

APPENDIX D

**FORMULAE AND DETAILED PROCEDURES FOR ESTIMATING MEDIA
CONCENTRATIONS AND QUANTIFYING EXPOSURE AND RISK**

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Acronyms and Abbreviations

Acronym/ Abbreviation	Definition
θ	temperature correction factor
θ_{bs}	bed sediment porosity
θ_{SW}	soil volumetric water content
λ_z	dimensionless viscous sublayer thickness
μ_a	viscosity of air at temperature
μ_g	microgram(s)
μ_w	viscosity of water at temperature
ρ_a	density of air
ρ_{soil}	solids particulate density
ρ_w	density of water
τ_{event}	lag time per event
a	empirical intercept coefficient
A_{beef}	concentration of chemical in beef tissue
ABS_d	dermal absorption fraction
ABS_{GI}	fraction of contaminant absorbed in the gastrointestinal tract
A_{chick}	concentration of chemical in chicken meat
A_{egg}	concentration of chemical in chicken eggs
AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model
AF	soil adherence factor
A_I	impervious watershed area receiving chemical deposition
AIEC	acute inhalation exposure criteria
A_L	total watershed area receiving chemical deposition
A_{milk}	concentration of chemical in dairy milk
A_{pork}	concentration of chemical in pork tissue
AT	averaging time
atm	atmosphere
ATSDR	Agency for Toxic Substances and Disease Registry
A_w	water body surface area
b	empirical slope coefficient
B	dimensionless ratio of the permeability coefficient through the stratum corneum relative to the permeability coefficient across the viable epidermis
Ba_{beef}	biotransfer factor for beef
Ba_{chick}	biotransfer factor for chicken
Ba_{egg}	biotransfer factor for eggs

Acronym/ Abbreviation	Definition
BAF_{fish}	bioaccumulation factor
Ba_{milk}	biotransfer factor for milk
Ba_{pork}	biotransfer factor for pork
BCF_{fish}	bioconcentration factor
BD	soil bulk density
Br_{ag}	plant-to-soil bioconcentration factor for above-ground produce
Bs	soil bioavailability factor
Bv_{ag}	air-to-plant biotransfer factor
BW	body weight
C	USLE cover management factor
$C_{(air)}$	concentration of chemical in air
$C_{(air),acute}$	acute air concentration
$Cancer Risk_D$	excess lifetime cancer risk via inhalation
$Cancer Risk_{D(VCl)}$	excess lifetime cancer risk via inhalation of vinyl chloride
$Cancer Risk_{D(ADAF\ mutagens)}$	excess lifetime cancer risk via inhalation of other mutagens (methylene chloride and trichloroethene)
$Cancer Risk_I$	excess lifetime cancer risk from indirect exposures
$Cancer Risk_{I(VCl)}$	excess lifetime cancer risk from indirect exposures to vinyl chloride
$Cancer Risk_{I(ADAF\ mutagens)}$	excess lifetime cancer risk from indirect exposures to other mutagens (methylene chloride and trichloroethene)
$C_{aqueous}$	concentration of chemical in maternal breast milk aqueous phase
C_{BS}	bed sediment concentration
CCR	Code of Colorado Regulations
C_d	drag coefficient
CDPHE	Colorado Department of Public Health and Environment
C_{dw}	chemical concentration in the dissolved water phase
C_{fish}	chemical concentration in fish
Chp	hourly air concentration of chemical
Chv	hourly air concentration of chemical
CHWR	Colorado Hazardous Waste Regulations
cm	centimeter(s)
cm ²	square centimeter(s)
cm ³	cubic centimeter(s)
$C_{milkfat}$	concentration of chemical in maternal breast milk fat
COPC	chemical of potential concern
CR_{ag}	consumption rate of above-ground exposed fruits and vegetables
CR_{beef}	consumption rate of beef
CR_{bg}	consumption of below-ground vegetables

Acronym/ Abbreviation	Definition
CR_{chick}	consumption rate of chicken
CR_{egg}	consumption rate of eggs
CR_{fish}	consumption rate of fish
CR_{milk}	consumption rate of dairy milk
CR_{pork}	consumption rate of pork
CR_{pp}	consumption rate of above-ground protected fruits and vegetables
CR_{soil}	consumption rate of soil
CR_{sw}	rate of consumption of surface water
C_s	chemical concentration in soil
CSF	cancer slope factor
CSF_i	inhalation cancer slope factor
CSF_o	oral cancer slope factor
$C_{s_{tD}}$	soil concentration at time tD
C_{wctot}	total chemical concentration in water column
C_{wtot}	total water concentration, including water column and bed sediment
C_{yp}	normalized particle phase air concentration
C_{yv}	normalized vapor phase air concentration
C_{ywv}	watershed vapor phase air concentration
D_a	diffusivity of chemical in air
DAD_{soil}	dermal absorbed dose from soil
DAD_{water}	dermal absorbed dose from water
DA_{event}	dermally absorbed dose per event
d_{bs}	depth of upper benthic layer
D_s	deposition term
D_w	diffusivity of chemical in water
d_{wc}	depth of water column
$Dydp$	yearly dry deposition from particle phase
$Dydv$	yearly dry deposition from vapor phase
$Dytwp$	yearly watershed total deposition from particle phase
$Dytwv$	yearly watershed total deposition from vapor phase
$Dywdp$	yearly watershed dry deposition from particle phase
$Dywdv$	yearly watershed dry deposition from vapor phase
$Dywp$	yearly wet deposition from particle phase
$Dywv$	yearly wet deposition from vapor phase
$Dywwp$	yearly watershed wet deposition from particle phase
$Dywwv$	yearly watershed wet deposition from vapor phase
d_z	total water body depth

Acronym/ Abbreviation	Definition
<i>EC</i>	inhalation exposure concentration
<i>EC_{VC,early life}</i>	additional early-life inhalation exposure concentration of vinyl chloride
<i>ED</i>	exposure duration
<i>EDS</i>	Explosive Destruction System
<i>EF</i>	exposure frequency
<i>ER</i>	soil enrichment ratio
<i>ET</i>	exposure time
<i>E_v</i>	average annual evapo-transpiration
<i>EV</i>	event frequency
<i>F</i>	fraction of plant grown on contaminated soil
<i>f₁</i>	fraction of ingested chemical that is stored in fat
<i>f₂</i>	fraction of mother's weight that is fat
<i>f₃</i>	fraction of fat in breast milk
<i>f₄</i>	fraction of chemical which is absorbed
<i>FA</i>	fraction absorbed water
<i>F_{ag}</i>	fraction of above-ground fruits and vegetables that is contaminated
<i>F_{beef}</i>	fraction of consumed beef that is contaminated
<i>F_{bg}</i>	fraction of below-ground vegetables that is contaminated
<i>f_{bs}</i>	fraction of total water body chemical concentration that occurs in benthic sediment
<i>F_{chick}</i>	fraction of consumed chicken that is contaminated
<i>F_{egg}</i>	fraction of consumed eggs that is contaminated
<i>F_{fish}</i>	fraction of consumed fish that is contaminated
<i>F_{milk}</i>	fraction of consumed dairy milk that is contaminated
<i>f_{pl}</i>	fraction of ingested chemical that is stored in the blood plasma
<i>f_{pm}</i>	fraction of mother's weight that is blood plasma
<i>F_{pork}</i>	fraction of consumed pork that is contaminated
<i>F_{soil}</i>	fraction of consumed soil that is contaminated
<i>F_{sw}</i>	swimming frequency
<i>F_v</i>	fraction of air concentration in vapor phase
<i>FW</i>	fraction of wet deposition that adheres to plant
<i>f_{wc}</i>	fraction of total water body chemical concentration that occurs in the water column
<i>g</i>	gram(s)
<i>h</i>	half-life of chemical in adults
<i>H</i>	Henry's Law constant
<i>HHRAP</i>	Human Health Risk Assessment Protocol
<i>HI</i>	hazard index (total)

Acronym/ Abbreviation	Definition
HI _A	acute HI for direct inhalation exposure
HI _D	HI from direct inhalation exposures
HI _I	HI from indirect exposures
HQ	hazard quotient
HQ _A	acute HQ for direct inhalation exposure to chemical <i>i</i>
HQ _D	HQ for direct inhalation exposure
HQ _I	HQ for indirect exposure
<i>I</i>	average annual irrigation
<i>I</i> _{ag}	daily intake of chemical from fruits and vegetables
<i>I</i> _{beef}	daily intake of chemical from beef
<i>I</i> _{bm}	daily intake of chemical from breast milk
<i>I</i> _{chick}	daily intake of chemical from chicken meat
<i>I</i> _{direct}	direct inhalation intake of chemical
<i>I</i> _{egg}	daily intake of chemical from eggs
<i>I</i> _{fish}	daily intake of chemical from fish
<i>I</i> _{indirect}	total indirect exposure
<i>I</i> _{indirect (VC, early life)}	additional early-life indirect exposure to vinyl chloride
<i>I</i> _{ingested}	average daily ingestion dose
<i>I</i> _{milk}	daily intake of chemical from dairy milk
<i>I</i> _{pork}	daily intake of chemical from pork
<i>IR</i>	inhalation rate
<i>IR</i> _{milk}	ingestion rate of breast milk
<i>I</i> _{soil}	daily intake of chemical from soil
<i>I</i> _{sw}	daily intake of chemical from incidental ingestion of surface water
<i>I</i> _{total}	total daily intake of chemical through ingestion
IUR	inhalation unit risk
<i>k</i>	von Karman's constant
K	Kelvin
<i>K</i>	USLE erodibility factor
<i>k</i> _b	benthic burial rate constant
<i>Kd</i> _{bs}	bed sediment/sediment pore water partition coefficient
<i>Kd</i> _s	soil-water partition coefficient
<i>Kd</i> _{sw}	suspended sediment/surface water partition coefficient
kg	kilogram(s)
<i>K</i> _G	gas phase transfer coefficient
<i>K</i> _L	liquid phase transfer coefficient
<i>kp</i>	plant surface loss coefficient

Acronym/ Abbreviation	Definition
K_p	dermal permeability coefficient of chemical in water
k_s	soil loss constant
k_{se}	loss constant due to soil erosion
k_{sg}	loss constant due to degradation
k_{sl}	loss constant due to leaching
k_{sr}	loss constant due to surface runoff
k_{sv}	loss constant due to volatilization
k_v	water column volatilization rate constant
K_v	overall transfer rate
k_{wt}	total water body dissipation rate constant
ℓ	liter(s)
L_{Dep}	direct deposition load to water body
L_{Dif}	vapor phase diffusion load to water body
L_E	soil erosion load to water body
L_R	pervious surface runoff load to water body
L_{RI}	impervious surface runoff load to water body
LS	USLE length-slope factor
L_T	total chemical load to water body
m	average maternal intake of chemical
m^2	square meter(s)
m^3	cubic meter(s)
MF	metabolism factor
mg	milligram(s)
$m\ell$	milliliter(s)
mol	mole(s)
MPHRA	Multiple Pathway Health Risk Assessment
NCEA	The National Center for Environmental Assessment
NOAA	National Oceanic & Atmospheric Administration
NRCS	National Resource Conservation Service
Overall Cancer Risk	overall excess lifetime cancer risk via all routes of exposure
P	average annual precipitation
PCAPP	Pueblo Chemical Agent-Destruction Pilot Plant
$P_{C_{bm}}$	partition coefficient for chemical between plasma and breast milk aqueous phase
PCBs	polychlorinated biphenyls
PCD	Pueblo Chemical Depot
P_d	chemical concentration in plant due to direct deposition
PF	USLE supporting practice factor

Acronym/ Abbreviation	Definition
P_r	chemical concentration in above-ground plants due to root uptake from soil
$P_{r_{bg}}$	chemical concentration in below-ground plants due to root uptake from soil
P_{total}	total concentration of chemical in plant
P_v	chemical concentration in the plant due to air-to-plant transfer
Q	stack emission rate
Q_p	animal consumption rate of plant
Q_s	animal consumption rate of soil
R	universal gas constant
RAGS	Risk Assessment Guidance for Superfund
RCF	root concentration factor
RF	USLE rainfall (or erosivity) factor
RfC	inhalation reference concentration
RfD _o	oral reference dose
RME	reasonably maximally exposed
RO	average annual runoff
R_p	interception fraction of edible portion of plant
RUSLE	Revised Universal Soil Loss Equation
s	second(s)
SA	skin surface area available for contact
SD	watershed sediment delivery ratio
T_1	time at the beginning of emission
T_2	exposure duration
T_a	ambient air temperature
tD	total time period over which deposition occurs
t_{event}	duration of the swimming event
$Total\ Cancer\ Risk_D$	total excess cancer risk via direct exposures
$Total\ Cancer\ Risk_i$	total excess cancer risk via indirect exposures
T_p	length of plant exposure to deposition of edible portion of plant, per harvest
TSS	total suspended solids
T_{wk}	water body temperature
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
Vf_x	average volumetric flow rate through water body
VG_{ag}	above-ground fruit/vegetable correction factor

Acronym/ Abbreviation	Definition
$VG_{rootveg}$	correction factor for below-ground produce
W	wind speed
X_e	unit soil loss
Y_p	yield or standing crop biomass of the edible portion of the plant
yr	year
Z_s	soil mixing depth

D FORMULAE AND DETAILED PROCEDURES FOR ESTIMATING MEDIA CONCENTRATIONS AND QUANTIFYING EXPOSURE AND RISK

This appendix provides a detailed outline of all the calculations performed in this Multiple Pathway Health Risk Assessment (MPHRA) to quantify the concentrations of chemicals of potential concern (COPCs) in various media including:

- air
- soil
- surface water
- above-ground (exposed and protected) fruits and vegetables
- below-ground vegetables
- beef
- pork
- dairy milk
- breast milk
- chicken and eggs
- fish

Additionally, this appendix provides a detailed outline of the procedures used to calculate direct and indirect COPC exposure through the inhalation, ingestion, and dermal uptake mechanisms and the excess lifetime cancer risk and noncarcinogenic health effects caused by those exposures.

The conceptual site model includes multiple life stages for each receptor represented by exposure periods of 1 year for an infant, 5 years for a child, and 25 to 40 years for the adult populations (25 years for the adult worker, 30 years for the adult resident and subsistence fisher, and 40 years for the adult subsistence farmer). Calculated exposures are those expected to result due to operation of the Pueblo Chemical Agent-Destruction Pilot Plant (PCAPP) and Explosive Destruction System (EDS), both located at the Pueblo Chemical Depot (PCD). Because ambient air concentrations and wet and dry deposition resulting from emissions from PCAPP and EDS sources occur only during their respective 5-year operational periods, the infant and child individuals are assumed to be directly and indirectly exposed to COPCs during the 5-year operational period, while the adult individual is assumed to be exposed directly to COPCs during the 5-year operational period and indirectly for the entire population-specific exposure duration (i.e., 25, 30, or 40 years). However, with the exception of soil concentrations, the indirect pathway media concentration equations conservatively use the highest 6-year average ambient air COPC concentrations and the highest 6-year average COPC deposition rates for the entire exposure duration. The resulting media concentrations for the adult exposure scenarios are therefore overestimated.

Because the individual receptors are assumed to be directly and indirectly exposed for up to 40 years, two composite lifetime exposure scenarios (lifetime (I) and lifetime (II)) were evaluated to address the risk and hazard that may occur across multiple consecutive life stages. The lifetime (I) exposure scenario assumes that the human receptor is born at the start of the 5-year operational period of the PCAPP and EDS, is directly and indirectly exposed to emissions for the first 5 years of life, and indirectly exposed for the remainder of the scenario-specific exposure duration. This exposure scenario, therefore, consists of the cumulative exposure to carcinogenic COPCs from each life stage and the exposure duration-weighted average over the lifetime to noncarcinogenic COPCs from the following pathways:

- 1 year of inhalation exposure as an infant, plus
- 4 years of inhalation exposure as a child, plus
- 1 year of indirect exposure as an infant, plus
- 5 years of indirect exposure as a child, plus
- 24 (resident and subsistence fisher) or 34 (subsistence farmer) years of indirect exposure as an adult

The lifetime (II) exposure scenario assumes that the human receptor is a child (i.e., 1 year old) at the start of the 5-year operational period, is directly and indirectly exposed to the PCAPP and EDS emissions as a child (ages 1 through 6), and indirectly exposed as an adult for the remainder of the scenario-specific exposure duration. Like the lifetime (I) exposure scenario, the lifetime (II) exposure scenario, therefore, consists of the cumulative exposure to carcinogenic COPCs from each life stage and the exposure duration-weighted average over the lifetime to noncarcinogenic COPCs from the following pathways:

- 5 years of inhalation exposure as a child, plus
- 5 years of indirect exposure as a child, plus
- 25 (resident and subsistence fisher) or 35 (subsistence farmer) years of indirect exposure as an adult

In the following subsections, five different types of parameter values are used to quantify the concentrations of COPCs in various media. These parameter types are:

- Modeled values: parameter values that are the direct outputs from the air dispersion modeling.
- Site-specific values: parameter values that are specific to the area surrounding the PCD, such as average annual precipitation, water body surface area, and the total watershed area receiving chemical deposition.
- Chemical-specific values: parameter values that are specific to each COPC such as physical, chemical, and transport properties, biotransfer factors, and toxicity data.
- Exposure scenario-specific values: parameters that vary between the different exposure scenarios evaluated under this MPHRA including such items as the body weight of an individual and the exposure duration of the scenario.
- Default values: values that are recommended in guidance documents (United States Environmental Protection Agency [USEPA], 2005; USEPA, 2004) for use when reliable site-specific or chemical-specific data are unavailable. Default values are described in the following subsections where they are first used in the media quantification calculations.

Appendix E presents example calculations for the farmer lifetime (I) scenario using the equations presented in this appendix.

D.1 COPC CONCENTRATIONS IN AIR

Maximum COPC air concentrations were calculated using the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) unit response outputs discussed in Section 3 of the main report. Maximum annual and 1-hour unit responses at any receptor were used to calculate COPC concentrations for use in the chronic and acute risk assessments, respectively. (Air is the only medium that enters into the acute risk assessment.) The COPC concentrations for the chronic assessment were calculated as an annual average over the 6 years of meteorological data. The COPC concentrations for the acute assessment

were calculated as the highest 1-hour average concentration from the entire 6-year meteorological data set.

