June 16, 1998

Draft Risk Assessment for Cement Kiln Dust Used as an Agricultural Soil Amendment

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Prepared for

The Office of Solid Waste
U.S. Environmental Protection Agency
401 M St., SW (5307W)
Washington, DC 20460

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1.0 Summary

This report presents the risk assessment methodology used to estimate the incremental increase in individual lifetime risk from the use of cement kiln dust (CKD) as an agricultural soil amendment. It includes the documentation and results of a central tendency and high-end deterministic risk analysis and a quantitative uncertainty analysis using commercially available Monte Carlo simulation software.

RTI conducted this risk assessment in accordance with the U.S. Environmental Protection Agency (EPA) human health risk assessment guidance (U.S. EPA, 1991, 1988, and 1989). The risk estimates used for regulatory decisionmaking have been developed using a deterministic method, which produces point estimates of risk based upon single values for input parameters. The deterministic results in this analysis have been estimated using a double high-end risk assessment methodology. In this method, the input parameters are varied between the central tendency (50th percentile) value and the high-end (95th percentile) value one at a time and then in pairs of any two independent variables to produce a series of point risk estimates. The point estimate in which all variables are set at central tendency is assumed to be the central tendency risk estimate, and the highest risk estimate for any combination of double high-end variables is assumed to be the high-end estimate (approximately 95th percentile) of risk.

A deterministic risk analysis was conducted for the use of CKD as an agricultural soil supplement, supported by a quantitative uncertainty/variability analysis conducted using Monte Carlo simulation.

In support of the point risk estimates, an uncertainty/variability analysis was conducted. The first step of the uncertainty/variability analysis is a sensitivity analysis using the deterministic methodology to determine the risk-driving parameters. After the risk drivers were determined, the quantitative uncertainty/variability analysis was conducted using commercially available software to perform a Monte Carlo simulation by randomly varying the risk-driving parameters.

Monte Carlo simulation is a statistical technique that calculates an individual risk value or hazard quotient repeatedly, using randomly selected inputs for each parameter in the exposure scenario for each calculation. Although the simulation is internally complex, commercial software performs the calculations as a single operation, presenting results in simple graphs and tables. The tables and graphs present the range of possible outcomes and the likelihood of each. However, this approach has limitations that prevent EPA from using it as a single methodology for estimating risk. These limitations are

- The software cannot distinguish between variability and uncertainty.

- Ignoring or misrepresenting parameter correlations may bias Monte Carlo results.
- Exposure factors developed from short-term studies with large populations may not accurately reflect long-term conditions in small populations.
- The tails of the Monte Carlo risk distributions are very sensitive to the shape of the input distributions.

Therefore, the Monte Carlo results for the CKD risk assessment are provided solely as support for the deterministic risk estimates.

The risk analysis for mercury presented in this document is consistent with the methodology presented in the current Science Advisory Board (SAB) review draft (U.S. EPA, 1996c) of the Mercury Study Report to Congress (RTC). This methodology is currently under review and will likely change significantly when the revised draft is published in early 1998. The time frame for the publication of the revised RTC for mercury is expected to be the same as the time frame for publication of the proposed rule for CKD. Changes in the methodology for mercury will be addressed in the response to comments on the proposed rule.

In addition to the individual human health risk analysis, a screening analysis for ecological risk and phytotoxicity has been included using the methodology and data provided in the *Technical Support Document for Land Application of Sewage Sludge* (U.S. EPA, 1992c).

This report documents data inputs and the risk assessment methodology used for the deterministic analysis and the Monte Carlo simulation used in the uncertainty/variability analysis conducted for CKD used as an agricultural soil amendment. The scope of this risk assessment includes individual risk for the following receptor scenarios: farmer, fisher, home gardener, and child of the farmer.

This methodology has also been adapted to establish regulatory cutoff levels that are protective of individual human health and the environment regardless of the agricultural practices used. These cutoff levels, established for all constituents of CKD, are also provided in this document.

The equations used in the evaluations of these scenarios and the values for the exposure parameters used in the equations are presented in Appendix A. The compound-specific data required for the risk assessment are presented in Appendix B. A detailed discussion of the sensitivity analysis is provided in Appendix C. The original constituent concentration data from the Agency's 1992 and 1993 sampling study used in this analysis are presented in Appendix D. Graphs of air modeling results for a large land-based unit are presented in Appendix E.

2.0 Characterization of CKD

The chemical description of CKD was obtained from the 1992 Portland Cement Survey and 1993 U.S. EPA Sampling, 1992 3007 Data, and 1994 Comments Data (U.S. EPA 1996d).

The sampling, analysis, and quality assurance (QA) methods used to develop these data are described in detail in the source documents and are not repeated in this report. The constituent concentrations used in this analysis are from measurements obtained during EPA's 1992 and 1993 sampling study. The data set includes a total of 45 CKD samples from 20 different facilities, 10 that burn hazardous waste and 10 that do not. Not all samples were analyzed for every constituent, however. Metals were analyzed for 15 facilities and dioxins for 11 facilities. All constituent concentration values have been reviewed by EPA and determined to be valid for inclusion in this analysis; therefore, all measured concentrations for all constituents of concern are included in the analysis.

The deterministic risk estimates were calculated using the 95th percentile value as the high-end constituent concentration and the 50th percentile concentration as the central tendency concentration value. Tables 2-1 and 2-2 present these concentrations for metals and dioxin congeners, respectively, and include soil background concentrations for each constituent for comparison.

The concentration parameters were determined to be risk drivers, so the distribution of all measured concentrations was included in the uncertainty/variability analysis. The constituent concentration data for metals and dioxin congeners in this analysis that are used as assumptions in the Monte Carlo simulation are presented in Appendix D. These data are considered independent variables in this analysis.

The constituents of CKD are also characterized by physical and chemical parameters and by health benchmarks. The physical and chemical parameters used in this analysis are documented in Appendix B of this document and are identical to the parameters used in the risk analysis performed on the air emissions from hazardous waste combustion units, including cement kilns. The health benchmark data are also identical to those used in the combustion risk analysis and are from the Integrated Risk Information System (IRIS) database or from the Health Effects Assessment Summary Tables (HEAST) document. The reference doses (RfDs) for noncarcinogens and cancer slope factors (CSFs) for carcinogens are estimated to be protective of an individual for a lifetime (70-year) daily exposure to the constituent of concern. The sources of the health benchmark data are presented in Appendix B as well. The benchmarks for the dioxin and furan congeners are based on the Toxicity Equivalent Factor (TEF) for 2,3,7,8-tetrachlorodibenzodioxin (TCDD2). Table 2-3 presents the TEFs for the dioxin congeners used in this risk analysis.

Table 2-1. Soil Background Concentration Compared to Concentrations of Metals in CKD

Metal	**Median (mg/kg)[a]**	**95th Percentile (mg/kg)[a]**	**Background Soil Conc.[b] (mg/kg)**
Silver	3	15	0[c]
Arsenic	9	59	5.2[c]
Barium	137	410	452[c]
Beryllium	1	4	0.065[c]
Cadmium	5	32	--[c]
Chromium	26	75	37[c]
Mercury	0	1	0.058[c]
Nickel	15	49	13[c]
Lead	113	1,346	20[d]
Antimony	5	64	0.51[c]
Selenium	6	37	0.26[c]
Thallium	5	146	0[c]

[a] U.S. EPA, 1993, EPA Sampling and Analysis Data from U.S. EPA, 1996b.

[b] Represents the geometric mean of the data for the entire United States.

[c] Dragun, J., and A. Chiasson. 1991. *Elements in North American Soils.* HMCRI. Greenbelt, MD.

[d] Agency for Toxic Substances and Disease Registry. 1988. *Toxicological Profile for Lead*. Atlanta, GA.

Table 2-2. Soil Background Levels Compared to Concentrations of Dioxin Congeners in CKD

Congener	**Median Conc. (ppb)**	**95th Percentile Conc. (ppb)**	**Background Soil Conc.[a] (ppb)**
1,2, 3, 4, 6, 7,8- Heptachlorodibenzodioxin	0.02	0.428	0.194
1, 2, 3, 4, 6, 7, 8-Heptachlorodibenzofuran	0.01	0.228	0.047
1, 2, 3, 4, 7, 8, 9-Heptachlorodibenzofuran	0.008	0.0235	0.00188
1, 2, 3, 4, 7, 8-Hexachlorodibenzodioxin	0.008	0.0335	0.00188
1, 2, 3, 6, 7, 8-Hexachlorodibenzodioxin	0.008	0.0674	0.004
1, 2, 3, 7, 8, 9-Hexachlorodibenzodioxin	0.008	0.065	0.009
1, 2, 3, 7, 8, 9-Hexachlorodibenzofuran	0.0065	0.1269	0.00188
2, 3, 4, 6, 7, 8-Hexachlorodibenzofuran	0.005	0.06386	0.00188
1, 2, 3, 6, 7, 8-Hexachlorodibenzofuran	0.005	0.01891	0.00188
1,2, 3, 4, 7, 8-Hexachlorodibenzofuran	0.0065	0.09186	0.002
Octachlorodibenzodioxin	0.0449	0.461	0.096
Octachlorodibenzofuran	0.01	0.0335	0.0231
1, 2, 3, 7, 8-Pentachlorodibenzodioxin	0.0065	0.037	0.00188
1, 2, 3, 7, 8-Pentachlorodibenzofuran	0.004	0.06736	0.00331
2, 3, 4, 7, 8-Pentachlorodibenzofuran	0.004	0.1650	0.00188
2, 3, 7, 8-Tetrachlorodibenzodioxin	0.00274	0.02	0.00081
2, 3, 7, 8-Tetrachlorodibenzofuran	0.0055	0.184	0.00139

[a] U.S. Environmental Protection Agency. 1994c. *Estimating Exposure to Dioxin-Like Compounds*. EPA/600/6-88/005cb. Office of Research and Development, Washington, DC. June.

Table 2-3. Toxicity Equivalency Factors Used for Dioxin Congeners in this Risk Analysis

CAS No.	Name	Oral CSF (mg/kg/d)-1	TEF
1746-01-6	TCDD, 2,3,7,8-	1.6E+05	1
3268-87-9	OCDD, 1,2,3,4,5,7,8,9-	1.6E+02	0.001
19408-74-3	HxCDD, 1,2,3,7,8,9-	1.6E+04	0.1
39001-02-0	OCDF, 1,2,3,4,6,7,8,9-	1.6E+02	0.001
39227-28-6	HxCDD, 1,2,3,4,7,8-	1.6E+04	0.1
40321-76-4	PeCDD, 1,2,3,7,8-	7.8E+04	0.5
51207-31-9	TCDF, 2,3,7,8-	1.6E+04	0.1
55673-89-7	HpCDF,1,2,3,4,7,8,9-	1.6E+03	0.01
57117-31-4	PeCDF, 2,3,4,7,8-	7.8E+04	0.5
57117-41-6	PeCDF, 1,2,3,7,8-	7.8E+03	0.05
57117-44-9	HxCDF, 1,2,3,6,7,8-	1.6E+04	0.1
57653-85-7	HxCDD, 1,2,3,6,7,8-	1.6E+04	0.1
60851-34-5	HxCDF, 2,3,4,6,7,8-	1.6E+04	0.1
67562-39-4	HpCDF,1,2,3,4,6,7,8-	1.6E+03	0.01
70648-26-9	HxCDF, 1,2,3,4,7,8-	1.6E+04	0.1

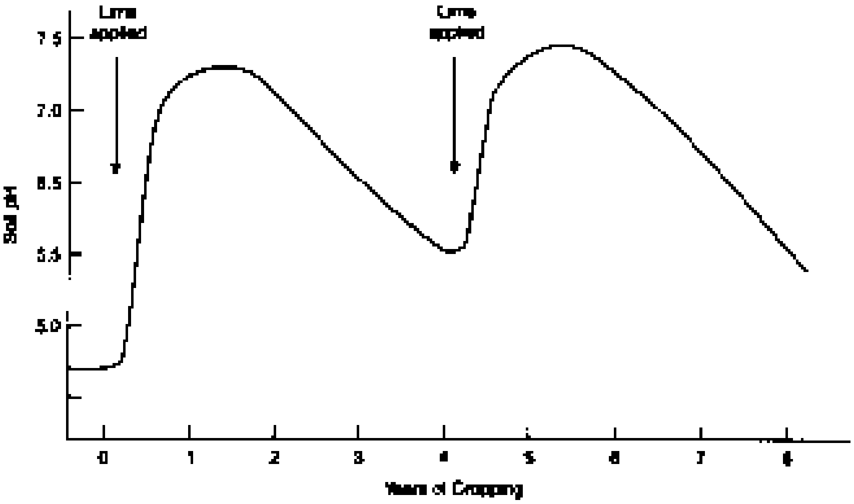
72918-21-9	HxCDF, 1,2,3,7,8,9-	1.6E+04	0.1
99999-99-9	HpCDD, 1,2,3,4,6,7,8,-	1.6E+03	0.01

CAS = Chemical Abstracts Service.
CSF = Cancer slope factor.
TEF = Toxicity equivalency factor.

3.0 Agricultural Liming Practices

CKD is assumed to be applied only to soils that are acid (low pH).

CKD is used as an agricultural soil amendment to raise the pH of acid soils to a level appropriate for crops. Therefore, it is assumed to be applied only to soils that are naturally acid. Using fertilizers increases the rate of removal of the soluble calcium and magnesium components of liming agents, and the pH is lowered over time. This removal may be through leaching or through plant uptake. Thus, repeated applications of liming materials are required to maintain the pH in the appropriate range (Figure 3-1) (Brady, 1990).



Source: Adapted from Brady, 1990.

Figure 3-1. Influence of liming on soil pH.

3.1 Application Rate and Frequency

Liming frequency and liming rates are both considered in maintaining proper soil pH. The quantity of liming material required per acre to raise the pH to an acceptable level is determined by several factors (Brady, 1990):

- Desired change in pH
- Buffering capacity of the soil

practices described in the literature (Brady, 1990) and confirmed in a telephone conversation with Terry Logan of Ohio State University, an expert in the field of agricultural uses of CKD (Greenwood, 1997). Economic factors also influence the rates and frequency of application of all liming agents to agricultural soils. It is not financially sound to apply less than 2 tons per acre because of the cost of operating the spreading equipment (Brady, 1990). Thus, reapplication of liming agents is usually delayed until soil testing indicates that at least 2 tons per acre of liming agent are required to achieve the desired pH. This application rate is assumed to be the same for the agricultural field and the home garden.

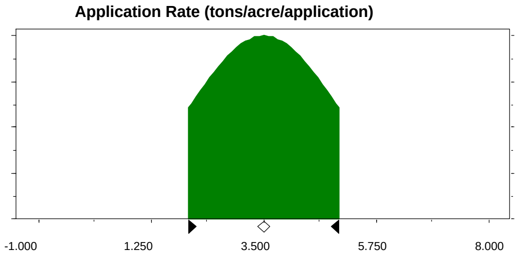
The application frequency for liming agents including CKD is assumed to vary from once every 2 years to once every 5 years. These values are consistent with agricultural practices described in the literature (Brady, 1990) and confirmed in a telephone conversation with Terry Logan of Ohio State University (Greenwood, 1997). This application frequency is assumed to be the same for the agricultural field and the home garden.

