5.0 ENVIRONMENTAL MEDIA CONCENTRATIONS

In this section, the results of the air dispersion and deposition modeling are used in various fate, transport, and uptake models in order to generate estimates of the exposure point concentrations of the chemicals of concern in the environmental media surrounding the facility. The media concentrations can then be combined with data on human exposure to arrive at intake values which can then be compared to relevant toxicity data in order to characterize the potential human health risks associated with the facility's operations. The models employed are based on those presented in the various U.S. EPA guidance, particularly the U.S. EPA 1998 HHRAP document, as well as on media-specific physical data collected from the areas surrounding the facility. The specific migration pathways and environmental media evaluated in this section include:

- Air--estimates of ambient air concentrations of vapor phase and particulate matter chemicals

- Soil--estimates of the cumulative soil concentration due to wet and dry deposition of chemicals onto the soil and the adsorption of vapor phase chemicals onto soil particles

- Ground water--an evaluation of the potential for chemicals deposited onto soil to leach into ground water

- Surface water--estimates of the cumulative concentration of chemicals of concern in surface water through air deposition, runoff, and soil erosion loading

- Fish uptake--estimates of the uptake of the chemicals of concern in surface water by fish and the resultant fish tissue concentrations

- Crop/plant uptake--estimates of the uptake of chemicals of concern by plants via direct deposition on plant surface, root uptake; and direct air to plant transfer and the resultant plant tissue concentration

- Livestock uptake: an estimate of the uptake of chemicals of concern by livestock through ingestion of locally grown feed and pasture grass and the resultant tissue concentration.

5.1 AIR

In this section, long term average air concentrations of chemicals emitted from the kiln and fugitive emission sources are calculated for the receptor locations considered in this assessment. Total air concentrations at the receptor locations are determined to be the sum of chemicals present as both vapor phase and particulate bound matter.

As discussed in Section 3.0, the list of chemicals of concern for the inhalation exposure pathway includes: all organic and inorganic chemicals identified in the kiln emissions and modeled fugitive volatile emissions from liquid waste derived fuel storage and transfer operations.

The emission rates used to determine the air concentrations are presented on Table 3-9. These stack emission rates were determined from the average two-kiln emission rates for each chemical. The LWDF fugitive emission rates were those determined by SCI-TECH (Appendix B) as presented on Table 3-9. The emission rates from Table 3-9 used in this evaluation were the total volatile emissions for all sources.

The air concentrations of all chemicals detected in emissions from the ESSROC facility were calculated using the following equation:

$$Ca = Q*[Fv*Cyv+(1-Fv)*Cyp]$$

For mercury, air concentrations were calculated for both elemental mercury and divalent mercury using the following equations:

Elemental Mercury $Ca = 0.002Q*[Fv*Cyv+(1-Fv)*Cyp]$

Divalent Mercury $Ca = 0.48Q*[Fv*Cyv+(1-Fv)*Cyp]$

where:

Ca = air concentration (ug/m^3)
Q = chemical emission rate (g/s)
Fv = fraction of chemical in vapor phase (unitless)
Cyv = unitized yearly air concentration from vapor phase (ug-s/g-m)
Cyp = unitized yearly air concentration from particle phase (ug-s/g-m^3)

The estimated air concentrations for all chemicals of concern (both the direct and indirect exposure pathways) are presented on Table 5-1.

5.2   SOIL

Contaminants of concern emitted from the ESSROC facility are subject to deposition onto soil surfaces in the vicinity of the site. The cumulative soil contaminant concentrations are the result of two general processes: 1) wet and dry particle phase and vapor deposition of chemicals onto the soil; and 2) the cumulative loss of contaminants from soil due to processes such as leaching, surface runoff, soil erosion, and environmental degradation. The following sections provide a description of the methodologies used to calculate the chemical-specific soil concentrations. Table 5-2 presents a summary of the chemical-specific parameters used to calculate the concentrations of chemicals of concern in soils and Table 5-3 presents a summary of the non-chemical dependent parameter values used to calculate the chemical concentrations in soil.

The concentrations of the chemicals of concern in soils resulting from airborne emissions from the ESSROC facility were estimated according to the following equations (U.S. EPA, HHRAP, 1998).

Carcinogens

For $T_2 \leq T_c$

$$Sc = \frac{Ds}{(ks*(Tc-T_1))} * \left[\left\{ Tc + \frac{\exp(-ks*Tc)}{ks} \right\} - \left\{ T_1 + \left(\frac{\exp*(-ks*T_1)}{ks} \right) \right\} \right] \text{Equation } 5\text{-}1a$$

For $T_1 < Tc < T_2$

$$Sc = \frac{\left(\dfrac{Ds * Tc * Sc_{Tc}}{ks}\right) + \left(\dfrac{Sc_{Tc}}{ks}\right) * \left(1 - \exp[-ks * (T2 - Tc)]\right)}{(T_2 - T_1)} \quad \text{Equation 5-1b}$$

Noncarcinogens

$$Sc = \frac{Ds * [1 - \exp(-ks * Tc)]}{ks} \quad \text{Equation 5-1c}$$

where:

Sc = average soil concentration of chemical over exposure period (mg chemical/kg soil)

Ds = Deposition term (mg chemical/kg soil/yr)

T_1 = time period at beginning of combustion (yr)

ks = chemical soil loss constant (yr^{-1})

Tc = total time period over which deposition occurs (time period of combustion (yrs)

Cs_{Tc} = soil concentration at time Tc (mg/kg)

T2 = length of exposure duration (yr)

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

where:

Q = chemical-specific emission rate (g/s)

Z = soil mixing depth (cm)

BD = soil bulk density (g soil/cm^3 soil)

Fv = fraction of chemical air concentration in vapor phase (unitless)

Vdv = dry deposition velocity (cm/s)

Cyv = unitized yearly average air concentration from vapor phase (ug-s/g-m^3)

Dywv = unitized yearly average wet deposition from vapor phase (s/m^2-yr)

Dydp = unitized yearly average dry deposition from particle phase (s/m^2-yr)

$Dywp$ = unitized yearly average wet deposition from particle phase (s/m^2-yr)

As described in the U.S. EPA 1998 HHRAP, the emission rate for mercury was adjusted to account for that portion of mercury emitted from combustion sources that enters the global cycle and is not deposited in the area of the combustion source. Specifically, the measured mercury emission rate (Q) was multiplied by a factor of 0.48 to account for the loss in the global cycle. The resulting mercury deposition value was then speciated into divalent and methyl mercury by multiplying the mercury deposition rate by 0.98 and 0.02, respectively.

5.2.1 AIR MODELING OUTPUT PARAMETERS

The air modeling output parameters used in the above equations were estimated using the air modeling methods described in Section 4.0. Soil concentrations were calculated using air modeling scaling factors derived for the following three modeling scenarios previously described in Section 4.0: maximum exposure area; France Park discrete receptor; and watershed exposure. The maximum exposure scaling factors were derived by calculating areal average factors for an area extending approximately 4.0 kilometers from the ESSROC facility. Specifically, all receptor points located outside of the ESSROC facility boundary, and extending radially to a distance of 4.0 kilometers from the ESSROC facility, were used to calculate the areal average values. These areal average values provide an estimate of reasonable maximum exposures to modeled air emissions from the ESSROC facility. The modeled output parameters are presented in Table 4-4.

The France Park complex is a local recreational area located west of the ESSROC facility. In order to evaluate potential exposures at this location, the modeled dispersion and deposition scaling factors for this discrete receptor point were used in this risk assessment. The modeled output parameters are presented on Table 4-4.

The air dispersion and deposition scaling factors for the Eel and Wabash River watersheds were derived by calculating areal averages for all receptor points located east of the ESSROC facility to a distance of 30 kilometers. Section 5.4.1.1 provides the rationale for this approach. The modeled output parameters are presented on Table 4-4.

5.2.2 DEPOSITION TIME (Tc)

The total time period over which deposition occurs (Tc) is equal to the estimated lifetime of the combustor. For this evaluation, a time period of 30 years deposition was evaluated for the typical and high end exposure scenarios.