AERMOD was run in a unit response mode - i.e., using a unit emission rate of 1 gram per second (g/s) for each source group to determine unit response (normalized) concentrations at each modeled receptor location. Because the calculated concentrations are linearly proportional to emission rate, chemical-specific concentrations were then calculated at each receptor location by multiplying the unit response concentrations by the chemical-specific emission rates discussed in Section 2.6 of the main report. Additional details on the air dispersion modeling and the adjustments from unit response results to chemical-specific results are provided in Section 3 of the main report.

D.2 COPC CONCENTRATIONS IN SOIL

Annual COPC concentrations in soil were obtained from the AERMOD wet and dry deposition unit response outputs discussed in Section 3 at the receptor locations of maximum wet and dry deposition rates (i.e., reasonable maximally exposed [RME] individual location). The maximum dry and wet deposition unit response outputs were used to calculate soil concentrations for each exposure scenario evaluated under this MPHRA. COPC concentrations in soil resulting from wet and dry deposition onto the soil are subsequently impacted by soil loss processes, including leaching, erosion, runoff, degradation, and volatilization.

The AERMOD results used in the MPHRA included maximum yearly dry and wet deposition rates for use in the chronic risk assessments. The maximum yearly COPC deposition rates were calculated as the highest total deposition rate for each COPC occurring over one of the 6 years of meteorological data (i.e., the calendar year producing the highest total deposition rate). As discussed above, the model was run in a unit response mode. Because the calculated deposition rates are linearly proportional to emission rates, chemical-specific deposition rates were calculated at each receptor location by multiplying the unit response (normalized) deposition rates by the chemical-specific emission rates discussed in Section 2.6. Additional details on the deposition modeling and the adjustments from unit response results to chemical-specific results are provided in Section 3.

D.2.1 Deposition Term

COPCs emitted from PCAPP and EDS emission sources ultimately deposit onto nearby soils. This process occurs through both wet and dry deposition of vapor and particle-phase COPCs. The deposition term (D_s) represents the annual loading of COPC into 1 kilogram (kg) of soil prior to subsequent soil loss processes such as leaching, erosion, runoff, biotic and abiotic degradation, and COPC volatilization. The maximum yearly wet and dry deposition rates obtained from AERMOD were used to calculate the deposition term using the equation presented in Table B-1-1 of the Human Health Risk Assessment Protocol (HHRAP) (USEPA, 2005) and below:

$$D_s = \frac{100 \cdot Q}{Z_s \cdot BD} \cdot [F_v (Dydv + Dywv) + (Dydp + Dywp) \cdot (1 - F_v)] \quad \text{Eq. D-1}$$

where

D_s	=	deposition term (mg/kg-yr)
$Dydp$	=	normalized yearly dry deposition from particle phase (g/m ² -yr per g/s), (modeled value)
$Dywp$	=	normalized yearly wet deposition from particle phase (g/m ² -yr per g/s), (modeled value)
$Dydv$	=	normalized yearly dry deposition from vapor phase (g/m ² -yr per g/s), (modeled value)
$Dyvw$	=	normalized yearly wet deposition from vapor phase (g/m ² -yr per g/s), (modeled value)
100	=	unit conversion factor ([mg-m ²]/[kg-cm ²])
Z_s	=	soil mixing depth (2 cm), (default value)
BD	=	soil bulk density (1.5 g/cm ³), (default value)
Q	=	stack emission rate (g/s) (chemical-specific value)
F_v	=	fraction of air concentration in vapor phase (dimensionless), (chemical-specific value)

The soil mixing zone depth (Z_s) and soil bulk density (BD) used throughout this MPHRA are default values of 2 centimeters (cm) and 1.5 grams per cubic centimeter (g/cm³), respectively. The value of 2 cm was selected for soil mixing zone depth because it is the default value recommended in Table B-1-1 of the HHRAP (USEPA, 2005) for untilled soil. Table B-1-1 also recommends the use of the value of 1.5 g/cm³ when site-specific soil bulk density is unknown.

The fraction of air concentration in the vapor phase is a chemical-specific parameter that is correlated with vapor pressure and was obtained from the HHRAP Companion Database or calculated according to the methodology presented in Junge (1977) when data were unavailable.

D.2.2 Soil Loss Constant

COPCs are removed from the soil through several mechanisms. Soil loss is impacted by several mechanisms such as:

- leaching
- erosion
- surface runoff
- biotic and abiotic degradation
- volatilization

The soil loss constant (ks) is the sum of the rates at which soil losses occur by these mechanisms and was calculated according to Table B-1-2 of the HHRAP (USEPA, 2005) and below:

$$ks = ksl + kse + ksr + ksg + ksv \quad \text{Eq. D-2}$$

where

ks	=	soil loss constant (yr ⁻¹)
ksl	=	loss constant due to leaching (yr ⁻¹), (calculated by Eq. D-3)
kse	=	loss constant due to soil erosion (0 yr ⁻¹), (default value)

- ksr* = loss constant due to surface runoff (yr⁻¹), (calculated by Eq. D-4)
ksg = loss constant due to degradation (yr⁻¹), (chemical-specific value)
ksv = loss constant due to volatilization (yr⁻¹), (calculated by Eq. D-5)

D.2.2.1 Loss Constant Due to Leaching

The amount of water available to generate a leachate and the physical properties of the soil determine the rate at which COPCs are lost from soil due to leaching. The soil loss constant due to leaching (*ksl*) was calculated using the equation presented in Table B-1-5 of the HHRAP (USEPA, 2005) and below:

$$ksl = \frac{P + I - RO - E_v}{\theta_{sw} \cdot Z_s \cdot [1.0 + (BD \cdot Kd_s / \theta_{sw})]} \quad \text{Eq. D-3}$$

where

- ksl* = loss constant due to leaching (yr⁻¹)
P = average annual precipitation (31.5 cm/yr), (site-specific value)
I = average annual irrigation (0 cm/yr), (site-specific value)
RO = average annual runoff (1.27 cm/yr), (site-specific value)
E_v = average annual evapo-transpiration (121.9 cm/yr), (site-specific value)
θ_{sw} = soil volumetric water content (0.2 ml/cm³), (default value)
Z_s = soil mixing depth (2 cm), (default value)
Kd_s = soil-water partition coefficient (cm³/g), (chemical-specific value)
BD = soil bulk density (1.5 g/cm³), (default value)

The average annual precipitation (31.5 cm/yr), irrigation (0 cm/yr), runoff (1.27 cm/yr), and evapo-transpiration (121.9 cm/yr) are values site-specific to Pueblo, Colorado. The values were obtained from the National Oceanic & Atmospheric Administration (NOAA) (2004) and Miller (1963). Precipitation and irrigation provide water that could form a leachate while runoff and evapo-transpiration remove water from the soil.

A default value of 0.2 ml/cm³ was used for the soil volumetric water content. This was the recommended value in Table B-1-5 of the HHRAP (USEPA, 2005) and represents the midpoint of the range of measured values (0.1 for very sandy soils to 0.3 for heavy loam/clay soils). Soil-water partition coefficients are chemical-specific values that were obtained from various references. Site-specific precipitation, irrigation, runoff, and evapo-transpiration values for Pueblo result in a negative value for *ksl*. Because a negative value for *ksl* is physically unrealistic, *ksl* was set to zero for all COPCs.

D.2.2.2 Loss Constant Due to Erosion

The soil loss constant due to soil erosion (*kse*) was set to zero in this analysis following guidance in Table B-1-3 of the HHRAP (USEPA, 2005). Setting *kse* to zero provides a conservative assumption that COPC losses from erosion do not occur. The rationale for setting *kse* to zero is that contaminated soil can erode both onto and off of the site, causing no net gain or loss of COPC.

D.2.2.3 Loss Constant Due to Surface Runoff

Losses of COPCs due to runoff depend on the amount of runoff at a given site as well as the physical properties of the soil. The soil loss constant due to surface runoff (ksr) was calculated using the equation presented in Table B-1-4 of the HHRAP (USEPA, 2005) and below:

$$ksr = \frac{RO}{\theta_{sw} \cdot Z_s} \cdot \frac{1}{1.0 + (Kd_s \cdot BD / \theta_{sw})} \quad \text{Eq. D-4}$$

where

ksr	=	loss constant due to surface runoff (yr^{-1})
RO	=	average annual runoff (1.27 cm/yr), (site-specific value)
θ_{sw}	=	soil volumetric water content (0.2 ml/cm^3), (default value)
Z_s	=	soil mixing depth (2 cm), (default value)
Kd_s	=	soil-water partition coefficient (cm^3/g), (chemical-specific value)
BD	=	soil bulk density (1.5 g/cm^3), (default value)

D.2.2.4 Loss Constant Due to Biotic and Abiotic Degradation

The soil loss constant due to biotic and abiotic degradation (ksg) is an empirically-determined chemical-specific value. Degradation rates assume first-order kinetics and are derived from the half-lives of COPCs in soil. Values were obtained following guidance in the HHRAP (USEPA, 2005) as well as the HHRAP Companion Database. When no data were available for the half-life of a chemical in soil, the degradation rate was assumed to be zero. By assuming no losses for chemicals with insufficient data, worst-case soil concentrations were obtained.

D.2.2.5 Loss Constant Due to Volatilization

Semi-volatile and volatile COPCs which become adsorbed to soil particles may subsequently volatilize, causing COPC losses from soil. This type of soil loss is represented by the soil loss constant due to volatilization (ksv). The soil loss constant due to volatilization was calculated using the equation presented in Table B-1-6 of the HHRAP (USEPA, 2005) and below:

$$ksv = \left(\frac{3.1536 \times 10^7 \cdot H}{Z_s \cdot Kd_s \cdot R \cdot T_a \cdot BD} \right) \cdot \frac{D_a}{Z_s} \cdot \left[1 - \frac{BD}{\rho_{soil}} - \theta_{sw} \right] \quad \text{Eq. D-5}$$

where

ksv	=	loss constant due to volatilization (yr^{-1})
3.1536×10^7	=	conversion constant (s/yr)
H	=	Henry's Law constant ($\text{atm}\cdot\text{m}^3/\text{mol}$), (chemical-specific value)
Z_s	=	soil mixing depth (2 cm), (default value)
Kd_s	=	soil-water partition coefficient (cm^3/g), (chemical-specific value)
R	=	universal gas constant ($8.205 \times 10^{-5} \text{ atm}\cdot\text{m}^3/\text{mol}\cdot\text{K}$)
BD	=	soil bulk density (1.5 g/cm^3), (default value)
T_a	=	ambient air temperature (298 K), (default value)
ρ_{soil}	=	solids particulate density (2.7 g/cm^3), (default value)
D_a	=	diffusivity of chemical in air (cm^2/sec), (chemical-specific value)
θ_{sw}	=	soil volumetric water content (0.2 ml/cm^3 soil), (default value)

The Henry's Law constant and the diffusivity of the chemical in air are chemical-specific values that were obtained from various references. Throughout this screening-level MPHRA, default values were used for the ambient air temperature (298 K, T_a) and the solids particulate density (2.7 g/cm^3 , ρ_{soil}). In the absence of site-specific values, these values were selected according to the recommendations of Table B-1-6 of the HHRAP (USEPA, 2005).

D.2.3 Soil Concentration

COPC concentrations in soil were calculated from the deposition term, soil loss constant, and the exposure scenario-specific exposure durations using the equations presented in Table B-1-1 of the HHRAP (USEPA, 2005) and below:

$$C_s = \frac{\frac{D_s \cdot tD - C_{s_{tD}}}{k_s} + \frac{C_{s_{tD}}}{k_s} \cdot [1.0 - \exp(-k_s \cdot (T_2 - tD))]}{(T_2 - T_1)} \quad \text{Eq. D-6a}$$

$$C_s = \frac{D_s}{k_s \cdot (tD - T_1)} \cdot \left(\left[tD + \frac{\exp(-k_s \cdot tD)}{k_s} \right] - \left[T_1 + \frac{\exp(-k_s \cdot T_1)}{k_s} \right] \right) \quad \text{Eq. D-6b}$$

$$C_{s_{tD}} = \frac{D_s \cdot [1 - \exp(-k_s \cdot tD)]}{k_s} \quad \text{Eq. D-7}$$

where

C_s	=	chemical concentration in soil (mg/kg)
D_s	=	deposition term (mg/kg-yr) (calculated by Eq. D-1)
k_s	=	soil loss constant (yr^{-1}) (calculated by Eq. D-2)
tD	=	total time period over which deposition occurs (5 yr) (site-specific value, period that PCAPP and EDS operate)
$C_{s_{tD}}$	=	soil concentration at time tD (mg/kg)
BD	=	soil bulk density (1.5 g/cm^3), (default value)
T_2	=	exposure duration (yr) (exposure scenario-specific value)
T_1	=	time at the beginning of emission (0 yr) (site-specific value)

Soil concentrations might require many years to reach a steady state, and as a result, the HHRAP (USEPA, 2005) has derived equations to calculate the average soil concentration over the period of COPC deposition based on the integration of the instantaneous soil concentration equation over the entire period of deposition.

Equations D-6a and D-6b present two variations the soil concentration equation which was used for carcinogens. For exposure durations greater than the operational lifetime of the PCAPP or EDS, Equation D-6a was used to calculate the COPC concentration in soil. For exposure durations less than or equal to the operating lifetime of the PCAPP or EDS (i.e., infant and child exposure scenarios), Equation D-6b was used. For carcinogens, the COPC soil concentration was averaged over the exposure duration because carcinogenic risk is averaged over an individual's lifetime.

Equation D-7 was used to calculate soil concentrations for noncarcinogens and represents the highest annual average COPC soil concentration. The highest annual average concentration typically occurs at the end of the operating life of an emission source. Equation D-7 was used for noncarcinogens because a noncarcinogenic effect is based on a threshold dose (maximum annual average concentration) rather than a lifetime cumulative exposure (average concentration over the exposure duration).

The time period over which deposition occurs, tD , is the site-specific 5-year operational lifetime of the PCAPP. Exposure duration is a scenario-specific parameter that varied from a minimum of 1 year for infant exposures to a maximum of 40 years for the adult farmer scenario.

D.3 COPC CONCENTRATIONS IN SURFACE WATER

COPCs emitted from PCAPP and EDS emission sources may be introduced into local surface water bodies. The mechanisms that may cause the introduction of COPCs into these water bodies include:

- diffusive transfer from air into the water body
- deposition directly into the water bodies
- runoff from impervious surfaces
- runoff from pervious surfaces
- erosion of COPC-containing soils

The equations used in this MPHRA to calculate the surface water concentrations of COPCs are presented in Appendix B-4 of the HHRAP (USEPA, 2005). These equations were used to calculate the loading into the water bodies, through the mechanisms discussed above, and the partitioning between the sediment and aqueous phase of the water column. Additionally, these equations address the losses of COPCs in the water bodies from water column volatilization and burial in benthic sediment.

Two different sets of AERMOD receptors were used to quantify COPC concentrations in surface water. The first set includes receptors located over a local water body (Thatcher Reservoir). These receptors were locations at which maximum air concentrations and deposition rates were calculated at the surface of the water body. The second set of AERMOD receptor locations is the same as was discussed in Section D.2 (RME individual location for soil concentrations) and was used to calculate the loading from impervious surface runoff, pervious surface runoff, and erosion. The use of these two AERMOD receptors constitutes a worst-case annual water body loading. The annual COPC concentrations in the water body associated with these receptors were then used in the calculations for several exposure pathways, including consumption of locally-caught fish, ingestion of human breast milk, incidental surface water ingestion during swimming, and dermal exposure during swimming.

D.3.1 Total COPC Load

The total COPC load to the water body from wet and dry deposition, pervious and impervious surface runoff, erosion, and diffusion processes was calculated using the equation presented in Table B-4-7 of the HHRAP (USEPA, 2005) and below:

$$L_T = L_{Dep} + L_{Dif} + L_{RI} + L_R + L_E \quad \text{Eq. D-8}$$

where

L_T	=	total chemical load to water body (g/yr)
L_{Dep}	=	direct deposition load to water body (g/yr), (calculated by Eq. D-9)
L_{Dif}	=	vapor phase diffusion load to water body (g/yr), (calculated by Eq. D-15)
L_{RI}	=	impervious surface runoff load to water body (g/yr), (calculated by Eq. D-10)
L_R	=	pervious surface runoff load to water body (g/yr), (calculated by Eq. D-11)
L_E	=	soil erosion load to water body (g/yr), (calculated by Eq. D-12)

D.3.1.1 Direct Deposition Loading

Particles and gaseous species in the air can be deposited into bodies of water by dry and wet deposition. The area of the water body and the modeled deposition rates at the water body receptor location of maximum impact determine the magnitude of the deposition load. The chemical load to Thatcher Reservoir from direct deposition (L_{Dep}) was calculated using the equation presented in Table B-4-8 of the HHRAP (USEPA, 2005) and below:

$$L_{Dep} = Q \cdot [F_v \cdot Dytww + (1 - F_v) \cdot Dytwp] \cdot A_w \quad \text{Eq. D-9}$$

where

L_{Dep}	=	direct deposition load to water body (g/yr)
Q	=	stack emission rate (g/s) (chemical-specific value)
F_v	=	fraction of air concentration in vapor phase (dimensionless), (chemical-specific value)
$Dytww$	=	normalized yearly watershed total deposition rate from vapor phase (g/m ² -yr per g/s), ($Dywwv + Dyw dv$, modeled value)
$Dytwp$	=	normalized yearly watershed total deposition rate from particle phase (g/m ² -yr per g/s), ($Dywwp + Dyw dp$, modeled value)
A_w	=	water body surface area (75,000 m ²), (site-specific value)

A total of 13 AERMOD receptors were placed on Thatcher Reservoir, which is approximately 4,000 m (~2.5 miles) north of PCAPP and represents the water body that is available for direct deposition. The surface area (A_w) of Thatcher Reservoir (75,000 m²) was determined by directly calculating the area of the Reservoir from a Google Earth image (2013). Previously, a small pond at the Thatcher homestead was considered the most representative water body. However, this spring-fed pond has since become dry.