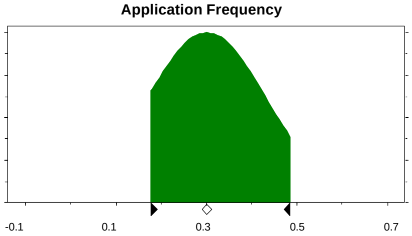
In this analysis standard tilling equipment is assumed to be used to incorporate the liming agent in soil to depths of 10, 15, or 20 cm. Similar practices are assumed for the home garden. Tilling is assumed to occur 15 days each year.

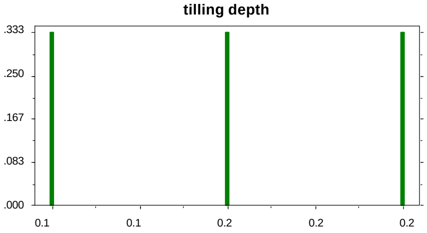
The input values used in the deterministic and probabilistic risk assessment for application rate, application frequency, and tilling depth are presented in Table 3-1, followed by a graphical representation of the data distribution.

Table 3-1. Input Values for Agricultural Liming Practice Parameters

	Deterministic Values		Probabilistic Values		
Parameter	**Central Tendency**	**High End**	**Mean**	**Standard Deviation**	
Application Rate (ton/acre/application)	3	5	3.5	1.5	
Application Frequency (yr)	1/3	½	0.3	0.1	
			Equal Probability		
Tilling Depth (cm)	15	10	20	15	10







The lifetime of the agricultural field, assumed to be 100 years, is consistent with the lifetime of the agricultural field assumed in the risk assessment conducted for the application of municipal sewage sludge to agricultural fields (U.S. EPA, 1992c). The assumption was confirmed for the application of CKD to agricultural fields by Dr. Logan (Greenwood, 1997). These agricultural practice parameter inputs were included in the sensitivity analysis and determined to be risk drivers, and distributions of values for these parameters were included in the Monte Carlo analysis as described.

3.2 Geographic Location

The geographic location of the agricultural field determines the meteorologic conditions and the soil parameters applicable to the risk analysis. The application of CKD as a liming agent is assumed to occur only in areas with initial soil pH less than 6 and areas that are near active cement kilns generating large quantities of CKD. Potentially appropriate sites were selected using a generalized soils map of North America (Figure 3-2). This soils map is based on

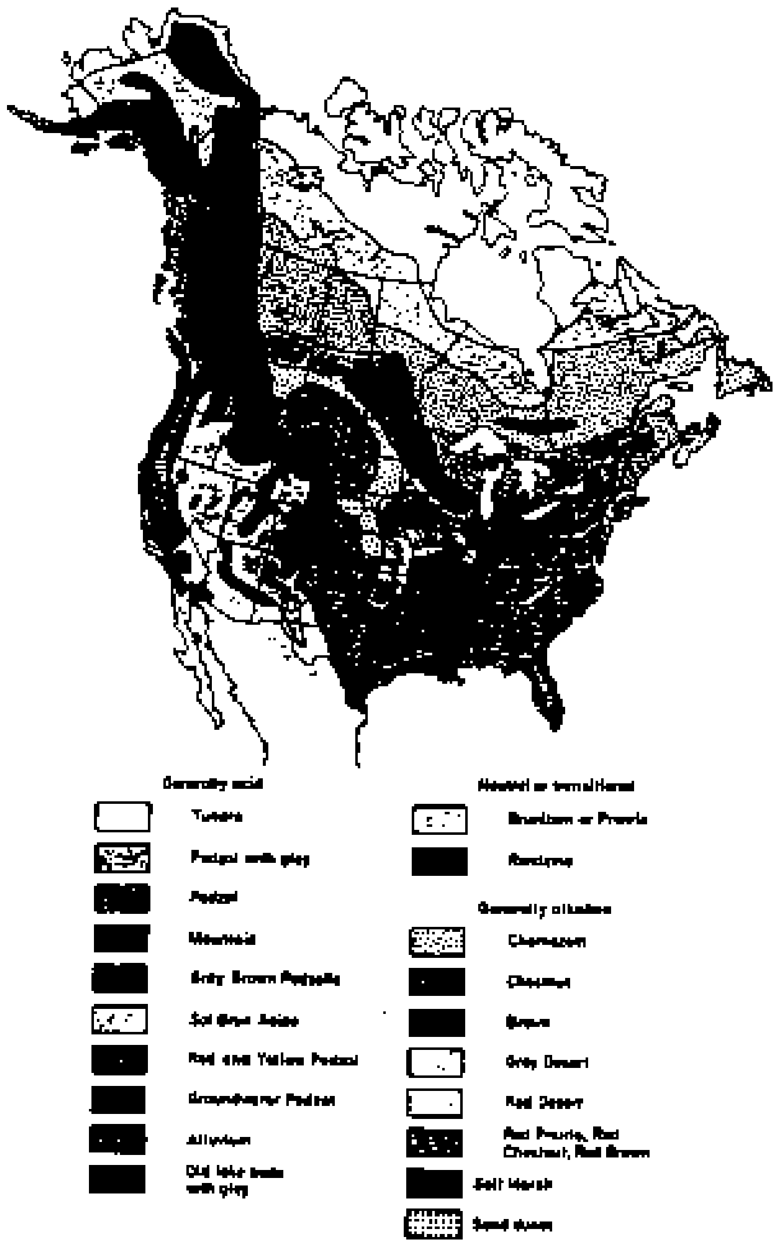


Figure 3-2. Generalized soils map of North America.

information compiled in 1968 by the U.S. Department of Agriculture (USDA) (Hunt, 1974). It broadly segregates soil types into generally acidic, transitional, and generally alkaline groupings. Only areas with a potential for having generally acidic soils were considered appropriate for soil amendment with CKD. A listing of cement kiln locations (U.S. EPA, 1996d) was used to identify cement kiln locations in or near the areas with acid soil. Figure 3-3 shows the distribution of cement kilns throughout the United States. The initial list of cement kiln facilities was reviewed and the facilities ranked according to the quantity of CKD produced, as shown in Table 3-2.

Geographic locations considered in this risk analysis were selected based on the presence of cement kilns producing large volumes of CKD within a radius of 20 miles of acidic soil.

The sites selected for evaluation were:

- Holly Hills, SC
- Indianapolis, IN
- Alpena, MI
- Ravena, NY
- Florence, CO.

More detailed site-specific soil parameters were obtained for these four initial sites. Based on these detailed data, Florence, Colorado, was determined to be unsuitable for evaluation because the baseline soil pH was too high to require liming.

3.3 Site-Specific Soil Parameters

The soils of the four preliminary sites were evaluated using the taxonomic descriptions and soil map units as delineated in a 1967 compilation map of soil great groups, orders, and suborders in the United States (USGS, 1970). This generalized soils map was used in conjunction with specific county soils data from the *Pesticide Assessment Tool for Rating Investigations of Transport (PATRIOT), Version 1.10* (U.S. EPA, 1993b), and selected USDA soil surveys available for counties in these regions.

A range of probable values for soil parameters for these sites were identified using PATRIOT database and selected USDA soil surveys for evaluating soils for the screening analysis. The soils were considered independent of the meteorologic locations because soil parameters were found to be variable at each site and similar soils were present in all locations. These values are listed in Table 3-3.

3.4 Site-Specific Meteorologic Parameters

The impact of site-specific meteorologic conditions was evaluated in the sensitivity analysis and they were found not to be risk drivers. Thus, meteorologic parameters were not varied in the deterministic or probabilistic analysis. The sensitivity analysis that was performed for meteorologic inputs is described in detail in Appendix C.

United States and Canadian Portland Cement Plant Locations

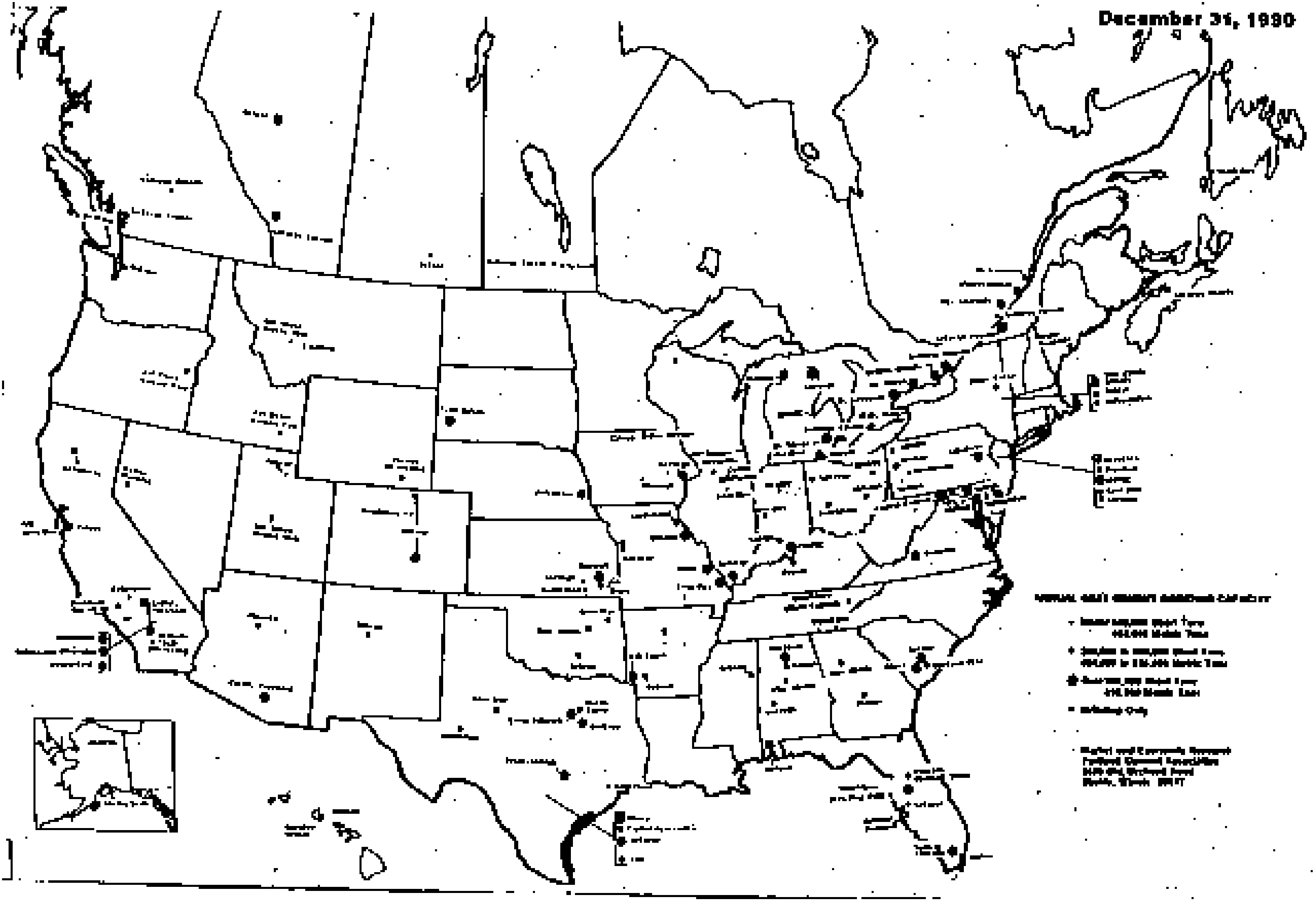


Figure 3-3. Cement Kilns Map

Table 3-2. Location of Active Cement Kiln Plants Reporting Generating CKD, 1990/1994

Location	Net CKD (MT/yr)	Location	Net CKD (MT/yr)
Alpena, MI[a,b]	430,569	Buffalo, LA	36,280
Holly Hills, SC[a]	258,706	Foreman, AR	35,808
Clarksville, MO	226,750	Nazareth, PA	35,404
Ada, OK	143,504	Logansport, IN	35,404
Martinsburg, WV	123,709	Dundee, MI	34,084
Midlothian, TX	115,971	Cementon, NY	33,721
Ravena, NY[a]	110,321	Three Forks, MT	33,191
Florence, CO[c]	108,028	Thomaston, ME	33,164
Pryor, OK	97,049	Bath, PA	31,773
Louisville, NE	93,031	Demopolis, AL	29,200
Chattanooga, TN	91,869	Paulding, OH	29,024
Laporte, CO	85,252	Seattle, WA	28,403
Chanute, KS	77,363	Speed, IN	28,271
Charlevoix, MI	77,298	Tejeras, NM	25,752
Fredonia, KS	67,438	Midlothian, TX	25,418
Hannibal, MO	67,082	Fairborn, OH	25,396
Lyons, CO	65,000	Hagerstown, MD	23,901
Lebec, CA	63,490	Mitchell, IN	22,687
Colton, CA	59,363	San Antonio, TX	21,690
Harleyville, SC	58,001	Greencastle, IN[b]	20,226
Catskill, NY	57,287	Mohave, CA	20,092
Rapid City, SD	56,855	Montana City, MT	19,047
Festus, MO	53,778	Knoxville, TN	16,505
Cloverdale, VA	49,471	Humboldt, KS	15,568
Calera, AL	44,159	Artesia, MS	15,394
Odessa, TX	43,209	Union Bridge, MD	14,734
Ponce, PR	42,397	Independence, KS	13,851
Morgan, UT	37,253	Victorville, CA	12,917
Frederick, MD	36,857	Pittsburgh, PA	11,791

Table 3-2. (continued)

Location	Net CKD (MT/yr)	Location	Net CKD (MT/yr)

See footnotes at end of table. (continued)

Location	Net CKD (MT/yr)	Location	Net CKD (MT/yr)
New Braunfels, TX	9,614	Waco, TX	1,362
Mason City, IA	9,548	Stockertown, PA	908
Medley, FL	8,641	Miami, FL[b]	907
Grand Chain, IL	8,163	Cape Girardeau, MO	608
York, PA	6,439	Inkom, ID	454
Rillito, AZ	3,909	Sugar Creek, MO	435
Oglesby, IL	3,447	Permanente, CA	200
Wampum, PA	1,542		

[a] Site for screening analysis.
[b] Site for sensitivity analysis.
[c] Site dropped after initial evaluation.

Source: 1992 Portland Cement Survey and 1992 3007 Data, and 1994 Comments Data, U.S. EPA, 1996d.

Table 3-3. Soil Parameter Values for CKD Sites

Location	Porosity (%)	Soil Temperature (C)	Bulk Density (kg/L)	Organic Matter (%)	pH	Iron Oxide (wt%)
Holly Hills, SC	43	18	1.5	1	5	0.31
Alpena, MI	47	8	1.5	2	5.5	0.31
Ravena, NY	53	9	1.5	4	5.5	0.31

4.0 Fate and Transport in the Environment

Soil partitioning equations were used to determine the concentration of CKD constituents in the environment. Losses through leaching, runoff, and/or volatilization for organic compounds (dioxins and furans) and metals were estimated using equations presented in Jury et al. (1983, 1984, and 1990). The MINTEQ model was used to determine metal speciation and, thus, soil-water distribution coefficients (K_d s) for metals. Transport of constituents through air deposition of particles and vapors, root uptake of dissolved constituents, and soil erosion of bound constituents is also presented in this section.