5.2.3 SOIL MIXING DEPTH (Z)

The soil mixing depth parameter (Z) is based on the particular activities conducted on soils. For this risk assessment, soil depths of 1 cm and 20 cm were used in the soil concentration algorithm, depending on the land use being evaluated. Specifically, soil concentrations assuming a depth parameter value of 20 cm were used for evaluation of the plant consumption pathway, since it is assumed that tilling of soils would result in contaminant disposition in soils at depths to 20 cm or more. For all other pathways modeled in this risk assessment, a soil depth of 1 cm was used.

5.2.4 BULK DENSITY (BD)

The soil bulk density (BD) value was obtained from the Cass and Carroll County Soil Survey documents (USDA 1981) published by the local soil conservation district. A soil bulk density representative of the predominant soil type in Cass and Carroll Counties was used for this assessment. The predominant soil type in Cass County is the cyclone silt loam. The soil survey document reports a moist bulk density range for cyclone silt loam of 1.3 to 1.5 g/cm^3. The predominant soil type in Carroll County is the Rockfield-Williamston complex. The Carroll County soil survey document reports a moist bulk density range for these soils of 1.3 to 1.45 g/cm^3. Based on this information, a soil bulk density value of 1.4 g/cm^3 was chosen.

5.2.5 SOIL LOSS EQUATION

The soil loss constant (ks) in the soil concentration equation was calculated using the following equation:

$$ks = ksl + kse + ksr + ksg \qquad \text{[Equation 5-2]}$$

where:

ks = soil loss constant due to all processes (yr^{-1})

ksl = loss constant due to leaching (yr^{-1})

kse = loss constant due to soil erosion (yr^{-1})

ksr = loss constant due to surface runoff (yr^{-1})

ksg = loss constant due to degradation (yr^{-1})

5.2.5.1 Leaching Soil Loss Constant (ksl)

The soil loss constant due to leaching is calculated according to the following equation:

$$ksl = (P + I - R - Ev)/[(o*Z\,(1 + (BD*Kds)/o))] \qquad \text{[Equation 5-3]}$$

where:

ksl = loss constant due to leaching (yr^{-1})

P = average annual precipitation (cm/yr)

I = average annual irrigation (cm/yr)

R = average annual runoff (cm/yr)

Ev = average annual evapotranspiration (cm/yr)

o = soil volumetric water content (mL/cm^3)

Z = soil depth from which leaching removal occurs (cm)

BD = soil bulk density (g/cm^3)

Kds = soil water partitioning coefficient (mL/g)

Average annual precipitation (P)

An average annual precipitation of 96.5 cm/year for the study area was obtained from the Water Resources Data Indiana Water Year 1992 (Stewart et al., 1992).

Irrigation (I)

Information provided in the Cass County comprehensive plan indicates that the irrigation potential for Cass County is good, but that an insignificant amount of land is actually

irrigated (approximately 20 acres in 1982). For this reason, an annual average irrigation (I) value of 0 cm/year was used.

Evapotranspiration (E)

An evapotranspiration (E) value of 60 cm/yr for the study area was obtained from Baes et al. (1984) and is used in this assessment.

Runoff (R)

An average annual runoff value (R) 30 cm/year is used in this risk assessment and was obtained from Water Resources Data for Indiana (Stewart et al., 1992). This is the average value for the entire Wabash River basin (within which the entire site lies).

Soil volumetric water content (o)

A soil volumetric water content (o) of 0.25 mL/cm^3 was used based on guidance presented in the interim guidance document. This value represents volumetric water content for predominantly loamy soils.

Bulk Density (BD)

A soil bulk density (BD) of 1.4 g/cm^3 was used, as described previously.

Soil Depth (Z)

As described previously, soil depths (Z) of 1 and 20 cm were used.

Soil Water Partitioning Coefficient (Kds)

The soil water partitioning coefficients (Kds) for the chemicals of concern were obtained from Appendix A-3 of the U.S. EPA 1998 HHRAP guidance document. These values are shown on Table 5-2.

5.2.5.2 Erosion Soil Loss Constant (kse)

The soil loss constant due to erosion (kse) was calculated using the following equation:

$$kse = [(0.1 \ Xe \ SD \ ER)/(BD \ Z)] * [(Kd_s \ BD)/(o + Kd_s \ BD)] \qquad \text{[Equation 5-4]}$$

where:

kse	=	soil loss constant due to erosion (yr^{-1})
Xe	=	unit soil loss ($kg/m^2/yr$)
Kds	=	soil water partition coefficient (cm^3/g)
BD	=	soil bulk density (g/cm^3)
Z	=	soil mixing zone depth (cm)
o	=	volumetric water content (cm^3/cm^3)
SD	=	sediment delivery ratio (unitless)
ER	=	contaminant enrichment ratio
0.1		= units conversion (g-kg/cm^2-m^2)

Sediment Delivery Ratio (SD)

The sediment delivery ratio is calculated according to the following equation presented in the addendum to the interim guidance document:

$$SD = a(WA_L)^{-b} \qquad \text{[Equation 5-5]}$$

where:

SD	=	sediment delivery ratio
WA_L	=	watershed surface area receiving fallout (m^2)
b	=	empirical slope coefficient (=0.125)
a	=	empirical intercept coefficient

Empirical intercept coefficients (a) have been compiled by Vanoni et al. 1975 and are based on the area of the watershed. A watershed area of $7.85 \times 10^9 \ m^2$ (watershed area for the Wabash River Basin) was used giving an empirical intercept coefficient of 0.6. This results in an SD value of 0.035.

Contaminant Enrichment Ratio (ER)

The enrichment ratio (ER) accounts for the fact that erosion favors the lighter soil particles, which have higher surface area to volume ratio and are higher in organic matter content. Enrichment ratios have been assigned values that range from 1 to 5. The enrichment ratio is expected to be higher in sandy soils as compared to silty or loamy soils because the finer silt particles which erode from a soil generally characterized as sandy are more a deviation from the norm compared to silt particles which erode from a soil generally characterized as silty or loamy. Based on guidance presented in the addendum interim guidance document, a value of 3 was chosen for the enrichment ratio.

Unit Soil Loss (Xe)

The unit soil loss parameter (Xe) was calculated using the universal soil loss equation:

$$Xe = (R * K * LS * C * P_s * 907.18 \text{ kg/ton})/(4047 \text{ m}^2/\text{acre}) \text{ [Equation 5-6]}$$

where:

Xe = soil loss rate per unit area over time (kg/m^2-yr)

R = erosivity factor (yr^{-1})

K = erodibility factor (tons/acre)

LS = slope length factor (unitless)

C = cover management factor (unitless)

Ps = supporting practice factor (unitless)

Several of the factors included in this equation are most generally applicable to agricultural situations. Distinctions between the tilled agricultural soils (mixing depth of 20 cm) and non-tilled soils (mixing depth of 1 cm) are noted where appropriate in the discussion of these factors provided below.

Erosivity Factor (R)

The erosivity factor (R) reflects the influence of rainfall on erosion of soils. For this risk assessment an erosivity factor of 180 was used for both the tilled and untilled soils. This value was obtained from "Predicting Rainfall Erosion Losses" (Wischmeir, 1978).

Erodibility factor (K)

The erodibility factor (k) was obtained from the Cass and Carroll County Soil Survey documents. An erodibility factor representative of the predominant soil type in Cass and Carroll Counties was used. As described previously, the predominant soil type in Cass County is the cyclone silt loam. The soil survey document for Cass County reports an erodibility factor for cyclone silt loam of 0.28.

The predominant soil type in Carrol County is the Rockfield-Williamston complex. The Carroll County soil survey document reports an erodibility factor for these soils of 0.37.

An average of these two factors for Cass and Carroll Counties was used for the soil erodibility factor (0.33) for both the tilled and untilled soils.

Topographic factor (LS)

The topographic factor (LS) is an estimate of the expected soil loss as a function of steepness and length of the individual plots modeled. The indirect guidance document uses a topographic factor of 0.179, which is indicative of flat terrain and small unit fields. For this evaluation, the topographic factor of 0.179 was used for both till and untilled soils. This value is consistent with the relatively flat terrain of the majority of Cass and Carroll Counties.

