RESEARCH TRIANGLE INSTITUTE

MEMORANDUM

Date: July 20, 1999

To: David Layland EPA/OSW/EMRAD

From: Miriam Gilkinson

Subject: Sample Calculation for Dioxin in Support of the HWC Background Document

The following provides a sample calculation of indirect exposures following the outline provided in Appendix C of *Human Health and Ecological Risk Assessment Support to the Development of Technical Standards for Emissions from Combustion Units Burning Hazardous Wastes: Background Document*. Sources of equations and variable values are documented in Appendix D of the same report.

The sample calculation is provided for Site 325, Sector 8, Waterbody 1 (Verdigris River) and farm ponds, for the adult (>19 yr) subsistence farmer scenario. The calculation uses a single dioxin congener, 2,3,4,7,8-PeCDF, and shows the method used to combine calculated results for all congeners into a single TCDD-TEQ.

The equations that follow were used to calculate media and food concentrations of contaminants for the indirect exposure pathways. The equations were used to arrive at specific concentrations including terrestrial pathway exposures, terrestrial food chain concentrations, aquatic food chain concentrations, and drinking water concentrations (including soil concentrations averaged over the watershed). Equations used to estimate air concentrations, individual cancer risk, and breastmilk concentrations follow.

Four sets of results are included in these sample calculations: untilled and tilled sector soils and farm pond and Verdigris River watershed soils. These soil concentrations are developed for different uses in the model:

- Untilled sector soils — Soil concentrations for ingestion and forage
- Tilled sector soils — Soil concentrations for agricultural crops (forage not included)
- Farm pond watershed soils — Soil concentrations used to calculate waterbody (farm pond) concentrations for the aquatic food chain

- Verdigris River watershed soils — Soil concentrations used to calculate waterbody (Verdigris River) concentrations for drinking water

Exposure pathways are labeled as appropriate in the tables that follow. If a value is included with no specific pathway identified, it applies to all pathways. Equations are presented so that the end result, i.e., soil concentration, is first and is followed by all required supporting subcalculations.

To allow the reader to duplicate the original spreadsheet calculations, many of the following numerical values have been shown to several significant figures. If these numbers are rounded, the calculations will no longer yield the same results as the spreadsheet model. Results of this sample calculation can be compared to the results for the adult subsistence farmer in Section IX of the risk results. Specifically, the results are found in Table IX-A9 *Individual Risks and Hazard Quotients by Pathway for the Subsistence Farmer, Baseline: Commercial Incinerator (Stack Number 325) - Sector 8*.

The soil concentration due to deposition for carcinogenic compounds is calculated as shown in Table 1. The inputs into the soil concentration equation include a deposition term (Ds), time period of deposition (Tc), time of beginning of exposure relative to the period of deposition (T_1), and a soil loss constant (ks) (further described in Table 2). The deposition term is calculated using air model output from ISCST3. These outputs include the normalized (i.e., the model-assumed emission rate of 1 g/s) dry and wet deposition rates for particles and the normalized wet deposition rate for vapors (Dydp, Dywp, and Dywv). Because ISCST3 does not perform dry deposition calculations for vapors, the normalized dry deposition rate for vapors is calculated internally by the equation using the normalized air concentration of vapors (Cyv) from ISCST3 and the dry deposition velocity (Vdv). Calculation of the deposition term also requires the actual stack emission rate at the facility (Q), the soil mixing depth (Z), the bulk density of the soil (BD), and the fraction of the pollutant released in the vapor phase (Fv).

Table 1. Soil Concentration Due to Deposition for Carcinogenic Compounds

$$Sc = \frac{Ds}{ks \cdot (Tc - T_1)} \bullet \left[\left(Tc + \frac{\exp(-ks \bullet Tc)}{ks}\right) - \left(T_1 + \frac{\exp(-ks \bullet T_1)}{ks}\right)\right] \text{ for } T_1 < Tc$$

$$Ds = \frac{100 \bullet Q}{Z \bullet BD} \bullet \left[Fv\,(0.31536 \bullet Vdv \bullet Cyv + Dywv) + (Dydp + Dywp) \bullet (1 - Fv)\right]$$

Parameter Name and Definition		Pathway	Value(s)
Sc	Average soil 2,3,4,7,8-PeCDF concentration over exposure duration (mg/kg)	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	3.69920424007183E-07 4.51486913129371E-08 1.15806286680837E-07 1.13543471270988E-08
Ds	Deposition term (mg/kg-yr)	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	4.42324578347032E-08 2.21162289173516E-09 4.42324578347032E-08 9.08338065043125E-10
ks	Soil loss constant (yr^{-1}) [see Table 2]	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	0.105048501242399 0.00399572380366973 0.381495952539503 0.0535884060275203
Tc	Time period over which deposition occurs (yr)		30
T_1	Time at beginning of exposure period (yr)		12.69
100	Units conversion factor ($[mg\text{-}m^2]/[kg\text{-}cm^2]$)		
Q	Stack emissions (g/s)		1.47450532724505E-08
Z	Soil mixing depth (cm)	Sector, untilled Sector, tilled Watershed	1 20 1
BD	Soil bulk density (g/cm^3)		1.5
Fv	Fraction of air concentration in vapor phase (dimensionless)		0.3
0.31536	Units conversion factor (m-g-s/cm-µg-yr)		
Vdv	Dry deposition velocity (cm/s)		0.2
Cyv	Normalized vapor phase air concentration ($\mu g\text{-}s/g\text{-}m^3$)		0.194537
Dywv	Normalized yearly wet deposition from vapor phase (s/m^2-yr)		0.00862
Dydp	Normalized yearly dry deposition from particle phase (s/m^2-yr)		0.049376
Dywp	Normalized yearly wet deposition from particle phase (s/m^2-yr)		0.005953

The calculation of the soil loss constant, ks, is shown in Table 2. The soil loss constant is simply the summation of the loss of soil due to all of the possible processes. These processes include leaching (ksl), erosion (kse), runoff (ksr), degradation (ksg), and volatilization (ksv). These values, except for degradation, are calculated using the equations in Tables 3, 4, 5, and 6, respectively. Loss due to erosion was calculated only for watersheds under the assumption that soil lost would be transported into waterbodies. Sector soil loss constants were calculated separately because the soil was not necessarily in those watersheds chosen for the analysis, so it was assumed that soil was not carried into waterbodies but redeposited on land. This produces a more conservative result by minimizing soil loss for individual sectors.

Table 2. Soil Loss Constant

$$ks = ksl + kse + ksr + ksg + ksv$$

Parameter Name and Definition		Pathway	Value(s)
ks	Soil loss constant due to all processes (yr^{-1})	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	0.105048501242399 0.00399572380366973 0.381495952539503 0.0535884060275203
ksl	Loss constant due to leaching (yr^{-1}) [see Table 3]	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	0.000320695659959917 0.0000160347829979959 0.000320695659959917 0.000320695659959917
kse	Loss constant due to soil erosion (yr^{-1}) [see Table 4]	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	0 0 0.280357291984799 0.0022908018978621
ksr	Loss constant due to surface runoff (yr^{-1}) [see Table 5]	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	0.000165576563566261 8.27882817831308E-06 0.000165576563566261 0.000165576563566261
ksg	Loss constant due to degradation (yr^{-1})		0
ksv	Loss constant due to volatilization (yr^{-1}) [see Table 6]	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	0.104562229018873 0.00397141019249342 0.100652388331177 0.050811331906132

Leaching is the downward transport of water-soluble chemicals through the soil. Leaching results in a net loss of the contaminant from the upper layers of soil. As the equation in Table 3 indicates, leaching is highly dependent on the local water balance, which includes annual average values of precipitation (P), irrigation (I), runoff (R), and evapotranspiration (E_v). Soil properties also affect leaching. These include volumetric water content (θ_s); depth from which leaching occurs (Z), or mixing depth; soil-water partition coefficient (Kd_s); fraction of organic carbon in soil (f_{oc}); organic carbon partition coefficient (K_{oc}); and the bulk density (BD).

Table 3. Loss Constant Due to Leaching

$$ksl = \frac{P + I - R - E_v}{\theta_s \bullet Z \bullet \left[1.0 + \left(BD \bullet \frac{Kd_s}{\theta_s}\right)\right]}$$

$$Kd_s = f_{oc} \bullet K_{oc}$$

Parameter Name and Definition		Pathway	Value(s)
ksl	Loss constant due to leaching (yr^{-1})	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	0.000320695659959917 0.0000160347829979959 0.000320695659959917 0.000320695659959917
P	Average annual precipitation (cm/yr)		74.4
I	Average annual irrigation (cm/yr)		0
R	Average annual runoff (cm/yr)		7.6
E_v	Average annual evapotranspiration (cm/yr)		52.08
θ_s	Soil volumetric water content (mL/cm^3)		0.215805352087004
Z	Soil depth from which leaching removal occurs (cm)	Sector, untilled Sector, tilled Watershed	1 20 1
BD	Soil bulk density (g/cm^3)		1.5
Kd_s	Soil-water partition coefficient (cm^3/g)		30,600
f_{oc}	Fraction organic carbon in soil (unitless)		0.006
K_{oc}	Organic carbon partition coefficient (mL/g)		5,100,000

Erosion is the removal and transport of soil from one location to another by wind, rain, or flowing water. The primary inputs used to calculate the soil loss constant due to erosion are unit soil loss (X_e), sediment delivery ratio (SD), contaminant enrichment ratio (ER), soil mixing depth (Z), volumetric water content (θ_s), soil-water partition coefficient (Kd_s), and soil bulk density (BD). The unit soil loss is based on the rainfall, or erosivity, factor (RF), erodibility factor (E), slope-length factor (LS), cover management factor (C), and supporting practice factor (P). Erosivity is primarily a function of rainfall, and erodibility is a function of soil properties. The sediment delivery ratio (SD) determines the amount of sediment removed by erosion. The contaminant enrichment ratio (ER) is a site-specific factor that accounts for the tendency of different types of soils to erode more easily.