D.3.1.2 Impervious Surface Runoff Load

Precipitation events within the watershed lead to some runoff from impervious surfaces into the water body. Water from impervious surfaces is washed into the water body when precipitation events occur. The impervious surface area and modeled deposition rates determine the magnitude of this load. The impervious surface runoff load to the ponds (L_{RI}) was calculated using the equation presented in Table B-4-9 of the HHRAP (USEPA, 2005) and below:

$$L_{RI} = Q \cdot [F_v \cdot Dytww + (1 - F_v) \cdot Dytwp] \cdot A_i \quad \text{Eq. D-10}$$

where

L_{RI}	=	impervious surface runoff load to water body (g/yr)
Q	=	stack emission rate (g/s) (chemical-specific value)
F_v	=	fraction of chemical in vapor phase (dimensionless), (chemical-specific value)
$Dytwv$	=	normalized yearly watershed total deposition from vapor phase (g/m ² -yr per g/s), ($Dywwv + Dywdv$, modeled value)
$Dytwp$	=	normalized yearly watershed dry deposition from particle phase (g/m ² -yr per g/s), ($Dywwp + Dywdp$, modeled value)
A_I	=	impervious watershed area receiving chemical deposition (3,670,320 m ²), (site-specific value)

The impervious area of the watershed receiving chemical deposition was calculated as a percentage of the total watershed area according to guidance provided in the HHRAP (USEPA, 2005). Impervious areas are those areas that do not allow water infiltration, such as roads, parking lots, and buildings. The total impervious area within the watershed is a function of the degree of urbanization in the watershed. The rural nature of the area around the PCD and examination of a Google Earth satellite image (2013) and a USGS map (USGS, 2013) led to the selection of a value of 2 percent of the total watershed area as impervious surfaces. This is a conservative assumption that overestimates the impervious surfaces in the watershed.

D.3.1.3 Pervious Surface Runoff Load

Runoff from pervious surfaces interacts with soil prior to discharge into the water body. The soil concentration, soil physical properties, and amount of runoff determine the chemical load to the water body due to pervious surface runoff. The pervious surface runoff load to the pond (L_R) was calculated using the formula presented in Table B-4-10 of the HHRAP (USEPA, 2005) and below:

$$L_R = RO \cdot (A_L - A_I) \cdot \frac{Cs \cdot BD}{\theta_{sw} + Kd_s \cdot BD} \cdot 0.01 \quad \text{Eq. D-11}$$

where

L_R	=	pervious surface runoff load to water body (g/yr)
RO	=	average annual runoff (1.27 cm/yr), (site-specific value)
Cs	=	chemical concentration in soil (mg/kg), (calculated by Eq. D-6a or b, or Eq. D-7)
BD	=	soil bulk density (1.5 g/cm ³), (default value)
Kd_s	=	soil-water partition coefficient (cm ³ /g), (chemical-specific value)
A_L	=	total watershed area receiving chemical deposition (183,516,000 m ²), (site-specific value)
A_I	=	impervious watershed area receiving chemical deposition (3,670,320 m ²), (site-specific value)
0.01	=	units conversion factor (kg-cm ² /mg-m ²)
θ_{sw}	=	soil volumetric water content (0.2 cm ³ /cm ³), (default value)

The average annual surface runoff for the modeling domain was determined from Miller (1963). The total watershed area receiving chemical deposition was obtained from USGS Watershed

Boundary Dataset for the Haines Creek watershed, and the impervious watershed area receiving chemical deposition is described in Eq. D-10.

D.3.1.4 Soil Erosion Load

Erosion of soil contaminated with COPCs contributes to the total chemical load to the water body. The soil erosion load to the pond (L_E) was calculated using the equation presented in Table B-4-11 of the HHRAP (USEPA, 2005) and below:

$$L_E = X_e \cdot (A_L - A_I) \cdot SD \cdot ER \cdot \frac{Cs \cdot Kd_s \cdot BD}{\theta_{sw} + Kd_s \cdot BD} \cdot 0.001 \quad \text{Eq. D-12}$$

where

L_E	=	soil erosion load to water body (g/yr)
X_e	=	unit soil loss (kg/m ² -yr), (calculated by Eq. D-13)
Cs	=	chemical concentration in soil (mg/kg), (calculated by Eq. D-6a or b, or Eq. D-7)
BD	=	soil bulk density (1.5 g/cm ³), (default value)
θ_{sw}	=	soil volumetric water content (0.2 cm ³ /cm ³), (default value)
Kd_s	=	soil-water partition coefficient (l/kg), (chemical-specific value)
A_L	=	total watershed area receiving chemical deposition (183,516,000 m ²), (site-specific value)
A_I	=	impervious watershed area receiving chemical deposition (3,670,320 m ²), (site-specific value)
SD	=	watershed sediment delivery ratio (dimensionless), (calculated by Eq. D-14)
ER	=	soil enrichment ratio (3.0 dimensionless), (default value)
0.001	=	units conversion factor ([g/kg]/[mg/kg])

The soil enrichment ratio, ER , is included because the COPC concentrations are expected to be higher in loosely held, erodible soil on the surface than in the bulk soil. Table B-4-11 of the HHRAP (USEPA, 2005) provides two recommended values for the enrichment ratio. The recommended value is 3 (dimensionless) for organic COPCs and 1 for inorganic COPCs. Because most of the COPCs of interest at PCAPP are organic, the value 3 was used throughout the risk assessment. For any inorganic species, using the higher organic COPC value overestimates the COPC load to the water body and is thus a conservative assumption.

D.3.1.4.1 Unit Soil Loss

The unit soil loss (X_e) was calculated using the Universal Soil Loss Equation (USLE), which is described in Table B-4-13 in the HHRAP (USEPA, 2005) and below:

$$X_e = RF \cdot K \cdot LS \cdot C \cdot PF \cdot \frac{907.18}{4047} \quad \text{Eq. D-13}$$

where

X_e	=	unit soil loss (kg/m ² -yr)
RF	=	USLE rainfall (or erosivity) factor (31 yr ⁻¹), (site-specific value)
K	=	USLE erodibility factor (0.37 ton/acre), (site-specific value)

<i>LS</i>	=	USLE length-slope factor (1.5 dimensionless), (default value)
<i>C</i>	=	USLE cover management factor (0.1 dimensionless), (default value)
<i>PF</i>	=	USLE supporting practice factor (1.0 dimensionless), (default value)
907.18	=	conversion factor (kg/ton)
4047	=	conversion factor (m ² /acre)

The USLE rainfall (or erosivity) factor (*RF*) is a site-specific value of 31 yr⁻¹. This value was obtained from the Revised Universal Soil Loss Equation (RUSLE2) computer program provided by the National Resource Conservation Service (NRCS, 2006). The USLE erodibility factor (*K*) is a site-specific value of 0.37 ton/acre. The erodibility factor was the maximum erodibility factor for soil types found in the vicinity of the PCD as listed in the Environmental Impact Statement for PCAPP (US Army, 2002). Erodibility factors for the individual soil types were found in the RUSLE2 program.

Table B-4-13 of the HHRAP (USEPA, 2005) provides the basis for many values used in Equation D-13. The USLE length-slope factor (*LS*) was a default value of 1.5 (dimensionless). This value reflects a variety of possible distance and slope conditions and was chosen to be representative of the whole watershed, not just an agricultural field. A value of 0.1 (dimensionless) was selected to represent the USLE cover management factor (*C*). According to Table B-4-13, a range of values up to 0.1 for the USLE cover management factor reflects dense vegetative cover, such as pasture grass. This value most appropriately represents the conditions near the PCD. Finally, a value of 1.0 was chosen for the USLE supporting practice factor (*PF*) to conservatively reflect the absence of any erosion or runoff control measures.

D.3.1.4.2 Sediment Delivery Ratio

The sediment delivery ratio for the watershed (*SD*) was calculated using the equation presented in Table B-4-14 in the HHRAP (USEPA, 2005) and below:

$$SD = a \cdot (A_L)^{-b} \quad \text{Eq. D-14}$$

where

<i>SD</i>	=	watershed sediment delivery ratio (dimensionless)
<i>A_L</i>	=	total watershed area receiving chemical deposition (183,516,000 m ²), (site-specific value)
<i>b</i>	=	empirical slope coefficient (0.125 dimensionless), (default value)
<i>a</i>	=	empirical intercept coefficient (1.9 dimensionless), (site-specific value)

Table B-4-14 of the HHRAP (USEPA, 2005) provides the basis for the selection of the empirical slope coefficient (*b*) and the empirical intercept coefficient (*a*). The empirical slope coefficient is the default value of 0.125 (dimensionless). The empirical intercept coefficient varies based on the watershed area receiving fallout. The value chosen was 1.9 (dimensionless) for watershed areas greater than 0.1 square mile but less than or equal to 1.0 square mile.

D.3.1.5 Diffusive Load from Atmospheric COPCs

The chemical load to a water body due to diffusion of vapor-phase chemicals in the atmosphere into the surface water (*L_{Dif}*) was calculated using the equation presented in Table B-4-12 in the HHRAP (USEPA, 2005) and below:

$$L_{Dif} = \frac{K_v \cdot Q \cdot F_v \cdot C_{yww} \cdot A_w \cdot 10^{-6}}{H} \cdot \frac{1}{R \cdot T_{wk}} \quad \text{Eq. D-15}$$

where

L_{Dif}	=	vapor phase diffusion load to water body (g/yr)
Q	=	stack emission rate (g/s) (chemical-specific value)
F_v	=	fraction of air concentration in vapor phase (dimensionless), (chemical-specific value)
K_v	=	overall transfer rate (m/yr), (calculated by Eq. D-16)
C_{yww}	=	normalized yearly watershed vapor phase air concentration ($\mu\text{g}/\text{m}^3$ per g/s), (modeled value)
A_w	=	water body surface area ($75,000 \text{ m}^2$), (site-specific value)
H	=	Henry's Law constant ($\text{atm}\cdot\text{m}^3/\text{mol}$), (chemical-specific value)
R	=	universal gas constant ($8.205 \times 10^{-5} \text{ atm}\cdot\text{m}^3/\text{mol}\cdot\text{K}$)
T_{wk}	=	water body temperature (298 K), (default value)
10^{-6}	=	units conversion factor (g/ μg)

A water body temperature (T_{wk}) of 298 K was used, as recommended by Table B-4-12 of the HHRAP (USEPA, 2005) for use in the absence of site-specific water body temperature data. The overall COPC transfer rate coefficient (K_v) used in Equation D-15 is the chemical-specific rate calculated according to Equation D-16.

D.3.1.5.1 Overall Transfer Rate Coefficient

Volatile chemicals can move between the atmosphere and surface water by diffusion. The transfer of chemicals between the two phases is modeled by a two-layer resistance model. In this model, there are two thin films with concentration gradients at the boundary between air and water. The bulk air and water compartments are assumed to be well mixed. Transfer of chemicals between air and water is governed by different mechanisms depending on whether the water body is flowing or stagnant. For this risk assessment, the affected water bodies are ponds (stagnant) rather than rivers (flowing). The overall transfer rate coefficient of contaminant from the liquid and gas phases in surface water (K_v) was calculated using the equation presented in Table B-4-19 of the HHRAP (USEPA, 2005) and below:

$$K_v = \left[K_L^{-1} + \left(K_G \cdot \frac{H}{R \cdot T_{wk}} \right)^{-1} \right]^{-1} \cdot \theta^{(T_{wk}-293)} \quad \text{Eq. D-16}$$

where

K_v	=	overall transfer rate (m/yr)
K_L	=	liquid phase transfer coefficient (m/yr), (calculated by Eq. D-17)
K_G	=	gas phase transfer coefficient (m/yr), (calculated by Eq. D-18)
H	=	Henry's Law constant ($\text{atm}\cdot\text{m}^3/\text{mol}$), (chemical-specific value)
R	=	universal gas constant ($8.205 \times 10^{-5} \text{ atm}\cdot\text{m}^3/\text{mol}\cdot\text{K}$)
T_{wk}	=	water body temperature (298 K), (default value)
θ	=	temperature correction factor (1.026 dimensionless), (default value)

The temperature correction factor (θ) was assigned the default value of 1.026 (dimensionless) which is recommended by Table B-4-19 of the HHRAP (USEPA, 2005).

Liquid Phase Transfer Coefficient. The transfer rate of chemicals from the liquid phase in surface water of a stagnant system (i.e., pond or lake) (K_L) was calculated using the equation presented in Table B-4-20 of the HHRAP (USEPA, 2005) and below:

$$K_L = C_d^{0.5} \cdot W \cdot \left(\frac{\rho_a}{\rho_w} \right)^{0.5} \frac{k^{0.33}}{\lambda_z} \cdot \left(\frac{\mu_w}{\rho_w \cdot D_w} \right)^{-0.67} \cdot 3.1536 \times 10^7 \quad \text{Eq. D-17}$$

where

K_L	=	liquid phase transfer coefficient (m/yr)
D_w	=	diffusivity of chemical in water (cm ² /s), (chemical-specific value)
W	=	wind speed (3.9 m/s), (default value)
C_d	=	drag coefficient (0.0011 dimensionless), (default value)
ρ_a	=	density of air (0.0012 g/cm ³), (default value)
ρ_w	=	density of water (1 g/cm ³), (default value)
k	=	von Karman's constant (0.4 dimensionless)
λ_z	=	dimensionless viscous sublayer thickness (4 dimensionless), (default value)
μ_w	=	viscosity of water at temperature (1.69 x 10 ⁻² g/cm-s), (default value)
3.1536×10^7	=	units conversion factor (s/yr)

This equation was chosen to calculate the liquid phase transfer coefficient from the two equations recommended in the HHRAP (USEPA, 2005). Equation D-17 is recommended for stagnant water bodies; a separate equation is recommended for flowing water bodies.

Many of the values used in Equation D-17 were assigned default values recommended by Table B-4-20 of the HHRAP (USEPA, 2005). The drag coefficient (C_d) was assigned the value of 0.0011 (dimensionless), the density of air (ρ_a) assigned a value of 0.0012 g/cm³ in the absence of site-specific air density, the density of water (ρ_w) assigned the default value of 1 g/cm³ (the density of water at standard conditions), the dimensionless viscous sublayer thickness (λ_z) assigned a value of 4 (dimensionless), and the viscosity of water (μ_w) assigned a value of 1.69 · 10⁻², which corresponds to the default water temperature of 298 K. The wind speed (W) was assigned a value of 3.9 m/s.

Gas Phase Transfer Coefficient. The gas phase transfer coefficient for stagnant water bodies (K_G) was calculated using the equation presented in Table B-4-21 of the HHRAP (USEPA, 2005) and below:

$$K_G = C_d^{0.5} \cdot W \cdot \frac{k^{0.33}}{\lambda_z} \cdot \left(\frac{\mu_a}{\rho_a \cdot D_a} \right)^{-0.67} \cdot 3.1536 \times 10^7 \quad \text{Eq. D-18}$$

where

K_G	=	gas phase transfer coefficient (m/yr)
D_a	=	diffusivity of chemical in air (cm ² /s), (chemical-specific value)
W	=	wind speed (3.9 m/s), (default value)
C_d	=	drag coefficient (0.0011 dimensionless), (default value)

ρ_a	=	density of air (0.0012 g/cm ³), (default value)
k	=	von Karman's constant (dimensionless)
λ_z	=	dimensionless viscous sublayer thickness (4 dimensionless), (default value)
μ_a	=	viscosity of air at temperature (1.81 x 10 ⁻⁴ g/cm-s), (default value)
3.1536×10^7	=	units conversion factor (s/yr)

The viscosity of air (μ_a) is the default value of 1.81 x 10⁻⁴ g/cm-s recommended by Table B-4-21 of the HHRAP (USEPA, 2005).

D.3.2 Total Water Body Concentration

The total water body concentration (C_{wtot}) comprises the total COPC concentration in both the water column and bed sediment of the water body. This concentration was calculated using the equation presented in Table B-4-15 of the HHRAP (USEPA, 2005) and below:

$$C_{wtot} = \frac{L_T}{Vf_x \cdot f_{wc} + k_{wt} \cdot A_w \cdot (d_{wc} + d_{bs})} \quad \text{Eq. D-19}$$

where

C_{wtot}	=	total water concentration, including water column and bed sediment (g/m ³)
L_T	=	total chemical load to water body (g/yr), (calculated by Eq. D-8)
Vf_x	=	average volumetric flow rate through water body (2,680,560 m ³ /yr), (site-specific value)
f_{wc}	=	fraction of total water body chemical concentration that occurs in the water column (dimensionless), (calculated by Eq. D-20)
k_{wt}	=	total water body dissipation rate constant (yr ⁻¹), (calculated by Eq. D-22)
A_w	=	water body surface area (75,000 m ²), (site-specific value)
d_{wc}	=	depth of water column (5 m), (site-specific value)
d_{bs}	=	depth of upper benthic layer (0.03 m), (default value)

The average volumetric flow rate through the water body (Vf_x) is a measured value of 2,680,560 m³/yr. This value was obtained from the Environmental Impact Statement for PCAPP (US Army, 2002) as the flow rate through an intermittent stream (Chico Creek) in the area. Flow data for Haynes Creek, which feeds Thatcher Reservoir, were not available but would be expected to be greater than the Chico Creek flow data. Use of Chico Creek flow data would produce higher water concentrations than produced when using a greater flow rate. The depth of the water column (d_{wc}) is an estimated site-specific value of 5 m. The depth of the upper benthic layer (d_{bs}) used was a default value of 0.03 m, recommended by Table B-4-15 of the HHRAP (USEPA, 2005).

D.3.2.1 Fraction of Total Water Body Concentration that Occurs in the Water Column and in the Benthic Sediment

COPCs in surface water partition between the water column and sediments. The fraction of the total concentration in each compartment is important for calculating other media concentrations (i.e., COPC concentrations in fish). The fraction of the total water body chemical concentration that occurs in the water column (f_{wc}) was calculated using the equation presented in Table B-4-16 of the HHRAP (USEPA, 2005) and below:

$$f_{wc} = \frac{(1 + Kd_{sw} \cdot TSS \cdot 10^{-6}) \cdot (d_{wc} / d_z)}{(1 + Kd_{sw} \cdot TSS \cdot 10^{-6}) \cdot (d_{wc} / d_z) + (\theta_{bs} + Kd_{bs} \cdot C_{BS}) \cdot (d_{bs} / d_z)} \quad \text{Eq. D-20}$$

where

- f_{wc} = fraction of total water body chemical concentration that occurs in the water column (dimensionless)
- Kd_{sw} = suspended sediment/surface water partition coefficient (l/kg), (chemical-specific value)
- TSS = total suspended solids (10 mg/l), (default value)
- 10^{-6} = conversion factor (kg/mg)
- d_{wc} = depth of water column (5 m), (site-specific value)
- d_{bs} = depth of upper benthic layer (0.03 m), (default value)
- d_z = total water body depth (5.03 m), ($d_{wc} + d_{bs}$)
- θ_{bs} = bed sediment porosity (0.6 l_{water}/l), (default value)
- Kd_{bs} = bed sediment/sediment pore water partition coefficient (l/kg), (chemical-specific value)
- C_{BS} = bed sediment concentration (1.0 g/cm³), (default value)

Table B-4-16 provides the basis for many of the default parameters used in Equation D-20. The total suspended solids concentration (TSS) was assigned a default value of 10 mg/l, which was cited by the HHRAP (USEPA, 2005) from various sources for use in the absence of site- and water body-specific measured values. The bed sediment porosity (θ_{bs}) was assigned the value 0.6 l_{water}/l, which is consistent with the recommendation of Table B-4-16 of the HHRAP (USEPA, 2005). Finally, the bed sediment concentration (C_{BS}) was assigned the recommended default value of 1.0 g/cm³.