Cover management factor (C)

The cover management factor (C) reflects the influence of vegetative cover and cropping practices on soil erosion. As described previously, most agricultural land in Cass and Carroll Counties is used for the row crops corn and soybeans, which are the predominant crops grown in the area. The interim guidance document recommends a cover management factor of between 0.1 and 0.7 for areas where agricultural row crops are grown. Based on this guidance, a cover management factor of 0.4 was chosen for this risk assessment.

Support practice factor (P)

The support practice factor (P) is a correction factor that reflects the use of surface conditioning, dikes, or other methods to control runoff/erosion. For this assessment, a support practice factor of 1.0 is used in this risk assessment which assumes that no such support practices are in place to control erosion.

5.2.5.3 Degradation Rate Constant (ksg)

The degradation rate constant term (ksg) reflects the influence of biotic and abiotic degradation of a chemical on its soil concentration. The degradation rate constant was calculated using the following equation:

$$ksg = 0.693/t_{1/2} \hspace{3cm} \text{[Equation 5-7]}$$

The reported half life in soil ($t_{1/2}$) for each chemical of concern evaluated via the indirect pathways of exposure are presented on Table 5-2.

5.2.5.4 Runoff Rate Constant (ksr)

The soil loss constant due to runoff (ksr) was calculated using the following equation:

$$ksr = R / Z*o * (1/1+(Kds * BD/o)) \hspace{2cm} \text{[Equation 5-8]}$$

where:

ksr = soil loss constant due to runoff (yr^{-1})
R = average annual runoff (cm/yr)
Kds = soil water partition coefficient (cm^3/g)
BD = soil bulk density (g/cm^3)
Z = soil mixing zone depth (cm)
o = volumetric water content (cm^3/cm^3)

Values for each of the parameters in Equation 5-8 were those previously described in this section.

5.2.6 CALCULATED CONCENTRATIONS OF CHEMICALS IN SOILS

The chemical-specific parameter values used in the above equations to calculate the concentrations of chemicals of concern in soil attributable to emissions from the ESSROC facility are presented in Table 5-2. The values for the non chemical-specific parameters used in the above equations are presented in Table 5-3.

The estimated concentrations of chemicals of concern in soils attributable to emissions from cement kiln operations for the maximum exposure area are presented on Table 5-4.

5.3 GROUND WATER

The interim guidance document outlines methods for predicting concentrations of chemicals in ground water as a result of deposition of contaminants emitted from combustors onto soil and leaching through soil to the ground water. However, information presented in the interim final guidance document indicates that leaching of chemicals to ground water and subsequent ingestion of ground water is not considered a significant exposure pathway for combustor emissions.

Additionally, the constituents of concern for the indirect pathways of exposure evaluated in this risk assessment are metals and semi-volatile compounds that are characteristically persistent and bioaccumulative in the environment. These compounds are typically not mobile in soils, but rather, tend to adsorb to soil particles. Therefore, leaching to ground water is not considered a significant migration pathway for the constituents of concern deposited onto soil surfaces and is not evaluated quantitatively in this risk assessment.

5.4 SURFACE WATER AND FISH

5.4.1 ESTIMATION OF SURFACE WATER CONCENTRATIONS

In order to evaluate the impact of combustion emissions from the ESSROC facility on nearby surface water bodies, the concentrations of chemicals of potential concern in several individual surface water bodies were determined. Specifically, in this evaluation, potential human exposures to chemicals of concern in the following three surface water bodies were evaluated: (1) the Eel River which is the source for Logansport's drinking water supply; (2) the Wabash River which is assumed to represent a natural surface water

body used for fishing and other aquatic recreation; and (3) the swimming lake at France Park.

The concentrations of chemicals in these three surface water bodies attributable to emissions from the ESSROC facility were estimated using the methodology presented in the U.S. EPA 1998 HHRAP guidance document. These methodologies estimate surface water body chemical concentrations in the total water column. The total water column concentration for a chemical is the sum of the chemical concentration in the dissolved phase and the chemical concentration associated with suspended solids. The partitioning between the water and sediment varies depending on the physical and chemical properties of the particular chemical. The chemical-physical properties used to estimate surface water concentrations for the chemicals of concern are presented on Table 5-5. These values were obtained from Appendix A-3 of the U.S. EPA 1998 HHRAP guidance document. It is also noted, that per guidance presented in U.S. EPA 1998 HHRAP, the chemical-specific input values for Aroclor 1254 were used as surrogate values for the PCBs (both the ten congener classes and the coplanar PCBs).

5.4.1.1 Total Chemical Load to Surface Water Bodies

The first step in estimating the concentrations of chemicals in surface water is to calculate the total loading to the water body using the following equation:

$$L_t = L_{dep} + L_{ri} + L_r + L_o + L_{diff} \qquad \text{[Equation 5-9]}$$

where:

L_t = total chemical load to the water body (g/yr)
L_{dep} = total (wet and dry) particle phase and wet vapor phase deposition (g/yr)
L_{ri} = runoff load from impervious surfaces (g/yr)
L_r = runoff load from pervious surfaces (g/yr)
L_o = soil erosion load (g/yr)
L_{diff} = vapor phase chemical diffusion (dry deposition) load to water body (g/yr)

The following equation was used to estimate the dry and wet deposition loading to the water bodies:

$$L_{dep} = Q * [Fv * Dywwv + (1-Fv) * Dytwp] * WA_w \qquad \text{[Equation 5-10]}$$

where:

Ldep = chemical deposition load to water body (g/yr)
Q = chemical specific emission rate (g/s)
Fv = fraction of chemical in vapor phase (unitless).
Dywwv = unitized yearly average wet deposition from vapor phase (s/m²-yr)
Dytwp = unitized yearly average total (wet and dry) deposition from vapor phase (s/m²-yr)
WA_w = water body area (m²)

The air model parameter values (Dywwv and Dytwp) used to estimate surface water concentrations of chemicals of concern via deposition are presented on Table 4-4. For this evaluation, the actual Dywwv and Dytwp values modeled at the France Park receptor point were used to estimate the chemical load due to deposition.

For the Eel and Wabash Rivers, the air model values shown on Table 4-4 were derived in the following manner. The ESSROC facility lies within the Wabash River Basin. The Eel River and the Wabash River both lie within the Wabash River Basin. Based on information provided in the *U.S. Geological Survey Water-Data Report for 1992*, the total drainage areas for the Eel River and the Wabash River is 789 mile² (2.04 E+9 m²) and 3,779 mile² (9.78E+9 m²), respectively. These values represent the total drainage areas for these rivers upstream of the Logansport gauging station. As described previously, the air dispersion and deposition modeling rates were estimated at points radial from the ESSROC facility up to 50 kilometers (km). Therefore, the total area of deposition within a 50 km radius of the ESSROC facility is equal to 7.85E+9 m² (i.e., $\pi \times$ (50 km)²). Since the Logansport gauging station represents the total drainage areas for the Eel and Wabash Rivers upstream of Logansport, it can be assumed that ½ of the deposition area (i.e., 3.9 E+9 m²) would contribute to chemical loading at the location (Logansport) where indirect exposures to surface waters are evaluated in the risk assessment. Therefore, the watershed area for the Wabash River was estimated to be one half of the total deposition area. However, it is likely that deposition rates at points beyond 30 kilometers from the combustion source would have little or no contribution to the total chemical loading for the watershed. Therefore, the air model values used to model surface water exposures for the Eel and Wabash Rivers were derived by

calculating the areal average of those receptor points located upgradient of the combustion source to a distance of 30 kilometers (watershed area $1.4 \, E^{+9} \, m^2$). It is noted that the Eel River actually merges with the Wabash River at Logansport. Therefore, the watershed area for the Eel River essentially falls within the Wabash River watershed area.