Table 4. Soil Loss Constant Due to Erosion

$$kse = \frac{0.1 \bullet X_e \bullet SD \bullet ER}{BD \bullet Z} \bullet \left(\frac{Kd_s \bullet BD}{\theta_s + (Kd_s \bullet BD)} \right)$$

Parameter	Definition	Pathway	Value(s)
kse	Loss constant due to erosion (yr^{-1})	Farm pond Verdigris River	0.280357291984799 0.0022908018978621
X_e	Unit soil loss ($kg/m^2/yr$) [see Table 29]	Farm pond Verdigris River	1.88519490980974 0.254911697837852
SD	Sediment delivery ratio (unitless) [see Table 28]	Farm pond Verdigris River	0.743579904299173 0.0449334551498085
ER	2,3,4,7,8-PeCDF enrichment ratio (unitless)		3
BD	Soil bulk density (g/cm^3)		1.5
Z	Soil mixing depth (cm)		1
Kd_s	Soil-water partition coefficient (cm^3/g)		30,600
θ_s	Soil volumetric water content (mL/cm^3)		0.215805352087004

The loss constant due to runoff is calculated based on average annual runoff (R), volumetric water content of the soil (θ_s), soil mixing depth (Z), soil water partition coefficient (Kd_s), and soil bulk density (BD). Average annual runoff (R) was calculated by dividing the values found in the *Water Atlas* of the United States by 2, because the values in the *Water Atlas* include both surface and subsurface runoff.

Table 5. Loss Constant Due to Runoff

$$ksr = \frac{R}{\theta_s \bullet Z} \bullet \left(\frac{1}{1 + \left(Kd_s \bullet \frac{BD}{\theta_s} \right)} \right)$$

Parameter Name and Definition		Pathway	Value(s)
ksr	Loss constant due to runoff (yr^{-1})	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	0.000165576563566261 8.27882817831308E-06 0.000165576563566261 0.000165576563566261
R	Average annual runoff (cm/yr)		7.6
θ_s	Soil volumetric water content (mL/cm^3)		0.215805352087004
Z	Soil mixing depth (cm)	Sector, untilled Sector, tilled Watershed	1 20 1
Kd_s	Soil-water partition coefficient (cm^3/g)		30,600
BD	Soil bulk density (g/cm^3)		1.5

Volatilization is the process by which contaminants leave the soil and enter the atmosphere. The loss constant due to volatilization depends on chemical-specific properties, atmospheric variables, and soil properties. Chemical-specific properties involve the Henry's Law constant (H) and the diffusivity of the contaminant in the air (Da). Atmospheric variables include ambient air temperature (T), average annual wind speed (u), viscosity of air (μ_a), and the density of air (Da). Temperature and wind speed are available from the National Climatic Data Center (NCDC) climate data. Finally, the soil parameters associated with volatilization are soil mixing depth (Z), soil-water partition coefficient (Kd_s), bulk density (BD), and surface area (A).

Table 6. Loss Constant due to Volatilization

$$ksv = \left[\frac{3.1536 \times 10^7 \bullet H}{Z \bullet Kd_s \bullet R \bullet T \bullet BD}\right] \bullet \left[0.482 \bullet u^{0.78} \cdot \left(\frac{\mu_a}{\rho_a \bullet Da}\right)^{-0.67} \bullet \left(\sqrt{\frac{4 \bullet A}{\pi}}\right)^{-0.11}\right]$$

Parameter Name and Definition		Pathway	Value(s)
ksv	Loss constant due to volatilization (yr^{-1})	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	0.104562229018873 0.00397141019249342 0.100652388331177 0.050811331906132
3.1536×10^7	Conversion constant (s/yr)		
H	Henry's Law constant (atm-m^3/mol)		0.0000062
Z	Soil mixing depth (cm)	Sector, untilled Sector, tilled Watershed	1 20 1
Kd_s	Soil-water partition coefficient (cm^3/g)		30,600
R	Universal gas constant (atm-m^3/mol-K)		0.08205
T	Ambient air temperature (K)		287
BD	Soil bulk density (g/cm^3)		1.5
u	Average annual wind speed (m/s)		6.165351488
μ_a	Viscosity of air (g/cm-s)		0.000181
ρ_a	Density of air (g/cm^3)		0.00119
Da	Diffusivity of 2,3,4,7,8-PeCDF in air (cm^2/s)		0.0457363749329773
A	Surface area of contaminated area (m^2)	Sector, untilled Sector, tilled Watershed, farm pond Watershed, Verdigris River	2,024 300,000 4,047 1,010,768,000

The equation in Table 7 shows the calculation of the vegetable concentration due to the direct deposition of contaminants. Normalized wet and dry deposition of particles (Dywp and Dydp) are calculated by the ISCST3 air model. These are multiplied by the actual stack emission rate (Q) of the contaminant and particulate fractions (1-Fv). Vapor deposition is not included because it is used mainly in the calculation of air-to-plant biotransfer. Also important in this equation are the interception fraction of the edible portion of the plant (Rp), plant surface loss coefficient (kp), length of time that the plant is exposed (Tp), and edible plant yield (Yp).

Table 7. Vegetative Concentration Due to Direct Deposition

$$Pd = \frac{1{,}000 \bullet Q \bullet (1 - Fv) \bullet [Dydp + (Fw \bullet Dywp)] \bullet Rp \bullet [(1.0 - e^{(-kp \bullet Tp)})]}{Yp \bullet kp}$$

Parameter Name and Definition		Pathway	Value(s)
Pd	Concentration of 2,3,4,7,8-PeCDF in plant due to direct deposition (mg/kg DW)	Exposed vegetables Forage Exposed fruit Silage	7.07519448355554E-10 5.24538987079274E-08 1.14259339800623E-09 1.6398494008185E-08
1,000	Units conversion factor (mg/g)		
Q	Stack emissions (g/s)		1.47450532724505E-08
Fv	Fraction of air concentration of 2,3,4,7,8-PeCDF in vapor phase (dimensionless)		0.3
Dydp	Normalized yearly dry deposition from particle phase (s/m^2-yr)		0.049376
Fw	Fraction of wet deposition that adheres to plant (dimensionless)		0.6
Dywp	Normalized yearly wet deposition from particle phase (s/m^2-yr)		0.005953
Rp	Interception fraction of edible portion of plant (dimensionless)	Exposed vegetables Forage Exposed fruit Silage	0.0744633490248823 0.47 0.01 0.46
kp	Plant surface loss coefficient (yr^{-1})		18.07
Tp	Length of plant exposure to deposition of edible portion of plant, per harvest (yr)	Exposed vegetables Forage Exposed fruit Silage	0.16 0.12 0.16 0.16
Yp	Yield or standing crop biomass of the edible portion of the plant (kg DW/m^2)	Exposed vegetables Forage Exposed fruit Silage	3.00632481506389 0.24 0.25 0.80128236596075

The concentration of contaminant in vegetables due to air-to-plant transfer is calculated as shown in Table 8. Contaminants are assumed to be taken into the plant directly from the air based on a chemical specific biotransfer factor (Bv). The normalized air concentration (Cyv) is taken from the ISCST3 air model output and multiplied by the actual contaminant emission rate (Q) and fraction that is vapor (Fv). The density of air (Da) is also an important factor in this equation.

Table 8. Vegetative Concentration Due to Air-to-Plant Transfer

$$Pv = Q \bullet Fv \bullet \frac{Cyv \bullet Bv \bullet VG_{ag}}{\rho_a}$$

Parameter Name and Definition		Pathway	Value(s)
Pv	Concentration of 2,3,4,7,8-PeCDF in the plant due to air-to-plant transfer (mg/kg Dw)	Exposed vegetables Forage Exposed fruit Silage	3.3264475893097E-09 3.3264475893097E-07 3.3264475893097E-09 1.66322379465485E-07
Q	Stack emissions (g/s)		1.47450532724505E-08
Fv	Fraction of air concentration of 2,3,4,7,8-PeCDF in vapor phase (dimensionless)		0.3
Cyv	Normalized vapor phase air concentration of 2,3,4,7,8-PeCDF (µg-s/g-m^3)		0.194537
Bv	Air-to-plant biotransfer factor ([mg pollutant/kg plant tissue DW]/[µg pollutant/g air])		460,000
VG_{ag}	Empirical correction factor for aboveground produce (dimensionless)	Exposed vegetables Forage Exposed fruit Silage	0.01 1 0.01 0.5
ρ_a	Density of air (g/m^3)		1,190

Aboveground vegetation concentration due to root uptake is calculated based on the sector soil concentrations (Sc) from Table 1. The calculation of soil concentration due to root uptake is based on tilled soil for agricultural crops and untilled soil for forage. This is governed by a plant-soil bioconcentration factor for aboveground vegetation (Br).

Table 9. Aboveground Vegetation Concentration Due to Root Uptake

$$Pr = Sc \bullet Br$$

Parameter	Definition	Pathway	Value(s)
Pr	Concentration of 2,3,4,7,8-PeCDF in the plant due to direct uptake from soil (mg/kg Dw)	Exposed vegetables Forage Exposed fruit Silage	1.7493840652026E-10 1.43333699456694E-09 1.7493840652026E-10 1.7493840652026E-10
Sc	Average soil concentration of 2,3,4,7,8-PeCDF over exposure duration (mg/kg) [see Table 1]	Exposed vegetables Forage Exposed fruit Silage	4.51486913129371E-08 3.69920424007183E-07 4.51486913129371E-08 4.51486913129371E-08
Br	Plant-soil bioconcentration factor for aboveground vegetation ([µg/g DW]/[µg/g soil])		0.0038747171054797

The root vegetable concentration due to root uptake is calculated based on a root concentration factor (RCF), which is a ratio of the concentration of contaminant in the root vegetable to the concentration of contaminant in the soil pore water. The equation also takes into account the tilled sector soil concentration (Sc) and the soil water partition coefficient (Kd_s).