4.1 Metals Speciation and Partitioning

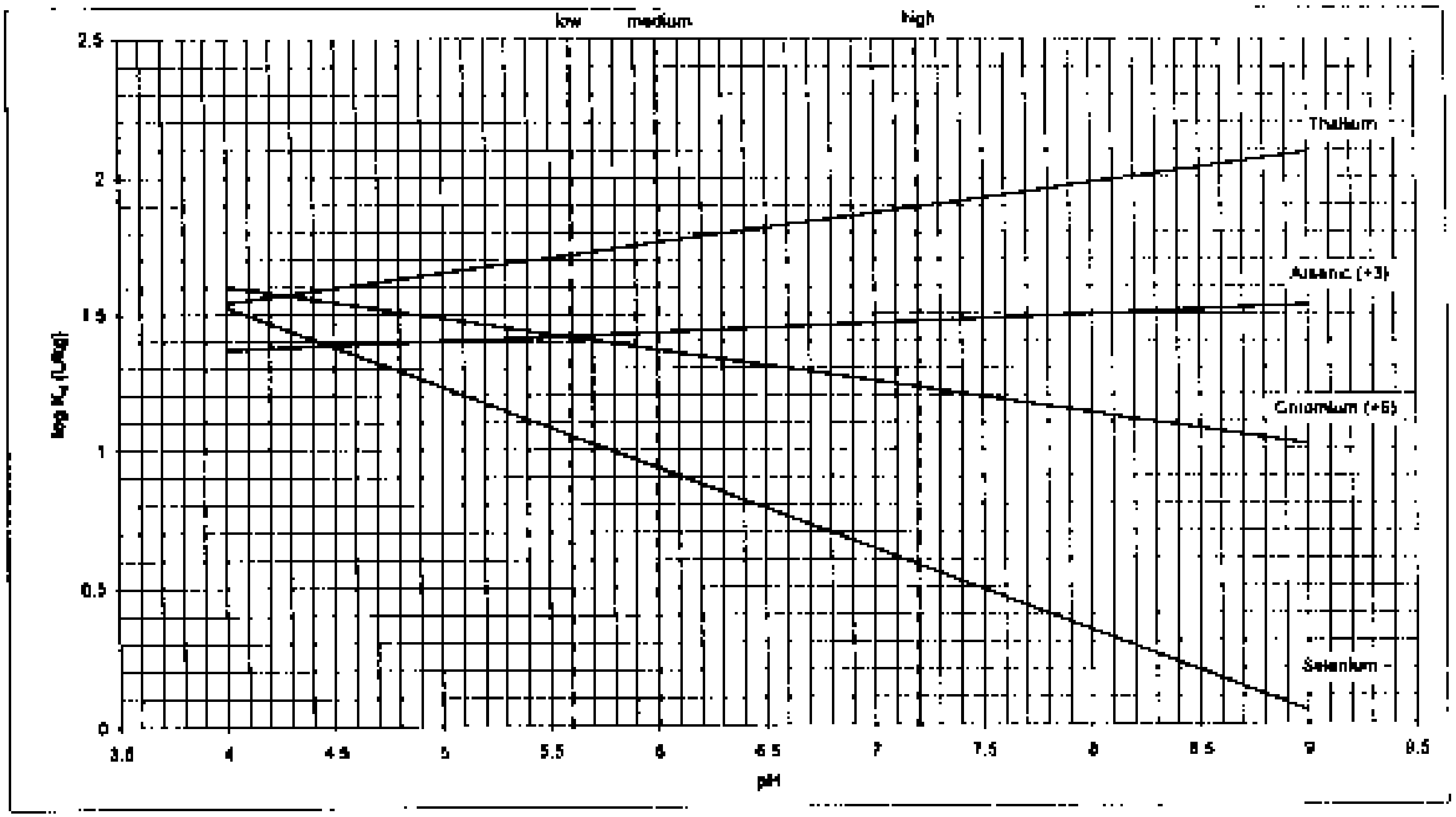
Metals speciation was determined through MINTEQ modeling using soil and meteorologic data identified for each geographic setting and chemical concentration data supplied in the initial data package.

The soil-water distribution coefficients (K_d s) for selected metals (i.e., silver, barium, beryllium, cadmium, mercury, and nickel) were calculated using the MINTEQ aqueous speciation model. The model used is an updated version of MINTEQA2 obtained from Allison Geoscience Consultants, Inc. Due to the poorly understood geochemistry for arsenic, chromium, selenium, and thallium, the K_ds for these four metals were determined using empirical pH-dependent adsorption relationships:

Arsenic (+3) $\log K_d = 0.0322\text{pH} + 1.24$
Chromium (+6) $\log K_d = -0.177\text{pH} + 2.07$
Selenium (+6) $\log K_d = -0.296\text{pH} + 2.71$
Thallium (+1) $\log K_d = 0.110\text{pH} + 1.102$.

Figure 4-1 graphically presents these relationships.

The MINTEQ analyses were conducted for three sites: Holly Hills, SC, Alpena, MI, and Ravena, NY. Site-specific typical soil parameter values were estimated using the median value when available. If a median value was not available, the mean value was used. All soils data available for the county in which the cement kiln was located were used to determine central tendency values. No attempt was made to normalize the data toward soils supporting agricultural uses. Values obtained from USDA’s Map Unit Interpretation Records (MUIR) database were compared to typical ranges reported for the same parameter in other sources (U.S. EPA, 1993b; Nielsen, 1990; Leeden, 1990; and Carsel et al., 1988). The soil parameters used in this analysis are presented in Table 3-3.



Thallium

Log K_d = 0.110 pH + 1.102

pH	log K_d	K_d
5.6	1.72	52.24
6	1.76	57.81
7.2	1.89	78.34

Arsenic (+3)

Log K_d = 0.0322 pH + 1.24

pH	log K_d	K_d
5.6	1.42	26.32
6	1.43	27.11
7.2	1.47	29.64

Selenium

Log K_d = -0.296 pH + 2.71

pH	log K_d	K_d
5.6	1.05	11.28
6	0.93	8.59
7.2	0.58	3.79

Chromium (+6)

Log K_d = -0.117 pH + 2.07

pH	log K_d	K_d
5.6	1.41	25.99
6	1.37	23.33
7.2	1.23	16.89

Figure 4-1 Empirical pH-dependent adsorption relationship: arsenic (+3), chromium (+6), selenium (+6), thallium (+1)

(+6), selenium (+6), and thallium (+1).

Soil parameters included porosity, temperature, dry bulk density, organic matter content, pH, iron oxide content, pore water chemistry, and metals concentration. For MINTEQ modeling purposes, baseline soil conditions (i.e., porosity, soil temperature, and bulk density) are considered to have only an arithmetic effect and are not included as variables in the model because they have limited impact on metal speciation.

Porosity Estimates. The soil series covering the greatest percentage of the county area was determined using the PATRIOT database. Porosity values were inferred from typical porosity ranges (Leeden, 1990) and textural descriptions found in the MUIR database, PATRIOT database, and the SOILS5 database for the soil series that constituted 60 percent or more of the county soils.

Soil Temperature. Soil temperature is assumed to be the mean annual air temperature given that the soil zone being investigated is at atmospheric pressure. The temperature values were obtained from county Internet sites containing local data for the area. These temperatures were also compared to other references for agreement (USGS, 1970; USDA, 1996).

Dry Bulk Density. Data for bulk density, which are used to calculate the amount of soil in contact with 1 L of water, were obtained directly from MUIR data.

Organic Matter Content. Organic matter is an important parameter in assessing the fate and mobility of metals in the environment because it represents surfaces to which metals may sorb. Specifically, the organic matter content is one of two sorbents (iron oxide content being the other) for which metal sorption reactions and the supporting thermodynamic databases are developed in the MINTEQ model. This parameter is used to determine the availability of metal sorption sites. If sufficient sites are available, and if the thermodynamics favor metal sorption, then less metal will be available for transport in the dissolved state. In contrast, if there are insufficient sites available for metal sorption to take place, the metal will remain in the dissolved state. The MUIR database was used to obtain the percent organic matter for the counties in which each of the three cement kiln sites is located.

It is probable that varying the organic matter content will affect metal speciation. The exact impact cannot be predicted because there are two components of organic matter content (dissolved and particulate), and data to assess the distribution of these components are not readily available. The metal speciation was determined not to be a risk driver in the sensitivity analysis, so no additional MINTEQ modeling was indicated for the uncertainty/variability analysis.

pH. The pH of the soil system describes the acid-base properties of the background pore water. It is an important parameter in assessing the fate and mobility of metals in the environment because it directly impacts metal speciation. Site-specific pH values were obtained directly from the MUIR database for modeling purposes. These values were assumed to be representative of natural pH values prior to CKD application. The pH was varied within a narrow range from what was defined as the central tendency value (i.e., the average between the baseline pH value and the target pH value) to the target pH value for alfalfa (pH = 7).

CKD is applied to agricultural fields to adjust the pH to higher, more basic levels. The target pH values for alfalfa and corn are 7 and 6, respectively (Helms, 1996). Without site-specific field measurements, it is impossible to say that the target pH values have been achieved. However, it can be assumed that the adjusted pH values lie between the natural and the target values. It is this intermediate pH value (or the average between the background pH value and the target pH value of 7) that is selected as the central tendency value for model simulations. The high-end pH was taken to be 7. Target pH values of the CKD-applied soils were given as 7 for alfalfa and 6 for corn. It was assumed that the central tendency value would likely be bounded by the untreated site-specific pH and the target pH values. Therefore, for modeling purposes, the central tendency was taken to be the value halfway between the site-specific and the target values. The high end was taken as the target value. The site-specific soil pH values used in this analysis are presented in Table 4-1.

Iron Oxide Content. Iron oxide content in soils is another important parameter in assessing the fate and mobility of metals in the environment. The iron oxide content represents one of two sorbents (natural organic matter being the second parameter input) for which metal sorption reactions and the supporting thermodynamic databases are developed in the MINTEQ geochemical model. This value is used in the determination of the availability of metal sorption sites. If sufficient sites are available, and if the thermodynamics favor metal sorption, then less metal will be available for transport in the dissolved state. In contrast, if there are insufficient sites available for metal sorption to take place, the metal will remain in the dissolved state. The iron oxide content in soils is difficult to determine. This is due to the ubiquitous nature of iron in the environment and to the crop-specific agricultural importance of iron. Values for percent iron oxide in soils were inferred from published typical ranges for this parameter (Brady, 1978). These values represent total iron concentration in the soil and are not representative of iron concentrations that would be available as sorption sites in the MINTEQ system. Using the total iron concentration values would overestimate the availability of sorption sites and, in turn, would overestimate the sorption potential. Therefore, use of total iron concentration values was deemed inappropriate for modeling purposes.

The weight percent amorphous iron hydroxide adsorbent in six samples collected from diverse geographic areas—Florida, New Jersey, Oregon, Texas, Utah, and Wisconsin—was analyzed to determine a more realistic value (U.S. EPA, 1992a). Although six samples are too few to develop a meaningful frequency distribution for this parameter, no better alternative is available. For this analysis, the lowest and highest of the six amorphous iron hydroxide concentrations were taken to represent the low and high iron oxide contents, respectively. The "average" value is assumed to be the average of all six values. It is this average value that is used in the model. Although the medium amorphous iron hydroxide content is probably more representative of aquifer material than soil material, the use of this value is more appropriate and yields more realistic results than the value representing total amorphous iron hydroxide in the soil. Use of the average value avoids biasing the results toward either the dissolved or the adsorbed phases. This parameter is not varied in the analysis.

Pore Water Chemistry. The constituents commonly occurring in the background pore water chemistry are also included in model simulations. Although there are a large number of constituents that might reasonably be included in model simulations, it is generally best to

Table 4-1. Site-Specific Soil pH
(Natural, Central Tendency, and Target Values)

Site	Site-Specific pH	Central Tendency pH	High-End pH
Holly Hills, SC	5	6	7
Alpena, MI	5.5	6.25	7
Ravena, NY	5.5	6.25	7

include only those that are known to be present and to be important in metal chemistry. This includes constituents that either complex with metals or compete for sorption sites, such as sulfate ions, potassium, calcium, and magnesium. Other constituents are included, not because of their direct effect on metal behavior, but because of their impact on ionic strength, and thus on the calculated activity coefficients of all solution species. Examples of ions of this type are sodium, chloride, and nitrate.

For this modeling effort, estimated solution parameters included the constituents that make up the background pore water chemistry. The concentrations of these constituents were inferred from average concentrations measured in rainfall (NADP/NTN, 1996). Based on this scenario, pore water concentrations in the upper 15 cm of soil (root zone) were of interest. Because water in the upper 15 cm of soil is affected more by precipitation events than by long-term contact with aquifer material, the primary basis for determining the composition of water in this zone was evaluation of rainwater compositions. The constituents in rainwater include calcium, chloride, magnesium, nitrate, potassium, sodium, and sulfate. The modeled system was assumed to be open to the atmosphere, and carbon dioxide gas was assumed constant at 0.0005 atm for all sites. The average composition of rainwater was evaluated for each of the three initial screening sites. This included both the constituents and their average concentration in the rainwater. Average values were selected for use in defining the background pore water chemistry. The typical rainwater composition data (NADP/NTN, 1996) used in this analysis are presented in Table 4-2.

Metals Concentrations. Central and high-end metal concentrations were determined for each of the metals to be modeled with MINTEQA2. The concentrations were estimated assuming that CKD was land-applied at a rate of 2 tons/acre and incorporated into the soil to a depth of 20 cm for a total of 14 applications. This is a very dilute solution of metals in soils and, for dilute metal concentrations, the adsorption isotherms are linear (i.e., the distribution coefficient does not change appreciably with respect to changes in metal concentration). Therefore, although this is a low estimation of metals concentration, the distribution coefficients should not vary significantly over the range of constituent concentrations in soils. This assumption does not begin to break down at concentrations in this system. These metal concentrations in soil are presented in Table 4-3.

Table 4-2. Composition of Rainwater in Selected Sites in mg/L

Constituent	Holly Hills, SC	Alpena, MI	Ravena, NY
Calcium	0.08	0.20	0.05
Chloride	0.37	0.06	0.11
Magnesium	31	35	14
Nitrate	0.7	1.8	1.6
Potassium	115	20	13
Sodium	217	58	70
Sulfate	1.1	1.6	1.9

Table 4-3. Range of Concentrations of Metals in Soils from the Use of CKD as an Agricultural Soil Amendment

Metal	Range of Soil Concentrations (mg/kg)
Lead	0.267 - 842
Mercury	0.00002-0.0769
Nickel	0.0414 - 3.76
Silver	0.00009 - 0.0647
Thallium	0.00552 - 24.13
Antimony	0.00005 - 0.267
Arsenic	0.00155 - 1.65
Barium	0.0202 - 159
Beryllium	0.00143 - 0.269
Cadmium	0.00190 - 4.708
Chromium	0.0174 - 1.42
Selenium	0.0001 - 0.3940

The MINTEQ modeling incorporates several basic simplifying assumptions, and the applicability and accuracy of the model results are subject to limitations. Some of the more significant assumptions and limitations are described below.

