sup>
SAF <sub>hand</sub>	= soil adherence factor - hand	mg-soil/cm <sup>2</sup>
AF <sub>dermal</sub>	= dermal absorption factor	unitless
ET	= exposure time	unitless
EF	= exposure frequency	days/year
ED	= exposure duration	years
CF	= conversion factor (1 x 10 <sup>-6</sup> )	kg/mg
BW	= body weight of receptor	kg
AT <sub>c</sub>	= averaging time carcinogen	days
AT <sub>nc</sub>	= averaging time non-carcinogen	days

$$CDI_{SDERMSO} = Intake_{SDERMSO\ nc} \times C_s$$

$$LADD_{SDERMSO} = Intake_{SDERMSO\ c} \times C_s$$

Where:		<u>Units</u>
CDI <sub>SDERMSO</sub>	= chronic daily intake from dermal contact of soil/dust - summer outdoor	mg/kg-day
LADD <sub>SDINGSO</sub>	= lifetime average daily dose from dermal contact of soil/dust - summer outdoor	mg/kg-day
Intake <sub>SDERMSO nc</sub>	= daily intake from dermal contact with soil/dust - summer outdoor (non-carcinogenic)	mg/kg-day
Intake <sub>SDERMSO c</sub>	= daily intake from dermal contact with soil/dust - summer outdoor (carcinogenic)	mg/kg-day
C <sub>s</sub>	= concentration of chemical in soil	mg/kg

### D.2.3.10 Soil/Dust Dermal – Summer – Indoor

$$Intake_{SDERMSI} = \frac{\left( (SA_{body} \times SAF_{body}) + (SA_{hand} \times SAF_{hand}) \right) \times AF_{dermal} \times FR_{soili} \times ET \times EF \times ED \times CF}{BW \times (AT_c \text{ or } AT_{nc})}$$

Where:		<u>Units</u>
Intake <sub>SDERMSI c or nc</sub>	= daily intake from dermal contact with soil/dust - summer outdoor	kg/kg-day
SA <sub>body</sub>	= exposed surface area - body (summer)	cm <sup>2</sup>
SAF <sub>body</sub>	= soil adherence factor - body	mg-soil/cm <sup>2</sup>
SA <sub>hand</sub>	= exposed surface area - hand	cm <sup>2</sup>
SAF <sub>hand</sub>	= soil adherence factor - hand	mg-soil/cm <sup>2</sup>
AF <sub>dermal</sub>	= dermal absorption factor	unitless
FR <sub>soili</sub>	= fraction of dust derived from soil	unitless
ET	= exposure time	unitless
EF	= exposure frequency	days/year
ED	= exposure duration	years
CF	= conversion factor (1 x 10 <sup>-6</sup> )	kg/mg
BW	= body weight of receptor	kg

$AT_c$  = averaging time carcinogen days  
 $AT_{nc}$  = averaging time non-carcinogen days

$$CDI_{SDERMSI} = Intake_{SDERMSI\ nc} \times C_s$$

$$LADD_{SDERMSI} = Intake_{SDERMSI\ c} \times C_s$$

Where:

	<u>Units</u>
$CDI_{SDERMSI}$	= chronic daily intake from dermal contact of soil/dust - summer outdoor mg/kg-day
$LADD_{SDINGSI}$	= lifetime average daily dose from dermal contact of soil/dust - summer outdoor mg/kg-day
$Intake_{SDERMSI\ nc}$	= daily intake from dermal contact with soil/dust - summer outdoor (non-carcinogenic) mg/kg-day
$Intake_{SDERMSI\ c}$	= daily intake from dermal contact with soil/dust - summer outdoor (carcinogenic) mg/kg-day
$C_s$	= concentration of chemical in soil mg/kg

#### D.2.3.11 Soil/Dust Dermal – Winter - Outdoor

$$Intake_{SDERMWO} = \frac{\left( (SA_{body} \times SAF_{body}) + (SA_{hand} \times SAF_{hand}) \right) \times AF_{dermal} \times FR_{snow} \times ET \times EF \times ED \times CF}{BW \times (AT_c \text{ or } AT_{nc})}$$