Table 10. Root Vegetable Concentration Due to Root Uptake

$$Pr_{bg} = \frac{Sc \bullet RCF \bullet VG_{bg}}{Kd_s}$$

Parameter	Definition	Value(s)
Pr_{bg}	Concentration of 2,3,4,7,8-PeCDF in belowground plant parts due to root uptake (mg/kg Fw)	9.44286354257508E-11
Sc	Soil concentration of 2,3,4,7,8-PeCDF (mg/kg) [see Table 1]	4.51486913129371E-08
RCF	Ratio of concentration of 2,3,4,7,8-PeCDF in roots to concentration of 2,3,4,7,8-PeCDF in soil pore water ([mg pollutant/kg plant tissue FW]/[µg pollutant/mL pore water])	6,400
VG_{bg}	Empirical correction factor for root vegetables (unitless)	0.01
Kd_s	Soil-water partition coefficient (mL/g)	30,600

Beef concentration of a contaminant due to plant and soil ingestion is calculated as shown in Table 11. All plants eaten by the animal are assumed to be grown in contaminated soil; the soil concentration is that of untilled sector soils. The quantity of plant matter eaten each day (Qp_i) is taken into account, as is the total concentration of pollutant in each plant type (P_i). The total concentration is calculated by summing the concentrations in plants due to different processes. Besides plants, it is assumed that cattle consume a certain amount of soil. The soil concentration (Sc) is multiplied by this amount. Finally a biotransfer factor for beef (Ba_{beef}) is applied.

Table 11. Beef Concentration Due to Plant and Soil Ingestion

$$A_{beef} = \left(\sum F_i \bullet Qp_i \bullet P_i + Qs \bullet Sc\right) \bullet Ba_{beef}$$

$$P_i = Pd_i + Pv_i + Pr_i$$

Parameter	Definition	Pathway	Value(s)
A_{beef}	Concentration of 2,3,4,7,8-PeCDF in beef (mg/kg Fw)		1.96522910911658E-07
F_i	Fraction of plant grown on contaminated soil and eaten by the animal (dimensionless) for each plant type	Forage Silage	1 1
Qp_i	Quantity of plant matter eaten by the animal each day (kg plant tissue DW/d)	Forage Silage	8.8 2.5
P_i	Total concentration of 2,3,4,7,8-PeCDF in the each plant type eaten by the animal (mg/kg Dw)	Forage Silage	3.86531994633464E-07 1.8289581188019E-07
Qs	Quantity of soil eaten by the animal (kg soil/d)		0.5
Sc	Soil concentration of 2,3,4,7,8-PeCDF (mg/kg) [see Table 1]		3.69920424007183E-07
Ba_{beef}	Biotransfer factor for beef (d/kg)		0.0486

Table 12 presents the calculation of pollutant concentration in milk due to plant and soil ingestion by the cow. In both cases, the soil concentration was assumed to be untilled sector soil. It should be noted that this equation is almost identical to the equation for beef concentration found in Table 11. The difference lies in the use of a biotransfer factor for milk (Ba_{milk}) rather than for beef.

Table 12. Milk Concentration Due to Plant and Soil Ingestion

$$A_{milk} = \left[\sum (F_i \bullet Qp_i \bullet P_i) + (Qs \bullet Sc)\right] \bullet Ba_{milk}$$

$$P_i = Pd_i + Pv_i + Pr_i$$

Parameter	Definition	Pathway	Value(s)
A_{milk}	Concentration of 2,3,4,7,8-PeCDF in milk (mg/kg Fw)		5.40005699472604E-08
F_i	Fraction of plant grown on contaminated soil and eaten by the animal (dimensionless)	Forage Silage	1 1
Qp_i	Quantity of plant matter eaten by the animal (kg plant tissue DW/d) for each plant type	Forage Silage	13.2 4.1
P_i	Total concentration of 2,3,4,7,8-PeCDF in the each plant type eaten by the animal (mg/kg)	Forage Silage	3.86531994633464E-07 1.8289581188019E-07
Qs	Quantity of soil eaten by the animal (kg soil/d)		0.4
Sc	Soil concentration of 2,3,4,7,8-PeCDF (mg/kg) [see Table 1]		3.69920424007183E-07
Ba_{milk}	Biotransfer factor for milk (d/kg)		0.009

Pork concentration due to plant and soil ingestion is calculated using the same method as for beef concentration. The only difference is that a biotransfer factor for pork (Ba_{pork}) is used. However, in the absence of an actual value for the pork biotransfer factor, the beef biotransfer value was used as a default. As with beef, all plants consumed by hogs were assumed to be grown in contaminated untilled sector soil.

Table 13. Pork Concentration Due to Plant and Soil Ingestion

$$A_{pork} = \left[\sum (F_i \bullet Qp_i \bullet P_i) + (Qs \bullet Sc)\right] Ba_{pork}$$

$$P_i = Pd_i + Pv_i + Pr_i$$

Parameter	Definition	Value(s)
A_{pork}	Concentration of 2,3,4,7,8-PeCDF in pork (mg/kg Fw)	1.82072664590876E-08
F_i	Fraction of silage grown on contaminated soil and eaten by the animal (dimensionless)	1
Qp_i	Quantity of silage matter eaten by the animal each day (kg plant tissue DW/d)	1.3
P_i	Total concentration of 2,3,4,7,8-PeCDF due to root uptake in silage eaten by the animal (mg/kg Dw)	1.8289581188019E-07
Qs	Quantity of soil eaten by the animal (kg soil/d)	0.37
Sc	Soil concentration of 2,3,4,7,8-PeCDF (mg/kg) [see Table 1]	3.69920424007183E-07
Ba_{pork}	Biotransfer factor for pork (d/kg)	0.0486

Eggs may be contaminated when chickens ingest contaminated soil. The level of concentration found in eggs is calculated as shown in the equation presented in Table 14. It is simply a function of the untilled sector soil concentration (Sc), fraction of the chicken's diet that is soil (Fd), and the bioconcentration factor for congener in eggs (BCF_{egg}). This calculation is only performed for dioxin congeners.

Table 14. Concentration in Eggs due to Soil Uptake by Chickens

$$A_{eggs} = Sc \bullet Fd \bullet BCF_{eggs}$$

Parameter	Definition	Value(s)
A_{eggs}	Concentration of 2,3,4,7,8-PeCDF in eggs (mg/kg Fw)	9.24801060017957E-08
Sc	Concentration of 2,3,4,7,8-PeCDF in soil (mg/kg) [see Table 1]	3.69920424007183E-07
Fd	Fraction of diet that is soil (dimensionless)	0.1
BCF_{eggs}	Bioconcentration factor for congener in eggs (unitless)	2.5

The equation in Table 15 shows the calculation of pollutant concentration in the meat of chicken thighs. This calculation is very similar to that for concentration of eggs, including the assumption of untilled sector soil concentration. This calculation is performed only for dioxin congeners.

Table 15. Concentration in Poultry Meat due to Soil Uptake by Chickens

$$A_{poultry} = Sc \bullet Fd \bullet BCF_{chick}$$

Parameter	Definition	Value(s)
$A_{poultry}$	Concentration of 2,3,4,7,8-PeCDF in poultry meat (mg/kg Fw)	4.43904508808619E-08
Sc	Concentration of 2,3,4,7,8-PeCDF in soil (mg/kg) [see Table 1]	3.69920424007183E-07
Fd	Fraction of diet that is soil (dimensionless)	0.1
BCF_{chick}	Bioconcentration factor for congener in thigh meat	1.2

The fish concentration from bed sediments is calculated by multiplying the concentration sorbed to bed sediment (C_{sb}) by the fish lipid content (f_{lipid}) and the biota to sediment accumulation factor (BSAF) and dividing by the fraction of organic carbon in the bottom sediment (OC_{sed}). The fish lipid content is a fraction.

Table 16. Fish Concentration from Farm Pond Bed Sediments

$$C_{fish} = \frac{C_{sb} \bullet f_{lipid} \bullet BSAF}{OC_{sed}}$$

Parameter	Definition	Value(s)
C_{fish}	Fish concentration of 2,3,4,7,8-PeCDF (mg/kg)	2.29035436407766E-07
C_{sb}	Concentration of 2,3,4,7,8-PeCDF sorbed to bed sediment (mg/kg) [see Table 17]	5.35639515549335E-07
f_{lipid}	Fish lipid content (fraction)	0.0264
BSAF	Biota to sediment accumulation factor (unitless)	0.388720449208143
OC_{sed}	Fraction organic carbon in bottom sediment (unitless)	0.024

The equation in Table 17 outlines the calculation of the concentration of a constituent sorbed to bed sediments. This variable is used to calculate the fish tissue concentration of a constituent from bed sediment. For the example calculation shown here, the subsistence farmer is evaluated. This receptor consumes fish caught in farm ponds; therefore, the values in Table 17 correspond to those in the farm pond pathway. In this equation, the total waterbody concentration (C_{wtot}) is multiplied by the fraction that is in the bed sediment (f_{benth}). Other important factors are the bed sediment concentration (BS), bed sediment porosity (θ_{bs}), bed sediment/sediment pore water partition coefficient (Kd_{bs}), depth of the water column (d_w), and depth of the upper benthic layer (d_b). The bed sediment/sediment pore water partition coefficient is calculated by taking the product of the fraction of organic carbon in the bed sediment (OC_{sed}) and the organic carbon partition coefficient (K_{oc}).

Table 17. Concentration of 2,3,4,7,8-PeCDF Sorbed to Bed Sediment in Farm Pond

$$C_{sb} = f_{benth} \bullet C_{wtot} \bullet \frac{Kd_{bs}}{\theta_{bs} + Kd_{bs} \bullet BS} \bullet \frac{d_w + d_b}{d_b}$$

$$Kd_{bs} = OC_{sed} \bullet K_{oc}$$

Parameter	Definition	Value(s)
C_{sb}	Concentration of 2,3,4,7,8-PeCDF sorbed to bed sediments (mg/kg)	5.35639515549335E-07
f_{benth}	Fraction of total waterbody concentration of 2,3,4,7,8-PeCDF that occurs in the bed sediment (unitless) [see Table 26]	0.998208561830134
C_{wtot}	Total water concentration of 2,3,4,7,8-PeCDF in surface water system, including water column and bed sediment (mg/L) [see Table 27]	7.93010146353119E-09
Kd_{bs}	Bed sediment/sediment pore water partition coefficient (L/kg)	122,400
θ_{bs}	Bed sediment porosity (unitless)	0.622641509433962
BS	Bed sediment concentration (kg/L)	1.0
d_w	Total depth of water column (m)	2.03
d_b	Depth of the upper benthic layer (m)	0.03
OC_{sed}	Fraction of organic carbon in bed sediment	0.024
K_{oc}	Organic carbon partition coefficient (mL/g)	5,100,000

The dissolved-phase water concentration is a function of total water concentration (C_{wt}), suspended sediment/surface water partition coefficient (Kd_{sw}), and total suspended solids (TSS). The suspended sediment/surface water partition coefficient is a function of the organic carbon partition coefficient (K_{oc}) and the fraction of organic carbon in suspended sediment (OC_{ss}).