- *The system is assumed to be at equilibrium.* This assumption is inherent in geochemical aqueous speciation models because the fundamental equations of mass action and mass balance are equilibrium based. Therefore, any possible influence of adsorption (or desorption) rate limits is not considered. If equilibrium conditions are not met, the sorption reactions will be incomplete and the metal concentration in the pore water will be greater than that predicted by the model.

- *Assessment of metal adsorption is limited.* A number of different sorbents have the potential to affect sorption reactions. To date, reactions and the supporting thermodynamic databases have been developed for two important sorbents, amorphous iron oxide (FeOx) and natural organic matter. Therefore, ***only metal adsorption*** to FeOX and solid organic matter is included in the model simulations. Although numerous other natural sorbents exist (e.g., clay and carbonate minerals), thermodynamic databases describing metal adsorption to these surfaces are not available. The lack of complete thermodynamic data requires simplification to the defined system; i.e., potential for adsorption to such surfaces is not considered. This assumption underpredicts sorption for soils with significant amounts of such sorption sites.

  It is not possible to quantify the degree to which sorption will be underpredicted; however, the results can be significant for soils having significant concentrations of clay and/or carbonate minerals. The background soils defined for the three sites are characterized by large quantities of clay. If sorption to clay materials were considered, it is assumed that larger concentrations of the metal would be associated with the soil medium than in solution. Therefore, it is expected that metal concentrations would be greater in any scenario involving the transport or movement of the soil.

- *Metal competition is not considered.* Model simulations were performed for systems comprised of only one metal (i.e., the potential for competition between multiple metals for available sorbent surfaces was not considered). Generally, the competition of multiple metals for available sorption sites results in higher dissolved metal concentrations than would exist in the absence of competition; however, this effect is most significant at greater concentrations than those of the defined systems.

  Metal competition is not considered in the model simulations. This is a deviation from the real-world scenario that incorporates multiple metals in the cement kiln dust. As the metals leach from the dust, multiple metals exist in the system. If sorption sites are limited, the metals must compete with one another for the limited sites. Metals having the most favorable

> thermodynamics generally "win" the competition and take up the limited number of sites; metals that compete less favorably remain in solution. Hence, competition affects the degree to which a metal is either sorbed to the substrate or dissolved in solution. This, in turn, affects the distribution coefficient, which is defined as the concentration of sorbed metal divided by the concentration of dissolved metal.
>
> One factor that would have to be considered in determining whether the exclusion of metal competition results in an over- or underestimate of the distribution coefficient is the availability of sorption sites. For the model simulations conducted as part of this effort, sorption sites are not limiting. Therefore, it may be assumed that the distribution coefficient is not significantly affected by the exclusion of metal competition.

Site-specific soil parameters were determined not to be risk drivers. The cyclical nature of pH over time, however, decreases the effect of the variation in pH over an extended duration. Therefore, an intermediate value for pH was assumed throughout the lifetime of the agricultural field.

4.2 Dioxin and Metal Partitioning in Soil Using the Jury Equations

A spreadsheet calculation model incorporating the Jury equations (Jury et al., 1990, 1984, and 1983) was used to determine the contaminant loss from a land application of CKD due to degradation, volatilization, leaching, and rainwater runoff of dioxins and metals. Enhancement of the volatilization rate due to convection of water vapor (i.e., evaporation) was also included in the model. The model tracks the average annual soil concentration and the annual mass of contaminant volatilized for a period of 100 years of active use (corresponding to the period over which waste application occurs) followed by 40 years of inactive use.

The total concentration of contaminant in the soil can be expressed as the sum of the masses of contaminant adsorbed on the soil, dissolved in the liquid, and volatilized in the air spaces divided by the total mass of contaminated soil as follows:

$$C_T = C_s + \theta_w C_w/\rho_b + \theta_a C_a/\rho_b \tag{4-1}$$

where

C_T = total contaminant concentration (mg/kg = g/Mg)
C_s = concentration of contaminant adsorbed on soil (mg/kg = g/Mg)
θ_w = water-filled soil porosity (m^3_{water}/m^3_{soil})
C_w = concentration of contaminant in liquid ($\mu g/cm^3 = g/m^3$)
ρ_b = soil dry bulk density ($g/cm^3 = Mg/m^3$)
θ_a = air-filled soil porosity (m^3_{air}/m^3_{soil})
C_a = concentration of contaminant in air ($\mu g/cm^3 = g/m^3$).

The adsorbed contaminant concentration was assumed to be linearly related to the liquid phase concentration as follows:

$$C_s = K_d\, C_w \tag{4-2}$$

where

K_d = soil-water partition coefficient ($cm^3/g = m^3/Mg$) = $K_{oc}\, f_{oc}$
K_{oc} = soil organic carbon partition coefficient (cm^3/g)
f_{oc} = organic carbon content of soil (g/g)
C_w = concentration of contaminant in liquid ($\mu g/cm^3 = g/m^3$).

The contaminant concentration in the vapor phase was assumed to be linearly related to the liquid phase concentration as follows:

$$C_a = H'\, C_w \tag{4-3}$$

where

H' = dimensionless Henry's law constant = $41 \times H$
H = Henry's law constant at 25 °C ($atm\text{-}m^3/mol$)
C_w = concentration of contaminant in liquid ($\mu g/cm^3 = g/m^3$).

Equations (4-2) and (4-3) assume linear equilibrium partitioning between the adsorbed contaminant, the dissolved contaminant, and the volatilized contaminant. Combining Equations (4-1), (4-2), and (4-3) yields:

$$C_T = C_s\, [1 + \theta_w/(K_d \rho_b) + \theta_a\, H'/(K_d \rho_b)]\ . \tag{4-4}$$

The total contaminant concentration, C_T, represents the measured soil concentration. However, it is the adsorbed soil concentration that is used to calculate the equilibrium partitioning equations between the air, water (runoff), and soil. Equation (4-4) can be rearranged to calculate the adsorbed soil contaminant concentration given the total contaminant concentration as follows:

$$C_s = C_T\, K_d\, \rho_b/(K_d\, \rho_b + \theta_w + \theta_a\, H')\ . \tag{4-5}$$

The total mass of contaminant applied to the soil during the first annual application can be calculated as follows:

$$M_{s,app} = (C_T\, Q_{app}) \times 1yr \tag{4-6}$$

where

$M_{s,app}$ = mass of contaminant in soil from waste application, g
Q_{app} = annual waste application rate, Mg/yr.

Contaminant loss through degradation is estimated from contaminant half-lives in soil. Contaminant loss to the air, to rainwater runoff, or to leachate is calculated from the mass flux of contaminant across the boundaries of the land treatment unit. A mass balance around the contaminated source can be written as follows:

$$M_{s,t+\Delta t} = M_{s,t} - M_{degr,t} - (J_{air,t} + J_{leach,t} + J_{runoff,t})(A\Delta t) \tag{4-7}$$

where

$M_{s,t+\Delta t}$ = mass of contaminant in soil at time t+Δt (g)
$M_{s,t}$ = mass of contaminant in soil at time t (g)
$M_{degr,t}$ = mass of contaminant degraded at time t (g)
$J_{air,t}$ = contaminant flux to the atmosphere at time t (g/m^2-s)
$J_{leach,t}$ = contaminant flux in leachate at time t (g/m^2-s)
$J_{runoff,t}$ = contaminant run-off rate at time t (g/m^2-s)
A = area of contaminant source (m^2).
Δt = time step of calculation (s).

Reported values for contaminant half-life in soil, expressed in terms of a first-order rate constant, were used to calculate the total contaminant loss from the system in a given time step as follows:

$$\Delta M_{half} = M_{s,t}\,[1 - \exp(k_{half}\,\Delta t)] \tag{4-8}$$

where

ΔM_{half} = expected mass of contaminant loss from half-time data, g
k_{half} = first-order rate constant based on contaminant half-life in soil, per s.

If the amount of contaminant loss through leaching, runoff, and volatilization exceeded the expected mass loss from the half-life data, then the mass degraded was set to zero. Otherwise, the mass degraded was calculated from the expected mass loss and the predicted leaching, runoff, and volatilization losses as follows:

If $\Delta M_{half} < (J_{air,t} + J_{leach,t} + J_{runoff,t})\ A\Delta t)$, (4- 9)
then: $M_{degr,t} = 0$.

Otherwise: $M_{degr,t} = \Delta M_{half} - (J_{air,t} + J_{leach,t} + J_{runoff,t})\ (A\Delta t)$. (4-10)

After each time step, which was approximately 1 week in duration, the mass of constituent remaining in the soil was calculated. It is assumed that the contaminant concentrations are uniform over the tilling depth starting with each new time step. That is, the model does not attempt to assess the concentration profiles (as a function of depth) that can develop over time in the tilled soil. This assumption is reasonable for active land treatment units that are tilled regularly.

The only mass additions to the system occurred during waste application. The depth of material added during the application for most land treatment model runs is negligible. However, because material is assumed to be applied for 100 years, some model scenarios could have substantial depth of accumulation of waste material over 100 years to the assumed tilling depth. During the application, it is therefore assumed that the effective tilling depth of soil and new waste is the same. Consequently, it is assumed that there is a thin layer of contaminated soil (the depth of which is equal to the depth of waste material added during the annual application) just below the tilling depth. As this thin, buried, contaminated layer is necessarily at a lower concentration than the tilled soil directly above, it is not expected to contribute significantly to the exposure pathway mechanisms (air emissions, surface soil concentration, and leachate concentration). Therefore, the mass of contaminant in this untilled, buried soil layer is essentially lost from the system and is subtracted from the mass of contaminant in the active land treatment unit. Consequently, the net mass of contaminant added to the land treatment unit at the start of Year 1 through Year 100 is:

$$M_{s,app} = C_T\, Q_{app} \{1 - [(Q_{app} \times \text{1-yr})/(A\, \rho_b\,)]/d_{till}\} \times \text{1-yr} \tag{4-11}$$

where

d_{till} = tilling depth.

This allows the system to reach a steady state. For very persistent constituents, such as metals and dioxins, the constituents initially build up rapidly and may not reach a steady-state concentration for approximately 40 to 50 years.

The primary mechanism of contaminant loss to the atmosphere is the diffusion of volatilized contaminant to the soil surface. During periods of evaporation, the flux of water vapor enhances contaminant transport to the soil surface. Consequently, the total contaminant flux to the atmosphere is:

$$J_{air,t} = J_{vol,t} + J_{evaptr,t} \tag{4-12}$$

where

$J_{vol,t}$ = contaminant flux to the atmosphere due to diffusion, g/m^2-s
$J_{evaptr,t}$ = contaminant flux to the atmosphere due to evaporative transport, g/m^2-s.

Assuming that there is no stagnant boundary air layer at the ground surface, the simplified finite source model for diffusional volatilization (Jury et al., 1990) can be written as:

$$J_{vol,t} = C_T\, (0.01 D_A/\pi t)^{½} \{1\text{-}\exp[-d_s^2/(0.04 D_A t)] \tag{4-13}$$

where

D_A = apparent diffusivity (cm^2/s)
π = 3.14

t = time (s)
d_s = depth of uniform soil contamination at t=0 (m).

$$D_A = [(\theta_a^{10/3}\, D_i\, H' + \theta_w^{10/3}\, D_w)/n^2]/(\rho_b\, K_d + \theta_w + \theta_a\, H') \qquad (4\text{-}14)$$

where

θ_a = soil air porosity ($L_{air\ pore}/L_{soil}$)
D_i = diffusivity in air (cm^2/s)
H' = dimensionless Henry's law constant
θ_w = soil water porosity ($L_{water\ pore}/L_{soil}$)
D_w = diffusivity in water (cm^2/s).
n = total soil porosity (L_{pore}/L_{soil}) = $1 - (\rho_b/\rho_s)$
ρ_s = soil particle density (g/cm^3).

As discussed in Jury et al. (1984), volatilization with evaporation is a complex problem, but evaporation always increases the overall volatilization rate. Jury et al. (1984) present an equation for the convection of contaminants caused by the flux of water in the soil. The convective volatilization flux caused by evaporation is then calculated by isolating the first half of the overall volatilization flux equation (Jury et al., 1983), which can be written as follows:

$$J_{evaptr,t} = \tfrac{1}{2}\, C_T\, \rho_b\, (0.01V_E)\, \{\mathrm{erfc}[V_E\, t/(4\, D_A\, t)\tfrac{1}{2}] - \mathrm{erfc}[(100d_s + V_E\, t)/(4\, D_A\, t)^{1/2}]\} \qquad (4\text{-}15)$$

where

V_E = evaporative convective velocity (cm/s)
erfc(x) = complementary error function

and

$$V_E = [E/(365 \times 24 \times 3600]/(\rho_b\, K_d + \theta_w + \theta_a\, H') \qquad (4\text{-}16)$$

where

E = average annual evaporation rate (cm/yr).

The mass flux loss of a contaminant due to leaching is estimated by assuming the leachate is in equilibrium with the soil (i.e., Equation 4-2 applies):

$$J_{leach,t} = C_T\, \rho_b\, (0.01V_L)/(\rho_b\, K_d + \theta_w + \theta_a\, H') \qquad (4\text{-}17)$$

where

V_L = $(P + I - R - E)/(365 \times 24 \times 3{,}600]$ = leachate rate (cm/s)
P = annual average precipitation rate (cm/yr)

I = annual average irrigation rate (cm/yr)
R = annual average runoff rate (cm/yr).

The equation describing the mass flux loss of a contaminant due to runoff is nearly identical to Equation 4-11, because the runoff is also assumed to be in equilibrium with the contaminated soil. Consequently, the total mass rate of contaminant loss due to runoff is:

$$J_{runoff,t} = C_T \rho_b (0.01V_R)/(\rho_b K_d + \theta_w + \theta_a H') \qquad (4\text{-}18)$$

where

V_R = R/(365 × 24 × 3,600] = runoff rate (cm/s).

The results of the Jury equations yield the effective average soil concentration and vapor concentration for individual constituents for the exposure period. This spreadsheet model was used in the point risk estimates, the sensitivity analysis, and the uncertainty/variability analysis. However, the sensitivity analysis showed that soil parameters and meteorological parameters were not risk-drivers in either the MINTEQ or Jury equations and, thus, they were not included as variable parameters in the uncertainty/variability analysis.

The resulting soil concentrations of dioxins are presented in Table 4-4.