A watershed area of $2.8 \, E^{+8} \, m^2$ was used for the Eel River in the risk assessment. This value represents 20% of the Wabash River watershed area (i.e., $1.4 \, E^{+9} \, m^2$) used in the risk assessment. A factor of 20% was used to estimate the Eel River watershed area based on the ratio of the drainage area of Eel River (789 mile^2) to the drainage area of the Wabash River (3,779 mile^2). Since the Logansport gauging station for the Wabash River is located downstream of the confluence of the Eel and Wabash Rivers, the drainage area for the Eel River comprises a portion (20%) of the total drainage area for the Wabash River at Logansport. Therefore, the 20% factor was used to estimate the watershed area for the Eel River lying within the deposition area.

The average two-kiln emission rates described previously were used in the equation. Additionally, the emission rate for mercury was multiplied by 0.48, for reasons described previously. The L_{dep} rates for mercury were speciated into divalent and methyl mercury by multiplying the L_{dep} by 0.85 and 0.15, respectively.

Local USGS and topographic maps were used to estimate the water body surface areas for the three surface water bodies. Since the point of exposure to surface water is the Logansport area and the air dispersion and deposition modeling rates were estimated at points radial from the ESSROC facility up to 30 kilometers (km), a lineal distance of 30 kilometers was used to estimate the water body surface areas for the Eel and Wabash Rivers. The resulting water body surface areas are $1.8 \times 10^6 \, m^2$ and $5 \times 10^6 \, m^2$ for the Eel and Wabash Rivers, respectively.

The water body area for the France Park swimming quarry was estimated using aerial photographs and topographic maps. A water body area of 83 m^2 was used for the France Park swimming quarry.

The impervious runoff load to the water body was calculated using the following equation:

$$L_{ri} = Q * [Fv * Dywwv + (1 - Fv) * Dytwp] * WA_i \qquad \text{[Equation 5-11]}$$

where:

L_{ri} = impervious runoff load (g/yr)

Dywwv = unitized yearly average wet deposition from vapor phase (s/m^2-yr)

Dytwp = unitized yearly average total (wet and dry) deposition from vapor phase (s/m^2-yr)

WA_i = impervious water shed area receiving deposition (m^2)

The fraction vapor and emission rates used in this equation were described previously. The impervious water shed area represents that portion of the water shed covered by an impervious surface (i.e., roads, buildings, etc.). Since the ESSROC facility is located in a rural setting, it was conservatively assumed that the impervious water shed area for the Eel and Wabash Rivers and the France Park swimming quarry comprises approximately 1% of the total water shed area. The methods for estimating the total water shed areas for the Wabash and Eel Rivers were described previously. The method for estimating the total water shed areas for the France Park swimming quarry is described in the following sections.

The following equation was used to estimate the total loading from pervious surface runoff:

$$L_r = R * (WA_L - WA_i) * (Sc * BD/0 + Kds * BD) * 0.01 \qquad \text{[Equation 5-12]}$$

where:

L_r = pervious surface runoff (g/yr)

R = average annual surface runoff (cm/yr)

Sc = pollutant concentration in water shed soils (mg/kg)

BD = soil bulk density (g/cm^3)

Kds = soil-water partition coefficient (cm3/g)

WA_L = total watershed area receiving pollutant deposition (m^2)

WA_i = impervious watershed area receiving pollutant deposition (m^2)

0.01 = units conversion factor (kg-cm^2/mg-m^2)

0 = volumetric soil water content (cm^3/cm^3)

An average annual runoff of 30 cm/yr was used as described previously. The soil concentrations calculated for untilled soils under the reasonable maximum exposure

scenario were used in this equation. A soil bulk density of 1.4 g/cm³ was used as described previously. A volumetric soil water content of 0.25 and chemical-specific soil water partition coefficients were used.

The watershed/drainage areas for the Eel and Wabash Rivers were described previously. The watershed/drainage area for the France Park swimming lake was estimated from the U.S.G.S. Topographic Map. Based on the review of the topographic map, the watershed/drainage area for the France Park swimming lake was estimated to be 250,914 m².

The erosion load to the water bodies was estimated using the following equation:

$$L_e = X_e*(WA_L-WA_i)*SD*ER (Sc*Kds*BD/0 + Kds * BD) * 0.001 \quad \text{[Equation 5-13]}$$

where:

Le = soil erosion load (g/yr)
Xe = unit soil loss (kg/m²/yr)
Sc = chemical concentration in watershed soils (mg/kg)
BD = soil bulk density (g/cm³)
Kds = soil-water partition coefficient (cm3/g)
0 = volumetric soil water content (cm³/cm³)
WA_L = total watershed area receiving pollutant deposition (m²)
WA_i = impervious watershed area receiving pollutant deposition (m²)
SD = sediment delivery ratio (unitless)
ER = soil enrichment ratio (unitless)
0.001 = units conversion factor ([g/kg]/[mg/kg])

The chemical concentration (Sc), soil bulk density (BD), volumetric water content (0), soil-water partition coefficient (Kds), total watershed area (WA_L), total impervious watershed area (WA_i), unit soil loss (X_e), and sediment delivery ratio (SD) parameter values used were the same as previously described. A soil enrichment ratio of 3 was used in accordance with the screening level guidance document.

The load to the water body due to dry vapor phase diffusion was calculated using the following equation:

$$L_{diff} = (K_v * Q*Fv * Cywv *WA_w * 10^{-6})/(H/R*T^{wk}) \quad \text{[Equation 5-14]}$$

where:

L_{diff} = dry vapor phase load to water body (g/yr)
Kv = overall transfer rate coefficient (m/yr)
Q = chemical-specific emission rate (g/s)
Fv = fraction of chemical in vapor phase (unitless)
$Cywv$ = unitized yearly air concentration from vapor phase (ug-s/g-m³)
WA_w = water body surface area (m²)
10^{-6} = unit conversion factor (g/ug)
H = Henry's Law Constant (atm-m³/mol)
R = universal gas constant (atm-m³/mol-K)
Twk = water body temperature (K)

The values for Q, Fv, Cywv, H, WA$_w$, and R have been previously described. A water body temperature of 289 K was used in this equation. The emission rate for mercury was multiplied by 0.48, for reasons described previously. Additionally, the Ldiff for mercury was speciated into divalent and methyl mercury by multiplying the resulting Ldiff for mercury by 0.85 and 0.15, respectively.

The overall chemical transfer rate coefficient (Kv) was calculated according to the following equation:

$$Kv = \left[K_L^{-1} + \left\{ K_G * \frac{H}{R*T_{wk}} \right\}^{-1} \right]^{-1} * \theta^{T_{wt}-29)} [Equation 5-15]$$

where:

Kv = overall transfer rate coefficient (m/yr)
K_L = liquid phase transfer coefficient (m/yr)

K_G = gas phase transfer rate coefficient (m/yr)
H   Henry's Law Constant (atm-m³/mol)
R   = universal gas constant (atm-m³/mol-K)
T_{wk} = water body temperature (K)
0   = temperature correction factor (unitless)

The Henry's Law Constant, universal gas constant and water body temperature parameter values have been described previously. The default value recommended in the U.S. EPA 1998 HHRAP document of 1.026 was used for the universal temperature correction factor.

The liquid phase transfer coefficient was calculated using the following equation:

For flowing rivers and streams:

$$K_L = \sqrt{\frac{10^{-4} * D_w * u}{d_z}} * 3.1536 * 10^7 \; [Equation \; 5\text{-}16]$$

For quiescent lakes or ponds:

$$K_L = \left(C_d^{\;0.5}\right) * \left(\frac{p_a}{p_w}\right)^{0.5} * \left(\frac{k^{0.33}}{\lambda_z}\right) * \left(\frac{u_w}{p_w * D_w}\right)^{-0.67} * 3.1536 * 10^7 \; [Equation \; 5\text{-}17]$$

where:

K_L = liquid phase transfer coefficient (m/yr)
Dw   = diffusivity of chemical in water (cm²/s)
u   = current velocity (m/s)
d_z = total water body depth (m)
3.1536 x 10^7 = units conversion factor (s/yr)
Cd   = drag coefficient (0.0011, unitless)
W   = average annual wind speed (m/s)
p_a = density of air (0.0012 g/cm³)
p_w = density of water (1 g/cm³)
k   = von Karman's coefficient (0.4, unitless)
lambda$_z$ = dimensionless viscous sublayer thickness (4)

u_w = viscosity of water corresponding to water temperature (0.0169 g/cm-s)

The chemical-specific water diffusivities were obtained from the U.S. EPA 1998 HHRAP guidance. For chemicals with no water diffusivity values, a water diffusivity value was derived according to the following equation presented in Section A3.3.5 of the U.S. EPA 1998 HHRAP document

$$Dw = 22 \times 10^{-5} / (MW)^{2/3}$$

The following total water body depths (d_z) were used in this equation: Eel River – 1.83 m; Wabash River – 2.43 m; and France Park swimming lake – 10.03 m. Consistent with the air dispersion modeling, an average annual wind speed of 2.16 m/s was used in the above equation.