Table 18. Dissolved Water Concentration

$$C_{dw} = \frac{C_{wt}}{1 + [Kd_{sw} \bullet TSS \bullet 10^{-6}]}$$

$$Kd_{sw} = OC_{ss} \bullet K_{oc}$$

Parameter Name and Definition		Pathway	Value(s)
C_{dw}	Dissolved phase water concentration of 2,3,4,7,8-PeCDF (mg/L)	Farm pond Verdigris River	4.3761398329194E-12 1.26684304758537E-14
C_{wt}	Total concentration of 2,3,4,7,8-PeCDF in water column (mg/L) [see Table 19]	Farm pond Verdigris River	1.44193807494694E-11 6.11593818082789E-13
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)		229500
TSS	Total suspended solids (mg/L)	Farm pond Verdigris River	10 206
OC_{ss}	Fraction of organic carbon in suspended sediment		0.045
K_{oc}	Organic carbon partition coefficient (mL/g)		5,100,000

The total concentration in the water column is a function of the fraction of total waterbody contaminant concentration in the water column (f_{water}), the total water concentration in surface water column and bed sediment (C_{wtot}), the depth of the upper benthic layer (d_b), and the depth of the water column (d_w).

Table 19. Total Water Column Concentration

$$C_{wt} = f_{water} \bullet C_{wtot} \bullet \frac{d_w + d_b}{d_w}$$

Parameter Name and Definition		Pathway	Value(s)
C_{wt}	Total concentration of 2,3,4,7,8-PeCDF in water column (mg/L)	Farm pond Verdigris River	1.44193807494694E-11 6.11593818082789E-13
f_{water}	Fraction of total waterbody concentration of 2,3,4,7,8-PeCDF that occurs in water column (unitless) [see Table 26]	Farm pond Verdigris River	0.0017914381698659 0.00247867385756936
C_{wtot}	Total water concentration of 2,3,4,7,8-PeCDF in surface water system, including water column and bed sediment (mg/L) [see Table 27]	Farm pond Verdigris River	7.93010146353119E-09 2.12942030025902E-10
d_b	Depth of upper benthic layer (m)		0.03
d_w	Depth of the water column (m)	Farm pond Verdigris River	2 0.189

The benthic burial rate constant is calculated as shown in Table 20. It depends upon the unit soil loss (X_e), watershed area which receives fallout (WA_L), sediment delivery ratio (SD), volumetric flow rate (Vf_x), total suspended solids (TSS), the waterbody surface area (WA_w), the benthic solids concentration (BS), and the depth of the upper benthic sediment layer (d_b).

Table 20. Benthic Burial Rate Constant

$$k_b = \left(\frac{X_e \bullet WA_L \bullet SD \bullet 10^3 - Vf_x \bullet TSS}{WA_w \bullet TSS} \right) \left(\frac{TSS \bullet 10^{-6}}{BS \bullet d_b} \right)$$

Parameter Name and Definition		Pathway	Value(s)
kb	Benthic burial rate constant (yr^{-1})	Farm pond Verdigris River	0.0934022033747741 0.0
X_e	Unit soil loss ($kg/m^2/yr$) [see Table 29]	Farm pond Verdigris River	1.88519490980974 0.254911697837852
WA_L	Watershed area receiving fallout (m^2)	Farm pond Verdigris River	4,047 1,010,768,000
SD	Watershed sediment delivery ratio (unitless) [see Table 28]	Farm pond Verdigris River	0.743579904299173 0.0449334551498085
10^3	Conversion factor (g/kg)		
Vf_x	Average volumetric flow rate through waterbody (m^3/yr)	Farm pond Verdigris River	307.572 1,724,230,800
TSS	Total suspended solids (mg/L) or (g/m^3)	Farm pond Verdigris River	10 206
WA_w	Waterbody surface area (m^2)	Farm pond Verdigris River	2,023.5 2,087,317.4413986
BS	Benthic solids concentration (kg/L)		1
10^{-6}	Conversion factor (kg/mg)		
d_b	Depth of upper benthic sediment layer (m)		0.03

Note: If the calculated value of kb is less than zero, kb is set equal to zero.

The gas-phase transfer coefficient is assumed to be constant for flowing streams and rivers. The coefficient for a quiescent pond, however, is calculated similarly to the liquid-phase transfer coefficient. The main difference in the formula is that the viscosity, density, and diffusivity are based on air instead of water, and that the density of air divided by density of water term is not present in this equation.

Table 21. Gas Phase Transfer Coefficient

Flowing stream or river

$$K_G = 36{,}500 \text{ m/yr}$$

Quiescent pond

$$K_G = (C_d^{0.5} \cdot W) \bullet \left(\frac{k^{0.33}}{\lambda_2}\right) \bullet \left(\frac{\mu_a}{\rho_a \bullet Da}\right)^{-0.67} \bullet 3.15 \times 10^7$$

Parameter Name and Definition		Pathway	Value(s)
K_G	Gas-phase transfer coefficient (m/yr)	Farm pond Verdigris River	532024.616612728 36500
C_d	Drag coefficient		0.0011
W	Wind velocity, 10 m above water surface (m/s)		6.165351488
k	von Karman's constant		0.4
λ_2	Dimensionless viscous sublayer thickness		4
μ_a	Viscosity of air corresponding to the air temperature (g/cm-s)		0.000181
ρ_a	Density of air corresponding to water temperature (g/cm^3)		0.00119
Da	Diffusivity of chemical in air (cm^2/s)		0.0457363749329773
3.15×10^7	Conversion constant (s/yr)		

The liquid-phase transfer coefficient is calculated differently for a flowing stream than for a quiescent pond. For a flowing stream, this value is controlled by flow-induced turbulence, and for a quiescent pond it is controlled by wind induced turbulence. The formula for a flowing stream accounts for current velocity (u), water depth (d_w), and the chemical-specific diffusivity in water (D_w). The quiescent pond formula takes into account the chemical-specific diffusivity in water (D_w), the densities of air and water (ρ_a and ρ_w), the viscosity of water (μ_w), the wind velocity above the water surface (W), the drag coefficient (C_d), von Karman's constant (k), and the dimensionless viscous sublayer thickness (λ_2).

Table 22. Liquid Phase Transfer Coefficient

Flowing stream

$$K_L = \sqrt{\frac{10^{-4} \bullet D_w \bullet u}{d_w}} \bullet 3.15 \times 10^7$$

Quiescent pond

$$K_L = (C_d^{0.5} \cdot W) \bullet \left(\frac{\rho_a}{\rho_w}\right)^{0.5} \bullet \left(\frac{k^{0.33}}{\lambda_2}\right) \bullet \left(\frac{\mu_w}{\rho_w \bullet D_w}\right)^{-0.67} \bullet 3.15 \times 10^7$$

Parameter Name and Definition		Pathway	Value(s)
K_L	Liquid-phase transfer coefficient (m/yr)	Farm pond Verdigris River	242.803029621019 1519.50875262865
D_w	Diffusivity of chemical in water (cm^2/s)		0.000008
u	Current velocity	Verdigris River	0.637
d_w	Total water column depth (m)	Farm pond Verdigris River	2.03 0.219
C_d	Drag coefficient		0.0011
W	Wind velocity, 10 m above water surface (m/s)		6.165351488
ρ_a	Density of air corresponding to water temperature (g/cm^3)		0.00119
ρ_w	Density of water corresponding to water temperature (g/cm^3)		0.9978
k	von Karman's constant		0.4
λ_2	Dimensionless viscous sublayer thickness		4
μ_w	Viscosity of water (g/cm-s)		0.0169190329067955
3.15×10^7	Conversion constant (s/yr)		

The overall transfer rate, which is used in calculating the vapor diffusion load to a waterbody, is also called the conductivity. It is dependent upon liquid- and gas-phase transfer coefficients (K_L and K_G), the chemical-specific Henry's Law constant (H), and the waterbody temperature (T_k).

Table 23. Overall Transfer Rate

$$K_v = \left[K_L^{-1} + \left(K_G \frac{H}{R \cdot T_k} \right)^{-1} \right]^{-1} \cdot \theta^{(T_k - 293)}$$

Parameter Name and Definition		Pathway	Value(s)
Kv	Overall transfer rate (m/yr)	Farm pond Verdigris River	98.5968565641563 10.4589781825139
K_L	Liquid phase transfer coefficient (m/yr) [see Table 22]	Farm pond Verdigris River	242.803029621019 1519.50875262865
K_G	Gas phase transfer coefficient (m/yr) [see Table 21]	Farm pond Verdigris River	532024.616612728 36500
H	Henry's Law constant (atm-m^3/mol)		0.0000062
R	Universal gas constant (atm-m^3/mol-K)		8.205 x 10^{-5}
θ	Temperature correction factor (unitless)		1.026
T_k	Waterbody temperature (K)		298

Loss of constituent from a waterbody due to volatilization is governed by the water column volatilization rate constant. This parameter is dependent upon the overall transfer rate (Kv), total water depth of the water column (d_w), total suspended solids (TSS), and suspended sediment/surface water partition coefficient (Kd_{sw}).