Assumptions

The Jury modeling incorporates several basic simplifying assumptions. In addition, the applicability and accuracy of the model results are subject to limitations. Some of the more significant assumptions and limitations are as follows:

- The adsorbed contaminant concentration is assumed to be linearly related to the liquid phase concentration.
- The contaminant concentration in the vapor phase is assumed to be linearly related to the liquid phase concentration.
- The only mass additions to the system occur during waste applications.
- The contaminant concentrations are assumed to be uniform over the tilling depth.
- There is a thin layer of untilled contaminated soil (depth equal to the depth of soil added during the annual application) just below the tilling depth. As this layer is buried it is lost from the system. It is not expected to contribute significantly to the exposure pathways.

Table 4-4. Range of Concentrations of Dioxin Congeners in Soils from the Use of CKD as an Agricultural Soil Amendment

Dioxin Congener	Soil Concentration Range (mg/kg)	Soil Concentration Range TEQ (ppt)
2,3,7,8-Tetrachlorodibenzodioxin	9.12E-09 - 3.70E-06	0.00912 -3.70
Octachlorodibenzodioxin	1.06E-07 - 1.97E-04	0.000106 - .197
1,2,3,7,8,9-Hexachlorodibenzodioxin	1.12E-08 - 2.75E-05	0.00112 - 2.75
Octachlorodibenzofuran	3.76E-08 -1.30E-05	.0000376 - 0.0130
1,2,3,4,7,8-Hexachlorodibenzodioxin	1.48E-08 - 1.10E-05	0.00148 - 1.10
1,2,3,7,8-Pentachlorodibenzodioxin	1.16E-08 - 1.05E-05	0.00578 - 5.23
2,3,7,8-Tetrachlorodibenzofuran	3.75E-09 - 9.24E-05	0.000375 - 9.24
1,2,3,4,7,8,9-Heptachlorodibenzodioxin	1.22E-08 - 7.45E-06	0.000122 - 0.0745
2,3,4,7,8-Pentachlorodibenzofuran	4.31E-09 - 3.73E-05	0.00216 - 18.6
1,2,3,7,8-Pentachlorodibenzofuran	4.82E-09 - 2.25E-05	0.000241 - 1.12
1,2,3,6,7,8-Hexachlorodibenzofuran	5.15E-09 - 7.59E-05	0.000515 - 7.59
1,2,3,6,7,8-Hexachlorodibenzodioxin	1.29E-08 -2.65E-05	0.00129 - 2.65
2,3,4,6,7,8-Hexachlorodibenzofuran	4.17E-09 - 2.22E-05	0.000417 - 2.22
1,2,3,4,6,7,8-Heptachlorodibenzofuran	5.35E-09 - 8.49E-05	0.0000535 - 0.849
1,2,3,4,7,8-Hexachlorodibenzofuran	1.29E-08 - 3.96E-05	0.00129 - 3.96
1,2,3,7,8,9-Hexachlorodibenzofuran	4.83E-09 - 5.18E-06	0.000483 - 0.518
1,2,3,4,6,7,8-Heptachlorodibenzodioxin	3.66E-08- 1.76E-04	0.000366 -1.76

4.3 Estimation of Air Concentrations of Metals and Dioxins

The risks via air pathways from exposures to CKD applied to agricultural fields as a soil amendment are assumed to be: (1) direct inhalation by the farmer, (2) vapor uptake by plants, and (3) dry deposition of particles to plants. Conservative estimates for exposure by the air pathways may be obtained by modeling the air concentration of constituents and deposition to plant surfaces grown on the amended agricultural field. Air dispersion of constituents to offsite locations (e.g., surface waterbody) was assumed to contribute insignificantly to exposures.

Constituents of CKD may be released into the air from the agricultural field by volatilization or by emission of particulate matter. For this analysis, volatile emissions from the agricultural field were estimated using the soil partitioning model presented in Section 4.1. Particulate emissions were estimated from two types of releases: emissions due to wind erosion and emissions due to agricultural tilling. The equations used to model particulate emissions are presented here.

Particulate emissions due to wind erosion were modeled assuming that the agricultural field is not covered by continuous vegetation or snow and that the surface soils have an unlimited reservoir of erodible surface particles. The factors for estimating emission of particles due to wind erosion and tilling were obtained from AP 42 (U.S. EPA, 1985b). The Emissions Factor and Inventory Group (EFIG) of the Office of Air Quality Planning and Standards (OAQPS) develops and maintains emission estimating tools to support the many activities of the Agency. AP-42 is the principal means by which EFIG documents the equations used to estimate emission factors. These emission factors relate the quantity of a pollutant released to the atmosphere with an activity associated with the release, for example, releases of soil particles through wind erosion of an agricultural field:

$$E_{wind} = 0.036 \bullet (1 - V) \bullet \left(\frac{u}{u_t} \right)^3 \bullet f(x) \qquad (4\text{-}19)$$

where

E_{wind} = emissions of PM_{10} (respirable particulate matter) from wind erosion ($g/m^2/s$)
V = vegetative cover (fraction)
u = mean windspeed (m/s)
u_t = threshold windspeed (m/s)
f(x) = function of roughness height.

This empirical equation estimates only the emission of respirable particulate matter (PM_{10}) from the site and is not applicable for the emission of larger particles. The emission of larger particles is not a factor due to wind erosion.

During agricultural tilling, particulate matter created from loosening and pulverizing the soils is released into the atmosphere as the soil is dropped to the surface. The emission factor used to estimate tilling emissions in this analysis is based on the factor presented in U.S. EPA (1985b):

$$E_{at} = 5.38 \bullet K_{at} \bullet S^{0.6} \bullet N_{op} \bullet CF \qquad (4\text{-}20)$$

where

E_{at} = emissions of soil (PM_{10} or PM_{30}) from agricultural tilling ($g/m^2/s$)

K_{at} = particle size multiplier to adjust results to PM_{10} or PM_{30} (unitless)
S = silt content of soil (%)
N_{op} = number of days of operations (d)
CF = conversion factor ([d•g•ha]/[s•kg•m^2]).

The silt content of the soils in the specific locations assessed in this analysis are presented in Table 4-5. Silt content of soils may vary from 3 percent for sandy soils to 87 percent for silty soils. The silt content of the soils in the geographic locations evaluated in the sensitivity analysis was found not to be a risk driver; therefore, variation in the silt content is not included as a variable in the deterministic analysis or the Monte Carlo simulation conducted as an uncertainty/variability analysis. Table 4-6 shows the representative percentage of silt for each soil-texture classification.

Inhalation risk was included in the screening deterministic. For this analysis, it is assumed that the CKD-amended agricultural field is tilled for 730 hours (1 month) distributed throughout the year. Tilling duration may be up to an order of magnitude lower from this value. No risk in excess of 1E-06 or hazard quotient in excess of 1 was estimated for the inhalation pathway in the screening analysis. This pathway was not evaluated in subsequent analyses.

No inhalation pathway risk in excess of 1.0 E-6 is estimated for CKD. Thus this pathway is eliminated from additional analyses.

It should be noted that releases of both particulate and volatile emissions was limited to releases from the agricultural field. Emissions from other potential sources such as storing, transporting, loading, and unloading the cement kiln dust at the farm or garden were considered to be minimal in this analysis because exposures from these short-term activities are expected to be insignificant compared to continuous releases from the agricultural field due to wind erosion and tilling.

4.4 ISCST3 Model for Air Dispersion and Deposition

Air dispersion modeling was conducted with the EPA's Industrial Source Complex Short Term, version 3 (ISCST3). ISCST3 is a Gaussian plume model that can simulate both wet and dry deposition and plume depletion. The ISCST3 outputs were used to estimate the vapor air concentrations and dry deposition rates needed to develop relative risk estimates associated with onsite exposures attributable to wind-blown fugitive emissions released from an agricultural field. Because it is assumed that wind-blown emissions would be negligible on rainy days due to a muddy barrier, exposures associated with wet deposition are not considered as part of this analysis. The EPA's ISCST3 model is applicable in simple, intermediate, and complex terrains. However, as discussed in Volume II of the ISCST3 User's Guide (U.S. EPA, 1996f), the complex terrain screening algorithms do not apply to area sources such as the emission source (i.e., an agricultural field) being investigated as part of this analysis.

The ISCST3 air model was used to estimate the average air concentration of particulate and vapor in the analysis.

Table 4-5. Silt Content of Site-Specific Soils

Location	Soil Type	Silt Content (%)
Holly Hills, SC	Silt	87
Alpena, MI	Silty till	60
Ravena, NY	Silty till	60

Table 4-6. Silt Content of Soils by Soil-Texture Classification

Soil Texture Classification	Silt Content (%)
Sand	3
Loamy sand	12
Sandy loam	25
Loam	40
Silty loam	63
Silt	87
Sandy clay loam	14
Clay loam	36
Silty clay loam	58
Sandy clay	8
Silty clay	47
Clay	15

Consequently, regardless of the location being modeled, receptor elevations and the terrain grid pathway were not specified in the ISCST3 input files. The ISCST3 model was run using "default" model options specified in the *Guideline on Air Quality Models* (U.S. EPA, 1993d).

As part of the sensitivity analysis, modeling was conducted using three different field sizes (Field 1 - 800 meters x 800 meters, Field 2 - 950 m x 950 m, Field 3 - 1150 m x 1150 m) assumed to be located in three geographic locations—Alpena, Michigan, Indianapolis, Indiana, and Miami, Florida. The three geographic locations were selected to represent a range of meteorologic conditions. The field sizes were determined from the farm sizes presented in the agricultural census for the counties near cement kilns where CKD may be available for use as a liming agent. These data are presented in the sensitivity analysis that is described in detail in Appendix C. Field size was determined not to be a risk-driving parameter in the sensitivity analysis and therefore was not varied in the uncertainty analysis. For onsite exposures, field size makes no difference since application rate is varied as a function of field size. The only scenario in which field size is of concern is the fisher scenario because the total soil eroded from the field to the adjacent stream will depend upon the size of the agricultural field amended with CKD. The air deposition to the stream is estimated to be equal to the onsite deposition of dry particles and vapors on the field. This is a conservative assumption. Deposition over the entire watershed was not considered in this analysis because soil erosion and direct air deposition to the waterbody are expected to be much more significant contributors to risk. A sensitivity analysis has been conducted that shows that windblown deposition of particles from area sources decreases rapidly as the distance from the source increases. The graphical results of that analysis are presented in Appendix E.

ISCST3 requires a variety of meteorologic data as input. For each location modeled, 5 years of surface and upper air data were obtained to determine long-term average air dispersion and deposition estimates. Surface data were obtained from the Solar and Meteorological Surface Observation Network (SAMSON) CD-ROM (NOAA, 1993) for each National Weather Service (NWS) station located in an area of interest. These data include 5 years of hourly observations of the following meteorologic parameters: opaque sky, temperature, wind direction, windspeed, ceiling height, current weather, station pressure, and precipitation type and amount. The corresponding upper air data were obtained from EPA's SCRAM (Support Center for the Regulatory Air Models) bulletin board and were paired with the surface data for air dispersion modeling through the use of the meteorologic preprocessor PCRAMMET. PCRAMMET pairs the surface data with the upper air data to create a meteorologic file that contains hourly windspeed, wind direction, atmospheric stability class, temperature, and mixing height. The preprocessor also requires additional inputs based on site-specific land use data. Table 4-7 identifies the NWS station locations that served as the sources of surface and upper air data and the preprocessor inputs used in conducting modeling for each of three geographic locations. PCRAMMET inputs were derived as recommended in the PCRAMMET User's Guide (U.S. EPA, 1995c) based on the site-specific land use data obtained from telephone surveys and assessed through topographic maps.

Table 4-8 identifies the particle size distribution and the associated scavenging coefficients that were used in conducting air dispersion modeling for this analysis. The scavenging coefficients associated with the particle size distribution were obtained from Jindal

Table 4-7. Air Modeling Inputs Used in ISCST3 Modeling

	Meteorological Locations		
Surface data	Alpena, MI	Indianapolis, IN	Miami, FL
Upper air data	St. Marie, MI	Dayton, OH	West Palm Beach, FL
Anemometer height (m)	6.7	6.1	7.0
	PCRAMMET Preprocessor Inputs		
Land use within 5 km	Rural	Rural	Rural
Min. M-O length (m)	50	2.0	50
Roughness height (m)	0.34[a]	0.2	1.0
Noontime albedo (fraction)	0.18	0.20	0.21
Bowen ratio (fraction)	0.90	0.50	0.69
Net radiation absorbed in ground (fraction)	0.15	0.15	0.27
Anthropogenic heat flux (W/m^2)	0.0	0.0	31.7

[a] Based on a maximum roughness height of 1/20th of the anemometer height.

Table 4-8. Particle Size Distribution and Scavenging Coefficients

Particle Size Diameter (µm)	**Weight Distribution (Fraction)**	**Liquid and Frozen Scavenging Coefficients (h/mm-s)**
5.0	0.50	3.7E-4
20.0	0.50	6.7E-4

and Reinhold (1991). Liquid and frozen scavenging coefficients were set equal (PEI, 1986). Although wet scavenging of vapors depends on the properties of the chemicals involved, not enough data are available to develop chemical-specific scavenging coefficients adequately at this time. Therefore, gases were assumed to be scavenged at the rate of small particles whose behavior in the atmosphere is assumed to be influenced more by the molecular processes that affect gases than the physical processes that often dominate behavior of larger particles. The value 1.7E-4 (h/mm-s) for the gas scavenging coefficient was also taken from Jindal and Reinhold (1991).

Receptors were evenly spaced across each field, which was centered on the origin. The vapor air concentrations and particle dry deposition rates obtained as outputs from the ISCST3 model were averaged across the receptors for each field and used to develop relative risk estimates. Table 4-9 presents the air modeling results from this effort. The results reflect a unit emission rate of 1 g/s/m^2. These air modeling results were converted to chemical-specific air concentrations and deposition rates by multiplying the values in the table by the chemical-specific emission rates (Q) obtained from the Jury model.

This analysis indicated that field size and meteorologic location are not risk drivers, and variation in these parameters was not considered in the Monte Carlo simulation conducted as the uncertainty and variability analysis. The central tendency air dispersion results were used to develop both the deterministic and probabilistic results presented in this document.

4.5 Estimation of Metals and Dioxin Concentrations in Plants Grown in Soil Amended with CKD

Air deposition of vapors and particulates and root uptake were considered for contamination of plants.

The mechanisms considered for the transport of constituent from the air to vegetation were uptake of vapors and dry deposition of particulates to plant surfaces. An air-to-plant bioconcentration factor is used to estimate plant uptake of constituents in the air. Dry deposition of particles onto the plant surface is calculated by applying the dry deposition velocity to the air concentration using an interception fraction to represent the fraction of area covered by vegetation. Wet deposition is assumed to be negligible with respect to dry deposition of vapors and particles.

Plants may absorb contaminants through the uptake of constituents through air-to-plant biotransfer and through soil-to-plant uptake through the roots. These transfer processes are important pathways in this risk analysis.

4.5.1 Air-to-Plant Biotransfer

One route of exposure for vegetation is direct deposition of particles and vapors to plant surfaces. The air-to-plant biotransfer factors for dioxins are constituent-specific values specifically developed for use for dioxin congeners (Lorber, 1995). These factors were developed through experiments conducted using azalea leaves and, for that reason, this algorithm may significantly overestimate the concentration of constituents in bulky aboveground produce.