Where:

	<u>Units</u>
$Intake_{SDERMWO\ c\ \text{or}\ nc}$	= daily intake from dermal contact with soil/dust - summer outdoor kg/kg-day
$SA_{body}$	= exposed surface area - body (summer) cm <sup>2</sup>
$SAF_{body}$	= soil adherence factor - body mg-soil/cm <sup>2</sup>
$SA_{hand}$	= exposed surface area - hand cm <sup>2</sup>
$SAF_{hand}$	= soil adherence factor - hand mg-soil/cm <sup>2</sup>
$AF_{dermal}$	= dermal absorption factor unitless
$FR_{snow}$	= fraction of winter that ground is not snow-covered unitless
$ET$	= exposure time unitless
$EF$	= exposure frequency days/year
$ED$	= exposure duration years
$CF$	= conversion factor (1 x 10 <sup>-6</sup> ) kg/mg
$BW$	= body weight of receptor kg
$AT_c$	= averaging time carcinogen days
$AT_{nc}$	= averaging time non-carcinogen days

$$CDI_{SDERMWO} = Intake_{SDERMWO\ nc} \times C_s$$

$$LADD_{SDERMWO} = \text{Intake}_{SDERMWOc} \times C_s$$

Where:		<u>Units</u>
$CDI_{SDERMWO}$	= chronic daily intake from dermal contact of soil/dust - winter outdoor	mg/kg-day
$LADD_{SDINGWO}$	= lifetime average daily dose from dermal contact of soil/dust - winter outdoor	mg/kg-day
$\text{Intake}_{SDERMWOnc}$	= daily intake from dermal contact with soil/dust - winter outdoor (non-carcinogenic)	mg/kg-day
$\text{Intake}_{SDERMWOc}$	= daily intake from dermal contact with soil/dust - winter outdoor (carcinogenic)	mg/kg-day
$C_s$	= concentration of chemical in soil	mg/kg

### Soil/Dust Dermal – Winter – Indoor

$$\text{Intake}_{SDERMWI} = \frac{\left( (SA_{\text{body}} \times SAF_{\text{body}}) + (SA_{\text{hand}} \times SAF_{\text{hand}}) \right) \times AF_{\text{dermal}} \times FR_{\text{snow}} \times FR_{\text{soili}} \times ET \times EF \times ED \times CF}{BW \times (AT_c \text{ or } AT_{nc})}$$

Where:		<u>Units</u>
$\text{Intake}_{SDERMWInc \text{ or } nc}$	= daily intake from dermal contact with soil/dust - summer outdoor	kg/kg-day
$SA_{\text{body}}$	= exposed surface area - body (summer)	cm <sup>2</sup>
$SAF_{\text{body}}$	= soil adherence factor - body	mg-soil/cm <sup>2</sup>
$SA_{\text{hand}}$	= exposed surface area - hand	cm <sup>2</sup>
$SAF_{\text{hand}}$	= soil adherence factor - hand	mg-soil/cm <sup>2</sup>
$AF_{\text{dermal}}$	= dermal absorption factor	unitless
$FR_{\text{snow}}$	= fraction of winter that ground is not snow covered	unitless
$FR_{\text{soili}}$	= fraction of dust derived from soil	unitless
$ET$	= exposure time	unitless
$EF$	= exposure frequency	days/year
$ED$	= exposure duration	years
$CF$	= conversion factor (1 x 10 <sup>-6</sup> )	kg/mg
$BW$	= body weight of receptor	kg
$AT_c$	= averaging time carcinogen	days
$AT_{nc}$	= averaging time non-carcinogen	days

$$CDI_{SDERMWI} = \text{Intake}_{SDERMWInc} \times C_s$$

$$LADD_{SDERMWI} = \text{Intake}_{SDERMWIC} \times C_s$$

Where:		<u>Units</u>
$CDI_{SDERMWI}$	= chronic daily intake from dermal contact of soil/dust - winter indoor	mg/kg-day