The fraction of the total water body concentration that occurs in the bed sediments (f_{bs}) was calculated by:

$$f_{bs} = 1 - f_{wc} \quad \text{Eq. D-21}$$

where

- f_{bs} = fraction of total water body chemical concentration that occurs in the benthic sediment (dimensionless)
- f_{wc} = fraction of total water body chemical concentration that occurs in the water column (dimensionless), (calculated by Eq. D-20)

D.3.2.2 Overall Total Water Body COPC Dissipation Rate Constant

The overall dissipation rate of chemicals in the water body due to volatilization and benthic burial (k_{wt}) was calculated using the equation presented in Table B-4-17 of the HHRAP (USEPA, 2005) and below:

$$k_{wt} = f_{wc} \cdot k_v + f_{bs} \cdot k_b \quad \text{Eq. D-22}$$

where

- k_{wt} = total water body dissipation rate constant (yr⁻¹)
- f_{wc} = fraction of total water body chemical concentration that occurs in the water column (dimensionless), (calculated by Eq. D-20)

- k_v = water column volatilization rate constant (yr^{-1}), (calculated by Eq. D-23)
 f_{bs} = fraction of total water body chemical concentration that occurs in benthic sediment (dimensionless), (calculated by Eq. D-21)
 k_b = benthic burial rate constant (yr^{-1}), (calculated by Eq. D-24)

D.3.2.1.1 Water Column Volatilization Rate Constant

The rate constant governing water column volatilization (k_v) was calculated using the equation presented in Table B-4-18 of the HHRAP (USEPA, 2005) and below:

$$k_v = \frac{K_v}{d_z \cdot (1 + Kd_{sw} \cdot TSS \cdot 10^{-6})} \quad \text{Eq. D-23}$$

where

- k_v = water column volatilization rate constant (yr^{-1})
 K_v = overall transfer rate (m/yr), (calculated by Eq. D-16)
 d_z = total water body depth (5.03 m), ($d_{wc} + d_{bs}$)
 Kd_{sw} = suspended sediment/surface water partition coefficient (ℓ/kg), (chemical-specific value)
 TSS = total suspended solids (10 mg/ ℓ), (default value)
 10^{-6} = conversion factor (kg/mg)

D.3.2.1.2 Benthic Burial Rate Constant

The rate constant governing burial in benthic sediment (k_b) was calculated using the equation presented in Table B-4-22 of the HHRAP (USEPA, 2005) and below:

$$k_b = \frac{X_e \cdot A_L \cdot SD \cdot 10^3 - Vf_x \cdot TSS}{A_w \cdot TSS} \cdot \frac{TSS \cdot 10^{-6}}{C_{BS} \cdot d_{bs}} \quad \text{Eq. D-24}$$

where

- k_b = benthic burial rate constant (yr^{-1})
 X_e = unit soil loss ($\text{kg}/\text{m}^2\text{-yr}$), (calculated by Eq. D-13)
 A_L = total watershed area receiving chemical deposition (183,516,000 m^2), (site-specific value)
 SD = watershed sediment delivery ratio (dimensionless), (calculated by Eq. D-14)
 10^3 = conversion factor (g/kg)
 Vf_x = average volumetric flow rate through water body (2,680,560 m^3/yr), (site-specific value)
 TSS = total suspended solids (10 mg/ ℓ), (default value)
 A_w = water body surface area (75,000 m^2), (site-specific value)
 C_{BS} = bed sediment concentration (1.0 kg/ ℓ), (default value)
 d_{bs} = depth of upper benthic layer (0.03 m), (default value)
 10^{-6} = conversion factor (kg/mg)

D.3.3 Concentration in the Water Column

The total water column chemical concentration, including dissolved chemicals and chemicals sorbed to suspended solids (C_{wctot}), was calculated using the equation presented in Table B-4-23 of the HHRAP (USEPA, 2005) and below:

$$C_{wctot} = f_{wc} \cdot C_{wtot} \cdot \frac{d_{wc} + d_{bs}}{d_{wc}} \quad \text{Eq. D-25}$$

where

C_{wctot}	=	total chemical concentration in water column (mg/L)
f_{wc}	=	fraction of total water body chemical concentration that occurs in the water column (dimensionless), (calculated by Eq. D-20)
C_{wtot}	=	total water concentration, including water column and bed sediment (mg/l), (calculated by Eq. D-19)
d_{bs}	=	depth of upper benthic layer (0.03 m), (default value)
d_{wc}	=	depth of water column (5.03 m), (site-specific value)

D.3.4 Concentration in the Dissolved Water Phase

The concentration of a COPC dissolved in the water column is the parameter used to calculate COPC concentrations in fish. The dissolved water concentration is used with both bioconcentration factors ($\log K_{ow} < 4$) and bioaccumulation factors ($\log K_{ow} > 4$). The concentration of chemical dissolved in the water column (C_{dw}) was calculated using the equation presented in Table B-4-24 of the HHRAP (USEPA, 2005) and below:

$$C_{dw} = \frac{C_{wctot}}{1 + Kd_{sw} \cdot TSS \cdot 10^{-6}} \quad \text{Eq. D-26}$$

where

C_{dw}	=	chemical concentration in the dissolved water phase (mg/l)
C_{wctot}	=	total chemical concentration in water column (mg/l), (calculated by Eq. D-25)
Kd_{sw}	=	suspended sediment/surface water partition coefficient (l/kg), (chemical-specific value)
TSS	=	total suspended solids (10 mg/l), (default value)
10^{-6}	=	conversion factor (kg/mg)

D.4 COPC CONCENTRATIONS IN PRODUCE FOR HUMAN CONSUMPTION

COPC concentrations in above-ground (exposed) fruits and vegetables are attributable to several uptake mechanisms, including direct deposition onto the plant with subsequent absorption, direct uptake of vapor phase chemicals through plant foliage, and root uptake of chemicals deposited on soil. The concentrations of COPCs in above-ground, exposed plants due to exposure to PCAPP emissions were calculated as the sum of these uptake processes. COPC concentrations in below-ground vegetables and above-ground protected fruits and vegetables are attributed to root uptake of chemicals deposited on soil. Protected fruits are above-ground produce in which the edible portion of the plant is covered by a protective inedible

coating that prevents uptake of chemicals into the edible portion by direct deposition or air-to-plant transfer.

D.4.1 Concentration in Above-Ground Produce Due to Direct Deposition

Chemical concentrations in above-ground produce due to direct deposition were calculated using the equation presented in Table B-2-7 of the HHRAP (USEPA, 2005) and presented below. This equation was used to calculate chemical concentrations in a typical dietary mix of fruiting vegetables, leafy vegetables, legumes, and fruits for human consumption.

$$P_d = \frac{1000 \cdot Q \cdot (1.0 - F_v) \cdot [Dydp + (F_w \cdot Dywp)] \cdot R_p \cdot [1.0 - \exp(-kp \cdot T_p)]}{Y_p \cdot kp} \quad \text{Eq. D-27}$$

where

P_d	=	chemical concentration in plant due to direct deposition (mg/kg)
1000	=	unit conversion factor (mg/g)
Q	=	stack emission rate (g/s), (chemical-specific value)
$Dydp$	=	normalized yearly dry deposition from particle phase (g/m ² -yr per g/s), (modeled value)
F_w	=	fraction of wet deposition that adheres to plant (dimensionless), (chemical-specific value)
F_v	=	fraction of air concentration in vapor phase (dimensionless), (modeled value)
$Dywp$	=	normalized yearly wet deposition from particle phase (g/m ² -yr per g/s), (modeled value)
R_p	=	interception fraction of edible portion of plant (dimensionless), (0.39 for human consumption), (default value)
kp	=	plant surface loss coefficient (18 yr ⁻¹), (default value)
T_p	=	length of plant exposure to deposition of edible portion of plant, per harvest (0.16 yr for human consumption), (default value)
Y_p	=	yield or standing crop biomass of the edible portion of the plant (2.24 kg/m ² for human consumption), (default value)

Table B-2-7 of the HHRAP (USEPA, 2005) provides the default values used for the calculation of chemical concentrations in produce for human consumption. As noted earlier, the deposition of stack emissions was assumed to continue over the entire duration of indirect exposure (i.e., up to 40 years depending upon the exposure scenario) even though the stack emission ceases after 5 years. This assumption was used to calculate all COPC concentrations in produce.

D.4.2 Concentration in Above-Ground Produce Due to Air-to-Plant Transfer

Chemical concentrations in above-ground produce due to air-to-plant transfer were calculated using the equation presented in Table B-2-8 of the HHRAP (USEPA, 2005) and below:

$$P_v = Q \cdot F_v \cdot \frac{C_{yv} \cdot B_{v_{ag}} \cdot V_{G_{ag}}}{\rho_a} \quad \text{Eq. D-28}$$

where

P_v	=	chemical concentration in the plant due to air-to-plant transfer (mg/kg)
Q	=	stack emission rate (g/s), (chemical-specific value)

F_v	=	fraction of air concentration in vapor phase (dimensionless), (modeled value)
C_{yv}	=	normalized vapor phase air concentration ($\mu\text{g}/\text{m}^3$ per g/s), (modeled value)
VG_{ag}	=	above-ground fruit/vegetable correction factor (dimensionless), (0.01 for $\log K_{ow} > 4$, and 1.0 for $\log K_{ow} < 4$ for human consumption), (default value)
Bv_{ag}	=	air-to-plant biotransfer factor ([mg chemical/g plant tissue]/[mg chemical/g air]), (chemical-specific value)
ρ_a	=	density of air ($1,200 \text{ g}/\text{m}^3$), (default value)

Table B-2-8 of the HHRAP (USEPA, 2005) recommends the following values for the above-ground fruit/vegetable correction factor (VG_{ag}) for human consumption, depending on the log of the octanol/water partition coefficient ($\log K_{ow}$) for each COPC:

- $VG_{ag} = 0.01$, if $\log K_{ow} > 4$
- $VG_{ag} = 1.0$, if $\log K_{ow} < 4$

These values address the potential to overestimate the transfer of lipophilic COPC (those with $\log K_{ow} > 4$) to the inner portions of bulky produce such as apples and leafy vegetables such as broccoli, brussels sprouts, cauliflower, celery, lettuce, and spinach. Because of the protective outer skin, size, and shape of bulky produce, transfer of lipophilic COPCs to the center of the produce is not as likely as for non-lipophilic COPCs, and the inner portions are less affected.

D.4.3 Concentration in Above-Ground Produce Due to Root Uptake

Chemical concentrations in above-ground produce due to direct uptake of contaminants from soil were calculated using the equation presented in Table B-2-9 of the HHRAP (USEPA, 2005) and below:

$$Pr = Cs \cdot Br_{ag} \quad \text{Eq. D-29}$$

where

Pr	=	concentration of chemical in above-ground plants due to root uptake from soil (mg/kg)
Cs	=	chemical concentration in soil (mg/kg), (calculated by Eq. D-6a or b, or Eq. D-7)
Br_{ag}	=	plant-to-soil bioconcentration factor for above-ground produce (dimensionless), (chemical-specific value)

D.4.4 Concentration in Below-Ground Produce Due to Root Uptake

COPCs enter below-ground produce (e.g., potatoes) only through direct uptake from soil. Direct uptake from soil by below-ground produce was calculated using the equation presented in Table B-2-10 of the HHRAP (USEPA, 2005) and below:

$$Pr_{bg} = \frac{Cs \cdot RCF \cdot VG_{rootveg}}{Kd_s} \quad \text{Eq. D-30}$$

where

Pr_{bg}	=	concentration of chemical in below-ground plants due to root uptake from soil (mg/kg)
Cs	=	chemical concentration in soil (mg/kg), (calculated by Eq. D-6a or b, or Eq. D-7)
$VG_{rootveg}$	=	correction factor for below-ground produce (dimensionless), (0.01 for $\log K_{ow} > 4$, and 1.0 for $\log K_{ow} < 4$), (default value)
RCF	=	root concentration factor ($\mu\text{g COPC/g plant}$)/($\mu\text{g COPC/ml soil water}$), (chemical-specific value)
Kd_s	=	soil-water partition coefficient (ml water/g soil), (chemical-specific value)

The correction factor for below-ground produce is analogous to the above-ground fruit/vegetable correction factor used in Equation D-29.

The calculation for root uptake for below-ground produce differs from that of root uptake for above-ground produce because, for below-ground produce, COPCs are taken up from soil directly into the edible portion of the plant. In above-ground produce, COPCs taken up through the roots must be transferred through the plant to get to the edible portion. The root concentration factor, used in Equation D-30, describes the ratio of the COPC concentration in the edible root to the COPC concentration in soil water.

D.5 COPC CONCENTRATIONS IN ANIMAL FEED

Chemical concentrations of COPCs in animal feed consisting of forage, silage, and grain are attributable to the same uptake mechanisms as produce for human consumption; specifically, direct deposition onto the plant with subsequent absorption, direct uptake of vapor phase chemicals, and root uptake of chemicals deposited on soil. The concentration of chemicals in each type of animal feed due to exposure to PCAPP emissions is the sum of these uptake processes. The chemical concentration in grain is calculated in the same manner as for above-ground protected produce for human consumption; that is, the only COPC uptake occurs through root uptake of chemicals that have deposited on soil. In this assessment, beef cattle, dairy cows, and pigs were assumed to consume contaminated forage, silage, and grain. Chickens were assumed to consume contaminated grain. Chemical concentrations in forage, silage, and grain were calculated at the location of the maximum off-site air concentration and deposition rate while again assuming the stack emission persisted over the entire exposure period.

D.5.1 Concentration in Forage and Silage Due to Direct Deposition

Chemical concentrations in forage and silage due to direct deposition were calculated using the equation presented in Table B-3-7 of the HHRAP (USEPA, 2005) and presented below. Different factors were used to calculate forage and silage concentrations for cow and pig consumption as described below:

$$Pd = \frac{1000 \cdot Q \cdot (1.0 - F_v) \cdot [Dydp + (Fw \cdot Dywp)] \cdot Rp \cdot [1.0 - \exp(-k_p \cdot T_p)]}{Yp \cdot kp} \quad \text{Eq. D-27}$$

where

P_d	=	chemical concentration in plant due to direct deposition (mg/kg)
1000	=	unit conversion factor (mg/g)
Q	=	stack emission rate (g/s), (chemical-specific value)
$Dydp$	=	normalized yearly dry deposition from particle phase (g/m ² -yr per g/s), (modeled value)
F_w	=	fraction of wet deposition that adheres to plant (dimensionless), (chemical-specific value)
F_v	=	fraction of air concentration in vapor phase (dimensionless), (modeled value)
$Dywp$	=	normalized yearly wet deposition from particle phase (g/m ² -yr per g/s), (modeled value)
R_p	=	interception fraction of edible portion of plant (dimensionless), (0.5 for forage, 0.46 for silage), (default values)
k_p	=	plant surface loss coefficient (18 yr ⁻¹), (default value)
T_p	=	length of plant exposure to deposition of edible portion of plant, per harvest (0.16 yr for and silage, 0.12 yr for forage), (default values)
Y_p	=	yield or standing crop biomass of the edible portion of the plant (0.24 kg/m ² for forage, 0.8 kg/m ² for silage), (default values)

Table B-3-7 of the HHRAP (USEPA, 2005) provides the default values used for the calculation of chemical concentrations in forage and silage.

D.5.2 Concentration in Forage and Silage Due to Air-to-Plant Transfer

Chemical concentrations in above-ground produce due to air-to-plant transfer were calculated using the equation presented in Table B-3-8 of the HHRAP (USEPA, 2005) and below:

$$P_v = Q \cdot F_v \cdot \frac{C_{yv} \cdot B_{v_{ag}} \cdot V_{G_{ag}}}{\rho_a} \quad \text{Eq. D-28}$$

where

P_v	=	chemical concentration of chemical in the plant due to air-to-plant transfer (mg/kg)
Q	=	stack emission rate (g/s), (chemical-specific value)
F_v	=	fraction of air concentration in vapor phase (dimensionless), (chemical-specific value)
C_{yv}	=	normalized vapor phase air concentration (µg/m ³ per g/s), (modeled value)
$V_{G_{ag}}$	=	above-ground fruit/vegetable correction factor (dimensionless), (1.0 for forage consumption and 0.5 for silage consumption), (default values)
$B_{v_{ag}}$	=	air-to-plant biotransfer factor ([mg pollutant/g plant tissue]/[mg chemical/g air]), (chemical-specific value)
ρ_a	=	density of air (1,200 g/m ³), (default value)

Table B-3-8 HHRAP (USEPA, 2005) recommends a default values for VG_{ag} as follows:

- $VG_{ag} = 1.0$ for forage
- $VG_{ag} = 0.5$ for silage

The rationale for these values is that plant forage consists of leafy vegetation, not bulky produce, and therefore the size and shape of leafy vegetation would not impede the transfer of lipophilic COPCs into the vegetation, as is the case with bulkier above-ground produce. The VG_{ag} for silage was assigned a default value of 0.5 by the HHRAP (USEPA, 2005) due to the lack of detailed information regarding silage materials.

In calculating the COPC concentrations in forage and silage, it was estimated that the COPC-specific air-to-plant biotransfer factors for forage and silage are equivalent to the air-to-plant biotransfer factors for above-ground produce.

D.5.3 Concentration in Forage, Silage, and Grain Due to Root Uptake

Chemical concentrations in forage, silage, and grain due to direct uptake of contaminants from soil were calculated using the equation presented in Table B-3-9 of the HHRAP (USEPA, 2005) and below:

$$Pr = Cs \cdot Br_{ag} \quad \text{Eq. D-29}$$

where

- Pr = concentration of chemical in above-ground plants due to root uptake from soil (mg/kg)
- Cs = chemical concentration in soil (mg/kg), (calculated by Eq. D-6a or b, or Eq. D-7)
- Br_{ag} = plant-to-soil bioconcentration factor for above-ground produce (dimensionless), (chemical-specific value)

In calculating concentrations due to this uptake mechanism, it was also estimated that the plant-soil bioconcentration factor for above-ground produce is equivalent to the plant-soil bioconcentration factor for forage and for silage.