A current velocity of 0.092 m/s was used for the Eel and Wabash Rivers. This value was obtained by dividing the average volumetric flow rate (6.75×10^8 m³/yr) by the cross-sectional area of the Wabash River (240 m²).

For flowing rivers and streams, the K_G value used in the overall transfer coefficient rate equation was 36,500 m/yr. For quiescent lakes or ponds, the KG was calculated according to the following equation:

$$K_G = \left(C_d^{0.5} * W \right) * \frac{k^{0.33}}{\lambda_z} * \frac{u_a}{p_a * D_a}^{-0.67} * 3.1536 \times 10^7 \quad \text{[Equation 5-18]}$$

The parameter values for K_G have been described previously.

5.4.1.2 Total Water Body Concentration

The total concentration of chemicals of concern in the individual water bodies (water column plus bed sediment) was calculated according to the following equation:

$$C_{wtot} = L_t / Vf_x * f_{wc} + k_{wt} * WA_w * (d_{wc} + d_{bs}) \quad \text{[Equation 5-19]}$$

where:

C_{tot} = total waterbody concentration (water column and bed sediment) (mg/L)

L_t = total chemical load to water body (g/yr)

Vf_x = average volumetric flow rate through the water body (m³/yr)

f_{wc} = fraction of total waterbody concentration in water column (unitless)

d_{wc} = depth of water column (m)

d_{bs} = depth of upper benthic layer (m)

WA_w = waterbody surface area (m²)

k_{wt} = total waterbody dissipation rate constant (yr⁻¹)

The total load to the water body (L_t) and waterbody area (WA_w) parameter values previously described were used. In accordance with the U.S. EPA 1998 HHRAP guidance document, a value of 0.03 m was used for the depth of upper benthic layer for all three waterbodies. The following waterbody depths were used: Eel River - 1.8 m; Wabash River - 2.4 m; and France Park swimming quarry - 10 m.

The average volumetric flow rates for the Eel and Wabash Rivers were obtained from U.S. Geological Survey Data (Stewart et al., 1992). The volumetric flow rate for both the Eel and Wabash Rivers are 6.75×10^8 m³/yr. For the France Park swimming quarry, the flow rate was assumed to be equal to the average annual inflow. The average annual inflow to the lake was estimated by multiplying the average annual runoff and the drainage area plus the surface area of the lake. The resulting flow rate for the France Park swimming quarry is estimated to be 76,805 m³/yr.

5.4.1.3 Water Column Fraction

The fraction of total waterbody concentration present in the water column (f_{wc}) was calculated according to the following equation:

$$f_{wc} = \frac{\left(1 + kd_{sw} * TSS * 1 * 10^{-6}\right) * d_{wc} / d_z}{\left(1 + kd_{sw} * TSS * 1 * 10^{-6}\right) * d_{wc} / dz + \left(o_{bs} + kd_{bs} * C_{bs}\right) * d_{bs} / d_z} \quad \text{[Equation 5-19]}$$

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

where:

f_{wc} = fraction of total water body contaminant concentration in water column (unitless)

kd_{sw} = suspended sediment/surface water partition coefficient ((L/kg)

TSS = total suspended solids (mg/L)

10^{-6} = conversion factor (kg/mg)

d_{wc} = depth of water column (m)

d_{bs} = depth of upper benthic layer (m)

0_{bs} = bed sediment porosity (L_{water}/L)

kd_{bs} = bottom sediment/sediment pore water partition coefficient (L/kg)

C_{BS} = bed sediment concentration (g/cm^3)

f_{bs} = fraction of total waterbody contaminant concentration in bed sediment (unitless)

The depth of water column and depth of benthic layer parameter values previously cited were used in this equation. The chemical-specific suspended sediment/surface water (Kd_{sw}) and bed sediment/sediment pore (Kd_{bs}) partition coefficient values were obtained from Appendix A-3 of the U.S. EPA 1998 HHRAP document. In accordance with the HHRAP document, the Kd_{bs} and Kd_{sw} values for Aroclor 1254 were used as surrogate values for the coplanar and total congener PCBs.

For chemicals with no Kd_{sw} or Kd_{bs} values, the following equations presented in Section A.3.3.8 of the U.S. EPA 1998 HHRAP guidance were used:

$$Kdsw = f_{oc,sw} * Koc$$

$$Kdbs = f_{oc,bs} * Koc$$

Values of 0.075 and 0.04 were used for $f_{oc,sw}$ and $f_{oc,bs}$, respectively.

Based on information presented in the screening level guidance document, values of 0.6 and 1.0 g/cm^3 were used for the bed sediment porosity and the bed sediment concentration parameters. A value of 0.03 m was used for the depth of the upper benthic layer. A value of 10 mg/L was used for total suspended solids for the France Park swimming quarry. This value represents a conservative high end value for this particular parameter. A TSS value of 96 mg/l was used for the Eel and Wabash Rivers. This is the

annual mean monitoring data for the U.S.G.S. water quality station on the White River, a tributary of the Wabash (Stewart et.al., 1992).

The following equation was used to calculate the total waterbody dissipation rate constant used in Equation 5-19:

$$k_{wt} = fwc * kv + fbs * kb \qquad \text{[Equation 5-20]}$$

where:

k_{wt} = total waterbody dissipation rate constant (yr^{-1})
f_{wo} = fraction of total waterbody concentration in water column (unitless)
kv = water column volatilization rate (yr^{-1})
f_{bs} = fraction total water body concentration in benthic sediment (unitless)
k_b = benthic burial rate constant (yr^{-1})

The fraction total water body concentration (f_{wc}), water column volatilization rate (yr^{-1}), and fraction total water body concentration in the benthic sediment (f_{bs}) were calculated according to the equations described previously.

The following equation was used to calculate the benthic burial rate constant (k_b):

$$k_b = [(Xe*WA_L*SD*10^3-Vfx*TSS)/WA_w*TSS]*[(TSS*10^{-6})/C_{bs}*d_{bs}] \qquad \text{[Equation 5-21]}$$

where:
k_b = benthic burial rate constant (yr^{-1})
Xe = unit soil loss (kg/m^2-yr)
WA_L = total water shed area receiving deposition (m^2)
SD = sediment delivery ratio (unitless)
10^3 = conversion factor (g/kg)
Vfx = average volumetric flow rate through water body (m^3/yr)
TSS = total suspended solids (mg/L)
WA_w = water body surface area (m^2)
10^{-6} = units conversion factor (kg/mg)
C_{bs} = bed sediment concentration (g/cm$_3$)
D_{bs} = depth of upper benthic sediment layer (m)

The parameters values used in Equation 5-21 have been described previously.

The following equation was used to calculate the concentration of chemicals present in the total water column:

$$C_{wctot} = f_{wc} * C_{wtot} (d_{wc} + d_{bs}/d_{wc})$$ [Equation 5-22]

where:

C_{wctot} = total concentration in water column (mg/L)
f_{wo} = fraction of total waterbody concentration in water column (unitless)
C_{wtot} = total waterbody concentration (mg/L)
d_{bs} = depth of upper benthic layer (m)
d_{wc} = depth of water column (m)

The total water concentration was calculated using Equation 5-18. The other parameter values used in Equation 5-22 have been previously described.