Table 24. Water Column Volatilization Loss Rate Constant

$$k_v = \frac{K_v}{d_w \bullet (1 + Kd_{sw} \bullet TSS \bullet 10^{-6})}$$

Parameter Name and Definition		Pathway	Value(s)
kv	Water column volatilization rate constant (yr^{-1})	Farm pond Verdigris River	14.7404795389576 0.989247286375622
Kv	Overall transfer rate (m/yr)[see Table 23]	Farm pond Verdigris River	98.5968565641563 10.4589781825139
d_w	Total water column depth (m)	Farm pond Verdigris River	2.03 0.219
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)		229500
TSS	Total suspended solids (mg/L)	Farm pond Verdigris River	10 206
10^{-6}	Conversion factor (kg/mg)		

The equation in Table 25 shows the calculation of the waterbody dissipation rate constant, which is used to calculate the total waterbody constituent concentration (see Table 27). The first component of the equation calculates the dissipation due to volatilization from the water column ,and the second component shows the amount of dissipation due to benthic burial.

Table 25. Overall Total Waterbody Dissipation Rate Constant

$$k_{wt} = [f_{water} \cdot kv] + [f_{benth} \cdot kb]$$

Parameter Name and Definition		Pathway	Value(s)
kwt	Overall total waterbody dissipation rate constant (yr^{-1})	Farm pond Verdigris River	0.119641536790715 0.00245202138741069
f_{water}	Fraction of total waterbody concentration of 2,3,4,7,8-PeCDF that occurs in water column [see Table 26]	Farm pond Verdigris River	0.0017914381698659 0.00247867385756936
kv	Water column volatilization loss rate constant (yr^{-1}) [see Table 24]	Farm pond Verdigris River	14.7404795389576 0.989247286375622
f_{benth}	Fraction of total waterbody concentration of 2,3,4,7,8-PeCDF that occurs in benthic sediment [see Table 26]	Farm pond Verdigris River	0.998208561830134 0.997521326142431
kb	Benthic burial rate constant (yr^{-1}) [see Table 20]	Farm pond Verdigris River	0.0934022033747741 0

The fraction of the total waterbody contaminant in the water column is calculated based on several factors. These factors include total suspended solids (TSS), depth of the water column (d_w), depth of the upper benthic layer (d_b), the suspended sediment/surface water partition coefficient (Kd_{sw}), the bed sediment/pore water partition coefficient (Kd_{bs}), the bed sediment porosity (θ_{bs}), and the bed sediment concentration (BS). The two partition coefficients are calculated using the fraction of organic carbon for suspended sediment (OC_{ss}) or bed sediment (OC_{sed}) multiplied by the organic carbon partition coefficient (K_{oc}).

Table 26. Fraction in Water Column and Benthic Sediment

$$f_{water} = \frac{(1 + [Kd_{sw} \bullet TSS \bullet 10^{-6}]) \bullet \frac{dw}{dz}}{(1 + [Kd_{sw} \bullet TSS \bullet 10^{-6}]) \bullet d_w/d_z + (\theta_{bs} + [Kd_{bs} \cdot BS]) \bullet \frac{dw}{dz}}$$

$$Kd_{sw} = OC_{ss} \bullet K_{oc}$$

$$Kd_{bs} = OC_{sed} \bullet K_{oc}$$

$$f_{benth} = 1 - f_{water}$$

Parameter Name and Definition		Pathway	Value(s)
f_{water}	Fraction of total waterbody concentration of 2,3,4,7,8-PeCDF in the water column (unitless)	Farm pond Verdigris River	0.0017914381698659 0.00247867385756936
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)		229,500
TSS	Total suspended solids (mg/L)	Farm pond Verdigris River	10 206
10^{-6}	Conversion factor (kg/mg)		
d_w	Depth of the water column (m)	Farm pond Verdigris River	2 0.189
d_z	Total waterbody depth (m)	Farm pond Verdigris River	2.03 0.219
θ_{bs}	Bed sediment porosity (L_{water}/L)		0.622641509433962
Kd_{bs}	Bed sediment/pore water partition coefficient (L/kg)		122400
BS	Bed sediment concentration (g/cm^3)		1.0
d_b	Depth of the upper benthic layer (m)		0.03
K_{oc}	Organic carbon partition coefficient (mL/g)		5,100,000
f_{benth}	Fraction of total waterbody concentration of 2,3,4,7,8-PeCDF in benthic sediment (unitless)	Farm pond Verdigris River	0.998208561830134 0.997521326142431
OC_{ss}	Fraction of organic carbon in suspended sediment		0.045
OC_{sed}	Fraction of organic carbon in bed sediment		0.024

The equation in Table 27 outlines the calculation of total waterbody concentration of a constituent. The numerator consists of the input into the waterbody (L_T), which is the load due to runoff, deposition, and erosion. The denominator contains the factors that tend to spread out the constituent, thus act against high concentrations. These factors include volumetric flow rate (Vf_x), waterbody dissipation rate constant (kwt), depth of water column (d_w), and depth of upper benthic layer (d_b). Also contained in the denominator is the fraction of the contaminant concentration that occurs in the water column (f_{water}).

Table 27. Total Waterbody Concentration

$$C_{wtot} = \frac{L_T}{Vf_x \cdot f_{water} + [kwt \cdot WA_w \cdot (d_w + d_b)]}$$

Parameter Definition		Pathway	Value(s)
C_{wtot}	Total waterbody concentration of 2,3,4,7,8-PeCDF, including water column and bed sediment (mg/L)	Farm pond Verdigris River	7.93010146353119E-09 2.12942030025902E-10
L_T	Total chemical load into waterbody, including deposition, runoff, and erosion (g/yr) [see Table 30]	Farm pond Verdigris River	3.90163478174767E-06 0.000910311565998522
Vf_x	Average volumetric flow rate through waterbody (m^3/yr)	Farm pond Verdigris River	307.572 1,724,230,800
f_{water}	Fraction of total waterbody concentration of 2,3,4,7,8-PeCDF that occurs in the water column (unitless) [see Table 26]	Farm pond Verdigris River	0.0017914381698659 0.00247867385756936
kwt	Overall total waterbody dissipation rate constant (unitless) [see Table 25]	Farm pond Verdigris River	0.119641536790715 0.00245202138741069
WA_w	Waterbody surface area (m^2)	Farm pond Verdigris River	2,023.5 2,087,317.4413986
d_w	Depth of water column (m)	Farm pond Verdigris River	2 0.189
d_b	Depth of upper benthic layer (m)	Farm pond Verdigris River	0.03 0.03

The sediment delivery ratio is a measure of the amount of sediment derived from the erosion of soil. It is calculated based on the area of a watershed receiving fallout (WA_L) and two empirical coefficients (a and b).

Table 28. Sediment Delivery Ratio

$$SD = a \bullet (WA_L)^{-b}$$

Parameter Name and Definition		Pathway	Value(s)
SD	Watershed sediment delivery ratio (unitless)	Farm pond Verdigris River	0.743579904299173 0.0449334551498085
a	Empirical intercept coefficient	Farm pond Verdigris River	2.1 0.6
WA_L	Watershed area receiving fallout (m^2)	Farm pond Verdigris River	4,047 1,010,768,000
b	Empirical slope coefficient		0.125

The equation in Table 29 calculates the unit soil loss due to erosion. This equation is also known as the Universal Soil Loss Equation (USLE). The USLE is the product of the rainfall erosivity factor (RF), the erodibility factor (K), a length-slope factor (LS), cover management factor (C), and supporting practice factor (P). The erosivity factor is primarily a function of rainfall amount, and the erodibility factor is primarily due to soil properties.

Table 29. Universal Soil Loss Equation (USLE)

$$X_e = RF \bullet K \bullet LS \bullet C \bullet P \bullet \frac{907.18}{4047}$$

Parameter Name and Definition		Pathway	Value(s)
X_e	Unit soil loss (kg/m^2/yr)	Farm pond Verdigris River	1.88519490980974 0.254911697837852
RF	USLE rainfall (or erosivity) factor (yr^{-1})	Farm pond Verdigris River	250 250
K	USLE erodibility factor (ton/acre)	Farm pond Verdigris River	0.29 0.34
LS	USLE length-slope factor (unitless)	Farm pond Verdigris River	1.45 0.327597079038197
C	USLE cover management factor (unitless)	Farm pond Verdigris River	0.08 0.0756597467596167
P	USLE supporting practice factor (unitless)	Farm pond Verdigris River	1 0.539766184360376
907.18	Conversion factor (kg/ton)		
4,047	Conversion factor (m^2/acre)		

The contaminant load to a waterbody is calculated by summing the particle and vapor depositions (L_{Dep}), vapor diffusion (L_{Dif}), runoff load from impervious and pervious surfaces (L_{RI} and L_R), and the soil erosion load (L_E). Table 30 gives the equation for this calculation.

Table 30. Total Waterbody Load

$$L_T = L_{Dep} + L_{RI} + L_R + L_E + L_{Dif}$$

Parameter Name and Definition		Pathway	Value(s)
L_T	Total 2,3,4,7,8-PeCDF load to the waterbody (g/yr)	Farm pond Verdigris River	3.90163478174767E-06 0.000910311565998522
L_{Dep}	Total (wet and dry) particle phase and wet vapor phase 2,3,4,7,8-PeCDF direct deposition load to waterbody (g/yr) [see Table 31]	Farm pond Verdigris River	1.23273854858733E-06 0.000050727651643031
L_{RI}	Runoff load from impervious surfaces (g/yr) [see Table 32]	Farm pond Verdigris River	9.86190838869863E-08 0.000447353301430746
L_R	Runoff load from pervious surfaces (g/yr) [see Table 33]	Farm pond Verdigris River	1.11744639187725E-09 0.0000273637118478824
L_E	Soil erosion load (g/yr) [see Table 34]	Farm pond Verdigris River	1.89208084536383E-06 0.000378585239864548
L_{Dif}	Vapor phase 2,3,4,7,8-PeCDF diffusion (dry deposition) load to waterbody (g/yr) [see Table 35]	Farm pond Verdigris River	6.77078857517652E-07 6.28166121231425E-06

The total deposition of constituent to a waterbody is calculated in Table 31. The normalized combined wet and dry deposition for particles (Dywbtp), as well as the normalized wet deposition for vapors (Dywbwv), are taken from ISCST3. Particles and vapors are weighted by their respective fractions using Fv, which was obtained from stack specific emission data, and total deposition (L_{Dep})is calculated over the waterbody area (WA_w) based on stack emission rate (Q).