LADD <sub>SDINGWI</sub>	= lifetime average daily dose from dermal contact of soil/dust - winter indoor	mg/kg-day
Intake <sub>SDERMWI nc</sub>	= daily intake from dermal contact with soil/dust - winter indoor (non-carcinogenic)	mg/kg-day
Intake <sub>SDERMWI c</sub>	= daily intake from dermal contact with soil/dust - winter indoor (carcinogenic)	mg/kg-day
C <sub>s</sub>	= concentration of chemical in soil	mg/kg <sup>3</sup>

## D.2.4 Exposure from Food Consumption

The following equations are used to assess the potential risk resulting from ingestion of produce grown in backyard gardens, wild game, and fish. The ingestion rates of produce, wild game, and fish differ depending on the receptor chosen. In general, food consumption rates were taken from the Exposure Factors Handbook (US EPA, 1997) or Health Canada, 2004a. Receptor specific inputs are discussed in the appropriate sections below.

### D.2.4.1 Ingestion of Above-ground Exposed Garden Produce

$$\text{Intake}_{\text{AGPROD } c \text{ or } nc} = \frac{\text{IR}_{\text{ap}} \times \text{F}_{\text{ap}} \times \text{WP} \times \text{AF}_{\text{oral}} \times \text{EF} \times \text{ED}}{\text{BW} \times (\text{AT}_c \text{ or } \text{AT}_{nc})}$$

Where:

	<u>Units</u>
Intake <sub>AGPROD c or nc</sub>	kg/kg-day
IR <sub>ap</sub>	kg/day
F <sub>ap</sub>	unitless
WP	unitless
AF <sub>oral</sub>	unitless
EF	days/year
ED	years
BW	kg
AT <sub>c</sub>	days
AT <sub>nc</sub>	days

$$\text{CDI}_{\text{AGPROD}} = \text{Intake}_{\text{AGPROD } nc} \times (\text{P}_d \times \text{Pr}_{\text{ag}} \times \text{P}_v)$$

$$\text{LADD}_{\text{AGPROD}} = \text{Intake}_{\text{AGPROD } c} \times (\text{P}_d \times \text{Pr}_{\text{ag}} \times \text{P}_v)$$

Where:

	<u>Units</u>
CDI <sub>AGPROD</sub>	mg/kg-day
LADD <sub>AGPROD</sub>	mg/kg-day
Intake <sub>AGPROD nc</sub>	mg/kg-day



Intake<sub>AGPROD c</sub> = daily intake from ingestion of above-ground produce (carcinogenic) kg/kg-day  
P<sub>d</sub> = concentration in produce due to direct (wet and dry) deposition mg/kg  
P<sub>v</sub> = concentration in produce from air-to-plant transfer mg/kg  
Pr<sub>ag</sub> = concentration in above-ground produce due to root uptake mg/kg  
Note: P<sub>d</sub> + P<sub>v</sub> + Pr<sub>ag</sub> is the total concentration in above-ground produce.

### D.2.4.2 Ingestion of Above-ground Protected Garden Produce

$$\text{Intake}_{\text{AGPPRODc or nc}} = \frac{\text{IR}_{\text{app}} \times \text{F}_{\text{app}} \times \text{WP} \times \text{AF}_{\text{oral}} \times \text{EF} \times \text{ED}}{\text{BW} \times (\text{AT}_{\text{c}} \text{ or } \text{AT}_{\text{nc}})}$$

Where:

	<u>Units</u>
Intake <sub>AGPPROD c or nc</sub> =	daily intake from the ingestion of above-ground protected produce kg/kg-day
IR <sub>app</sub> =	ingestion rate of above-ground protected produce kg/day
F <sub>app</sub> =	fraction of above-ground protected produce consumed from site unitless
WP =	washing/peeling factor unitless
AF <sub>oral</sub> =	oral absorption factor unitless
EF =	exposure frequency days/year
ED =	exposure duration years
BW =	body weight of receptor kg
AT <sub>c</sub> =	averaging time carcinogen days
AT <sub>nc</sub> =	averaging time non-carcinogen days

$$\text{CDI}_{\text{AGPPROD}} = \text{Intake}_{\text{AGPPROD nc}} \times \text{Pr}_{\text{ag}}$$

$$\text{LADD}_{\text{AGPPROD}} = \text{Intake}_{\text{AGPPROD c}} \times \text{Pr}_{\text{ag}}$$

Where:

	<u>Units</u>
CDI <sub>AGPPROD</sub> =	chronic daily intake from ingestion of above-ground protected produce mg/kg-day
LADD <sub>AGPPROD</sub> =	lifetime average daily dose from ingestion of above-ground protected produce mg/kg-day
Intake <sub>AGPPROD nc</sub> =	daily intake from ingestion of above-ground protected produce (non-carcinogenic) kg/kg-day
Intake <sub>AGPPROD c</sub> =	daily intake from ingestion of above-ground protected produce (carcinogenic) kg/kg-day
Pr <sub>ag</sub> =	concentration in above-ground produce due to root uptake mg/kg

### D.2.4.3 Ingestion of Belowground Garden Produce

$$\text{Intake}_{\text{BGPRODc or nc}} = \frac{\text{IR}_{\text{bp}} \times \text{F}_{\text{bp}} \times \text{WP} \times \text{AF}_{\text{oral}} \times \text{EF} \times \text{ED}}{\text{BW} \times (\text{AT}_{\text{c}} \text{ or } \text{AT}_{\text{nc}})}$$

Where:

	<u>Units</u>
Intake <sub>BGPROD c or nc</sub> =	daily intake from the ingestion of belowground produce kg/kg-day
IR <sub>bp</sub> =	ingestion rate of belowground produce kg/day

$F_{bp}$	= fraction of belowground produce consumed from site	unitless
WP	= washing/peeling factor	unitless
$AF_{oral}$	= oral absorption factor	unitless
EF	= exposure frequency	days/year
ED	= exposure duration	years
BW	= body weight of receptor	kg
$AT_c$	= averaging time carcinogen	days
$AT_{nc}$	= averaging time non-carcinogen	days

$$CDI_{BGPROD} = Intake_{BGPROD_{nc}} \times Pr_{bg}$$

$$LADD_{BGPROD} = Intake_{BGPROD_c} \times Pr_{bg}$$

Where:

	<u>Units</u>	
$CDI_{BGPROD}$	= chronic daily intake from ingestion of belowground produce	mg/kg-day
$LADD_{BGPROD}$	= lifetime average daily dose from ingestion of belowground produce	mg/kg-day
$Intake_{BGPROD_{nc}}$	= daily intake from ingestion of belowground produce (non-carcinogenic)	kg/kg-day
$Intake_{BGPROD_c}$	= daily intake from ingestion of belowground produce (carcinogenic)	kg/kg-day
$Pr_{bg}$	= concentration in belowground produce due to root uptake	mg/kg

#### D.2.4.4 Ingestion of Garden Fruit

$$Intake_{GFRUIT_{c \text{ or } nc}} = \frac{IR_{fr} \times F_{fr} \times WP \times AF_{oral} \times EF \times ED}{BW \times (AT_c \text{ or } AT_{nc})}$$

Where:

	<u>Units</u>	
$Intake_{GFRUIT_{c \text{ or } nc}}$	= daily intake from the ingestion of garden fruit	kg/kg-day
$IR_{fr}$	= ingestion rate of garden fruit	kg/day
$F_{fr}$	= fraction of garden fruit consumed from site	unitless
WP	= washing/peeling factor	unitless
$AF_{oral}$	= oral absorption factor	unitless
EF	= exposure frequency	days/year
ED	= exposure duration	years
BW	= body weight of receptor	kg
$AT_c$	= averaging time carcinogen	days
$AT_{nc}$	= averaging time non-carcinogen	days

$$CDI_{GFRUIT} = Intake_{GFRUIT_{nc}} \times (P_{d\text{-fruit}} \times Pr_{ag\text{-fruit}} \times P_v)$$

$$LADD_{GFRUIT} = Intake_{GFRUIT_c} \times (P_{d\text{-fruit}} \times Pr_{ag\text{-fruit}} \times P_v)$$

Where:

	<u>Units</u>	
$CDI_{GFRUIT}$	= chronic daily intake from ingestion of garden fruit	mg/kg-day
$LADD_{GFRUIT}$	= lifetime average daily dose from ingestion of garden fruit	mg/kg-day

$\text{Intake}_{\text{GFRUIT nc}}$	=	daily intake from ingestion of garden fruit (non-carcinogenic)	kg/kg-day
$\text{Intake}_{\text{GFRUIT c}}$	=	daily intake from ingestion of garden fruit (carcinogenic)	kg/kg-day
$P_{\text{d-fruit}}$	=	concentration in fruit due to direct (wet and dry) deposition	mg/kg
$P_v$	=	concentration in produce from air-to-plant transfer	mg/kg
$P_{\text{ag-fruit}}$	=	concentration in fruit due to root uptake	mg/kg

Note:  $P_{\text{d-fruit}} + P_v + P_{\text{ag-fruit}}$  is the total concentration in homegrown fruit.

### D.2.4.5 Ingestion of Wild Game

$$\text{Intake}_{\text{WGc or nc}} = \frac{\text{IR}_{\text{wg}} \times F_{\text{wg}} \times \text{AF}_{\text{oral}} \times \text{EF} \times \text{ED}}{\text{BW} \times (\text{AT}_{\text{c}} \text{ or } \text{AT}_{\text{nc}})}$$

Where:			<u>Units</u>
$\text{Intake}_{\text{WGc or nc}}$	=	daily intake from the ingestion of wild game	kg/kg-day
$\text{IR}_{\text{wg}}$	=	ingestion rate of wild game; discussed below	kg/day
$F_{\text{wg}}$	=	fraction of wild game consumed from site	unitless
$\text{AF}_{\text{oral}}$	=	oral absorption factor	unitless
$\text{EF}$	=	exposure frequency	days/year
$\text{ED}$	=	exposure duration	years
$\text{BW}$	=	body weight of receptor	kg
$\text{AT}_{\text{c}}$	=	averaging time carcinogen = (365 days/year) x (75 years)	days
$\text{AT}_{\text{nc}}$	=	averaging time non-carcinogen = (365 days/year) x (exposure duration)	days

$$\text{CDI}_{\text{WG}} = \text{Intake}_{\text{WG nc}} \times A_{\text{wg}}$$

$$\text{LADD}_{\text{WG}} = \text{Intake}_{\text{WG c}} \times A_{\text{wg}}$$

Where:			<u>Units</u>
$\text{CDI}_{\text{WG}}$	=	chronic daily intake from ingestion of wild game	mg/kg-day
$\text{LADD}_{\text{WG}}$	=	lifetime average daily dose from ingestion of wild game	mg/kg-day
$\text{Intake}_{\text{WG nc}}$	=	daily intake from ingestion of wild game (non-carcinogenic)	kg/kg-day
$\text{Intake}_{\text{WG c}}$	=	daily intake from ingestion of wild game (carcinogenic)	kg/kg-day
$A_{\text{wg}}$	=	concentration in belowground produce due to root uptake	mg/kg

The ingestion rate of wild game was receptor-dependent. Only the First Nations and Métis receptors were assumed to ingest wild game. The ingestion rates for the First Nations and Métis receptors were taken from Health Canada, 2004a.