The following equation was used to calculate the concentration of chemicals present in the dissolved fraction of the total water body:

$$C_{dw} = C_{wctot}/1 + Kd_{sw} * TSS * 10^{-6}$$ [Equation 5-23]

where:
C_{dw} = dissolved phase water concentration (mg/L)
C_{wctot} = total concentration in water column (mg/L)
Kd_{sw} = suspended sediments/surface water partition coefficient (L/kg)
TSS = total suspended solids (mg/L)

The parameter values used in Equation 5-23 have been described previously.

The following equation was used to calculate the concentration of chemicals sorbed to the bed sediments:

$$C_{sb} = f_{bs} * C_{wtot} * (Kd_{bs}/0_{bs} + Kd_{bs} * C_{BS}) * (d_{wo} * d_{bs})/d_{bs})$$ [Equation 5-24]

where:

C_{sb} = concentration sorbed to bed sediments (mg/kg)
f_{bs} = fraction of total waterbody concentration in bed sediment (unitless)

d_{wc} = depth of water column (m).
d_{bs} = depth of upper benthic layer (m)
0_{bs} = bed sediment porosity (L_{water}/L)
Kd_{bs} = bed sediment/sediment pore water partition coefficient (L/kg)
C_{BS} = bed sediment concentration (g/cm^3)

The parameter values used in Equation 5-24 have been described previously.

Table 5-6 presents the estimated surface water concentrations for the total water, dissolved, and bed sediment fractions of the total water body. The estimated chemical concentrations presented on Table 5-6 represent the chemical concentrations under the typical exposure scenario (i.e., exposure duration of 30 years).

5.4.2 ESTIMATION OF FISH CONCENTRATIONS

It was assumed that fish in natural waterbodies are caught and consumed by humans. To evaluate the significance of consuming fish from local water bodies, concentrations for each chemical of concern in fish were estimated for the Wabash River.

Concentrations of chemicals of potential concern in fish were estimated using the methods presented in the U.S. EPA 1998 HHRAP guidance document. These methods use bioaccumulation factors (BAFs), bioconcentration factors (BCFs) or biota-to-sediment accumulation factors (BSAF), which account for uptake of chemicals by aquatic organisms from either the dissolved or the bed sediment fractions of the total water body column.

The resulting chemical concentrations in fish attributable to the dissolved water or bed sediment fractions is dependent on the physical properties of the individual chemical of concern. These physical properties are reflected in the particular uptake factors (e.g., BCF, BAF, BSAF) for the chemical. For this evaluation, the fish uptake factors for the chemicals of concern were obtained from the U.S. EPA 1998 HHRAP guidance document. These factors are presented on Table 5-5.

The following equation was used to estimate concentrations of the chemicals of concern in fish from the dissolved fraction of the total waterbody using the bioconcentration factor:

$$C_{fish} = C_{dw} * BCF \qquad \text{[Equation 5-25]}$$

where:

C_{fish} = concentration of chemicals in fish (mg/kg tissue)
C_{dw} = dissolved phase water concentration (mg/L)
BCF = Bioconcentration factor for chemical (L/kg)

The following equation was used to estimate the concentration of the chemicals of concern in fish from uptake from the dissolved phase of the total water column using the bioaccumulation factor:

$$C_{fish} = C_{dw} * BAF \qquad \text{[Equation 5-26]}$$

where:

C_{fish} = fish concentration (mg/kg tissue)
C_{dw} = dissolved phase water concentration (mg/L)
BAF = bioaccumulation factor (L/kg)

For mercury, the estimated dissolved water concentrations for the divalent and methyl forms of mercury species are summed. The resulting sum is multiplied by the BAF for methyl mercury to estimate a total methyl mercury fish concentration.

The following equation was used to estimate the concentration of chemicals of concern in fish resulting from uptake from the bed sediment fraction of the total water body using the biota-to-sediment accumulation factor:

$$C_{fish} = C_{sb} * f_{lipid} * BSAF/OC_{sed} \qquad \text{[Equation 5-27]}$$

where:

C_{fish} = fish concentration (mg/kg tissue)
C_{sb} = concentration of chemical sorbed to bed sediment (mg/kg)
F_{lipid} = fish lipid content (fraction)
BSAF = biota to sediment accumulation factor (unitless)
OC_{sed} = fraction of organic carbon in bottom sediment (unitless)

A fish lipid content of 0.07 and a fraction organic carbon in bottom sediment value of 0.04 were used based on information provided in the HHRAP guidance document.

Table 5-6 presents the estimated fish concentrations for the Wabash and Eel rivers under the typical exposure scenario (i.e., exposure duration of 30 years).

5.5 CHEMICAL CONCENTRATION IN PLANTS

Information provided in the Indiana Agricultural Statistics 1997-98 indicates that approximately 83% of the land use in Cass County and approximately 95% of the land use in Carroll County would be classified as land in farms. The predominant crop grown in both counties is corn, with over 100,000 acres planted in each county. In 1997, approximately 53% of the agricultural land in Cass County and approximately 50% of the agricultural land in Carroll County were planted with corn. Soybeans were the next largest crop with approximately 30% of Cass and 28% of Carroll county agricultural lands used to produce this crop. Combined, corn and soybeans account for approximately 80% of the agricultural land use in both counties. Other crops grown in each county include wheat and oats, however, in terms of harvested acres, each of these crops accounted for 4% or less of the total planted acres in each county. A figure on the number of agricultural acres used for pasture is not presented in the Indiana Agricultural statistics. The Cass County Development Plan (CPC 1985) indicated that in 1982 approximately 7% of the agricultural land in Cass County was used for pasture.

For this risk assessment, the major agricultural land use in Cass and Carroll Counties (i.e., corn) is evaluated. Corn production and use of pasture land accounts for over 65% of the agricultural land use in Cass County (and likely a similar figure for Carroll County). Furthermore, these land uses account for the major sources of animal feed to which locally grown livestock may be exposed, which will be used as inputs to the equations presented in this section. Specifically, the production of corn also accounts for the production of both silage and grain animal feeds.

Statistics on the frequency of home gardening in Cass and Carroll Counties could not be obtained. The practice, however, is assumed to be common throughout both counties. For this risk assessment, it is assumed that most rural households within the study area

utilize home gardens as a source of a portion of their vegetable diets. Furthermore, it is assumed that these household home gardens consist of different combinations of vegetables that fall into one of three basic plant type categories: aboveground protected, aboveground unprotected, and below ground. These three plant type categories received their respective designations based on the mechanisms with which they accumulate chemicals. Therefore, the "generic home garden" modeled in this risk assessment is assumed to consist of a variety of vegetable which fall into one of the following three plant type categories:

Aboveground Protected (e.g., sweet corn, snap beans)
Aboveground Unprotected (e.g., tomatoes, spinach)
Below Ground (e.g., carrots, potatoes)

These vegetables were selected not only because they are commonly grown in home gardens, but also because they include at least one plant from the variety of crop types assumed to accumulate chemicals by the pathways described below.

In this section, the chemical concentration in the crops and home vegetables of concern are estimated. There are three standard mechanisms by which chemicals emitted into the environment can bioaccumulate in plants. These mechanisms are uptake through plant roots, direct deposition onto exposed plant surfaces, and the transfer of vapor phase contaminants directly to plant parts by adsorption. These processes each combine to result in a total chemical concentration in a particular plant part. The equations developed by U.S. EPA for determining the total concentration of a chemical in a plant by all routes of uptake is:

$$P = Pr + Pd + Pv \qquad \text{[Equation 5-28]}$$

where:
P = total concentration of the chemical in the plant part (mg/kg)
Pr = concentration in plant part due to root uptake (mg/kg)
Pd = concentration in plant part due to direct dry and wet deposition (mg/kg)
Pv = concentration in plant part due to vapor uptake (mg/kg)

A description of the methods for modeling each of the above pathways of plant uptake for the crops and home garden vegetables modeled in this risk assessment is provided below. In reviewing these equations, it should be noted that not all edible plant parts acquire chemicals by all three pathways of chemical uptake. For instance, a root crop such as a potato, will only accumulate chemicals by root uptake and it is not subject to direct deposition or vapor phase uptake.