Table 31. Deposition to Waterbody

$$L_{Dep} = Q \bullet [Fv \bullet Dywbwv + (1 - Fv) \bullet Dywbtp] \bullet WA_w$$

Parameter Name and Definition		Pathway	Value(s)
L_{Dep}	Total (wet and dry) particle phase and wet vapor phase 2,3,4,7,8-PeCDF direct deposition load to waterbody (g/yr)	Farm pond Verdigris River	1.23273854858733E-06 0.000050727651643031
Q	Stack emissions (g/s)		1.47450532724505E-08
Fv	Fraction of air in vapor phase (dimensionless)		0.3
Dywbwv	Normalized yearly waterbody average wet deposition from vapor phase (s/m^2-yr)	Farm pond Verdigris River	0.00862 0.000734
Dywbtp	Normalized yearly waterbody average total (wet and dry) deposition from particle phase (s/m^2-yr)	Farm pond Verdigris River	0.055329 0.00204
WA_w	Waterbody area (m^2)	Farm pond Verdigris River	2023.5 2087317.4413986

The load to a waterbody due to runoff from impervious surfaces is calculated by first calculating the deposition rate of particles (Dywstp) and vapor (Dywswv) to the watershed. This is done using the particulate and vapor fractions, the normalized deposition rates calculated in ISCST3, and the stack emission rate (Q). The total deposition over the entire watershed is multiplied by the impervious area (WA_I) of the watershed to determine the runoff load.

Table 32. Impervious Runoff Load to Watershed

$$L_{RI} = Q \bullet [Fv \bullet Dywswv + (1.0 - Fv) \bullet Dywstp] \bullet WA_I$$

Parameter	Definition	Pathway	Value(s)
L_{RI}	Impervious surface runoff load (g/yr)	Farm pond Verdigris River	9.86190838869863E-08 0.000447353301430746
Q	Stack emissions (g/s)		1.47450532724505E-08
Fv	Fraction of air concentration of 2,3,4,7,8-PeCDF in vapor phase (dimensionless)		0.3
Dywswv	Normalized yearly watershed average wet deposition from vapor phase (s/m^2-yr)	Farm pond Verdigris River	0.00862 0.00028
Dywstp	Normalized yearly watershed average total (wet and dry) deposition from particle phase (s/m^2-yr)	Farm pond Verdigris River	0.055329 0.000952
WA_I	Impervious watershed area receiving pollutant deposition (m^2)	Farm pond Verdigris River	161.88 40,430,720

Most of the watershed area at a facility is usually composed of pervious surfaces. The equation in Table 33 shows the calculation of runoff load to a waterbody from this portion of a watershed. In this calculation, the untilled watershed soil concentration (Sc), bulk density (BD), volumetric soil water content (θ_s), and soil-water partition coefficient (Kd_s) are important soil parameters. The soil-water partition coefficient is calculated by taking the product of the organic carbon partition coefficient (K_{oc}) and the fraction of organic carbon in the soil (f_{oc}). Other important factors in calculating the runoff load are the annual average surface runoff (R) and the pervious area in the watershed (WA_L-WA_I).

Table 33. Pervious Runoff Load to Waterbody

$$L_R = R \bullet (WA_L - WA_I) \bullet \frac{Sc \bullet BD}{\theta_s + Kd_s \bullet BD} \bullet 0.01$$

$$Kd_s = f_{oc} \bullet K_{oc}$$

Parameter	Definition	Pathway	Value(s)
L_R	Pervious surface runoff load (g/yr)	Farm pond Verdigris River	1.11744639187725E-09 0.0000273637118478824
R	Average annual surface runoff (cm/yr)		7.6
WA_L	Total watershed area receiving pollutant deposition (m^2)	Farm pond Verdigris River	4,047 1,010,768,000
WA_I	Impervious watershed area receiving pollutant deposition (m^2)	Farm pond Verdigris River	161.88 40,430,720
Sc	Concentration of 2,3,4,7,8-PeCDF in watershed soils (mg/kg)	Farm pond Verdigris River	1.15806286680837E-07 1.13543471270988E-08
BD	Soil bulk density (g/cm^3)		1.5
θ_s	Volumetric soil water content (cm^3/cm^3)		0.215805352087004
Kd_s	Soil-water partition coefficient (L/kg)		30,600
0.01	Units conversion factor ($kg\text{-}cm^2/mg\text{-}m^2$)		
f_{oc}	Fraction organic carbon in soil (unitless)		0.006
K_{oc}	Organic carbon partition coefficient (mL/g)		5,100,000

Soil erosion load to a waterbody is calculated as shown in Table 34. Because erosion primarily affects the pervious area of the watershed, the pervious area is calculated in the equation. The unit soil loss (X_e), as well as the pollutant concentration in the untilled watershed soil (Sc), sediment delivery ratio (SD), enrichment ratio (ER), volumetric soil water content (θ_s), the soil-water partition coefficient (Kd_s), and bulk density of the soil (BD), are also factors in the equation.

Table 34. Erosion Load to Waterbody

$$L_E = X_e \bullet (WA_L - WA_I) \bullet SD \bullet ER \bullet \left[\frac{Sc \bullet Kd_s \bullet BD}{\theta_s + Kd_s \bullet BD}\right] \bullet 0.001$$

$$Kd_s = f_{oc} \bullet K_{oc}$$

Parameter Name and Definition		Pathway	Value(s)
L_E	Soil erosion load (g/yr)	Farm pond Verdigris River	1.89208084536383E-06 0.000378585239864548
X_e	Unit soil loss (kg/m²/yr) [see Table 29]	Farm pond Verdigris River	1.88519490980974 0.254911697837852
WA_L	Total watershed area receiving pollutant deposition (m²)	Farm pond Verdigris River	4,047 1,010,768,000
WA_I	Impervious watershed area receiving pollutant deposition (m²)	Farm pond Verdigris River	161.88 40,430,720
SD	Watershed sediment delivery ratio (unitless) [see Table 28]	Farm pond Verdigris River	0.743579904299173 0.0449334551498085
ER	Soil enrichment ratio (unitless)		3
Sc	Concentration of 2,3,4,7,8-PeCDF in watershed soils (mg/kg)[see Table 1]	Farm Pond Verdigris River	1.15806286680837E-07 1.13543471270988E-08
Kd_s	Soil-water partition coefficient (L/kg)		30,600
BD	Soil bulk density (g/cm³)		1.5
θ_s	Volumetric soil water content (cm³/cm³)		0.215805352087004
0.001	Units conversion factor ([g/kg]/[mg/kg])		
f_{oc}	Fraction organic carbon in soil (unitless)		0.006
K_{oc}	Organic carbon partition coefficient (mL/g)		5,100,000

Unlike soil, waterbody constituent load from vapor is considered to occur by diffusion rather than deposition. As a result, the equation in Table 35 contains no deposition velocity. Instead, an overall transfer rate is used in the calculation. This transfer rate (Kv) is multiplied by the normalized concentration of vapors (Cywbv) over the waterbody, the fraction of constituent in vapor phase (Fv), the stack emission rate (Q), and the waterbody surface area (WA_W). Other terms include the chemical specific Henry's Law constant (H), Universal gas constant (R), and the temperature of the waterbody (T_W).

Table 35. Diffusion Load to Waterbody

$$L_{Dif} = \frac{Kv \bullet Q \bullet Fv \bullet Cywbv \bullet WA_w \bullet 10^{-6}}{\frac{H}{R \bullet T_w}}$$

Parameter Name and Definition		Pathway	Value(s)
L_{Dif}	Dry vapor phase 2,3,4,7,8-PeCDF diffusion load to waterbody (g/yr)	Farm pond Verdigris River	6.77078857517652E-07 6.28166121231425E-06
Q	Stack emissions (g/s)		1.47450532724505E-08
Fv	Fraction of air concentration of 2,3,4,7,8-PeCDF in vapor phase (dimensionless)		0.3
Kv	Overall transfer rate (m/yr) [see Table 23]	Farm pond Verdigris River	98.5968565641563 10.4589781825139
Cywbv	Normalized yearly waterbody average vapor phase air concentration of 2,3,4,7,8-PeCDF (µg-s/g-m^3)	Farm pond Verdigris River	0.194537 0.016494
WA_w	Waterbody surface area (m^2)	Farm pond Verdigris River	2023.5 2,087,317.4413986
10^{-6}	Units conversion factor (g/µg)		
H	Henry's Law constant (atm-m^3/mol)		0.0000062
R	Universal gas constant (atm-m^3/mol-K)		8.205E-05
T_w	Waterbody temperature (K)		298

The equation in Table 36 shows the calculation of air concentration. It accounts for both particulate and vapor air concentrations. The normalized air concentrations of particles and vapor (Cywbp and Cywbv) are taken from ISCST3 and multiplied by the particle and vapor fractions (1-Fv and Fv), respectively. These figures are added and finally multiplied by the actual stack emission rate (Q) to convert normalized values to stack specific values.