D.6 COPC CONCENTRATIONS IN ANIMAL PRODUCTS

Chemical concentrations in animal products occur through consumption of contaminated feed and incidental ingestion of contaminated soil by the animal. The feed items may be contaminated through the three major mechanisms discussed above: direct deposition onto and vapor phase air-to-plant transfer into forage and silage, and direct uptake from soil through the plant roots for forage, silage, and grain. Soil may be contaminated through wet and dry deposition processes. Chemical concentrations of forage, silage, grain, and soil were calculated at the location of the maximum off-site air concentration and deposition rate.

D.6.1 Concentration in Beef Cattle

Chemical concentrations in beef tissue due to ingestion of forage, silage, grain, and soil by beef cattle were calculated using the equation presented in Table B-3-10 in the HHRAP (USEPA, 2005) and below:

$$A_{beef} = \left(\sum_i (F_i \cdot Qp_i \cdot P_{total,i}) + Qs \cdot Cs \cdot Bs \right) \cdot Ba_{beef} \cdot MF \quad \text{Eq. D-31}$$

where

A_{beef}	=	concentration of chemical in beef tissue (mg/kg)
F_i	=	fraction of plant type i grown on contaminated soil (1.0 dimensionless) (default value)
Qp_i	=	animal consumption rate of plant type i (kg plant tissue/day) (8.8, 2.5, and 0.47 kg/day for forage, silage, and grain, respectively), (default values)
$P_{total,i}$	=	total concentration of chemical in the plant type i (mg/kg), (the sum of the results of Eq. D-27, D-28, and D-29, for forage, silage, and grain)
Qs	=	animal consumption rate of soil (0.5 kg soil/day), (default value)
Cs	=	chemical concentration in soil (mg/kg), (calculated by Eq. D-6a or b, or Eq. D-7),
Ba_{beef}	=	biotransfer factor for beef (day/kg), (chemical-specific value)
Bs	=	soil bioavailability factor (1.0 dimensionless), (default value)
MF	=	metabolism factor (1.0 dimensionless), (default value)

Throughout this MPHRA, the fraction of plant type i which is grown on COPC-contaminated soil (F_i) and eaten by animals was assigned a default value of 1.0 (dimensionless) which represents the worst case scenario that all of the feed consumed by the animal has been grown on COPC-contaminated soil.

The HHRAP (USEPA, 2005) recommends using beef cattle consumption rates of forage, silage, and grain (Qp) as 8.8, 2.5, and 0.47 kilograms per day (kg/day), respectively. These values are based on a total daily consumption rate for beef cattle of 12 kg/day. Additionally, Table B-3-10 recommends that the quantity of soil eaten by the animal (Qs) be assigned a default value of 0.5 kg/day.

The soil bioavailability factor (Bs) can be thought of as the ratio of bioconcentration factors for soil and vegetation. If the soil bioavailability factor is greater than 1, bioconcentration of a COPC occurs more readily from soil than from vegetation; if the factor is less than 1, the opposite is true. Table B-3-10 of the HHRAP recommends a default value of 1.0 for all COPCs due to the limited data available regarding this bioavailability factor. This default value has been used throughout this MPHRA.

The basis for the default value for the metabolism factor (MF) is discussed in the HHRAP (USEPA, 2005). The metabolism factor estimates the amount of COPC that remains in fat and muscle. Due to the lack of data to support the derivation of chemical-specific metabolism factors for individual COPCs, the HHRAP (USEPA, 2005) recommends a default value of 1.0 for the metabolism factor for all COPCs identified at the PCAPP. This default value has been used throughout this MPHRA.

D.6.2 Concentration in Pork

Chemical concentrations in pork tissue due to ingestion of silage, grain, and soil by pigs and hogs were calculated using the equation presented in Table B-3-12 of the HHRAP (USEPA, 2005) and below:

$$A_{pork} = \left(\sum_i (F_i \cdot Qp_i \cdot P_{total,i}) + Qs \cdot Cs \cdot Bs \right) \cdot Ba_{pork} \cdot MF \quad \text{Eq. D-32}$$

where

A_{pork}	=	concentration of chemical in pork tissue (mg/kg)
F_i	=	fraction of plant type i grown on contaminated soil (1.0 dimensionless), (default value)
Qp_i	=	animal consumption rate of plant type i (kg plant tissue/day), (1.4 and 3.3 kg/day for silage and grain, respectively), (default values)
$P_{total,i}$	=	total concentration of chemical in plant type i (mg/kg), (the sum of the results of Eq. D-27, D-28, and D-29, for silage and grain)
Qs	=	animal consumption rate of soil (0.37 kg soil/day), (default value)
Cs	=	chemical concentration in soil (mg/kg), (calculated by Eq. D-6a or b, or Eq. D-7),
Ba_{pork}	=	biotransfer factor for pork (day/kg), (chemical-specific value)
Bs	=	soil bioavailability factor (1.0 dimensionless), (default value)
MF	=	metabolism factor (1.0 dimensionless), (default value)

The HHRAP (USEPA, 2005) recommends using swine consumption rates of 1.4 kg/day of silage and 3.3 kg/day of grain. These values are based on a total daily consumption rate for swine of 4.7 kg/day and assuming that 70 percent of the swine diet is grain and 30 percent silage. Additionally, the quantity of soil eaten by pigs is recommended as a default value of 0.37 kg/day.

D.6.3 Concentration in Dairy Milk

Chemical concentrations in dairy milk due to ingestion of forage, silage, grain, and soil by dairy cows were calculated using the equation presented in Table B-3-11 of the HHRAP (USEPA, 2005) and below:

$$A_{milk} = \left(\sum_i (F_i \cdot Qp_i \cdot P_{total,i}) + Qs \cdot Cs \cdot Bs \right) \cdot Ba_{milk} \cdot MF \quad \text{Eq. D-33}$$

where

A_{milk}	=	concentration of chemical in dairy milk (mg/kg)
F_i	=	fraction of plant type i grown on contaminated soil (1.0 dimensionless) (default value)
Qp_i	=	animal consumption rate of plant type i (kg plant tissue/day), (13.2, 4.1, and 3.0 kg/day for forage, silage, and grain, respectively), (default values)

$P_{total,i}$	=	total concentration of chemical in the plant type i (mg/kg), (the sum of the results of Eq. D-27, D-28, and D-29, for forage, silage, and grain)
Q_s	=	animal consumption rate of soil (0.4 kg soil/day), (default value)
C_s	=	chemical concentration in soil (mg/kg), (calculated by Eq. D-6a or b, or Eq. D-7)
Ba_{milk}	=	biotransfer factor for milk (day/kg), (chemical-specific value)
B_s	=	soil bioavailability factor (1.0 dimensionless), (default value)
MF	=	metabolism factor (1.0 dimensionless), (default value)

The HHRAP (USEPA, 2005) recommends using dairy cattle consumption rates of forage, silage, and grain as 13.2, 4.1, and 3.0 kg/day, respectively. These values are based on a total daily consumption rate for dairy cattle of 20 kg/day. Additionally, the quantity of soil eaten by dairy cattle is recommended as a default value of 0.4 kg/day.

D.6.4 Concentration in Fish

Chemical concentrations in fish tissue are the result of several uptake mechanisms, including bioconcentration of dissolved chemicals from surface water and bioaccumulation of dissolved and suspended chemicals from surface water. The bioconcentration factor is used for chemicals with a log K_{ow} less than 4.0, where K_{ow} is the octanol/water partitioning coefficient. Chemicals with a log K_{ow} greater than 4.0 have a high tendency to bioaccumulate; therefore, the bioaccumulation factor is used for chemicals with a log K_{ow} greater than 4.0. Chemical concentrations of dissolved and suspended chemicals in surface water were calculated at the location of the maximum chemical uptake at nearby Thatcher Reservoir which is north of PCD. The fish tissue concentration for each COPC was calculated based on the uptake mechanism associated with the COPC.

D.6.4.1 Fish Concentration from Bioconcentration

Dissolved water concentrations of COPCs were used to calculate the uptake of COPCs through bioconcentration. The bioconcentration factor for fish (BCF_{fish}) is the ratio of COPC concentration in fish to the COPC concentration in the water column where the fish is exposed, and it accounts for uptake of COPCs by fish from water flowing across the gills. For COPCs with a log K_{ow} of less than 4.0, most of the contaminant is associated with the dissolved phase of the water column and a negligible amount is associated with the suspended sediment phase in the water column. Therefore, for COPCs with a log K_{ow} of less than 4.0, BCF_{fish} values were used to calculate the fish tissue concentrations resulting from bioconcentration of COPCs dissolved in surface water using the equation presented in Table B-4-26 of the HHRAP (USEPA, 2005) and below:

$$C_{fish} = C_{dw} \cdot BCF_{fish} \quad \text{Eq. D-34}$$

where

C_{fish}	=	chemical concentration in fish (mg/kg)
C_{dw}	=	dissolved water concentration (mg/l), (calculated by Eq. D-26)
BCF_{fish}	=	bioconcentration factor (l/kg), (chemical-specific value)

D.6.4.2 Fish Concentration from Bioaccumulation

Chemical concentrations in fish tissue are the result of bioaccumulation of COPCs from the total water column. The bioaccumulation factor for fish (BAF_{fish}) is the ratio of the COPC concentration in fish to the contaminant concentration in the water body where the fish are exposed, and it accounts for uptake of contaminants by fish from water and sediments passing across the gills and consumption of various contaminated foods. For COPCs with a log K_{ow} of greater than 4.0, contaminants can significantly partition into the suspended sediment organic carbon of the water column. Therefore, for COPCs with a log K_{ow} greater than 4.0, BAF_{fish} values were used to calculate the fish tissue concentrations resulting from bioaccumulation of COPCs from the total (dissolved and suspended) water column concentration. However, the BAF_{fish} presented in the Companion Database for the HHRAP (USEPA, 2005) was adjusted to include only the dissolved water column fraction. Therefore, the formula presented in Table B-4-27 of the HHRAP (USEPA, 2005) to calculate the fish tissue concentration from bioaccumulation uses the dissolved water concentration, as presented below:

$$C_{fish} = C_{dw} \cdot BAF_{fish} \quad \text{Eq. D-35}$$

where

C_{fish}	=	chemical concentration in fish (mg/kg)
C_{dw}	=	dissolved water concentration (mg/l), (calculated by Eq. D-26)
BAF_{fish}	=	bioaccumulation factor (l/kg), (chemical-specific value)

D.6.5 Concentration in Chicken Meat and Chicken Eggs

Exposure of each receptor to COPCs in chicken meat and eggs was based on uptake of COPCs by chickens from soil and grain. The COPC concentrations in the meat of chickens were calculated using the equation presented in Table B-3-14 of the HHRAP (USEPA, 2005) and below:

$$A_{chick} = ((F \cdot Qp \cdot P_{total}) + Qs \cdot Cs \cdot Bs) \cdot Ba_{chick} \quad \text{Eq. D-36}$$

where

A_{chick}	=	concentration of chemical in chicken meat (mg/kg)
F	=	fraction of grain grown on contaminated soil (1.0 dimensionless), (default value)
Qp	=	animal consumption rate of grain (0.2 kg plant tissue/day), (default value)
P_{total}	=	total concentration of chemical in grain (mg/kg), (calculated by Eq. D-29)
Qs	=	animal consumption rate of soil (0.022 kg soil/day), (default value)
Cs	=	chemical concentration in soil (mg/kg), (calculated by Eq. D-6a or b, or Eq. D-7)
Ba_{chick}	=	biotransfer factor for chicken (day/kg), (chemical-specific value)
Bs	=	soil bioavailability factor (1.0 dimensionless), (default value)

The HHRAP (USEPA, 2005) recommends default values of 0.2 kg plant tissue/day and 0.022 kg/day for the quantity of grain eaten by chickens (Qp) and the quantity of soil ingested by the animal (Qs), respectively.

The COPC concentrations in chicken eggs were calculated using the equation presented in Table B-3-13 of the HHRAP (USEPA, 2005) and below:

$$A_{egg} = ((F \cdot Qp \cdot P_{total}) + Qs \cdot Cs \cdot Bs) \cdot Ba_{egg} \quad \text{Eq. D-37}$$

where

A_{egg}	=	chemical concentration in chicken eggs (mg/kg)
F	=	fraction of grain grown on contaminated soil (1.0 dimensionless), (default value)
Qp	=	animal consumption rate of grain (0.2 kg plant tissue/day) (default value)
P_{total}	=	total chemical concentration in grain (mg/kg), (calculated by Eq. D-29)
Qs	=	animal consumption rate of soil (0.022 kg soil/day), (default value)
Cs	=	chemical concentration in soil (mg/kg), (calculated by Eq. D-6a or b, or Eq. D-7)
Ba_{egg}	=	biotransfer factor for eggs (day/kg), (chemical-specific value)
Bs	=	soil bioavailability factor (1.0 dimensionless), (default value)

D.7 COPC CONCENTRATIONS IN BREAST MILK

The National Center for Environmental Assessment (NCEA) report (USEPA, 1998) describing the breast milk pathway includes three groups of chemicals which may be found in breast milk: lipophilic compounds (i.e., dioxins and polychlorinated biphenyls [PCBs]), organic chemicals with low octanol/water partitioning coefficients, and inorganic (metallic or organometallic) compounds. COPC emissions produced by the PCAPP design do not include any chemicals that fall into the lipophilic class of compounds. COPC concentrations for the other groups of chemicals in breast milk were calculated for COPCs with available toxicity data that were identified in literature (USEPA, 1998; Agency for Toxic Substances and Disease Registry [ATSDR] Toxicological Profiles, 2007; and Byczkowski et al., 1994) as inorganic chemicals or organic chemicals with low octanol/water partitioning coefficients that may be found in the aqueous or lipid phase of breast milk. Concentrations of these COPCs were calculated in both the aqueous and lipid portions of breast milk using Equations 9-2 and 9-10 in the NCEA report (USEPA, 1998). These calculations were performed using the equations noted above and modified (for consistency with parameter names used in the HHRAP) as shown below:

$$C_{milkfat} = \frac{m \cdot h \cdot f_1}{0.693 \cdot f_2} \quad \text{Eq. D-38a}$$

$$C_{aqueous} = \frac{m \cdot h \cdot f_{pl} \cdot Pc_{bm}}{0.693 \cdot f_{pm}} \quad \text{Eq. D-38b}$$

where

$C_{milkfat}$	=	concentration of chemical in maternal breast milk fat (mg/kg of milk fat)
m	=	average maternal intake of chemical (mg/kg of body weight-day), (exposure scenario-specific value) (calculated by Eq. D-38c)
h	=	half-life of chemical in adults (days) (chemical-specific value)
f_1	=	fraction of ingested chemical that is stored in fat (dimensionless) (chemical-specific value)

f_2	=	fraction of mother's weight that is fat (0.3 dimensionless), (default value)
0.693	=	ln 2
$C_{aqueous}$	=	concentration of chemical in maternal breast milk aqueous phase (mg/kg of aqueous milk)
f_{pl}	=	fraction of ingested chemical that is stored in the blood plasma (dimensionless), (chemical-specific value)
f_{pm}	=	proportion of mother's weight that is blood plasma (0.046 dimensionless), (default value)
$P_{C_{bm}}$	=	partition coefficient for chemical between plasma and breast milk aqueous phase (1 dimensionless), (default value)

The average maternal intake of a chemical (m) was calculated for an adult corresponding to each infant exposure scenario. Total daily intake is the sum of direct intake (via inhalation) and indirect intake (via ingestion and dermal contact) and is calculated using Equation D-38c as follows:

$$m = \frac{EC \cdot 0.001 \cdot IR \cdot 24}{BW} + I_{indirect} \quad \text{Eq. D-38c}$$

where:

m	=	average maternal intake of chemical (mg/kg of body weight-day), (exposure scenario-specific value)
EC	=	inhalation exposure concentration of chemical ($\mu\text{g}/\text{m}^3$) (calculated by Eq. D-39)
0.001	=	unit conversion factor ($\mu\text{g}/\text{mg}$)
IR	=	inhalation rate (m^3/hr) (exposure scenario-specific value)
24	=	unit conversion factor (hours/day)
BW	=	body weight (kg), (exposure scenario-specific value)
$I_{indirect}$	=	total indirect exposure (mg/kg of body weight-day) (calculated by Eq. D-56)

When selecting the half-life of a chemical in adults (h), the preferred value is one that is reported as the chemical half-life in the whole body or fat, in this order. These values are generally not available in literature. A limited literature search indicated that the half-life of benzene, toluene, and xylenes ranged from approximately 1 hour to 5 days (ATSDR; 2000, 2007b, 2007c). These values represented the upper range of half-life values for the majority of non-lipophilic organic compounds. A longer half-life leads to a greater breast milk concentration. Therefore, as a conservative assumption, a half-life of 5 days was used for all non-lipophilic organic COPCs for which the breast milk pathway was evaluated. A limited literature review conducted by Colorado Department of Public Health and Environment (CDPHE) indicated that, of the metal COPCs (i.e., aluminum, arsenic, cadmium, copper, lead and silver), whole-body half-life values in adults are available only for cadmium (26 years) and arsenic (44 days). Per direction of CDPHE, the 26-year half-life of cadmium was used as the default half-life for all metal COPCs without a specific value. The published 44-day half-life was used for arsenic.

The NCEA report (USEPA, 1998) suggests that the proportion of ingested chemicals stored in maternal fat (f_1) can be greater than 90 percent. For these calculations, contaminants were assumed to partition into either maternal fat or maternal blood plasma (i.e., the sum of the two partition fractions is 1.0). No data were found regarding the partitioning of individual chemicals

evaluated in this MPHRA into either compartment. Therefore, a conservative value of 0.5 (50 percent) was used for f_1 in calculations involving organic compounds; at the direction of CDPHE, a value of 0.1 (10 percent) was used for f_1 in calculations involving metal COPCs. The fraction of ingested COPC stored in maternal blood plasma (f_{pl}) was 0.5 (50 percent) for calculations involving organic compounds, and 0.9 (90 percent) in calculations involving metal COPCs.

Default values obtained from NCEA (USEPA, 1998) were used for the remaining variables (f_2 , f_{pm} , PC_{bm}) used in the breast milk concentration calculations.