5.5.1 PLANT CHEMICAL CONCENTRATION DUE TO ROOT UPTAKE (Pr)

The following equation was used to calculate the concentration of chemicals of concern attributable to root uptake in below ground produce used for human consumption:

$$Pr_{below} = (Cs * Br_{rootveg} * VG\ rootveg) \quad [\text{Equation 5-29}]$$

Estimation of the chemical-specific soil concentrations used in Equation 5-29 have been described previously and are presented in Table 5-4. The plant-soil bioconcentration factor ($Br_{rootveg}$) for organic chemicals is a function of the water solubility of the chemical while the $Br_{rootveg}$ for inorganic chemicals is a function of the bioavailability of the compound in soil. The plant-soil bioconcentration factors used in Equation 5-29 were obtained from Appendix A-3 of the 1998 U.S. EPA HHRAP guidance document. These factors are presented on Table 5-8.

Chemicals uptake through soil also occurs in above ground plants. For above ground plants modeled for human consumption, a plant-soil bioconcentration factor Br_{ag} was used in equation 5-29. Similarly, for plants used as forage, a Br_{forage} factor was applied to Equation 5-29. The Br_{ag} and Br_{forage} factors were obtained from Appendix A-3 of the U.S. EPA 1998 HHRAP guidance. For chemicals without Br_{ag} or Br_{forage} factors, factors were derived using the regression equations presented in A.3.4.3 of the U.S. EPA 1998 HHRAP guidance document. These regression equations use the logKow of the chemical to derive the plant-soil bioconcentration factors.

The empirical correction factor (VGrootveg) accounts for chemical loss during preparation (i.e., washing, peeling) of below ground produce for human consumption. Therefore, an empirical correction factor of 0.01 was used in Equation 5-29 only in the estimation of the chemical concentrations in below ground produce for human

consumption. The VGrootveg empirical correction factor was dropped from Equation 5-29 when estimating the chemical concentrations due to root uptake for aboveground protected and unprotected produce for human consumption and forage and silage used for animal feed.

5.5.2 PLANT CONCENTRATION DUE TO DIRECT DEPOSITION

Pollutants can be deposited on exposed plant surfaces by both dry and wet (precipitation related) deposition. This pathway of chemical uptake is only considered important for leafy plant parts and exposed produce. Protected produce and root crops are assumed to be unaffected by this pathway of uptake. The equation for determining this is:

$$Pd=1000*Q*(1-Fv)*[Dydp+(Fw*Dywp]*Rp*[1.0-exp^{(-kp*Tp)}]/(Yp*kp) \quad [Equation \ 5-30]$$

Where:

Pd	= chemical concentration in plant part due to direct deposition (mg/kg)
Q	= chemical-specific emission rate (g/s)
Fv	= fraction of chemical air concentration in vapor phase (unitless)
Dydp	= unitized yearly dry deposition from particle phase (s-m²-yr)
Fw	= fraction of wet deposition that adheres to plants (unitless)
Dywp	= unitized yearly wet deposition from particle phase (s/m²-year)
Rp	= interception fraction of the edible plant part (unitless)
Tp	= length of plant exposure to deposition before harvest (yrs)
kp	= plant surface loss coefficient (yr^{-1})
Yp	= yield or standing crop biomass of the edible portion of the plant (kgDW/m²)
1000	= conversion factor (mg/g)

5.5.2.1 Dry and Wet Deposition (Dydp and Dywp)

The dry (Dydp) and wet (Dywp) deposition rates were determined in Section 4.0. Additionally, the emission rates described previously were used in this equation. The emission rate for mercury was multiplied by a factor of 0.48 for reasons described previously. The concentration of mercury in the plant attributed to deposition was speciated into divalent and methyl mercury by multiplying the mercury concentration by 0.78 and 0.22, respectively.

5.5.2.2 Fraction Wet Deposition (Fw)

A value of 0.6 for Fw is recommended when applying this methodology to hydrophobic contaminants such as dioxins, PCBs, other organic chemicals whose log Kow exceeds 3.0, or cationic metals. For anionic metals an Fw of 0.20 is used.

5.5.2.3 Interception Fraction (Rp)

The interception fraction is a factor that accounts for the fact that all chemicals depositing per square meter will not land on edible plant parts. The interception fraction is essentially that fraction of the surface area per square meter that would be covered by edible plant parts during the growing season. Because of the diversity in the plants modeled, this factor should be determined for individual crops of crop types. In this section, methodologies for determining the interception fractions for pasture grasses, silage, leafy vegetables, and exposed produce are presented.

Rp - Pasture Grasses and Silage

The Rp values used in equation 5-30 for pasture grasses and silage were obtained from the U.S. EPA 1998 HHRAP guidance document. These values are 0.5 for forage (pasture grasses) and 0.46 for silage.

Rp – Exposed Produce

The Rp value for leafy vegetables was used to represent exposed produce. An Rp value of 0.39, as presented in the U.S. EPA 1998 HHRAP guidance document, was used in this assessment for aboveground protected and unprotected produce used for human consumption.

5.5.2.4 Plant Exposure Time (Tp)

This variable is defined as the amount of time that the edible plant part is exposed to direct deposition. For animal forage including pasture grasses, the appropriate Tp values

have been determined to be 0.12 yr (assuming an average of 30 days between successive grazing and 60 days between successive hay harvests).

U.S. EPA has not determined suggested values for Tp for other field crops and garden vegetables. In lieu of actual site specific data for crops affected by direct deposition, U.S. EPA recommends that a value of 0.164 yrs (corresponding to approximately 60 days) be used for this value. This is a reasonable time period for the duration of exposure of the edible portions of most of the garden vegetables modeled in this assessment.

5.5.2.5 Plant Surface Loss Coefficient (Kp)

The plant surface loss coefficient, Kp, accounts for several environmental processes by which deposited materials are removed from plant surfaces. These processes include wind removal, water removal and growth dilution. As presented in the U.S. EPA 1998 HHRAP guidance document, a value of 18 yr^{-1} is recommended as the value for the surface loss coefficient for chemicals that do not degrade or degrade very slowly.

5.5.2.6 Yield (Yp)

Consistent with the U.S. EPA 1998 HHRAP guidance document, yields of 0.24, 0.8, and 2.24 were used for forage, silage, and above-ground plants for human consumption, respectively.

5.5.3 PLANT POLLUTANT CONCENTRATIONS DUE TO AIR-TO-PLANT TRANSFER

Vapor phase pollutants can be adsorbed directly onto exposed plant parts. This pathway is most important for leafy plants and to a lesser extent exposed produce. The recommended equation for modeling chemical uptake by this pathway is presented below:

$$Pv = Q * Fv * [(Cyv * Bv_{ag} * VG_{ag})/pa] \quad \text{[Equation 5-31]}$$

where:

Pv = chemical concentration in plant due to air-to-plant transfer (ug/g) or (mg/kg)

Q = chemical-specific emission rate (g/s)

Cyv = unitized yearly vapor-phase air concentration (ug-s/g-m^3)

Bv_{ag} = air to plant biotransfer factor ((ug/g dry plant)/(ug/g air)) (unitless)

pa = density of air (g/m^3)

VG_{ag} = surface/volume ratio correction factor

The chemical-specific air-to-plant transfer factors were obtained from Appendix A-3 of the U.S. EPA 1998 HHRAP guidance document. Chemical-specific air-to-plant transfer factors for forage (Bv_{forage}) were used in Equation 5-31 to estimate chemical concentrations in forage. These values are presented on Table 5-7. For those chemicals for which no Bv_{ag} or Bv_{forage} factors were available in the U.S. EPA 1998 HHRAP, the factors were derived in the following manner.