Table 36. Congener Air Concentration

$$C_a = Q \bullet [\, Fv \bullet Cywbv + ([1 - Fv] \bullet Cywbp) \,]$$

Parameter	Definition	Value(s)
C_a	Total air concentration of 2,3,4,7,8-PeCDF (µg/m^3)	2.7978797564688E-09
Q	Stack emissions (g/s)	1.47450532724505E-08
Fv	Fraction of air concentration of 2,3,4,7,8-PeCDF in vapor phase (dimensionless)	0.3
Cywbv	Normalized yearly waterbody average vapor phase air concentration of 2,3,4,7,8-PeCDF (µg-s/g-m^3)	0.194537
Cywbp	Normalized yearly waterbody average particle phase air concentration of 2,3,4,7,8-PeCDF (µg-s/g-m^3)	0.187699

Table 37a. Congener-Specific Media Concentrations, Untilled Sector Soil

Constituent	CAS	Soil Conc (mg/kg)	Above Ground Veg Conc (mg/kg)	Below-ground Veg Conc (mg/kg)	Above Ground Fruit Conc (mg/kg)	Beef Conc (mg/kg)	Milk Conc (mg/kg)	Pork Conc (mg/kg)	Chicken Egg Conc (mg/kg)	Chicken Thigh Meat Conc (mg/kg)	Fish Conc (mg/kg)	Drinking Water Conc (mg/l)	Air Conc (µg/m3)
2,3,7,8-TCDD	1746016	1.58E-09	3.34E-11	1.73E-12	3.99E-11	1.47E-09	4.08E-10	1.15E-10	2.00E-10	1.75E-10	4.51E-09	3.16E-16	6.56E-11
OCDD, 1,2,3,4,5,7,8,9-	3268879	1.62E-07	1.60E-10	1.18E-11	2.47E-10	1.02E-09	2.29E-10	3.49E-10	7.63E-09	6.49E-10	4.51E-09	5.42E-16	3.87E-10
HxCDD, 1,2,3,7,8,9-	19408743	1.44E-08	3.62E-11	2.71E-12	5.27E-11	1.05E-09	2.64E-10	2.11E-10	1.51E-09	7.18E-10	8.62E-10	1.73E-16	7.50E-11
OCDF, 1,2,3,4,6,7,8,9-	39001020	4.05E-07	3.63E-10	1.57E-11	5.81E-10	2.47E-09	5.47E-10	8.68E-10	1.22E-08	2.84E-09	1.11E-09	8.33E-17	9.70E-10
HxCDD, 1,2,3,4,7,8-	39227286	1.64E-08	3.43E-11	1.40E-12	4.55E-11	1.17E-09	2.93E-10	2.45E-10	2.39E-09	1.39E-09	2.53E-09	4.32E-17	5.39E-11
PeCDD, 1,2,3,7,8-	40321764	1.53E-08	5.99E-11	3.84E-12	7.56E-11	2.82E-09	7.35E-10	4.37E-10	1.94E-09	1.69E-09	1.22E-08	8.75E-16	9.49E-11
TCDF, 2,3,7,8-	51207319	5.41E-08	1.22E-09	4.62E-11	1.33E-09	1.75E-08	4.84E-09	1.37E-09	2.49E-09	4.98E-09	4.54E-08	1.10E-14	1.86E-09
HpCDF,1,2,3,4,7,8,9-	55673897	8.91E-08	2.39E-10	1.22E-11	3.45E-10	3.63E-09	9.22E-10	6.77E-10	4.37E-09	1.43E-09	3.57E-09	2.70E-16	4.87E-10
PeCDF, 2,3,4,7,8-	57117314	3.70E-07	4.21E-09	9.44E-11	4.64E-09	1.97E-07	5.40E-08	1.82E-08	9.25E-08	4.44E-08	2.29E-07	1.27E-14	2.80E-09
PeCDF, 1,2,3,7,8-	57117416	1.70E-07	3.46E-09	5.75E-11	3.69E-09	3.60E-08	1.00E-08	2.88E-09	4.25E-08	2.04E-08	8.38E-08	9.54E-15	1.79E-09
HxCDF, 1,2,3,6,7,8-	57117449	2.99E-07	5.35E-10	4.09E-11	7.76E-10	1.70E-08	4.12E-09	4.15E-09	5.02E-08	2.18E-08	2.98E-08	2.81E-15	1.15E-09
HxCDD, 1,2,3,6,7,8-	57653857	7.46E-09	2.18E-11	1.41E-12	3.03E-11	5.38E-10	1.38E-10	9.67E-11	1.21E-09	7.39E-10	1.70E-09	9.02E-17	3.95E-11
HxCDF, 2,3,4,6,7,8-	60851345	2.34E-07	5.45E-10	4.02E-11	7.83E-10	1.36E-08	3.39E-09	2.84E-09	1.27E-08	9.14E-09	5.15E-08	2.64E-15	1.15E-09
HpCDF,1,2,3,4,6,7,8-	67562394	3.70E-07	1.07E-09	5.05E-11	1.51E-09	5.45E-09	1.40E-09	9.65E-10	2.52E-08	6.66E-09	5.97E-09	1.13E-15	2.04E-09
HxCDF, 1,2,3,4,7,8-	70648269	8.04E-07	2.25E-09	1.68E-10	3.26E-09	7.46E-08	1.89E-08	1.41E-08	1.52E-07	6.92E-08	6.45E-08	1.06E-14	4.83E-09
HxCDF, 1,2,3,7,8,9-	72918219	2.09E-08	5.37E-11	3.59E-12	7.47E-11	1.63E-09	4.11E-10	3.16E-10	3.52E-09	1.53E-09	4.05E-09	2.38E-16	1.05E-10
HpCDD, 1,2,3,6,7,8,9-	99999999	8.45E-08	9.47E-11	4.76E-12	1.43E-10	6.03E-10	1.39E-10	1.86E-10	8.28E-09	1.86E-09	2.41E-09	7.30E-17	2.19E-10

Table 37b. Derivation of TCDD-TEQ

Constituent	Cas	Soil Conc (mg/kg)	Above Ground Veg Conc (mg/kg)	Below-Ground Veg Conc (mg/kg)	Above Ground Fruit Conc (mg/kg)	Beef Conc (mg/kg)	Milk Conc (mg/kg)	Pork Conc (mg/kg)	Chicken Egg Conc (mg/kg)	Chicken Thigh Meat Conc (mg/kg)	Fish Conc (mg/kg)	Drinking Water Conc (mg/l)	Air Conc (µg/m3)
2,3,7,8-TCDD	1746016	1.58E-09	3.34E-11	1.73E-12	3.99E-11	1.47E-09	4.08E-10	1.15E-10	2.00E-10	1.75E-10	4.51E-09	3.16E-16	6.56E-11
OCDD, 1,2,3,4,5,7,8,9-	3268879	1.62E-11	1.60E-14	1.18E-15	2.47E-14	1.02E-13	2.29E-14	3.49E-14	7.63E-13	6.49E-14	4.51E-13	5.42E-20	3.87E-14
HxCDD, 1,2,3,7,8,9-	19408743	1.44E-09	3.62E-12	2.71E-13	5.27E-12	1.05E-10	2.64E-11	2.11E-11	1.51E-10	7.18E-11	8.62E-11	1.73E-17	7.50E-12
OCDF, 1,2,3,4,6,7,8,9-	39001020	4.05E-11	3.63E-14	1.57E-15	5.81E-14	2.47E-13	5.47E-14	8.68E-14	1.22E-12	2.84E-13	1.11E-13	8.33E-21	9.70E-14
HxCDD, 1,2,3,4,7,8-	39227286	1.64E-09	3.43E-12	1.40E-13	4.55E-12	1.17E-10	2.93E-11	2.45E-11	2.39E-10	1.39E-10	2.53E-10	4.32E-18	5.39E-12
PeCDD, 1,2,3,7,8-	40321764	1.53E-08	5.99E-11	3.84E-12	7.56E-11	2.82E-09	7.35E-10	4.37E-10	1.94E-09	1.69E-09	1.22E-08	8.75E-16	9.49E-11
TCDF, 2,3,7,8-	51207319	5.41E-09	1.22E-10	4.62E-12	1.33E-10	1.75E-09	4.84E-10	1.37E-10	2.49E-10	4.98E-10	4.54E-09	1.10E-15	1.86E-10
HpCDF,1,2,3,4,7,8,9-	55673897	8.91E-10	2.39E-12	1.22E-13	3.45E-12	3.63E-11	9.22E-12	6.77E-12	4.37E-11	1.43E-11	3.57E-11	2.70E-18	4.87E-12
PeCDF, 2,3,4,7,8-	57117314	1.85E-07	2.10E-09	4.72E-11	2.32E-09	9.83E-08	2.70E-08	9.10E-09	4.62E-08	2.22E-08	1.15E-07	6.33E-15	1.40E-09
PeCDF, 1,2,3,7,8-	57117416	8.50E-09	1.73E-10	2.88E-12	1.84E-10	1.80E-09	5.00E-10	1.44E-10	2.13E-09	1.02E-09	4.19E-09	4.77E-16	8.94E-11
HxCDF, 1,2,3,6,7,8-	57117449	2.99E-08	5.35E-11	4.09E-12	7.76E-11	1.70E-09	4.12E-10	4.15E-10	5.02E-09	2.18E-09	2.98E-09	2.81E-16	1.15E-10
HxCDD, 1,2,3,6,7,8-	57653857	7.46E-10	2.18E-12	1.41E-13	3.03E-12	5.38E-11	1.38E-11	9.67E-12	1.21E-10	7.39E-11	1.70E-10	9.02E-18	3.95E-12
HxCDF, 2,3,4,6,7,8-	60851345	2.34E-08	5.45E-11	4.02E-12	7.83E-11	1.36E-09	3.39E-10	2.84E-10	1.27E-09	9.14E-10	5.15E-09	2.64E-16	1.15E-10
HpCDF,1,2,3,4,6,7,8-	67562394	3.70E-09	1.07E-11	5.05E-13	1.51E-11	5.45E-11	1.40E-11	9.65E-12	2.52E-10	6.66E-11	5.97E-11	1.13E-17	2.04E-11
HxCDF, 1,2,3,4,7,8-	70648269	8.04E-08	2.25E-10	1.68E-11	3.26E-10	7.46E-09	1.89E-09	1.41E-09	1.52E-08	6.92E-09	6.45E-09	1.06E-15	4.83E-10
HxCDF, 1,2,3,7,8,9-	72918219	2.09E-09	5.37E-12	3.59E-13	7.47E-12	1.63E-10	4.11E-11	3.16E-11	3.52E-10	1.53E-10	4.05E-10	2.38E-17	1.05E-11
HpCDD, 1,2,3,6,7,8,9-	99999999	8.45E-10	9.47E-13	4.76E-14	1.43E-12	6.03E-12	1.39E-12	1.86E-12	8.28E-11	1.86E-11	2.41E-11	7.30E-19	2.19E-12
TCDD-TEQ		**3.61E-07**	**2.85E-09**	**8.68E-11**	**3.28E-09**	**1.17E-07**	**3.19E-08**	**1.21E-08**	**7.35E-08**	**3.61E-08**	**1.56E-07**	**1.08E-14**	**2.60E-09**

The total daily intake of a contaminant is the sum of the daily intake of contaminant in soil, daily intake of contaminant in all animal tissues, daily intake of contaminant in produce, daily intake of contaminant in fish tissue, and daily intake of contaminant in drinking water.