Table 4-9. Results of ISCST3 Air Modeling

Location	Field Size (m^2)	Dry Deposition of Particles ($(g/m^2\text{-}yr)/(g/s/m^2)$)	Air Concentration of Vapors ($(\mu g/m^3)/(g/s/m^2)$)
Indianapolis, IN	9.0E+05	5.81e+06	1.80E+07
Indianapolis, IN	6.4E+05	5.86E+06	2.23E+07
Indianapolis, IN	1.3E+06	6.90E+06	2.39E+07
Miami, FL	9.0E+05	NA	1.98E+07
Alpena, MI	9.0E+05	6.12E+10	1.87E+07

NA = Not available.

Given the shape of bulky produce, transfer of contaminant to the center of the fruit or vegetable is unlikely to occur, so the inner portions of the dietary item will be largely unimpacted. In addition, typical removal mechanisms, such as washing, peeling, and cooking, will further reduce contaminant residues. Therefore, applying these air-to-plant biotransfer factors directly will result in significant overestimation of contaminant concentrations. An adjustment factor (VG_{AG}) has been incorporated into the equations to address the overestimation for lipophilic compounds (K_{OW} >4). In this analysis, VG_{AG} has been assigned a value of 0.01 for dioxins for all exposed fruits and vegetables intended for human consumption. (The forage crops used as cattle feed in the beef and dairy pathways have been assigned a VG_{AG} value of 1.) The chemical-specific air-to-plant biotransfer factors for exposed fruits and vegetables are presented in Appendix B.

The interception fraction is another factor that "accounts for the fact that not all of the airborne material depositing within a unit area will initially deposit on edible vegetation surfaces" (U.S. EPA, 1990). Interception fraction is calculated from crop yield. The interception fraction for exposed fruits is calculated directly using the following equation (Baes et al., 1984):

$$Rp = 1 - e^{-\Upsilon * Yp} \tag{4-21}$$

where

Υ = empirical constant
Yp = crop yield (kg DW/m^2).

The interception fraction for exposed vegetables is estimated as a consumption-weighted average for the three components of this category. The interception fractions for the categories of fruiting vegetables, leafy vegetables, and legumes are calculated using the same equation. Table 4-10 lists the specific vegetables included in the three groups. The unweighted crop yields were used with values for the empirical constant suggested by Baes et al. (1984) for each type of vegetable.

4.5.1.1 Crop Yield. The crop yields for exposed fruit, exposed vegetables, and forage were derived using a method similar to that used in the Hazardous Waste Identification Rule (HWIR) analysis. Crop yields were estimated from dry harvest yield and area harvested as follows (Shor et al., 1982):

$$Yp \approx Yh/Ah \tag{4-22}$$

where

Yp = crop yield (kg DW/m^2)
Yh = dry harvested yield (kg DW)
Ah = area harvested (m^2).

Crop Yields for Exposed Vegetable and Exposed Fruit

Crop yield for exposed vegetables was estimated as a consumption-weighted average of values for fruiting vegetables, leafy vegetables, and legumes. The crop yield for exposed fruit did not need to be weighted because there was only one category of produce in the fruit group. Table 4-10 lists the specific fruits and vegetables included in each of the groups. Table 4-11 summarizes the calculations. U.S. average harvest yield and area harvested values for 1993 for the fruits and vegetables listed in Table 4-9 were used (USDA, 1994a and 1994b). Average harvest yield values were converted to dry weight using average conversion factors for fruits, fruiting vegetables, leafy vegetables, and legumes (Baes et al., 1984). Crop yields were then calculated for fruits, fruiting vegetables, leafy vegetables, and legumes using Equation 4-22. The exposed vegetable crop yields were then weighted by relative consumption of each group to determine the exposed vegetables weighted average crop yield of 3 kg DW/m^2. The exposed fruit crop yield was determined to be 0.25 kg DW/m^2.

Table 4-10. Fruits and Vegetables Included in Yp and Rp Calculations

Fruits	Fruiting Vegetables	Legumes	Leafy Vegetables
Apple Apricot Berry Cherry Cranberry Grape Peach Pear Plum/Prune Strawberry	Asparagus Cucumber Eggplant Sweet Pepper Tomato	Snap Beans	Broccoli Brussels Sprout Cabbage Cauliflower Celery Lettuce Spinach

Table 4-11. Calculation of Crop Yield (Yp) for Fruits and Aboveground Vegetables

	Area Harvested (acres)	**Area Harvested (m^2)**	**Harvested Yield (kg WW)**	**Harvested Yield (kg DW)**	**Unweighted Crop Yield (kgDW/m^2)**	**Intake (gDW/d)**	**Weight Based on Intake (unitless)**	**Weighted Crop Yield (kg DW/m^2)**
Fruit	2E+06	8.10E+09	1.36E+10	2.05E+09	0.25	NA	NA	NA
Leafy Vegetables	5.86E+05	2.37E+09	6.77E+09	5.82E+08	0.24	2.0	0.133	0.032
Fruiting Vegetables	6.52E+05	2.64E+09	4.41E+11	2.78E+10	10.5	4.2	0.28	2.94
Legumes	2.84E+05	1.15E+09	7.73E+08	8.59E+07	0.075	8.8	0.587	0.044
Total								**3**

DW = Dry weight.
NA = Not applicable.
WW = Whole weight

Note: WW to DW conversion factors: fruits 0.15, leafy vegs 0.086, fruit vegs 0.063, and legumes 0.11.

The consumption rates for the fruiting vegetables, leafy vegetables, and legumes are from the *Technical Support Document for Land Application of Sewage Sludge* (U.S. EPA, 1992c); these were presented as dry weight in the source document. The consumption rates used for weighting the three vegetable categories do not correspond exactly to the consumption rate of exposed vegetables used to calculate exposure. The consumption rates used to calculate exposure were considered to be the best currently available; however, it was assumed that similar relative intake fractions of each vegetable category would exist in both sets of consumption rate data.

Crop Yield for Forage

Crop yield for forage was estimated as a weighted average of crop yields for pasture grass and hay. A crop yield value for pasture grass of 0.15 kg DW/m^2 was used (U.S. EPA, 1994a); this was a direct estimate because estimates of harvest yield and acres are not available for pasture grass. For hay, a dry harvest yield of 1.22E+11 kg DW was estimated from the U.S. average harvest yield for hay for 1993 of 1.35E+11 kg WW (USDA, 1994c) using a dry weight conversion factor of 0.9 (Fries, 1994). U.S. average area harvested for hay for 1993 was 2.45E+11 m^2 (USDA, 1994c). Using these figures, a crop yield of 0.5 kg DW/m^2 was estimated using Equation 4-22. The crop yields were weighted based on the fraction of a year cattle could be pastured; the weights used were 0.75 for pasture grass and 0.25 for hay, based on 9 months per year in pasture and 3 months per year not in pasture (and fed hay). This resulted in a weighted crop yield for forage of 0.24 kg DW/m^2.

4.5.1.2 <u>Interception Fractions</u>. Interception fractions for exposed vegetables were estimated as a consumption-weighted average of values for fruiting vegetables, leafy vegetables, and legumes. The interception fraction for exposed fruit did not need to be weighted because there was only one category of produce in the fruit group. Table 4-9 lists the specific fruits and vegetables included in each of the groups.

Baes et al. (1984) gives the following general equation for calculating interception fraction:

$$Rp - (1-e^{-\gamma Yp}) \qquad (4\text{-}23)$$

where

γ = empirical constant
Yp = crop yield (kg WW/m^2).

Interception Fractions for Exposed Vegetables and Exposed Fruit

Table 4-12 summarizes the calculations for interception fractions. Unweighted whole weight crop yields were used with values for the empirical constant suggested by Baes et al. (1984) for each type of fruit or vegetable. The unweighted dry weight crop yields (see previous section) were converted to whole weights. The interception fractions for fruiting vegetables, leafy vegetables, and legumes were then weighted by relative consumption of each group to determine the weighted average exposed vegetable interception fraction of 0.3. The exposed fruit interception fraction was determined to be 0.05.

Table 4-12. Calculation of Interception Fraction (Rp) for Exposed Fruits and Exposed Vegetables

	Unweighted Crop Yield (kg WW/m^2)	γ	Unweighted Interception Fraction (unitless)	Intake (g DW / d)	Weight	Weighted Interception Fraction (unitless)
Fruit	1.68	0.0324	0.053	NA	NA	NA
Leafy Vegetables	2.85	0.0846	0.21	2.0	0.133	0.028
Fruiting Vegetables	167	0.0324	1.0	4.2	0.28	0.15
Legumes	0.67	0.0324	0.022	8.8	0.587	0.013
Total vegetable						**0.3**

DW = Dry weight.
WW = Whole weight.
Unweighted Crop Yield was estimated based on data presented in Table 4-10 for Area Harvested (m^2) and Harvested Yield (kg WW).
NA = Not applicable.

The consumption rates for the fruiting vegetables, leafy vegetables, and legumes are from the *Technical Support Document for Land Application of Sewage Sludge* (U.S. EPA, 1992c); they were presented as dry weight in the source document. The consumption rates used for weighting the three vegetable categories do not correspond exactly to the consumption rate of exposed vegetables used to calculate exposure. The consumption rates used to calculate exposure were considered to be the best currently available; however, it was assumed that similar relative intake fractions of each vegetable category would exist in both sets of consumption rate data.

Interception Fraction for Forage

The interception fraction for forage was estimated from the weighted average crop yield for pasture grass and hay (see previous section) as follows (Chamberlain, 1970):

$$Rp = (1-e^{-\gamma Yp}) \tag{4-24}$$

where

γ = empirical constant
Yp = crop yield (kg WW/m^2).

Chamberlain (1970) gives a range for the empirical constant of 2.3 to 3.33. The midpoint of the range, 2.88, is used, as suggested by Baes et al. (1984). Both the hay and the pasture grass dry weight crop yields (see previous section) were converted to a whole weight basis prior to use in the above equation. The resulting interception fraction is 0.5.

4.5.2 Plant-Soil Bioconcentration Factor

The plant-soil bioconcentration factor (Br) accounts for the uptake of constituent from soil and the subsequent transport of constituent through the plant tissue. The factor is defined as the ratio of constituent concentration in the plant to constituent concentration in the soil. The Br factors are a function of the constituent's bioavailability from the soil. Bioconcentration factors for metal constituents of cement kiln dust presented in this section were obtained from the literature (U.S. EPA, 1992c; U.S. EPA, 1996b; Baes et al., 1984). Empirical correlations were used to estimate transfer of dioxins from the soil to plant tissue.

The Br factors for metals were obtained from the *Technical Support Document for Land Application of Sewage Sludge, Volume 1* and *Technical Support Document for the Round Two Sewage Sludge Pollutants* (U.S. EPA, 1992c and 1996e). The uptake slopes are calculated from existing field data, such as metal loading rates and measured soil metal concentrations. Separate Br values are estimated for different types of vegetation including forage, leafy vegetables, and root vegetables. The following assumptions are used in the document to develop bioconcentration factors for metals:

- The available literature was reviewed and relevant data compiled into a database.
- The uptake slope was determined for each study using linear regression of the concentration of pollutant in plant tissue against the application rate of the pollutant.
- The plants were classified (e.g., leafy vegetable, garden fruit), and an uptake slope was calculated for each plant group using the geometric mean of the uptake slopes from relevant studies.

The response slopes presented in the initial sewage sludge document (U.S. EPA, 1992c) are presented in terms of a field area rather than in terms of soil mass. A bulk density of 1.33 g/cm^3 and a mixing depth of 15 cm were assumed in estimating these parameters.

The Br values used in this analysis for metal constituents are presented in Table 4-13. When a separate value for forage was not available, the value presented in the sludge document for grains and cereals was used (U.S. EPA, 1992c). Br factors not covered in the sludge document were obtained from Baes et al. (1984).

4.5.3 Dioxins

For dioxins, the methodology presented in *Estimating Exposure to Dioxin-Like Compound, Volumes I-III: Site-Specific Assessment Procedures* (U.S. EPA, 1994a) was followed for this analysis. Vegetation was classified as aboveground or belowground with belowground vegetation including root vegetables such as carrots, potatoes, and radishes. The Br parameter was used only for aboveground fruits and vegetables. The following equation from Travis and Arms (1988) is used by EPA (1993a and 1995a) to calculate the bioconcentration factor in aboveground vegetables for organic chemicals when experimental data are not available in the literature:

$$\log(Br) = 1.588 - 0.578 \log(K_{ow}) \tag{4-25}$$

where

Br = plant-soil bioconcentration factor [(µg/g plant tissue)/(µg/g soil)]
K_{ow} = octanol-water partition coefficient (L/kg).

A different factor, a root concentration factor (Rcf), is used for root vegetables. The Rcf is a ratio of the concentration in roots to the concentration in soil pore water. A relationship between Rcf and K_{ow} was derived by Briggs et al. (1982) from experimental measurement of chemical uptake by barley roots:

$$\log(Rcf - 0.82) = 0.77\log(K_{ow}) - 1.52 \tag{4-26}$$

where

Rcf = root concentration factor [(µg/g plant tissue)/(µg/mL soil water)].

Table 4-13. Plant Biotransfer Factors for Metals (µg/g DW plant)/(µg/g soil)

Metal	Forage	Leafy Vegetable	Root Vegetable
Antimony[a]	2.0E-01	2.0E-01	3.0E-02
Arsenic[b]	6.0E-02	3.6E-02	8.0E-03
Barium[a]	1.5E-01	1.5E-01	1.5E-02
Beryllium[a]	1.0E-02	1.0E-02	1.5E-03
Cadmium[b]	1.4E-01	3.6E-01	6.4E-02
Chromium[a]	7.5E-03	7.5E-03	4.5E-03
Lead[a]	1.3E-05	1.3E-05	9.0E-03
Mercury[b,c]	2.0E-03	8.0E-02	1.4E-02
Nickel[b]	1.1E-01	3.2E-02	8.0E-03
Selenium[b]	6.0E-03	1.6E-02	2.2E-02
Silver[a]	4.0E-01	4.0E-01	1.0E-01
Thallium[b]	4.0E-03	4.0E-03	4.0E-04

[a] Baes et al., 1984, as applied in U.S. EPA, 1995a.
[b] U.S. EPA, 1992b as converted in U.S. EPA, 1995a.
[c] Mercury is subject to revision based upon the Mercury Report to Congress.

Note: Br factors for beryllium and thallium (leafy vegetables) are based on nonsewage sludge studies. Therefore, these values may be higher than expected for sewage sludge or cement kiln dust.

Dioxin-like compounds are thought to sorb to the outer portion of belowground vegetables, and translocation to inner portions of bulky roots is thought to be insignificant due to very low water solubility (U.S. EPA, 1994a). To account for the difference in uptake of dioxins by bulky roots versus by barley roots, an empirical correction factor of 0.01 is used to adjust the estimated Rcf. This value represents a surface-volume-to-whole-plant-volume ratio estimated for a carrot (U.S. EPA, 1994a).