### Fish Ingestion - Lake

There are two equations presented below for the assessment of intake from fish in a lake and a river. This allows the model to calculate different concentrations for a lake and a river within the same watershed. For the assessment of risk, all fish is assumed to come from whichever waterbody yields the highest intake for each CoPC. For the purposes of this assessment, all fish was assumed to come from the lake.

$$\text{Intake}_{\text{FISH-LAKE c or nc}} = \frac{\text{IR}_{\text{fish}} \times \text{F}_{\text{fish}} \times \text{F}_{\text{fish\_cont}} \times \text{F}_{\text{fish\_lake}} \times \text{AF}_{\text{oral}} \times \text{EF} \times \text{ED}}{\text{BW} \times (\text{AT}_{\text{c}} \text{ or } \text{AT}_{\text{nc}})}$$

Where:		<u>Units</u>
$\text{Intake}_{\text{FISH-LAKE c or nc}}$	= daily intake from the ingestion of fish - lake	kg/kg-day
$\text{IR}_{\text{fish}}$	= ingestion rate of fish	kg/day
$\text{F}_{\text{fish}}$	= fraction of total fish consumed that is caught by receptor	unitless
$\text{F}_{\text{fish\_cont}}$	= fraction of caught fish from site (i.e., that is potentially contaminated)	unitless
$\text{F}_{\text{fish\_lake}}$	= fraction of total fish ingestion from lake	unitless
$\text{AF}_{\text{oral}}$	= oral absorption factor	unitless
EF	= exposure frequency	days/year
ED	= exposure duration	years
BW	= body weight of receptor	kg
$\text{AT}_{\text{c}}$	= averaging time carcinogen	days
$\text{AT}_{\text{nc}}$	= averaging time non-carcinogen	days

$$\text{CDI}_{\text{fish\_lake}} = \text{Intake}_{\text{fish\_lake nc}} \times \text{C}_{\text{fish\_lake}}$$

$$\text{LADD}_{\text{fish\_lake}} = \text{Intake}_{\text{fish\_lake c}} \times \text{C}_{\text{fish\_lake}}$$

Where:		<u>Units</u>
$\text{CDI}_{\text{fish\_lake}}$	= chronic daily intake from ingestion of fish from the lake	mg/kg-day
$\text{LADD}_{\text{fish\_lake}}$	= lifetime average daily dose from ingestion of fish from the lake	mg/kg-day
$\text{Intake}_{\text{fish\_lake nc}}$	= daily intake from ingestion of fish from the lake (non-carcinogenic)	kg/kg-day
$\text{Intake}_{\text{fish\_lake c}}$	= daily intake from ingestion of fish from the lake (carcinogenic)	kg/kg-day
$\text{C}_{\text{fish\_lake}}$	= fish tissue concentration (lake)	mg/kg

## D.2.5 Exposure from Surface Water

The following equation is used to assess the potential risk resulting from ingestion of surface water as drinking water. For the purposes of this assessment, it was assumed that the surface water was not filtered or treated prior to ingestion.

$$\text{Intake}_{\text{WATER c or nc}} = \frac{\text{IR}_{\text{water}} \times \text{F}_{\text{water}} \times \text{AF}_{\text{oral}} \times \text{EF} \times \text{ED}}{\text{BW} \times (\text{AT}_{\text{c}} \text{ or } \text{AT}_{\text{nc}})}$$

Where:		<u>Units</u>
$\text{Intake}_{\text{WATER}}$	= daily intake from the ingestion of surface water	L/kg-day
$\text{IR}_{\text{water}}$	= ingestion rate of surface water	L/day
$\text{F}_{\text{water}}$	= fraction of surface water consumed from site	unitless
$\text{AF}_{\text{oral}}$	= oral absorption factor	unitless
EF	= exposure frequency	days/year
ED	= exposure duration	years
BW	= body weight of receptor	kg
$\text{AT}_{\text{c}}$	= averaging time carcinogen	days