D.8 DIRECT EXPOSURE THROUGH INHALATION

Direct exposure by each human receptor through inhalation was calculated using Equation 6 of *Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment)* (RAGS, Part F) (USEPA, 2009). The inhalation exposure concentrations are time-weighted average concentrations derived from the modeled contaminant concentrations in air and adjusted based on the characteristics of the exposure scenario being evaluated. The inhalation exposure concentration of each COPC for each human receptor was calculated using the equation presented below:

$$EC = \frac{Q \cdot [F_v \cdot Cyv + (1 - F_v) \cdot Cyp] \cdot ET \cdot EF \cdot ED}{AT \cdot 365 \cdot 24} \quad \text{Eq. D-39}$$

where

EC	= chemical-specific inhalation exposure concentration ($\mu\text{g}/\text{m}^3$)
Q	= stack emission rate (g/s), (chemical-specific value)
F_v	= fraction of air concentration in vapor phase (dimensionless), (chemical-specific value)
Cyv	= normalized vapor phase air concentration ($\mu\text{g}/\text{m}^3$ per g/s), (modeled value)
Cyp	= normalized particle phase air concentration ($\mu\text{g}/\text{m}^3$ per g/s), (modeled value)
ET	= exposure time (hr/day), (exposure scenario-specific value)
EF	= exposure frequency (days/yr), (exposure scenario-specific value)
ED	= exposure duration (yr), (exposure scenario-specific value)
AT	= averaging time (yr), (exposure scenario-specific value)
365	= unit conversion factor (days/yr)
24	= unit conversion factor (hours/day)

The individual's exposure time (ET), exposure frequency (EF), exposure duration (ED), and averaging time (AT) are all exposure scenario-specific values.

The direct exposure durations used in these calculations are 5 years for all adult and child exposure scenarios and 1 year for all infant exposure scenarios.

The averaging time used in this calculation depends on whether potential carcinogenic health effects or potential noncarcinogenic health hazards of a COPC are being evaluated. When evaluating the potential carcinogenic health effects, the averaging time was set equal to an individual's lifetime (i.e., 78 years) for all scenarios. Therefore, when calculating the cancer risk

for either of the lifetime exposure scenarios, the portion of risk accumulated during each period of life is summed for the total lifetime risk.

When evaluating potential noncarcinogenic health hazards, the averaging time was an exposure scenario-specific value due to the fact that subsequent hazard evaluations are based on a threshold dose rather than a lifetime cumulative exposure. Therefore, when calculating the noncarcinogenic health hazards for either of the lifetime exposure scenarios, the averaging time is the sum of the exposure durations for the individual life stages.

D.9 INDIRECT EXPOSURES

D.9.1 COPC Intake through Ingestion

Ingestion of COPCs occurs through the following ingestion pathways:

- incidental soil ingestion
- consumption of contaminated locally grown produce
- consumption of contaminated locally raised animal products
- incidental surface water ingestion while swimming
- consumption of breast milk (for infant exposure scenarios, only)

D.9.1.1 Incidental Soil Ingestion

Incidental ingestion of soil was calculated based on the maximum soil concentration at any receptor location (as previously discussed in Section D.2). The equation used to calculate daily intake of COPCs through incidental ingestion of soil is described in Table C-1-1 of the HHRAP (USEPA, 2005) and below:

$$I_{soil} = C_s \cdot CR_{soil} \cdot F_{soil} \quad \text{Eq. D-40}$$

where

I_{soil}	=	daily intake of chemical from soil (mg/day)
C_s	=	chemical concentration in soil (mg/kg), (calculated by Eq. D-6a, b, or D-7)
CR_{soil}	=	consumption rate of soil (kg/day), (exposure scenario-specific value)
F_{soil}	=	fraction of consumed soil that is contaminated (dimensionless), (exposure scenario-specific value)

The consumption rate of soil (CR_{soil}) is an exposure scenario-specific value. The fraction of consumed soil that is contaminated (F_{soil}) is also an exposure scenario-specific value that has been assigned a value of 1 for all exposure scenarios.

D.9.1.2 Ingestion of Fruits and Vegetables

Another possible route of COPC ingestion is through the consumption of locally-grown produce that has been impacted by COPC emissions from the PCAPP or EDS. As discussed in Section D.4, daily intake of COPCs via ingestion of fruits and vegetables was calculated based on the maximum soil concentration at any receptor location for all exposure scenarios except the adult worker. The equation used to calculate daily intake of COPCs through ingestion of fruits and vegetables is described in Table C-1-2 of the HHRAP (USEPA, 2005) and below:

$$I_{ag} = [((Pd + Pv + Pr) \cdot CR_{ag} + (Pr \cdot CR_{pp})) \cdot F_{ag} + (Pr_{bg} \cdot CR_{bg}) \cdot F_{bg}] \quad \text{Eq. D-41}$$

where

I_{ag}	=	daily intake of chemical from fruits and vegetables (mg/day)
Pd	=	chemical concentration in above-ground (exposed) fruits and vegetables due to direct deposition (mg/kg), (calculated by Eq. D-27 for each exposure scenario)
Pv	=	chemical concentration in above-ground (exposed) fruits and vegetables due to air-to-plant transfer (mg/kg), (calculated by Eq. D-28 for each exposure scenario)
Pr	=	chemical concentration in above-ground (exposed and protected) fruits and vegetables due to root uptake (mg/kg), (calculated by Eq. D-29 for each exposure scenario)
Pr_{bg}	=	chemical concentration in below-ground vegetables due to root uptake (mg/kg), (calculated by Eq. D-30 for each exposure scenario)
CR_{ag}	=	consumption rate of above-ground exposed fruits and vegetables (kg/day) (exposure scenario-specific value)
CR_{pp}	=	consumption rate of above-ground protected fruits and vegetables (kg/day) (exposure scenario-specific value)
F_{ag}	=	fraction of above-ground fruits and vegetables that is contaminated (dimensionless) (exposure scenario-specific value)
CR_{bg}	=	consumption of below-ground vegetables (kg/day) (exposure scenario-specific value)
F_{bg}	=	fraction of below-ground vegetables that is contaminated (dimensionless) (exposure scenario-specific value)

The consumption rates of above-ground exposed, above-ground protected, and below-ground produce (CR_{ag} , CR_{pp} , and CR_{bg} , respectively) and the fractions of above-ground and below-ground fruits and vegetables that are contaminated (F_{ag} and F_{bg} , respectively) are values that are specific to each exposure scenario.

D.9.1.3 Ingestion of Beef

As previously discussed in Section D.6.1, ingestion of COPCs through consumption of contaminated beef is an ingestion pathway for all exposure scenarios except for the adult worker. The daily intake of COPCs through ingestion of contaminated beef was calculated for these exposure scenarios based on the maximum soil concentration at any receptor location. The equation used to calculate daily intake of COPCs by ingestion of beef is described in Table C-1-3 of the HHRAP (USEPA, 2005) and below:

$$I_{beef} = A_{beef} \cdot CR_{beef} \cdot F_{beef} \quad \text{Eq. D-42}$$

where

I_{beef}	=	daily intake of chemical from beef (mg/day)
A_{beef}	=	concentration of chemical in beef tissue (mg/kg), (calculated by Eq. D-31)
CR_{beef}	=	consumption rate of beef (kg/day) (exposure scenario-specific value)

F_{beef} = fraction of consumed beef that is contaminated (dimensionless)
(exposure scenario-specific value)

The consumption rate of beef and the fraction of consumed beef that is contaminated (CR_{beef} and F_{beef} , respectively) are values that are specific to each exposure scenario.

D.9.1.4 Ingestion of Pork

Consumption of contaminated pork is an ingestion pathway for all exposure scenarios except the adult worker. The daily intake of COPCs through ingestion of contaminated pork was calculated based on the maximum soil concentration at any receptor location for these exposure scenarios using the equation described in Table C-1-3 of the HHRAP (USEPA, 2005) and below:

$$I_{pork} = A_{pork} \cdot CR_{pork} \cdot F_{pork} \quad \text{Eq. D-43}$$

where

I_{pork} = daily intake of chemical from pork (mg/day)
 A_{pork} = concentration of chemical in pork tissue (mg/kg), (calculated by Eq. D-32)
 CR_{pork} = consumption rate of pork (kg/day), (exposure scenario-specific value)
 F_{pork} = fraction of consumed pork that is contaminated (dimensionless), (exposure scenario-specific value)

The consumption rate of pork and the fraction of consumed pork that is contaminated (CR_{pork} and F_{pork} , respectively) are values that are specific to each exposure scenario.

D.9.1.5 Ingestion of Dairy Milk

All exposure scenarios, with the exception of the adult worker, ingest COPCs through the consumption of contaminated dairy milk. The daily intake of COPCs through this ingestion pathway was calculated for these exposure scenarios based on the dairy milk concentration calculated from the maximum soil concentration at any receptor location. The equation used to calculate daily intake of COPCs by ingestion of dairy milk is described in Table C-1-3 of the HHRAP (USEPA, 2005) and below:

$$I_{milk} = A_{milk} \cdot CR_{milk} \cdot F_{milk} \quad \text{Eq. D-44}$$

where

I_{milk} = daily intake of chemical from dairy milk (mg/day)
 A_{milk} = concentration of chemical in dairy milk (mg/kg), (calculated by Eq. D-33)
 CR_{milk} = consumption rate of dairy milk (kg/day), (exposure scenario-specific value)
 F_{milk} = fraction of consumed milk that is contaminated (dimensionless), (exposure scenario-specific value)

The consumption rate of dairy milk and the fraction of consumed milk that is contaminated (CR_{milk} and F_{milk} , respectively) are values that are specific to each exposure scenario.

D.9.1.6 Ingestion of Fish

The daily intake of COPCs through ingestion of contaminated fish was calculated for all exposure scenarios except for the adult worker. The equation used to calculate intake through ingestion of fish is described in Table C-1-4 of the HHRAP (USEPA, 2005) and below:

$$I_{fish} = C_{fish} \cdot CR_{fish} \cdot F_{fish} \quad \text{Eq. D-45}$$

where

I_{fish}	=	daily intake of chemical from fish (mg/day)
C_{fish}	=	chemical concentration in fish (mg/kg), (calculated by Eq. D-34 or D-35, as appropriate)
CR_{fish}	=	consumption rate of fish (kg/day), (exposure scenario-specific value)
F_{fish}	=	fraction of consumed fish that is contaminated (dimensionless), (exposure scenario-specific value)

The consumption rate of fish and the fraction of fish that is contaminated (CR_{fish} and F_{fish} , respectively) are values that are specific to each of the exposure scenarios.

D.9.1.7 Ingestion of Chicken and Chicken Eggs

The daily intake of COPCs through ingestion of contaminated chicken and eggs was calculated for all exposure scenarios, with the exception of the adult worker. The equation used to calculate daily intake of COPCs by ingestion of eggs is described in Table C-1-3 of the HHRAP (USEPA, 2005) and below:

$$I_{egg} = A_{egg} \cdot CR_{egg} \cdot F_{egg} \quad \text{Eq. D-46}$$

where

I_{egg}	=	daily intake of chemical from eggs (mg/day)
A_{egg}	=	concentration of chemical in eggs (mg/kg), (calculated by Eq. D-37)
CR_{egg}	=	consumption rate of eggs (kg/day), (exposure scenario-specific value)
F_{egg}	=	fraction of consumed eggs that is contaminated (dimensionless), (exposure scenario-specific value)

The equation used to calculate daily intake of COPCs through ingestion of chicken meat is described in Table C-1-3 of the HHRAP (USEPA, 2005) and below:

$$I_{chick} = A_{chick} \cdot CR_{chick} \cdot F_{chick} \quad \text{Eq. D-47}$$

where

I_{chick}	=	daily intake of chemical from ingested chicken meat (mg/day)
A_{chick}	=	concentration of chemical in chicken meat (mg/kg), (calculated by Eq. D-36)
CR_{chick}	=	consumption rate of chicken (kg/day), (exposure scenario-specific value)
F_{chick}	=	fraction of consumed chicken that is contaminated (dimensionless), (exposure scenario-specific value)

The consumption rate of chicken and eggs and the fraction of chicken and eggs that are contaminated (CR_{egg} , CR_{chick} , F_{egg} , and F_{chick} , respectively) are values that are specific to each exposure scenario.

D.9.1.8 Incidental Ingestion of Surface Water

Daily intake of COPCs from incidental ingestion of surface water from recreational swimming in local water bodies was calculated for the adult and child resident, fisher, and farmer receptors. The equation used to calculate incidental ingestion of surface water is a modification of the equation described in Table C-1-5 of the HHRAP (USEPA, 2005) and is presented below:

$$I_{sw} = \frac{C_{wctot} \cdot CR_{sw} \cdot F_{sw} \cdot EF}{1000 \cdot 365} \quad \text{Eq. D-48}$$

where

I_{sw}	=	daily intake of chemical from incidental ingestion of surface water (mg/day)
C_{wctot}	=	total chemical concentration in water column (mg/l), (calculated by Eq. D-25 for each exposure scenario)
CR_{sw}	=	rate of consumption of surface water (ml/hr), (exposure scenario-specific value)
F_{sw}	=	swimming frequency (3 hr/day), (site-specific value)
EF	=	exposure frequency (12 days/yr), (site-specific value)
365	=	conversion factor (days/yr)
1000	=	conversion factor (ml/l)

The consumption rate of surface water and swimming frequency (CR_{sw} and F_{sw} , respectively) are values that are specific to each of the exposure scenarios.

The swimming frequency (F_{sw}), exposure frequency (EF), and exposure duration (ED) are site-specific values that have been obtained from communication with local residents.

D.9.1.9 Ingestion of Breast Milk

The daily intake of bioaccumulative COPCs via ingestion of breast milk by infants was calculated for the infant exposure scenarios. The equation used to calculate daily intake of bioaccumulative COPCs through ingestion of breast milk is described by the NCEA (1998) and modified (to be consistent with parameters used in the HHRAP (USEPA, 2005) below:

$$I_{bm} = \frac{(C_{milkfat} \cdot f_3 + C_{aqueous} \cdot (1 - f_3)) \cdot f_4 \cdot IR_{milk} \cdot ED}{AT} \quad \text{Eq. D-49}$$

where

I_{bm}	=	daily intake of chemical from breast milk (mg/day)
$C_{milkfat}$	=	concentration of chemical in maternal breast milk fat (mg/kg), (calculated by Eq. D-38a)
$C_{aqueous}$	=	concentration of chemical in maternal breast milk aqueous phase (mg/kg of aqueous milk), (calculated by Eq. D-38b)

f_3	=	fraction of fat in breast milk (0.04 dimensionless), (default value)
f_4	=	fraction of chemical which is absorbed (dimensionless) (chemical-specific value)
IR_{milk}	=	ingestion rate of breast milk (0.98 kg/day), (exposure scenario-specific value)
ED	=	exposure duration (1 yr), (exposure scenario-specific value)
AT	=	averaging time (1 yr), (exposure scenario-specific value)

The fraction of ingested contaminant that is absorbed (f_4) has been established for dioxin and dioxin-like PCBs as 0.9. However, for non-lipophilic compounds, all of the ingested contaminant is assumed to be absorbed (i.e., $f_4 = 1.0$). The fraction of fat in breast milk (f_3) is a default value of 0.04 (USEPA, 1998).

D.9.1.10 Cumulative Daily Intake through Ingestion

The total daily intake of COPCs via ingestion pathways, as described in Table C-1-6 of the HHRAP (USEPA, 2005), is the summation of all indirect daily intake rates calculated from Equations D-40 through D-49 as provided below:

$$I_{total} = I_{soil} + I_{ag} + I_{beef} + I_{pork} + I_{milk} + I_{fish} + I_{egg} + I_{chick} + I_{sw} + I_{bm} \quad \text{Eq. D-50}$$

where

I_{total}	=	total daily intake of chemical through ingestion (mg/day)
I_{soil}	=	daily intake of chemical from soil (mg/day), (calculated by Eq. D-40)
I_{ag}	=	daily intake of chemical from fruits and vegetables (mg/day), (calculated by Eq. D-41)
I_{beef}	=	daily intake of chemical from beef (mg/day), (calculated by Eq. D-42)
I_{pork}	=	daily intake of chemical from pork (mg/day), (calculated by Eq. D-43)
I_{milk}	=	daily intake of chemical from dairy milk (mg/day), (calculated by Eq. D-44)
I_{fish}	=	daily intake of chemical from fish (mg/day), (calculated by Eq. D-45)
I_{egg}	=	daily intake of chemical from eggs (mg/day), (calculated by Eq. D-46)
I_{chick}	=	daily intake of chemical from chicken meat (mg/day), (calculated by Eq. D-47)
I_{sw}	=	daily intake of chemical from incidental ingestion of surface water (mg/day), (calculated by Eq. D-48)
I_{bm}	=	daily intake of chemical from breast milk (mg/day), (calculated by Eq. D-49)

Daily intake rates from exposure pathways that are not evaluated in a respective exposure scenario have been assumed to be zero when calculating the total daily COPC intake. For example, the exposure pathways for the infant receptor do not include incidental ingestion of surface water; therefore, the daily COPC intake from incidental ingestion of surface water in the infant exposure scenarios is zero.

D.9.1.11 Average Daily Ingestion Dose

The average daily ingestion dose is the mass of pollutant ingested per body weight averaged over the exposure duration. The conversion of intake to average daily ingestion dose is

required in order to directly use available toxicity data. The average daily dose was calculated using the equation presented below:

$$I_{ingested} = \frac{I_{total} \cdot EF \cdot ED}{BW \cdot AT \cdot 365} \quad \text{Eq. D-51}$$

where

$I_{ingested}$	=	average daily ingestion dose (exposure scenario-specific value; mg/kg of body weight-day)
I_{total}	=	total daily intake of chemical through ingestion (mg/day), (exposure scenario-specific value; calculated by Eq. D-50)
EF	=	exposure frequency (day/yr), (exposure scenario-specific value)
ED	=	exposure duration (yr), (exposure scenario-specific value)
BW	=	body weight (kg), (exposure scenario-specific value)
AT	=	averaging time (yr), (exposure scenario-specific value)
365	=	conversion factor (day/yr)

Exposure frequency (EF), exposure duration (ED), body weight (BW), and averaging time (AT) are all exposure scenario-specific values.

The exposure duration used in this calculation is the exposure duration for indirect exposures and has values of 30 years for the adult resident and subsistence fisher, 40 years for the adult subsistence farmer, 25 years for the adult worker, 5 years for child receptors, and 1 year for infant receptors.

The averaging time used in this calculation depends on whether potential carcinogenic health effects or potential noncarcinogenic health hazards of a COPC are being evaluated. When evaluating the potential carcinogenic health effects, the averaging time was set equal to an individual's lifetime (i.e., 78 years). Therefore, when calculating the cancer risk for either of the lifetime exposure scenarios, the portion of risk accumulated during each period of life is summed for the total lifetime risk.