4.6 Estimation of Metals and Dioxin Concentrations in Beef and Dairy Fed on Vegetation Amended with CKD

Risks in the farmer scenario may occur through the ingestion of plants grown on amended soil and products from animals raised on fields amended with CKD. In this analysis, the only animal products considered are beef and milk. Beef and dairy items have high lipid content and therefore may be expected to have higher concentrations of lipophilic constituents than other animal products. The biotransfer factors for these dietary items are also more thoroughly documented than those for pork, poultry, lamb, etc. The beef and milk biotransfer factors for all constituents are presented in Appendix B.

The estimated constituent concentrations in beef and dairy products were estimated based on the dietary intake assumptions for cattle. The diet was assumed to consist of forage (i.e., pasture grass and hay), silage, and grain grown on soil amended with CKD. In addition, the cattle are assumed to ingest the amended soil.

The intake of grain, silage, forage, and soil was assumed to vary between dairy and beef cattle. The diet of the beef cattle is assumed to be mainly pasture grasses, hay, and silage. Soil consumption is assumed to be high because of the time spent in pasturage. The total consumption rates for typical beef cattle are lower because they are slaughtered younger and lighter. Unlike beef cattle, dairy cows were assumed to be confined so that grazing was infrequent, their diet was supplemented with increased grain, and their soil intake was limited.

The total consumption of constituents of concern in feed is calculated as a sum of the constituent concentrations resulting from the following mechanisms:

- Root uptake - constituents available from the soil and their transfer to the aboveground portion of the plant

- Deposition of particles - dry deposition of particle-bound constituents on plants

- Vapor transfer - the uptake of vapor phase constituents by plants through their foliage.

The vegetation is classified as protected or unprotected. Grain and silage are considered to be protected because the outer covering acts as a barrier to the deposition of particles and vapor transfer and only root uptake is assumed to occur. Forage is assumed to be unprotected, and all routes of contamination are assumed to be present. The cattle dietary factors affecting concentrations of constituents of concern are presented in Table 4-14.

4.7 Estimation of Soil Erosion from Agricultural Site Amended with CKD to a Nearby Stream

The fisher scenario is used to develop estimates of risk through the ingestion of fish taken from a waterbody adjacent to fields amended with CKD. For this analysis, the waterbody is assumed to be a stream 75 meters from the agricultural field. This assumption may or may not be conservative because the distance to waterbodies is variable, as is the area of the agricultural field. A field of 2 million m^2 (>420 acres) is used in this analysis as the source to which CKD is applied. The constituents may reach the stream from the agricultural field through soil erosion or be windblown. Windblown deposition has been conservatively estimated to be equal to the onsite deposition. The soil erosion from the agricultural field to the adjacent waterbody is

Table 4-14. Cattle Consumption Factors Affecting Concentrations of Constituents in Beef and Dairy Products

Parameter	Beef Cattle	Dairy Cows	Reference
Length of exposure to deposition			
Forage	0.12 yr	0.12 yr	
Silage	0.16 yr	0.16 yr	U.S. EPA, 1990
Consumption by cattle			
Forage	8.8 kg/d (DW)	13.2 kg/d (DW)	NAS, 1987; Boone et al., 1981, and Rice, 1994
Grain	0.47 kg/d (DW)	3.0 kg/d (DW)	
Silage	2.5 kg/d (DW)	4.1 kg/d (DW)	
Soil	0.5 kg/d	0.4 kg/d	Soil only: Fries, 1994

modeled using the integrated setting approach (Beaulieu et al., 1996) that was developed for the petroleum refinery listing decision's nongroundwater risk analysis and was presented in the *Background Document for the Interim Notice of Data Availability for the Petroleum Refining Listing Decision*. See Figure 4-2 for a diagram of the integrated setting as it is used in this analysis.

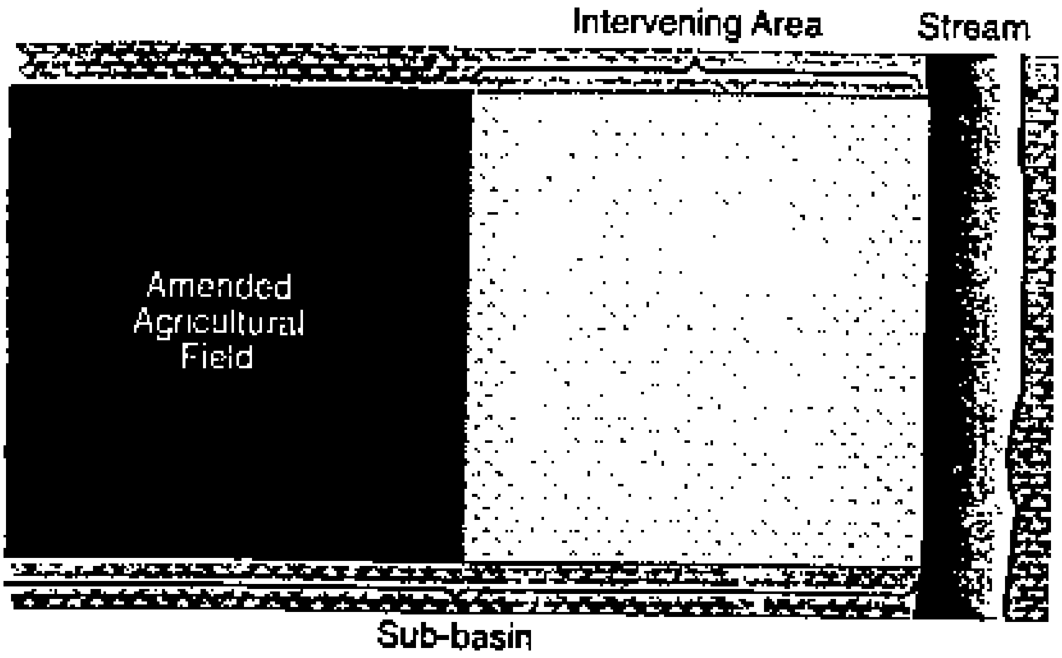


Figure 4-2. Diagram of integrated soil erosion setting.

4.7.1 Methodology for Estimating Soil Erosion in an Integrated Setting

The method of estimating risk from the overland transport pathways was modified by EPA's Office of Solid Waste (OSW) and the Office of Research and Development (ORD). The Universal Soil Loss Equation (USLE) was modified to estimate soil erosion and overland transport of sediment from agricultural fields amended with CKD across intervening areas to nearby waterbodies by evaluating this process in an integrated setting (Beaulieu et al., 1996). The area including the agricultural field and the intervening area is considered for the purposes of this analysis to be an independent drainage subbasin. The soil erosion load from the subbasin to the waterbody is estimated using a distance-based sediment delivery ratio, and the sediment not reaching the waterbody is considered to be deposited evenly over the area of the subbasin. Thus, using mass balance equations, contributions to the constituent concentrations of the waterbody and of the soil may be estimated. The equations implementing the concept of the integrated setting are based on the following assumptions:

- The area of the agricultural field and the area between the field and the nearest waterbody make up a discrete drainage subbasin. This area is shown in Figure 4-2.

- The sediment delivery ratio (SD_{SB}) and the soil loss rate per unit area are assumed to be constant for all areas within the subbasin.

- The amount of soil deposited onto the intervening area through soil erosion is estimated by assuming that the fraction of soil that does not reach the waterbody remains in the subbasin.

- The entire subbasin drainage system is assumed to be at steady state. Consequently, steady-state soil concentrations for the different subareas (e.g., surrounding area) can be calculated using a mass balance approach.

- The soils within the watershed are assumed (on the average) to have the same soil properties (e.g., bulk density, soil moisture content), a reasonable assumption for areas with similar irrigation rates with infrequent tilling.

- The soil/constituent movement within the entire watershed is evaluated separately from the soil/constituent movement that occurs in the drainage subbasin. Only air deposition of constituents contributes to the constituent concentrations in soil outside the subbasin. The contribution of each area within the watershed to the constituent concentration in the waterbody is estimated independently and summed to estimate the total waterbody concentration.

- No contributions to constituent concentrations are assumed to occur from sources other than the agricultural field within the subbasin.

The values for these factors are presented in Appendix A with the equations in which they are used.

4.7.2 Total Constituent Load to Waterbody

The total load to the waterbody (L_T) is the sum of the constituent load via erosion (L_E) and the constituent load from pervious runoff (L_R). The total load to the waterbody is used to estimate risk to the subsistence and/or recreational fisher from the ingestion of fish. The estimation of L_E requires the calculation of a weighted average constituent concentration in watershed soils based on the eroded soil contribution ($S_{c,erode}$), and the L_R term requires the calculation of a weighted average constituent concentration based on the pervious runoff contribution ($S_{c,run}$). The weighted average constituent concentration represents the effective watershed soil concentration based on contributions from the subbasin and the remainder of the watershed. Most important, the weighted average concentration accounts for the differences in constituent concentrations in the different areas within the watershed. The calculation of L_T requires constituent concentrations to be calculated for each of the following areas within the watershed: the source, the buffer and surrounding area and the watershed area, outside the drainage subbasin. For the watershed soils outside the subbasin, it is assumed that constituents reach the watershed solely via air deposition (i.e., no erosion component).

Calculation of L_T requires constituent concentrations for each of the following areas within the watershed: the source, the buffer and surrounding area within the subbasin, and the watershed area outside the drainage subbasin. If we consider the erosion load (L_E) to the surface waterbody for each of these areas individually, the equation may be written as:

$$\begin{aligned} L_E = {} & [X_{e,SB} \times ER \times SD_{SB} \times A_0 \times C_0 \times (\frac{Kd_s\ BD}{\theta + Kd_s\ BD}) \times 0.001] \\ & + [X_{e,SB} \times ER \times SD_{SB} \times (\frac{Kd_s\ BD}{\theta + Kd_s\ BD}) \times 0.001] \\ & + [X_{e,SB} \times ER \times SD_{SB} \times A_{B/Surr} \times C_{B/Surr} \times (\frac{Kd_s\ BD}{\theta + Kd_s\ BD}) \times 0.001] \\ & + [X_e \times ER \times SD_{WS} \times [A_{WS} - (A_0 + A_{B/Surr})] \times C_{WS} \times (\frac{Kd_s\ BD}{\theta + Kd_s\ BD}) \end{aligned} \tag{4-27}$$

where

L_E = constituent load to watershed due to erosion (g/yr)
$X_{e,SB}$ = unit soil loss in subbasin (kg/m^2/yr)
ER = enrichment ratio
SD_{SB} = sediment delivery ratio for subbasin
A_0 = area of source (m^2)
C_0 = constituent concentration at the source (mg/kg)
Kd_s = soil water partition coefficient (L/kg)
BD = bulk density of soil (g/cm^3)
θ = volumetric soil content of soil (cm^3/cm^3)

0.001 = unit conversion factor ([g/kg]/[mg/kg])
$A_{B/Surr}$ = area of buffer and surrounding area (m^2)
$C_{B/Surr}$ = constituent concentration in buffer and surrounding area (mg/kg)
X_e = unit soil loss in watershed outside of subbasin ($kg/m^2/yr$)
SD_{WS} = sediment delivery ratio for watershed (unitless)
A_{WS} = area of entire watershed (m^2)
C_{WS} = constituent concentration in watershed soils outside of subbasin (mg/kg).

The enrichment ratio (ER) is included in the revised soil erosion equations. This factor represents the reality that erosion favors the lighter soil particles, which have higher surface-area-to-volume ratios and are higher in organic matter content. Therefore, concentrations of organic constituents, which are a function of organic carbon content of sorbing media, would be expected to be higher in eroded soil than in in situ soil. This factor is generally assigned values in the range of 1 to 5. A value of 3 for organic contaminants and a value of 1 for metals would be reasonable first estimates and have been used in this analysis (U.S. EPA, 1993a).

Alternatively, this equation can be written in terms of an average weighted soil concentration for the watershed that results in the same constituent load as a function of erosion and sediment delivery. The $S_{c,erode}$ term shown at the end of Equation 4-28 reflects this modification:

$$L_E = [X_e \times ER \times SD_{WS} \times A_{WS} \times (\frac{Kd_s\ BD}{\theta + Kd_s\ BD}) \times 0.001] \times S_{c,erode}. \tag{4-28}$$

L_T also requires the constituent load from pervious runoff (L_R). The L_R term is calculated using Equation 4-29:

$$L_R = R \times (A_{ws} - A_I) \times \frac{S_c \times BD}{\theta + Kd_s \times BD} \times 0.01 \tag{4-29}$$

where

L_R = pervious surface runoff load (g/yr)
R = average annual surface runoff (cm/yr)
A_{ws} = area of entire watershed (m^2)
A_I = impervious watershed area receiving constituent deposition (m^2)
S_c = weighted average constituent concentration in total watershed soils (watershed and subbasin) based on surface area (mg/kg)
BD = soil bulk density (g/cm^3)
θ = volumetric soil content of soil (cm^3/cm^3)
Kd_s = soil water partition coefficient (L/kg) or (cm^3/g)
0.01 = units conversion factor ($kg\text{-}cm^2/mg\text{-}m^2$).

Assuming that the ratio of pervious and impervious soils is the same for each of the designated areas, a correction for areas that do not erode (streets, rocks, etc.) can be added to Equation 4-28 by replacing A_{WS} with A_{WS} - A_I , where A_I equals the total impervious area in the watershed. Setting the L_R equal to each other in the previous two equations and solving for $S_{c,erode}$ yields:

$$S_{c,erode} = \frac{(X_{e,SB} \times A_s \times C_0 \times SD_{SB}) + (X_{e,SB} \times A_{B/Surr} \times C_{B/Surr} \times SD_{SB}) + (X_{e,SB} \times SD_{SB})}{X_e \times SD_{WS} \times A_{WS}} + \frac{\{[A_{WS} - (A_0 + A_{B/Surr})] \times C_{WS}\}}{A_{WS}}. \qquad (4\text{-}30)$$

Equation 4-30 accounts for differences in the sediment delivery ratios (SD), surface areas (A), and mixing depths (Z) for discrete areas of the watershed (i.e., source, receptor field, buffer/surrounding areas, and the remaining watershed). Similarly, the weighted average for runoff losses (ksr) was derived using the areas for various watershed components (e.g., receptor site field, watershed outside drainage subbasin); however, different sediment delivery ratios were not required because soils in the area were considered to be similar and the slope was considered uniform. It was possible to generate simple area-based weighting factors because the rainfall runoff per unit area was assumed to be constant for the entire watershed area.

4.7.2.1 <u>Constituent Concentrations in Various Watershed Components</u>. The constituent concentrations for the buffer and surrounding area ($C_{B/Surr}$) and the watershed area outside of the drainage subbasin (C_{WS}) are required to solve $S_{c,erode}$. As suggested previously, a mass balance approach was used to calculate the constituent concentrations for all watershed components.