$AT_{nc}$  = averaging time non-carcinogen days

$$CDI_{water} = Intake_{water\ nc} \times C_{sw}$$

$$LADD_{water} = Intake_{water\ c} \times C_{sw}$$

Where:		<u>Units</u>
$CDI_{water}$	= chronic daily intake from ingestion of surface water	mg/kg-day
$LADD_{water}$	= lifetime average daily dose from ingestion of surface water r	mg/kg-day
$Intake_{water\ nc}$	= daily intake from ingestion of surface water (non-carcinogenic)	L/kg-day
$Intake_{water\ c}$	= daily intake from ingestion of surface water (carcinogenic)	L/kg-day
$C_{sw}$	= surface water concentration	mg/L

## D.2.6 Exposure from Breast Milk

The following equations are used to assess the potential risk resulting from ingestion of breast milk for an infant receptor. For the purposes of this assessment, all organics are assumed to transfer through breast milk. The equations are detailed in McKone (1993) and US EPA (2005). The same equation is used for all organics, with the exception of dioxins and furans and PCBs. The equations for dioxins and furans are presented separately, below, where appropriate:

The intake of breast milk for all organics (including dioxins and furans and PCBs) is calculated using the following equation:

$$Intake_{BMILK} = \frac{IR_{BMILK} \times EF \times ED \times \rho_{b\text{milk}}}{BW_{\text{infant}} \times AT_{nc}}$$

Where:		<u>Units</u>
$Intake_{BMILK}$	= daily intake from the ingestion of breast milk	kg/kg-day
$IR_{BMILK}$	= ingestion rate of breast milk (0.742)	L/day
$EF$	= exposure frequency	days/year
$ED$	= exposure duration	years
$\Delta_{b\text{milk}}$	= density of breast milk (1.03)	g/mL or kg/L
$BW$	= body weight of receptor	kg
$AT_{nc}$	= averaging time non-carcinogen	days

The concentration of a CoPC in breast milk ( $C_{BMILK}$ ) is calculated using the following equations:

$$C_{BMILK} = [EXP_{\text{mother}} \times BW_{\text{mother}} \times BTF_{\text{b\text{milk}}}]$$

$$C_{BMILK\text{dioxins}} = \frac{EXP_{\text{mother}} \times h \times f_1}{0.693 \times f_2}$$

Where:		<u>Units</u>
$C_{\text{BMILK}}$	= concentration in breast milk	mg/kg
$\text{EXP}_{\text{mother}}$	= total intake of the mother (via all pathways)	mg/kg-day
$\text{BW}_{\text{mother}}$	= body weight of the mother	kg
$\text{BTF}_{\text{bmilk}}$	= breast milk biotransfer factor; discussed below	day/kg
$h$	= half-life of dioxin in mother (2,555)	days
$f_1$	= fraction of ingested dioxin that is stored in fat (1.0)	unitless
$f_2$	= fraction of mother's body weight that is fat (0.3)	unitless

For the intake of breast milk, an inter-media transfer factor must be used for organics (excluding dioxins and furans and PCBs). This is the ratio of the concentration of the chemical in the contact or exposure medium of breast milk to the concentration of the chemical in the "environmental compartment" of the mother due to the exposure of the mother to the chemical in each of the environmental compartments of ambient air, water, and soil (McKone, 1993). The inter-media transfer factor in this circumstance is the partition factor,  $\text{BTF}_{\text{bmilk}}$ , the ratio of chemical concentration in mother's milk (days/kg milk) and is calculated using the following equation:

$$\text{BTF}_{\text{bmilk}} = 2.0 \times 10^{-07} \times K_{\text{ow}}$$

Where:		<u>Units</u>
$\text{BTF}_{\text{bmilk}}$	= breast milk biotransfer factor	d/kg milk
$K_{\text{ow}}$	= octanol-water partition coefficient	unitless