Table 38. Total Daily Intake of TCDD-TEQ

$$I = I_{soil} + I_{ag} + I_{fruit} + I_{bg} + I_{beef} + I_{milk} + I_{pork} + I_{poultry} + I_{eggs} + I_{fish} + I_{dw}$$

Parameter	Description	Value(s)
I	Total daily intake of TCDD-TEQ (mg/d)	3.24349185290915E-08
I_{soil}	Daily intake of TCDD-TEQ from soil (mg/d) [see Table 39]	1.80418508306408E-11
I_{ag}, I_{fruit}, I_{bg}	Daily intake of TCDD-TEQ from produce (mg/d) [see Table 40]	1.74457355774921E-11+7.5 3595736021453E-12+3.132 20489272975E-11 **=5.63037418650042E-11**
I_{beef}, I_{milk}, I_{pork}, I_{eggs} $I_{poultry}$	Daily intake of TCDD-TEQ from animal tissue (mg/d) [see Table 41]	9.10046357079958E-09+ 1.61709462906894E-08+ 4.46519759934192E-10+ 3.20387803867309E-09+ 1.62990965830754E-09 **=3.05517173184038E-08**
I_{fish}	Daily intake of TCDD-TEQ from farm pond fish (mg/d) [see Table 42]	1.80884069232096E-09
I_{dw}	Daily intake of TCDD-TEQ from drinking water (mg/d) [see Table 43]	1.49256711392941E-14

The daily intake of contaminant from soil by humans is calculated as a product of TCDD-TEQ soil concentration (Sc), consumption rate of soil (CR_{soil}), and fraction of soil contaminated (F_{soil}). All of the ingested soil is assumed to be contaminated.

Table 39. TCDD-TEQ Intake from Soil

$$I_{soil} = Sc \bullet CR_{soil} \bullet F_{soil}$$

Parameter	Description	Value(s)
I_{soil}	Daily intake of TCDD-TEQ from soil (mg/d)	1.80418508306408E-11
Sc	Soil concentration as TCDD-TEQ (mg/kg) [see Table 37]	3.60837016612816E-07
CR_{soil}	Consumption rate of soil (kg/d)	0.00005
F_{soil}	Fraction of consumed soil contaminated (unitless)	1

Table 40 outlines the calculation of contaminant intake from consumption of produce. Contaminant intake from above ground vegetables, fruit, and root vegetables are calculated separately. These calculations are done by multiplying the concentration in the produce (Pd+Pv+Pr and Pr_{bg})by the consumption rate (CR_{ag}, CR_{fruit}, and CR_{bg}) and the fraction contaminated (F_{ag}, F_{fruit}, and F_{bg}).

Table 40. TCDD-TEQ Intake from Produce

$$I_{ag} = (Pd + Pv + Pr) \bullet CR_{ag} \bullet F_{ag}$$

$$I_{fruit} = (Pd + Pv + Pr) \bullet CR_{fruit} \bullet F_{fruit}$$

$$I_{bg} = Pr_{bg} \bullet CR_{bg} \bullet F_{bg}$$

Parameter	Description	Value(s)
I_{ag}	Daily intake of TCDD-TEQ from aboveground vegetables (mg/kg Fw)	1.74457355774921E-11
Pd +Pv+Pr	Concentration of TCDD-TEQ in aboveground produce (mg/kg Dw)	2.85366191934639E-09
CR_{ag}	Consumption rate of aboveground vegetables (kg Dw/d)	0.00611345564771312
F_{ag},F_{fruit},F_{bg}	Fraction contaminated (unitless)	1
I_{fruit}	Daily intake of TCDD-TEQ from fruit (mg/kg Fw)	3.13220489272975E-11
CR_{fruit}	Consumption rate of root vegetables (kg Fw/d)	0.0166049383402284
I_{bg}	Daily intake of TCDD-TEQ from belowground (root) vegetables (mg/kg Fw)	7.53595736021453E-12
Pr_{bg}	Concentration of TCDD-TEQ in root vegetables due to root uptake (mg/kg Fw)	8.68192710789198E-11
CR_{bg}	Consumption rate of fruits (kg Dw/d)	0.00955554080768087

In order to calculate the intake of contaminant from animal tissues, it is assumed that beef, milk, pork, eggs, and chicken are consumed. Each tissue type contaminant intake is calculated separately. The calculation involves the multiplication of the concentration of contaminant in the animal tissue (A_i), the consumption rate of animal tissue (CR_i), and the fraction of animal tissue contaminated (F_i).

Table 41. TCDD-TEQ Intake from Beef, Milk, Pork, Poultry and Eggs

$$I_i = A_i \bullet CR_i \bullet F_i$$

Parameter	Description		Value(s)
I_i	Daily intake of TCDD-TEQ from animal tissue *i* (mg/d)	Beef Milk Pork Eggs Chicken	9.10046357079958E-09 1.61709462906894E-08 4.46519759934192E-10 3.20387803867309E-09 1.62990965830754E-09
A_i	Concentration of TCDD-TEQ in animal tissue *i* (mg/kg Fw)	Beef Milk Pork Eggs Chicken	1.17145867598846E-07 3.19018668319722E-08 1.21485817349301E-08 7.34760177603032E-08 3.61298251985761E-08
CR_i	Consumption rate of animal tissue *i* (kg Fw/d)	Beef Milk Pork Eggs Chicken	0.0776848877159129 0.506896551724138 0.0367548879101124 0.0436044050335571 0.0451125807929947
F_i	Fraction of animal tissue *i* contaminated (unitless)		1

Fish tissue contaminant intake rate is calculated in the same fashion as the other animal tissues. All fish is assumed to be contaminated in this calculation.

Table 42. TCDD-TEQ Intake from Fish

$$I_{fish} = C_{fish} \bullet CR_{fish} \bullet F_{fish}$$

Parameter	Description	Value(s)
I_{fish}	Daily intake of TCDD-TEQ from farm pond fish (mg/d)	1.80884069232096E-09
C_{fish}	Concentration of TCDD-TEQ in farm pond fish (mg/kg)	1.55607603711691E-07
CR_{fish}	Consumption rate of farm pond fish (kg/d)	0.0116243721333333
F_{fish}	Fraction of fish contaminated (unitless)	1

Contaminant intake from drinking water is calculated as shown in Table 42. This calculation assumes that all of the water consumed is contaminated. The factors in this equation are consumption rate of drinking water from the water source (CR_{dw}) and the dissolved contaminant concentration in the water (C_{dw}).

Table 43. TCDD-TEQ Intake from Drinking Water

$$I_{dw} = C_{dw} \cdot CR_{dw} \cdot F_{dw}$$

Parameter	Description	Value(s)
I_{dw}	Daily intake of TCDD-TEQ from drinking water from Verdigris River (mg/d)	1.49256711392941E-14
C_{dw}	Dissolved TCDD-TEQ concentration in drinking water from Verdigris River (mg/L)	1.07822964608454E-14
CR_{dw}	Consumption rate of drinking water from Verdigris River (L/d)	1.3842757146861
F_{dw}	Fraction of drinking water contaminated (unitless)	1

In order to calculate final cancer risk numbers for indirect exposures (those exposures other than inhalation), lifetime average daily dose (LADD) must first be calculated. The factors involved in the calculation of LADD are the total contaminant intake (I), the exposure duration (ED), the exposure frequency (EF), the body weight of the individual (BW), and the averaging time of the exposure (AT). Averaging time is assumed to be 70 years and exposure frequency is assumed to be 350 days per year. Finally, the individual cancer risk is calculated by multiplying the LADD by the oral cancer slope factor (CSF). Note that the total intake is across all pathways (i.e., soil ingestion, inhalation, drinking water ingestion, and food consumption). A pathway-specific risk can be calculated but is not presented here.

Table 44. Individual Cancer Risk from Indirect Exposures to TCDD-TEQ

$$\text{Cancer Risk} = \text{LADD} \cdot \text{CSF}$$

$$\text{LADD} = \frac{I}{BW} \bullet \frac{ED}{AT} \bullet \frac{EF}{365}$$

Parameter	Description	Value(s)
Cancer Risk	Lifetime excess cancer risk	0.0000167104125995378
LADD	Lifetime average daily dose (mg/kg/d)	1.07118029484217E-10
I	Total daily intake of TCDD-TEQ (mg/d)	3.24349185290915E-08
ED	Exposure duration (yr)	17.31
EF	Exposure frequency (d/yr)	350
BW	Body weight (kg)	71.8
AT	Averaging time (yr)	70
365	Units conversion factor (d/yr)	
CSF	Oral cancer slope factor (per mg/kg/d)	156,000

Calculation of cancer risk due to direct inhalation is similar to that of indirect exposure. The first difference is that when calculating the LADD, the inhalation rate (IR) and total air concentration (C_a) are used instead of the intake rate. As with indirect exposure, the exposure duration (ED) and frequency (EF) are used in the numerator of the calculation and body weight (BW) and averaging time (AT) are in the denominator. Cancer risk is then the product of the LADD and the inhalation carcinogenic slope factor (CSF (inh)).

Table 45. Calculation of Cancer Risk due to Direct Inhalation of TCDD-TEQ using CSF

$$CR = LADD \bullet CSF\,(inh)$$

$$LADD_{inh} = \frac{C_a \bullet IR}{10^3\,BW} \bullet \frac{ED}{AT} \bullet \frac{EF}{365}$$

Parameter	Definition	Value(s)
CR	Lifetime Excess Cancer Risk	1.78230285365057E-08
LADD	Lifetime average daily dose of TCDD-TEQ (mg/kg/d)	1.14250182926319E-13
C_a	Total air concentration of TCDD-TEQ (µg/m^3)	2.60109071982385E-09
IR	Inhalation rate (m^3/day)	13.3
EF	Exposure frequency (d/yr)	350
ED	Exposure duration (years)	17.31
BW	Body weight (Kg)	71.8
AT	Averaging time (years)	70
1,000	Units conversion factor (µg/mg)	
365	Units conversion factor (d/yr)	
CSF (inh)	Inhalation carcinogenic slope factor (per mg/kg/d)	156,000