As presented in U.S. EPA 1993a, the air-to-plant biotransfer factor (Bv_{ag}) calculated on a mass to mass basis can be determined from a more generalized air-to-plant biotransfer factor presented on a volume to volume basis (Bvol).

$$Bv = [(1.19 (g/L) * Bvol)/(0.15 * 770)] \quad \text{[Equation 5-32]}$$

Bvol has been determined experimentally for fourteen chemicals (Bacci et al. 1992) and an empirical relationship for Bvol was determined to be:

$$Bvol = 10^{[(1.065 * \log Kow) - (\log(H/RT)) - 1.654]} \quad \text{[Equation 5-33]}$$

where:

Bvol = volumetric air-to-leaf transfer factor, unitless (ug/L wet leaf/ug/L air)

H = contaminant Henry's Law constant (atm-m^3/mol)

R = ideal gas constant, 8.205 x 10^{-5} atm-m^3/mol-deg K

T = temperature, 298.1 K

770 = grass leaf density (g/L)

0.15 = fraction of grass dry weight

Consistent with recommendations in the U.S. EPA 1998 HHRAP, a surface/volume ratio correction factor VGag value of 0.01 was used in Equation 5-31 for all chemicals with log Kow greater than 4.0 to estimate the uptake of chemicals via air-to-plant transfer for exposed produce for human consumption. A value of 1.0 was used for all chemicals with a log Kow less than 4.0 for exposed produce for human consumption. Surface/volume ratio correction factors of 1.0 and 0.5 were used for forage and silage, respectively.

The emission rate for mercury was multiplied by a factor of 0.48 for reasons described previously. The calculated plant concentration for mercury due to air-to-plant transfer was speciated into divalent and methyl mercury by multiplying the mercury concentration by 0.78 and 0.22, respectively.

5.5.4 CALCULATED PLANT CONCENTRATIONS

The estimated total concentrations of each chemical of concern in each of the plant types modeled under the typical exposure scenario (i.e., exposure duration of 30 years) is presented in Table 5-8.

5.6 UPTAKE OF CHEMICALS BY LIVESTOCK

This risk assessment evaluates potential human exposures to chemicals that could potentially accumulate in a number of livestock products. These products include beef, pork, poultry, dairy products and eggs.

Significant numbers of cattle and hogs are raised in both Cass and Carroll County. For the year 1997, the numbers of head of these livestock are shown below

	Cass County	Carroll County
All Hogs	90,800	261,000
Breeding	12,000	23,200
Pig Crop	154,000	375,000
All Cattle	12,400	6,400
Beef Cows	3,600	1,600
Milk Cows	Not Disclosed	Not Disclosed

Milk Production (lbs.)   Not Determined   Not Determined

Chicken and egg production numbers for Cass and Carroll County were not available in the 1996-97 Agricultural Statistics. For this risk assessment, it was assumed that chicken and egg production in these counties is typical of Indiana as a whole. As seen above, specific statistics for dairy cow and milk production in these two counties was not presented. In Carroll County production statistics were not presented because less than 500 dairy cattle were present. The figures for milk cows in Cass County were listed as not disclosed. However, according to the Logansport/Cass County Chamber of Commerce, 30 million pounds of milk were produced in Cass County in 1989.

In order to determine the concentration of chemicals in animal products consumed by humans, equations accounting for uptake of ingested chemicals in feed are required. The U. S. EPA 1998 HHRAP guidance document recommends the following equation for determining the chemical concentration in animal products:

$$A = [\text{summation}(Fi * Qpi * Pi) + (Qs * Sc * Bs)] * Ba_i * MF \quad \text{[Equation 5-34)}$$

where:

A	= chemical concentration in animal tissue, freshweight (mg/kg)
Fi	= fraction of the ith plant type grown on contaminated soils
Qpi	= quantity of ith plant type consumed by animal, dry weight (kg/day)
Pi	= concentration of chemical in ith plant group, dry weight (mg/kg DW)
Qs	= quantity of soil consumed by animal, (kg/day)
Sc	= concentration of chemical in soils (mg/kg)
Bs	= soil bioavailability factor (unitless)
Ba	= biotransfer factor for the ith animal tissue modeled (day/kg FW tissue)
MF	= metabolism factor (unitless)

5.6.1 FRACTION PLANT GROWTH ON CONTAMINATED SOIL (FI)

Given the relatively large study area, a conservative approach would be to assume that the fraction of feed grown in areas impacted by deposited chemicals is 1.0. Without site specific data that would suggest that significant quantities of feed originate from outside areas, this assumption is used in this risk assessment.

5.6.2 QUANTITY PLANTS CONSUMED (QP)

Animals from which food products are derived consume a variety of feed materials. For beef and dairy cattle these include grain, forage (pasture grasses) and silage. As presented in U.S. EPA 1990, the average consumption rate (in dry weight) for beef cattle from each of these categories has been determined to be 0.47 kg/day grain, 8.8 kg/day forage, and 2.5 kg/day silage. For dairy cattle, the average grain, forage, and silage consumption rates were determined to be 3.0 kg/day, 13.2 kg/day, and 4.1 kg/day. These average values are used for predicting beef and dairy product chemical concentrations.

For hogs, an average feed rate of 4.3 kg DW/day has been determined. Hogs are assumed to consume 70% grain (3.3 kg/day) and 30% silage (1.4 kg/day). Because hogs are not grazing animals, they are assumed not to eat forage.

The reported average ingestion rate for chickens is 0.2 kg/day. 100% of the average ingestion rate is assumed to be grain.

5.6.3 QUANTITY SOIL CONSUMED (QS)

The quantity of soil consumed by an animal is of greatest concern for grazing animals. Because pastures are infrequently tilled, deposited chemicals may tend to accumulate in the near surface soils. The soil ingestion rates presented in this risk assessment are assumed to be a percentage (approximately 3-4%) of the total forage intake of the animals modeled. For this risk assessment, as presented in the U.S. EPA 1998 HHRAP guidance document, the average soil ingestion rates for beef and dairy cattle are assumed to be 0.5 and 0.25 kg/day, respectively.

As discussed in U.S. EPA 1990, hogs and poultry are not grazing animals. However, each of these animals likely ingests some soil during feeding. As recommended in U.S. EPA 1993a, values of 8% of total feed ingestion rate for hogs and 3% of total feed ingestion rate for chickens are used in this risk assessment. These values come out to 0.37 and 0.022 kg/day, respectively.

5.6.4 PLANT CONCENTRATION (PI)

The quantity of chemical in the plant groups consumed by the modeled livestock (grain, forage (pasture grass) and silage) were determined according to the methods presented in Section 5.5.

5.6.5 SOIL CONCENTRATION (SC)

The concentration of chemicals in soils that may be consumed by grazing animals were determined according to the methods presented in Section 5.5 and assuming that deposited chemicals are mixed within the top 1 cm of soil.

5.6.6 BIO TRANSFER FACTORS (BA)

Biotransfer factors, as presented in the above equation, relate the concentration of chemicals in animal tissue to the daily intake of chemicals from all sources. These factors are both chemical and tissue specific.

In this risk assessment, the biotransfer factors for chemicals of concern were obtained from Appendix A-3 of the U.S. EPA 1998 HHRAP guidance document and are presented in Table 5-9.

The methods described in Section A.3.5.2, A.3.5.3 of the U.S. EPA 1998 HHRAP were used for determining Ba's for the other animal products modeled in this risk assessment (i.e., pork, chicken and eggs). Specifically, for organic compounds except dioxin and furans, the Ba_{pork} was obtained by multiplying the Ba_{beef} factor by the beef (23%) to pork (19%) fat content ratio of 1.2 (23/19). Similarly, the $Ba_{chicken}$ factor was obtained by multiplying the Ba_{beef} time the beef to chicken fat content ratio of 0.8.

The Ba_{egg} factors for organic compounds except dioxins and furans were obtained using the following regression equation presented in A.3.5.3 of the U.S. EAPA 1998 HHRAP guidance document:

$$\text{Log } Ba_{egg} = -5.1 + \log Kow \qquad \text{[Equation 5-35]}$$

Animal transfer factors for other classes of chemicals (metals, dioxins/furans, PCBs) were obtained from Appendix A-3 in the U.S. EPA HHRAP guidance document.

5.6.7 CALCULATED ANIMAL PRODUCT CONCENTRATIONS

The estimated total concentrations of each chemical of concern in each of the animal products modeled under the typical exposure scenario (i.e., exposure duration of 30 years) are presented in Table 5-10.