When evaluating potential noncarcinogenic health hazards, the averaging time was an exposure scenario-specific value due to the fact that subsequent hazard evaluations are based on a threshold dose rather than a lifetime cumulative exposure. Therefore, when calculating the noncarcinogenic health hazards for either of the lifetime exposure scenarios, the averaging time is the sum of the exposure durations for the individual life stages.

D.9.2 COPC Intake through Dermal Absorption

D.9.2.1 COPC Intake through Dermal Absorption from Surface Water

Dermally Absorbed Dose per Event. The dermally absorbed dose per event represents the final absorbed dose dissolved in the skin at the end of COPC exposure during a swimming event. For organic compounds, the dermally absorbed dose per event is calculated using either Equation 3.2 or 3.3 of *Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)* (RAGS, Part E) (USEPA, 2004) depending on whether the duration of the swimming event is greater than or less than the amount of time required for the COPC to achieve steady-state transfer in the skin.

When the duration of the swimming event is less than or equal to the time required to achieve steady-state ($t_{event} \leq t^*$), the dermally absorbed dose per event was calculated using Equation 3.2 of RAGS, Part E (USEPA, 2004) and below:

$$DA_{event} = 2FA \cdot K_p \cdot C_{dw} \sqrt{\frac{6\tau_{event} \cdot t_{event}}{\pi}} \quad \text{Eq. D-52a}$$

where

DA_{event}	=	dermally absorbed dose per event (mg/cm ² -event)
FA	=	fraction absorbed water (dimensionless), (default value)
K_p	=	dermal permeability coefficient of chemical in water (cm/hr), (chemical-specific value)
C_{dw}	=	chemical concentration in the dissolved water phase (mg/cm ³), (calculated by Eq. D-26)
τ_{event}	=	lag time per event (hr/event), (chemical-specific value)
t_{event}	=	duration of the swimming event (hr/event), (site-specific value)

When the duration of the swimming event is greater than the time required to achieve steady-state ($t_{event} > t^*$), the dermally absorbed dose per event was calculated using Equation 3.3 of RAGS, Part E (USEPA, 2004) and below:

$$DA_{event} = FA \cdot K_p \cdot C_{dw} \left[\frac{t_{event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right] \quad \text{Eq. D-52b}$$

where

DA_{event}	=	dermally absorbed dose per event (mg/cm ² -event)
FA	=	fraction absorbed water (dimensionless), (default value)
K_p	=	dermal permeability coefficient of chemical in water (cm/hr), (chemical-specific value)
C_{dw}	=	chemical concentration in the dissolved water phase (mg/cm ³), (calculated by Eq. D-26)
t_{event}	=	duration of the swimming event (hr/event), (site-specific value)
τ_{event}	=	lag time per event (hr/event), (chemical-specific value)
B	=	dimensionless ratio of the permeability coefficient of the compound through the stratum corneum relative to its permeability across the viable epidermis (dimensionless), (chemical-specific value)

As a conservative assumption in this MPHRA, the fraction absorbed water (FA) is assigned a value of 1 and represents the assumption that no COPCs that have been dissolved into the skin are lost due to desquamation (shedding of the outer layers of skin) during the absorption period.

For inorganic compounds, the dermally absorbed dose per event was calculated using Equation 3.4 of RAGS, Part E (USEPA, 2004) and below:

$$DA_{event} = K_p \cdot C_{dw} \cdot t_{event} \quad \text{Eq. D-52c}$$

where

DA_{event}	=	dermally absorbed dose per event (mg/cm ² -event)
K_p	=	dermal permeability coefficient of chemical in water (cm/hr), (chemical-specific value)
C_{dw}	=	chemical concentration in the dissolved water phase (mg/cm ³), (calculated by Eq. D-26)
t_{event}	=	duration of the swimming event (hr/event), (site-specific value)

The COPC concentration in the dissolved water phase is calculated by Equation D-26 and has units of mg/l. Prior to using the COPC concentration in the dissolved water phase in Equation D-52a, D-52b, or D-52c, the concentration must be reduced by 1,000 to convert the units to milligrams per cubic centimeter (mg/cm³).

Dermal Absorbed Dose. Daily intake of COPCs via dermal uptake from surface water was calculated for the adult and child resident, fisher, and farmer receptors. The equation used to calculate daily dermal uptake is described in Equation 3.1 of RAGS, Part E (USEPA, 2004), and below:

$$DAD_{water} = \frac{DA_{event} \cdot EV \cdot ED \cdot EF \cdot SA}{BW \cdot AT \cdot 365} \quad \text{Eq. D-53}$$

where

DAD_{water}	=	dermal absorbed dose from water (mg/kg of body weight-day)
DA_{event}	=	dermally absorbed dose per event (mg/cm ² -event), (calculated by Eq. D-52a or Eq. D-52b)
SA	=	skin surface area available for contact (cm ²) (adult = 18,000; child = 6,600) (exposure scenario-specific value)
EV	=	event frequency (1 events/day) (site-specific value)
EF	=	exposure frequency (12 days/yr) (site-specific value)
ED	=	exposure duration (yr) (exposure scenario-specific value)
BW	=	body weight (kg) (exposure scenario-specific value)
AT	=	averaging time (yr) (exposure scenario-specific value)
365	=	conversion factor (day/yr)

The absorbed dose per event, DA_{event} , represents the absorbed dose per square centimeter of exposed skin occurring during a single water contact event, such as swimming.

D.9.2.2 COPC Intake through Dermal Absorption from Soil

Dermally Absorbed Dose per Event. The dermally absorbed dose per event represents the dose of COPC absorbed resulting from contact with COPC-containing soils. The dermally absorbed dose per event was calculated using Equation 3.12 of RAGS, Part E (USEPA, 2004) and below:

$$DA_{event} = Cs \cdot 10^{-6} \cdot AF \cdot ABS_d \quad \text{Eq. D-54}$$

where

- DA_{event} = dermally absorbed dose per event (mg/cm²-event)
- C_s = chemical concentration in soil (mg/kg), (calculated by Eq. D-6a, D-6b, or D-7)
- 10^{-6} = conversion factor (kg/mg)
- AF = soil adherence factor (mg/cm²-event), (exposure scenario-specific value)
- ABS_d = dermal absorption fraction (dimensionless), (chemical-specific value)

Dermal Absorbed Dose. Daily intake of COPCs via dermal uptake from soil was calculated for all receptors. The equation used to calculate daily dermal uptake is described in Equation 3.11 of RAGS Part E (USEPA, 2004), and below:

$$DAD_{soil} = \frac{DA_{event} \cdot EV \cdot ED \cdot EF \cdot SA}{BW \cdot AT \cdot 365} \quad \text{Eq. D-55}$$

where

- DAD_{soil} = dermal absorbed dose from soil (mg/kg of body weight-day)
- DA_{event} = dermally absorbed dose per event (mg/cm²-event), (calculated by Eq. D-54)
- SA = skin surface area available for contact (cm²) (adult non-worker = 5,700; adult worker = 3,300; child = 2,800; infant = 2,625) (exposure scenario-specific value)
- EV = event frequency (1 events/day) (site-specific value)
- EF = exposure frequency (350 days/yr) (site-specific value)
- ED = exposure duration (yr) (exposure scenario-specific value)
- BW = body weight (kg) (exposure scenario-specific value)
- AT = averaging time (yr) (exposure scenario-specific value)
- 365 = conversion factor (day/yr)

The absorbed dose per event, DA_{event} , represents the absorbed dose per square centimeter of exposed skin occurring during a single soil contact event.

D.9.3 Total Indirect COPC Exposure

The total indirect COPC exposure is the sum of the average daily ingestion dose and the COPC intake through dermal absorption and was calculated using the following equation:

$$I_{indirect} = I_{ingested} + DAD_{soil} + DAD_{water} \quad \text{Eq. D-56}$$

where

- $I_{indirect}$ = total indirect exposure (exposure scenario-specific value; mg/kg of body weight-day)
- $I_{ingested}$ = average daily ingestion dose (mg/kg of body weight-day), (exposure scenario-specific value; calculated by Eq. D-51)
- DAD_{soil} = dermal absorbed dose from soil (mg/kg of body weight-day), (exposure scenario-specific value; calculated by Eq. D-55)

$$DAD_{water} = \text{dermal absorbed dose from water (mg/kg of body weight-day),}$$

(exposure scenario-specific value; calculated by Eq. D-53)

D.10 CHARACTERIZATION OF CARCINOGENIC EFFECTS

Risks for COPCs that display carcinogenic effects were calculated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (i.e., excess individual lifetime cancer risk).

Researchers have calculated and published toxicity values for chemicals with evidence of being a known or probable human carcinogen. The toxicity value defines the quantitative relationship between the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to a chemical. For direct exposures, the value is expressed as an inhalation unit risk (IUR) that quantifies the risk of exposure to an ambient air concentration of $1 \mu\text{g}/\text{m}^3$. For indirect exposures, the value is expressed as an oral cancer slope factor (CSF_o). The IUR converts calculated long-term average exposure concentrations to the incremental risk of an individual developing cancer. Similarly, a CSF_o converts calculated lifetime average daily indirect intakes of a chemical to incremental risk of an individual developing cancer. A critical assumption of this approach is that the dose-response relationship is linear in the low-dose portion of the dose-response curve. Under this assumption, the CSF_o is a constant, and risk is directly related to intake. Thus, the linear form of the carcinogenic risk equation is usually applicable for estimating lifetime risks.

Lifetime cancer risk is calculated by summing cancer risks during different stages of life (i.e. infant, child, adult). Exposure durations during each phase of life must be added to obtain the total lifetime exposure duration. For example, the 40-year exposure duration for a farmer can be apportioned for the following three lifetime scenarios:

- 1 year as an infant, 5 years as a child, and 34 years as an adult (i.e., exposure begins at birth)
- 5 years as a child and 35 years as an adult (i.e., exposure begins at age 1)
- 40 years as an adult (i.e., exposure begins during adulthood)

Therefore, for the lifetime (I) and (II) exposure scenarios the cancer risk was summed across the different life stages as follows:

Lifetime (I) Scenario (with infant exposure):

- Cancer risk from direct exposure for all receptors included the infant exposure plus 4/5 child exposure
- Cancer risk from indirect exposure for resident and subsistence fisher receptors included the infant exposure plus child exposure plus 24/30 adult exposure
- Cancer risk from indirect exposure for subsistence farmer receptor included the infant exposure plus child exposure plus 34/40 adult exposure

Lifetime (II) Scenario (without infant exposure):

- Cancer risk from direct exposure for all receptors included the child exposure
- Cancer risk from indirect exposure for resident and subsistence fisher receptors included the child exposure plus 25/30 adult exposure
- Cancer risk from indirect exposure for subsistence farmer receptor included the child exposure plus 35/40 adult exposure

Colorado Hazardous Waste Regulations, Title 6 Code of Colorado Regulations [CHWR 6 CCR] 1007-3 264.342 (a)(1)(i) indicate that a site presents acceptable risk if the cumulative lifetime cancer risk to a potentially exposed human receptor is less than 1×10^{-6} .

D.10.1 Early-Life Exposure Considerations

Some chemicals present increased risk if exposure occurs early in life. For these mutagenic chemicals (vinyl chloride, methylene chloride, and trichloroethene are the only mutagenic COPCs in this MPHRA), modified calculation procedures must be used to account for additional risk due to early-life exposure. Two distinct procedures were used to evaluate early-life exposure to mutagenic COPCs. The first procedure was used only for early-life exposure to vinyl chloride and is the procedure recommended in *Toxicological Review of Vinyl Chloride in Support of Summary Information on the Integrated Risk Information System (IRIS)* (USEPA, 2000). The second procedure was used for early-life exposure to methylene chloride and trichloroethene and is the procedure described in *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* (USEPA, 2005a).

The procedure for vinyl chloride partitions risk into segments that are calculated separately and summed together to determine total risk. The early-life portion of the risk occurs due to exposure immediately after birth and is not pro-rated over the exposure duration. This early-life risk is summed with the pro-rated portions later in life to determine the total risk from exposure to vinyl chloride. Early-life exposure to vinyl chloride does not take exposure duration or averaging time into account. Early-life exposure to vinyl chloride was calculated using the following equations:

$$EC_{VC,earlylife} = \frac{Q \cdot [F_v \cdot Cyv + (1 - F_v) \cdot Cyp] \cdot ET \cdot EF}{365 \cdot 24} \quad \text{Eq. D-57a}$$

where

$EC_{VC,earlylife}$	=	additional early-life inhalation exposure concentration ($\mu\text{g}/\text{m}^3$)
Q	=	stack emission rate (g/s), (chemical-specific value)
F_v	=	fraction of air concentration in vapor phase (dimensionless), (chemical-specific value)
Cyv	=	normalized vapor phase air concentration ($\mu\text{g}/\text{m}^3$ per g/s), (modeled value)
Cyp	=	normalized particle phase air concentration ($\mu\text{g}/\text{m}^3$ per g/s), (modeled value)
ET	=	exposure time (hr/day), (exposure scenario-specific value)
EF	=	exposure frequency (day/yr), (365 day/yr for early-life portion)
365	=	unit conversion factor (day/yr)
24	=	unit conversion factor (hours/day)

Because the lifetime (l) receptor includes indirect exposure starting as an infant and continuing through childhood, the vinyl chloride early-life exposure of indirect pathways is calculated as the time-weighted average of infant and child exposures over the total early-life exposure period.

EPA guidance¹ does not specify the duration during which increased risk due to early-life exposure may occur, other than stating “*Because the exact age window of susceptibility in humans is not known, but is likely to be much shorter in duration than 10 years...*” To provide a conservative estimate of the increased risk to vinyl chloride for the lifetime (I) exposure scenario, the early-life exposure period was assumed to occur over the first 6 years of life to correspond to the infant and child exposure periods. As such, the early-life exposure for carcinogenic effects of vinyl chloride was calculated for indirect pathways for the infant and child, using Equation D-57b, which were then averaged over the total early-life exposure period (6 years) as discussed below.

$$I_{indirect(VC,earlylife)} = \sum \frac{I_i \cdot EF}{BW \cdot 365} + \sum \frac{DA_{eventj} \cdot EV \cdot EF_j \cdot SA_j}{BW \cdot 365} \quad \text{Eq. D-57b}$$

where

- $I_{indirect(VC,earlylife)}$ = additional early-life indirect exposure to vinyl chloride for infant or child (mg/kg of body weight-day)
- I_i = total daily intake of chemical through ingestion of media type i (i = produce, beef, pork, milk, egg, poultry, fish, soil, surface water, or breast milk), (mg/day), (calculated by Eq. D-40 through D-49)
- EF = exposure frequency for ingestion (day/yr), (365 day/yr for early-life portion)
- BW = body weight (kg), (exposure scenario-specific value)
- 365 = conversion factor (day/yr)
- DA_{eventj} = dermally absorbed dose per dermal contact event of type j (j = soil or water), (mg/cm²-event), (calculated by Eq. D-52a, D-52b, or D-54)
- SA_j = skin surface area available for dermal contact of type j (cm²), (exposure scenario-specific value)
- EV = event frequency for dermal contact of type j (events/day), (site-specific value)
- EF_j = exposure frequency for dermal contact of type j (day/yr), (365 day/yr for early-life portion)

Because the exposure frequency for ingestion and body weights do not change when calculating the $I_{indirect(earlylife)}$ for either the infant or the child, Equation D-57b can be reduced to:

$$I_{indirect(earlylife,infant/child)} = \frac{\sum I_i \cdot EF}{BW \cdot 365} + \frac{\left[(DA_{soil} \cdot SA_{soil} \cdot EF_{soil}) + (DA_{water} \cdot SA_{water} \cdot EF_{water}) \right] \cdot EV}{BW \cdot 365}$$

where

- $\sum I_i$ = total daily intake of vinyl chloride through ingestion (mg/day), (calculated by Eq. D-50)

¹ Toxicological Review of Vinyl Chloride in Support of Summary Information on the Integrated Risk Information System (IRIS) (USEPA, 2000).

EF	=	exposure frequency for ingestion (day/yr), (365 day/yr for early-life portion)
BW	=	body weight (kg), (exposure scenario-specific value)
365	=	conversion factor (day/yr)
DA_{soil}	=	dermally absorbed dose per dermal contact event of soil (mg/cm^2 -event), (exposure scenario-specific value)
SA_{soil}	=	skin surface area available for dermal contact with soil (cm^2), (exposure scenario-specific value)
EF_{soil}	=	exposure frequency for dermal contact with soil (site-specific value; 365 days/yr for soil)
DA_{water}	=	dermally absorbed dose per dermal contact event of water (exposure scenario-specific value), (calculated by Eq. D-52b)
SA_{water}	=	skin surface area available for dermal contact with water (cm^2), (exposure scenario-specific value)
EF_{water}	=	exposure frequency for dermal contact with water (site-specific value; 12 days/yr for water)

Individual ingestion rates and exposure parameters were used to estimate the $I_{indirect(earlylife,infant)}$ and $I_{indirect(earlylife,child)}$. For lifetime (I) exposure scenarios, the time-weighted average early-life exposure for the entire early-life exposure period (6 years) is calculated as:

$$I_{indirect(earlylife)} = \left(\frac{1}{6} \cdot I_{indirect(earlylife,infant)} + \frac{5}{6} \cdot I_{indirect(earlylife,child)} \right)$$

For lifetime (II) exposure scenarios, only $I_{indirect(earlylife,child)}$ is used. By using $I_{indirect(earlylife)}$ in this way, the risk calculated for each lifetime scenario accounts for the uncertainty associated with the exact age window of susceptibility by including exposures from birth as well as during young childhood (1 to 6 years of age).

Guidance related to the procedure used for early-life exposure to methylene chloride and trichloroethene recommends the use of age dependent adjustment factors (ADAFs) combined with age-specific exposure estimates when assessing cancer risks. The ADAFs used in this method are:

- For exposures before 2 years of age (i.e., spanning a 2-year time interval from the first day of birth until a child's second birthday, a 10-fold adjustment (ADAF = 10)
- For exposures between 2 and less than 16 years of age (i.e., spanning a 14-year time interval from the child's second birthday up until their sixteenth birthday), a 3-fold adjustment (ADAF = 3)
- For exposures after turning 16 years of age, no adjustment (ADAF = 1).

The following sections provide the original and modified equations used to calculate cancer risk from direct and indirect exposures to mutagenic chemicals.