Finally, the chronic daily intake of breast milk by the infant is calculated as follows:

$$\text{CDI}_{\text{infant}} = \text{Intake}_{\text{bmilk}} \times C_{\text{bmilk}} \times \text{AF}_{\text{oral}}$$

$$\text{CDI}_{\text{infant dioxins}} = \text{Intake}_{\text{bmilk}} \times C_{\text{bmilk}} \times \text{AF}_{\text{oral}} \times F_{\text{bmfat}}$$

Where:		<u>Units</u>
$\text{CDI}_{\text{infant}}$	= chronic daily intake from ingestion of breast milk	mg/kg-day
$\text{Intake}_{\text{BMILK}}$	= daily intake from the ingestion of breast milk	kg/kg-day
$C_{\text{BMILK}}$	= concentration in breast milk	mg/kg
$F_{\text{bmfat}}$	= fraction of breast milk that is fat (0.04)	unitless
$\text{AF}_{\text{oral}}$	= oral absorption factor	unitless

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### D.3 Risk Characterization

After the various intakes are derived, the final step is the calculation of the incremental lifetime cancer risks (ILCR) and non-carcinogenic hazard quotient (HQ) values for each of the pathways and receptors

identified. ILCRs and HQs are then summed for individual receptors, across all applicable exposure pathways to obtain an estimate of the total individual ILCRs and HQs for specific receptors.

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### D.3.1 Carcinogenic chemicals

For carcinogenic chemicals, risk estimates represent the incremental probability that an individual will develop cancer over a lifetime as a result of a specific exposure to that chemical (US EPA, 2005). Since carcinogenic risk estimates are over a lifetime of exposure, a composite receptor comprising five separate life stages (infant, toddler, child, teen, adult) was used to evaluate carcinogenic intakes, with the exception of the commercial receptor, where an adult worker was used, as it is reasonable to assume that no person will be present in their working environment during other lifestages for any significant amount of time. A lifetime average daily dose was derived for each receptor and each exposure pathway to get a pathway specific cancer risk.

$$ILCR_x = LADD_x \times \frac{CSF_x}{AF_{CSF}}$$

Where:		<u>Units</u>
ILCR <sub>x</sub>	= incremental lifetime cancer risk for pathway x	unitless
LADD <sub>x</sub>	= CoPC-specific lifetime average daily dose for pathway x	mg/kg-day
CSF <sub>x</sub>	= CoPC-specific cancer slope factor for pathway x	(mg/kg-day) <sup>-1</sup>
AF <sub>CSF</sub>	= CoPC-specific cancer slope factor absorption factor	unitless

The total carcinogenic hazard attributable to exposure to a CoPC via all exposure pathways is calculated as follows:

$$ILCR_{total} = \sum_i ILCR_x$$

Where:		<u>Units</u>
ILCR <sub>total</sub>	= total risk for a specific CoPC	unitless
ILCR <sub>x</sub>	= incremental lifetime cancer risk for pathway x	unitless

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### D.3.2 Non-carcinogenic Chemicals

The potential for non-carcinogenic health effects resulting from exposure to a chemical is generally assessed by comparing an exposure estimate to a reference dose (RfD). An RfD is a daily oral intake rate that is estimated to pose no appreciable risk of adverse health effects, even to sensitive populations (US EPA, 1998a).

$$HQ_x = \frac{CDI_x}{RfD_x \times AF_{RfD}}$$

Where:		<u>Units</u>
HQ <sub>x</sub>	= hazard quotient for pathway x	unitless
CDI <sub>x</sub>	= CoPC-specific chronic daily intake for pathway x	mg/kg-day
RfD <sub>x</sub>	= CoPC-specific reference dose for pathway x	mg/kg-day

$AF_{RfD}$  = CoPC-specific reference dose absorption factor unitless

The total non-carcinogenic hazard attributable to exposure to a CoPC via all exposure pathways is calculated as follows:

$$HQ_{total} = \sum_i HQ_x$$

Where:

$HQ_{total}$  = hazard quotient for a specific CoPC Units  
unitless

$HQ_x$  = hazard quotient for a specific exposure pathway x unitless



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