D.10.2 Carcinogenic Effects from Direct Exposures

Cancer risk from direct exposure to (inhalation of) chemical emissions in air was calculated for COPCs with available inhalation unit risk factors. The cancer risk for each COPC with an available inhalation unit risk factor was calculated by multiplying the inhalation exposure

concentration by the inhalation unit risk factor as directed in Equation 11 of RAGS, Part F (USEPA, 2009) and presented below:

$$\text{Cancer Risk}_{D(\text{non-mutagen})} = EC \cdot IUR \quad \text{Eq. D-58}$$

where

Cancer Risk_D = excess lifetime cancer risk via inhalation (dimensionless)
 EC = inhalation exposure concentration of chemical ($\mu\text{g}/\text{m}^3$), (exposure scenario-specific concentration; calculated by Eq. D-39)
 IUR = inhalation unit risk ($[\mu\text{g}/\text{m}^3]^{-1}$), (chemical-specific value)

Vinyl Chloride

$$\text{Cancer Risk}_{D(\text{VC})} = (EC_{\text{VC,early life}} + EC) \cdot IUR \quad \text{Eq. D-58a}$$

where

$\text{Cancer Risk}_{D(\text{VC})}$ = excess lifetime cancer risk via inhalation of vinyl chloride (dimensionless)
 $EC_{\text{VC,early life}}$ = additional early-life inhalation exposure concentration of vinyl chloride ($\mu\text{g}/\text{m}^3$), (calculated by Eq. D-57a)
 EC = inhalation exposure concentration of vinyl chloride ($\mu\text{g}/\text{m}^3$), (exposure scenario-specific concentration; calculated by Eq. D-39)
 IUR = inhalation unit risk ($[\mu\text{g}/\text{m}^3]^{-1}$), (chemical-specific value)

Because the early-life portion of the risk occurs due to exposure immediately after birth, the term $EC_{\text{VC,early life}}$ is zero in the lifetime (II) scenarios.

Methylene chloride and Trichloroethene

$$\text{Cancer Risk}_{D(\text{ADAF mutagens})} = IUR \cdot EC \cdot ADAF \quad \text{Eq. D-58b}$$

where

$\text{Cancer Risk}_{D(\text{ADAF mutagens})}$ = excess lifetime cancer risk via inhalation of chemical (dimensionless)
 IUR = inhalation unit risk ($[\mu\text{g}/\text{m}^3]^{-1}$), (chemical-specific value)
 EC = inhalation exposure concentration of methylene chloride or trichloroethene ($\mu\text{g}/\text{m}^3$), (exposure scenario-specific concentration; calculated by Eq. D-39)
 $ADAF$ = age dependent adjustment factor for early-life exposure (dimensionless) (exposure scenario-specific value)

D.10.3 Carcinogenic Effects from Indirect Exposures

Cancer risk from indirect exposures to chemical contaminants was calculated for COPCs with available oral cancer slope factors. The lifetime cancer risk for each COPC with available oral cancer slope factors was calculated by multiplying the total indirect exposure by the oral cancer slope factor as presented below:

$$Cancer\ Risk_i = (I_{indirect}) \cdot CSF_O \quad \text{Eq. D-59}$$

where

$Cancer\ Risk_i$	= excess lifetime cancer risk from indirect exposures (dimensionless)
$I_{indirect}$	= indirect exposure to chemical (exposure scenario-specific value; mg/kg of body weight-day), (calculated by Eq. D-56)
CSF_O	= oral cancer slope factor for chemical ([mg/kg of body weight-day] ⁻¹) (chemical-specific value)

When calculating risk from dermal exposures to cadmium and nickel, Equation 4.2 of RAGS Part E (USEPA, 2004) applies an adjustment to the oral cancer slope factor for each of these chemicals by dividing them by the fraction of contaminant absorbed in the gastrointestinal tract (ABS_{GI}). This has the effect of adjusting the COPC oral cancer slope factor from an administered dose basis to an adsorbed dose basis. Cadmium and nickel are the only COPCs in this assessment with oral cancer slope factors for which RAGS Part E recommends that this adjustment be completed. The dimensionless ABS_{GI} used for cadmium and nickel are 0.025 and 0.04, respectively (note RAGS Part E identifies ABS_{GI} which are equal to 1.0 for all other COPCs with oral cancer slope factors in this assessment, thus indicating the adjustment is not required).

To apply the adjustment for cadmium and nickel, an intermediate step is completed prior to calculating risk according to Eq. D-59. This intermediate step entails dividing the dermal exposure (represented by the terms DAD_{soil} and DAD_{water} in Eq. D-56) for each exposure scenario by the COPC-specific ABS_{GI} . After this intermediate step is completed for all exposure scenarios, cancer risk from indirect exposure is then calculated as presented in Eq. D-59.

In addition to the adjustment for cadmium and nickel, Eq. D-59 is modified as follows for early-life exposure to mutagenic COPCs.

Vinyl chloride

$$Cancer\ Risk_{I(VC)} = (I_{indirect(VC,early\ life)} + I_{indirect}) \cdot CSF_O \quad \text{Eq. D-59a}$$

where

$Cancer\ Risk_{I(VC)}$	= excess lifetime cancer risk from indirect exposure to vinyl chloride (dimensionless)
$I_{indirect(VC,early\ life)}$	= additional early-life indirect exposure to vinyl chloride (mg/kg of body weight-day) (calculated by Eq. D-57b)
$I_{indirect}$	= indirect exposure to vinyl chloride (exposure scenario-specific value; mg/kg of body weight-day), (calculated by Eq. D-56)

CSF_o = oral cancer slope factor for vinyl chloride
([mg/kg of body weight-day]⁻¹) (chemical-specific value)

Because the early-life portion of the risk occurs due to exposure immediately after birth, the term $I_{indirect(VC,earlylife)}$ is zero in the lifetime (II) scenarios.

Methylene chloride and Trichloroethene

$$Cancer Risk_{I(ADAF\ mutagens)} = CSF_o \cdot I_{indirect} \cdot ADAF \quad \text{Eq. D-59b}$$

where

$Cancer Risk_{D(ADAF\ mutagens)}$ = excess lifetime cancer risk via indirect exposure to methylene chloride or trichloroethene (dimensionless)

CSF_o = oral cancer slope factor for chemical ([mg/kg of body weight-day]⁻¹) (chemical-specific value)

$I_{indirect}$ = indirect exposure to chemical (exposure scenario-specific value; mg/kg of body weight-day), (calculated by Eq. D-56)

$ADAF$ = age dependent adjustment factor for early-life exposure (dimensionless), (exposure scenario-specific value)

D.10.4 Cumulative Carcinogenic Risk Characterization

Total cancer risk from direct exposures was summed using the equation presented in Table 5.1.8 of *Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste* (USEPA, 1994) and also presented below:

$$Total\ Cancer\ Risk_D = \sum_{i=1}^n Cancer\ Risk_{D_i} \quad \text{Eq. D-60}$$

where

$Total\ Cancer\ Risk_D$ = total excess lifetime cancer risk from direct exposures (dimensionless)

$Cancer\ Risk_{D_i}$ = excess lifetime cancer risk via inhalation for chemical i (dimensionless), (calculated by Eq. D-58)

Total cancer risk from indirect exposures was summed using the same methodology as described above:

$$Total\ Cancer\ Risk_I = \sum_{i=1}^n Cancer\ Risk_{I_i} \quad \text{Eq. D-61}$$

where

$Total\ Cancer\ Risk_I$ = total excess lifetime cancer risk via indirect exposures (dimensionless)

$Cancer Risk_{ij}$ = excess lifetime cancer risk from indirect exposures for chemical i (dimensionless) (calculated by Eq. D-59)

Incremental cancer risk from all exposure pathways, both direct and indirect, was calculated using the equation presented on page C-5-59 of *Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste* (USEPA, 1994) and also presented below:

$$Overall\ Cancer\ Risk = Total\ Cancer\ Risk_D + Total\ Cancer\ Risk_I \quad Eq. D-62$$

where

$Overall\ Cancer\ Risk$ = overall excess lifetime cancer risk via all routes of exposure (dimensionless)

$Total\ Cancer\ Risk_D$ = total excess cancer risk via direct inhalation exposure (dimensionless) (calculated by Eq. D-60)

$Total\ Cancer\ Risk_I$ = total excess cancer risk via indirect exposures (dimensionless) (calculated by Eq. D-61)

D.11 CHARACTERIZATION OF NONCARCINOGENIC HEALTH EFFECTS

A chronic inhalation reference concentration (RfC) is an estimate of continuous inhalation exposure to a human population, including sensitive subpopulations, that is unlikely to cause an increase incidence of deleterious health effects during a lifetime. Similar to chronic RfC values, a chronic oral reference dose (RfD_o) is an estimate of the daily oral exposure to a human population, including sensitive subpopulations, that is unlikely to cause an increased incidence of deleterious health effects during a lifetime of exposure. Both chronic RfC and RfD_o values are specifically developed to be protective for long-term exposure to a chemical.

For chemicals with noncarcinogenic effects, the hazard quotient from direct exposures (HQ_D) is the exposure concentration divided by the RfC, and the hazard quotient from indirect exposure (HQ_I) is the indirect exposure divided by the RfD. The HQ assumes that there is a level of exposure (e.g., RfC and RfD_o) below which it is unlikely for even sensitive subpopulations to experience adverse health effects. The hazard index (HI, HI_I, or HI_D) is calculated as the summation of HQs for all COPCs that display a noncarcinogenic effect.

Unlike the infant, child, and adult exposure scenarios that include a single life stage, the noncarcinogenic hazard for lifetime (I) and (II) exposure scenarios is calculated as the exposure duration-weighted average during the different stages of life (i.e. infant, child, adult). Exposure durations during each phase of life must be weighted over the total lifetime exposure duration. For the lifetime (I) and (II) exposure scenarios this weighting was accomplished by the following:

Lifetime (I) Scenario:

- HQ_D for all receptors included 1/5 of the infant exposure plus 4/5 of the child exposure
- HQ_I for resident and subsistence fisher receptors included 1/30 of the infant exposure plus 5/30 of the child exposure plus 24/30 of the adult exposure
- HQ_I for subsistence farmer receptor included 1/40 of the infant exposure plus 5/40 of the child exposure plus 34/40 of the adult exposure

Lifetime (II) Scenario:

- HQ_D for all receptors is equal to the HQ_D from the child exposure
- HQ_I for resident and subsistence fisher receptors included 1/30 of the infant exposure plus 5/30 of the child exposure plus 24/30 of the adult exposure
- HQ_I for subsistence farmer receptor included 1/40 of the infant exposure plus 5/40 of the child exposure plus 34/40 of the adult exposure

CDPHE regulations cited earlier (CHWR 6 CCR 1007-3 264.342 (a)(1)(i)) indicate that a site presents acceptable risk if the calculated HI for all non-cancer adverse health effects is less than 0.25. The HI for acute exposures must be less than 1.0.

D.11.1 Noncarcinogenic Effects from Direct Exposures

The HQs for direct inhalation exposures to chemicals in the air that have non-cancer health effects data were calculated as described by Equation 12 of RAGS, Part F (USEPA, 2009):

$$HQ_D = \frac{EC}{RfC \cdot 1000} \quad \text{Eq. D-63}$$

where

HQ_D	=	HQ for direct inhalation exposure (dimensionless)
EC	=	inhalation exposure concentration of chemical, (exposure scenario-specific concentration; calculated by Eq. D-39)
RfC	=	inhalation reference concentration (mg/m^3), (chemical-specific value)

D.11.2 Noncarcinogenic Effects from Indirect Exposures

The HQs for indirect exposures to chemicals that have non-cancer health effects were calculated using equations provided by USEPA (1994) and presented below:

$$HQ_I = \frac{I_{indirect}}{RfD_o} \quad \text{Eq. D-64}$$

where

HQ_I	=	HQ for indirect exposures (dimensionless)
$I_{indirect}$	=	total indirect exposure as an infant (exposure scenario-specific exposure; mg/kg of body weight-day), (calculated by Eq. D-56)
RfD_o	=	oral reference dose (mg/kg of body weight-day), (chemical-specific value)

When calculating the hazard quotient for dermal exposures to cadmium, nickel and silver, Equation 4.3 of RAGS Part E (USEPA, 2004), applies an adjustment to the oral reference dose for each of these chemicals by multiplying them by the fraction of contaminant absorbed in the gastrointestinal tract (ABS_{GI}). This has the effect of adjusting the COPC oral reference dose from an administered dose basis to an adsorbed dose basis. Cadmium, nickel, and silver are the only COPCs with oral reference doses in this assessment for which RAGS Part E recommends that this adjustment be completed. The dimensionless ABS_{GI} used for cadmium, nickel, and silver are 0.025, 0.04, and 0.04, respectively (note RAGS Part E identifies ABS_{GI}

which are equal to 1.0 for all other COPCs with oral reference doses in this assessment, thus indicating the adjustment is not required).

To apply the adjustment for cadmium, nickel, and silver, an intermediate step is completed prior to calculating hazard quotient according to Eq. D-64. This intermediate step entails dividing the dermal exposure (represented by the terms DAD_{soil} and DAD_{water} in Eq. D-56) for each exposure scenario by the COPC-specific ABS_{Gj} . After this intermediate step is completed for all exposure scenarios, hazard quotient from indirect exposure is then calculated as presented in Eq. D-64.

D.11.3 Cumulative Noncarcinogenic Hazard Characterization

HQs were calculated to represent the noncarcinogenic hazard associated with a single chemical. HQs were summed to calculate the HI. The HI represents total noncarcinogenic hazard from all chemicals to which a human receptor may be exposed through a particular exposure pathway. The total HI was then calculated by summing total noncarcinogenic hazards from all chemicals and all exposure pathways associated with a particular human receptor.

The cumulative HI_D for direct inhalation exposures was calculated using the equation presented in Table 5.1.9 of *Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste* (USEPA, 1994) and also presented below:

$$HI_D = \sum_{i=1}^n HQ_{Di} \quad \text{Eq. D-65}$$

where

$$\begin{aligned} HI_D &= \text{HI from direct inhalation exposures (dimensionless)} \\ HQ_{Di} &= \text{HQ for direct inhalation exposure to chemical } i \text{ (dimensionless),} \\ &\quad \text{(calculated by Eq. D-63)} \end{aligned}$$

The cumulative HI_I for indirect exposures was calculated using the equation presented in Table 6.3.7 of *Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste* (USEPA, 1994) and also presented below:

$$HI_I = \sum_{i=1}^n HQ_{Ii} \quad \text{Eq. D-66}$$

where

$$\begin{aligned} HI_I &= \text{HI from indirect exposures (dimensionless)} \\ HQ_{Ii} &= \text{HQ for indirect exposures to chemical } i \text{ (dimensionless), (calculated by} \\ &\quad \text{Eq. D-64)} \end{aligned}$$

The total non-cancer HI from all exposure pathways, both direct and indirect, was calculated using the equation:

$$HI = HI_D + HI_I \quad \text{Eq. D-67}$$

where

$$HI = \text{total HI (dimensionless)}$$

$$HI_D = \text{HI from direct inhalation exposure (dimensionless), (calculated by Eq. D-65)}$$

$$HI_I = \text{HI from indirect exposures (dimensionless), (calculated by Eq. D-66)}$$

It should also be noted that different chemicals affect specific target organs (e.g., liver, kidney, etc.). It is possible (and acceptable according to USEPA risk assessment guidance [USEPA, 1989]) to calculate total HIs for individual target organs. However, for this MPHRA, the screening-level approach of summing all HIs, regardless of target organ, was taken.

D.12 CHARACTERIZATION OF ACUTE RISK EFFECTS

Potential acute hazards associated with short-term emission release events were assessed when a source has the potential to have a higher-than-average short-term emission rate. The basic approach was the same described above for noncarcinogenic effects, with the following differences: (1) only the direct (inhalation) pathway was evaluated, (2) short-term exposures were calculated using acute inhalation exposure criteria (AIEC), and (3) maximum calculated air concentrations calculated over time periods consistent with the toxicity data (e.g., 1-hr) were compared with levels that could produce effects due to direct contact. This approach calculated an HI, as described above, based on inhalation of chemicals for acute exposures.

D.12.1 Acute Air Concentration for Chemical

The acute air concentration for each chemical (for which an AIEC value was obtained from the hierarchical approach discussed in the main report Section 6.2) was calculated using the equation presented in Table B-6-1 of the HHRAP (USEPA, 2005) and below:

$$C_{(air)acute} = Q[F_v \cdot Chv + (1.0 - F_v) \cdot Chp] \quad \text{Eq. D-68}$$

where

$$C_{(air)acute} = \text{acute air concentration, } (\mu\text{g}/\text{m}^3)$$

$$Q = \text{short term stack emission rate (g/s), (chemical-specific value)}$$

$$F_v = \text{fraction of air concentration in vapor phase (dimensionless), (chemical-specific value)}$$

$$Chv = \text{normalized hourly air concentration in the vapor phase } (\mu\text{g}\cdot\text{s}/\text{g}\cdot\text{m}^3)$$

$$Chp = \text{normalized hourly air concentration of in the particle phase } (\mu\text{g}\cdot\text{s}/\text{g}\cdot\text{m}^3)$$

The chemical-specific short term emission rates used in the MPHRA are presented in Appendix B.

D.12.2 Acute Hazard Quotient

The acute HQ was calculated for each COPC with an AIEC value using Equation 7-9 in the HHRAP (USEPA, 2005) and below:

$$HQ_A = \frac{C_{(air)acute} \cdot 0.001}{AIEC} \quad \text{Eq. D-69}$$

where

HQ_A	=	acute HQ for direct inhalation exposure (dimensionless)
$C_{(air)acute}$	=	acute air concentration, ($\mu\text{g}/\text{m}^3$) (calculated by Eq. D-67)
0.001	=	unit conversion factor ($\text{mg}/\mu\text{g}$)
AIEC	=	acute inhalation exposure criteria (mg/m^3)

The hierarchical approach used to select AIEC values and the numerical value of the AIEC for each chemical have been previously discussed and are presented in Section 6.2.

D.12.3 Acute Hazard Index

As discussed on page 7-15 of the HHRAP (USEPA, 2005), the acute HQs for direct inhalation exposure for each individual chemical released from an acute event were summed to obtain a total acute HI (HI_A) as presented below:

$$HI_A = \sum_{i=1}^n HQ_{Ai} \quad \text{Eq. D-70}$$

where

HI_A	=	acute HI for direct inhalation exposure (dimensionless),
HQ_{Ai}	=	acute HQ for direct inhalation exposure to chemical i (dimensionless), (calculated by Eq. D-68)

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