The concentration in the buffer and surrounding area is given by

$$M_{B/Surr}(dC_{B/Surr} / dt) = (SL_{0,B/surr}\ C_0) + [M_{B/Surr}\ (Ds_{(1),B/Surr} - ks_{B/Surr}\ C_{B/Surr})] \qquad (4\text{-}31)$$

where

$M_{B/Surr}$ = mass of the buffer and surrounding area (kg)
$C_{B/Surr}$ = constituent concentration in the buffer and surrounding area (mg/kg)
$SL_{0,B/Surr}$ = soil load from source to buffer/surrounding areas (kg/yr)
C_0 = soil constituent concentration at the source (mg/kg)
$Ds_{(1),B/Surr}$ = air deposition rate from source to buffer and surrounding area (mg/kg-yr)
$ks_{B/Surr}$ = constituent loss rate coefficient for the buffer/surrounding area (per/yr).

At steady state, this equation may be solved for $C_{B/Surr}$ as follows:

$$C_{B/Surr} = (C_0\ SL_{0,B/Surr} + M_{B/Surr}\ Ds_{(1),B/Surr}) / (M_{B/Surr}\ ks_{B/Surr}) . \qquad (4\text{-}32)$$

For the watershed soils outside of the subbasin, we assumed that constituents reached the watershed solely via air deposition (i.e., no erosion component). Using similar mass balance and steady-state assumptions, the constituent concentration in watershed soils outside the subbasin may be calculated using

$$C_{WS} = Ds_{(1),WS} / ks_{WS} \tag{4-33}$$

where

C_{WS} = soil constituent concentration in the watershed (mg/kg)
$Ds_{(1),WS}$ = air deposition rate from source to the watershed (mg/kg/yr)
ks_{WS} = constituent loss rate coefficient for the watershed (per yr).

4.7.3 Summary

The equations and default input parameter values used to calculate soil concentrations and the waterbody concentrations of constituents of concern, including the revised overland transport pathways, are presented in Appendix A.

Contaminated particles are transported from the agricultural field to offsite locations via air deposition as well as runoff/erosion. The air deposition value for each area of interest is included in the evaluation of the mass balance. The air deposition over the entire subbasin area was considered to be uniform and equal to the air deposition modeled for the agricultural field.

The total load to the waterbody (L_T) is the sum of the constituent load via erosion (L_E) and the constituent load from pervious runoff (L_R). The total load to the waterbody is used to estimate risk to the fisher from the ingestion of contaminated fish. The estimation of L_E requires the calculation of a weighted average constituent concentration in watershed soils based on the eroded soil contribution ($S_{c,erode}$), and the L_R term requires the calculation of a weighted average constituent concentration based on the pervious runoff contribution ($S_{c,run}$). The weighted average constituent concentration represents the effective watershed soil concentration based on contributions from areas within the subbasin. Most important, the weighted average concentration accounts for the differences in constituent concentrations in the different areas within the subbasin. The calculation of L_T requires constituent concentrations for each of the following areas within the subbasin: the source (field) and buffer (the area between the agricultural field and the waterbody) (Beaulieu et al., 1996). The equations used to calculate the waterbody concentrations of constituents of concern including the overland transport pathways are presented in Appendix A. The values of the default input parameters used in each equation are also provided. The compound-specific data required in the risk assessment are presented in Appendix B.

4.8 Mercury Risk Assessment Methodology

The risk assessment methodology for mercury is unique in its complexity in comparison to other constituents. Much more information is available about mercury speciation in the environment and about the transport and toxicity of various mercury species (elemental, inorganic divalent, and methylmercury). The environmental transport parameters are unique to each species, therefore, each species of mercury is modeled independently within each media (air, soil, and water). The total mercury load transferred between media is determined to estimate the total mercury present in each media at steady state. Speciation is estimated for mercury in each media independently. Table 4-15 presents the steady state relative speciation of mercury in the environment reported in the mercury Report To Congress (RTC) which are applicable to CKD as an agricultural supplement. Because the steady-state distributions are used, internal transformations of the various species of mercury are not considered in the indirect exposure modeling. Also, as recommended in the mercury RTC, degradation losses in the water and soil are not considered in calculating media concentrations. The air concentration of mercury in this risk assessment is determined from the Henry's law constant for each species in the soil. The Henry's law constants are presented in Table 4-16.

Recent studies indicate that 95 to 100 percent of the total mercury in fish is in the form of methylmercury. Methylmercury concentrations in fish are estimated from total dissolved water concentrations using BAFs. The BAF of methylmercury is defined as the ratio of the methylmercury concentration in fish flesh divided by concentration of total dissolved mercury (inorganic and organic species) in the water column. The mercury RTC presents BAF data for trophic level 3 and 4 fish. To utilize these data in projecting human health impacts, human fish ingestion rates were apportioned into separate ingestion rates for trophic level 3 and 4 fish. Data characterizing fish ingestion contained in the Chemrisk 1991 study provided the appropriate fish ingestion rates for the two trophic levels. (The Chemrisk 1991 study was used by the US EPA in deriving the recreational adult fish ingestion value presented in the 1996 EFHB.) The ratio of trophic 3 fish ingestion to total fish ingestion was calculated as 0.36, and trophic level 4 fish ingestion to total fish ingestion was 0.64. A weighted BAF for mercury was calculated with these ratios and applied to the dissolved water concentration to estimate the concentration of methylmercury in fish.

The species of mercury ingested in other dietary products is assumed to be inorganic, divalent mercury, reflecting the speciation of mercury in soil and the lack of methylation mechanisms in many terrestrial organisms.

The small K_d's for elemental mercury cause this species to remain in the dissolved fraction of the water column. Methyl and divalent mercury are preferentially sorbed to suspended sediments and benthic layer due to high K_d values. As a result, the small fraction of elemental mercury in water (0.02 as given in Table 2-1) drives the concentration of mercury in fish. The methodology for indirect exposure modeling for mercury given in the mercury RTC is being used to estimate mercury concentrations in the current risk assessment. The results of this analysis are presented in Table 4-17.

Table 4-15. Steady-State Mercury Speciation in Environmental Media

Environmental Media	Mercury Species		
	Elemental (%)	Inorganic Divalent (%)	Methylmercury (%)
Soil	0	98	2
Water	2	83	15
Fish	0	0 - 5	95 - 100

Table 4-16. Physical/Chemical Properties for Mercury Species

Environmental Media	**Mercury Species**		
	Elemental	**Inorganic Divalent (chloride)**	**Methylmercury (chloride)**
Henry's law constant	7.1E-03	7.1E-10	4.7E-7
Molecular weight	201	201 (271.52)	216 (251.08)
Solubility	6E-05	69	
Vapor pressure (torr)	2.0E-03	1.2E-04	8.5E-03
Log K_{ow}	NA	-0.215	0.405
Diffusivity in air (cm^2/s)	0.055	0.045	0.053
Diffusivity in water (cm^2/s)	8E-06	8E-06	8E-06
Soil water partition coefficient Kd_s (L/kg)	1.3E+02	5.37E+04	5.37E+04
Suspended-sediment partition coefficient Kd_{sw} (L/kg)	1.3E+02	9.5E+04	6.5E+05
Benthic sediment partition coefficient Kd_b (L/kg)	1	1.57E+05	1.57E+05
$Bv_{aboveground\text{-}veg}$	NA	20,660	2,473
Bv_{fruits}	NA	18,000	5,000
$Bv_{forage/silage}$	NA	18,000	5,000
Br_{roots}	NA	0.068	0.15
$Br_{aboveground\text{-}veg}$	NA	0.012	0.016
Br_{fruits}	NA	0.018	0.024
$Br_{forage/silage}$	NA	0	0
Br_{grain}	NA	0.0093	0.019
Ba_{beef}	NA	NA	0.02
Ba_{milk}	NA	NA	0.02
BAF_{fish}	NA	NA	Trop 3 - 66,200 Trop 4 - 335,000
RfD	1E-04 (RfC)	3E-04	1E-04

NA = Not available.
RfC = Reference concentration.

Source: Review Draft Mercury Study Report to Congress, 1996

Table 4-17. Hazard Quotient for Mercury from Ingestion of Fish

Percentiles	Fish Ingestion HQ methylmercury
0	6.00E-10
5	1.00E-09
10	2.00E-09
15	5.00E-09
20	9.00E-09
25	1.00E-08
30	1.00E-08
35	2.00E-08
40	2.00E-08
45	2.00E-08
50	3.00E-08
55	4.00E-08
60	4.00E-08
65	5.00E-08
70	7.00E-08
75	1.00E-07
80	2.00E-07
85	2.00E-07
90	4.00E-07
95	5.00E-07
100	1.00E-06

5.0 Scenarios and Exposure Routes

The exposure factors used in this risk analysis are from the draft *Exposure Factors Handbook* (U.S. EPA, 1996a). This document presents the exposure factor data used in the deterministic and the probabilistic analyses. The probabilistic analysis has been conducted in accordance with the Policy for Use of Probabilistic Analysis in Risk Assessment at the U.S. Environmental Protection Agency (May 15, 1997).

5.1 Consumption Factors Required for Receptor Scenarios

The assumptions for each receptor scenario are presented in Table 5-1.

There is no distance to receptor for the farmer, child of farmer, or home gardener scenario since the CKD is added directly to the agricultural field or home garden soil. The nearby waterbody is assumed to be a fixed distance (75 m) from the agricultural field. In this risk assessment, it is assumed that the fisher does not have a home garden and thus consumes no contaminated produce. If the fisher did have a home garden, the risk for the fisher and gardener scenarios could be summed to estimate this risk.

Table 5-1. Dietary Consumption Patterns for Receptor Scenarios

	Receptor Scenario			
Dietary Item	**Home Gardener**	**Farmer**	**Child of Farmer**	**Fisher**
Soil	✓	✓	✓	
Exposed Fruits	✓	✓	✓	
Exposed Vegetables	✓	✓	✓	
Root Vegetables	✓	✓	✓	
Beef		✓	✓	
Dairy Products		✓	✓	
Fish				✓

A distribution of values from the draft 1996 *Exposure Factors Handbook* was used for the uncertainty/variability analysis.

The consumption rates used in this risk analysis are from the draft 1996 *Exposure Factors Handbook* (Handbook). These factors were determined to be risk-drivers in the sensitivity analysis described in Appendix C and, therefore, were included in the uncertainty/variability analysis. For the uncertainty analysis, the distribution of values from the Handbook was used. The Handbook has been reviewed by the EPA Science Advisory Board.

The intake rates presented in the Handbook are based where possible on the Nationwide Food Consumption Survey (NFCS) data. According to the 1996 Handbook, the USDA conducts the NFCS every 10 years to analyze the food consumption behavior and dietary status of Americans. The survey used as a basis for the 1996 Handbook is the 1987-1988 survey. The survey used a statistical sampling technique designed to ensure that all seasons, geographic regions of the 48 conterminous states, and socioeconomic and demographic groups were represented. The data on the socioeconomic and demographic characteristics of households, and the types, amount, value, and sources of foods consumed by the households were collected over a 7-day period. The individual intake data on food intakes of individuals within each household were collected over a 3-day period. Although these are the best data available, it is recognized that these intake data are derived from short-term studies that may not reflect long-term behaviors. The data collected represent the total amount of food product brought into the household during the week and divided by the number of household members. The data do not include losses due to preparation and cooking. The sample size for this survey was approximately 4,300 households (over 10,000 individuals). These data were used to generate homegrown intake rates because they are the most recent data and are believed to reflect current dietary patterns in the United States.

The percentiles of average daily intake derived for short time intervals will not be reflective of long-term patterns. The 1996 Handbook developed an approach to account for seasonal variability in consumption by using “seasonally adjusted distributions” to approximate regional long-term distributions and then combine these regional adjusted distributions (in proportion to the weights for each region) to obtain a U.S.-adjusted distribution to approximate the U.S. long-term distribution. The Handbook recommends using the intake rates presented in the document directly. However, in this analysis, consumption rates are required, thus an average body weight of 60 kg was used as described in the Handbook for adjusting the intake rate to a consumption rate.

5.1.1 Ingestion of Soil

No distribution of specific values is presented in the draft 1996 Handbook for soil ingestion for adults or children. Limited studies are available for estimating soil ingestion in adults. The 1996 Handbook presents two studies (Calabrese et al., 1990, and Hawley, 1985). These studies showed an average soil intake rate range of 0.5 mg/d to 110 mg/d. This includes the recommended soil intake rate of 50 mg/d used by many EPA programs. A triangular distribution of values is used in this analysis. The average soil intake value of 5E-05 kg/d is the most prevalent value for long-term ingestion and the minimum and maximum values are assumed to be 5E-07 kg/d and 4.8E-04 kg/d, respectively. The Handbook suggests that 480 mg/d for adults engaged in outdoor activity may be used in screening for noncarcinogens. This distribution may or may not overestimate the frequency of high-end adult soil ingestion rates. With such a limited data set (6 data points), an alternative to this distribution is to consider these values as a range of potential ingestion rates of equal probability. This will have no effect on the deterministic analysis and limited effect on the Monte Carlo analysis since adult soil ingestion rate is not one of the most important risk drivers.

Child soil ingestion rates have been studied more frequently and in greater detail than ingestion rates for adults. Six large studies have been examined in detail for the Handbook. It is assumed that all children (ages 1-6 years) ingest some soil through hand-to-mouth behavior. This normal pattern of ingestion is captured in the distribution of the range of means for child soil ingestion rates (39 to 245.5 mg/d; the average recommended value is 165 mg/d) presented in the Handbook. This range of means is consistent with the 200-mg/d value that EPA programs have used as a conservative mean estimate. However, the Handbook indicates that there is also an upper percentile range of child soil ingestion rates of 106 to 1,432 mg/d, with an upper percentile mean of 545 mg/d. The 1,432-mg/d value is presented as an upper percentile estimate in Calabrese et al. (1989), which includes children with pica behavior. Pica behavior is the intentional ingestion of soil. Pica behavior presents additional concern when establishing a distribution of child soil ingestion rates. The Handbook presents five key studies on soil ingestion in children. All studies are short term, and the prevalence of pica behavior is unknown. It is, therefore, suggested that the range of child soil ingestion may be underestimated if the pica child is excluded from the distribution. The Handbook presents data that indicate that an ingestion rate of 10 to 14 g/d may not be unreasonable for screening for noncarcinogens. The Handbook notes that pica behavior might have been observed in additional children if studies were for longer periods of time. In an initial attempt to use these data, a triangular distribution of values was selected to represent child soil ingestion. The range of values was assumed to be from 39 mg/d (low end of the mean ingestion range) to 1,432 mg/d (high end of the upper percentile range) with the likeliest value being the recommended value of 165 mg/d.

The data used in this risk analysis, presented in Table 5-2, are recognized as conservative and may overestimate the frequency of children and adults with high-end soil ingestion.

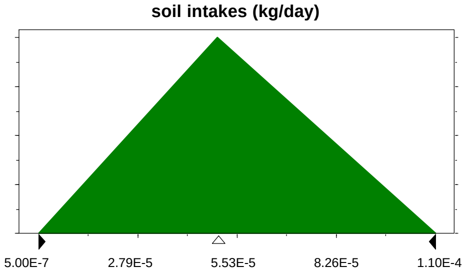
5.1.2 Ingestion of Exposed Fruits and Vegetables and Root Vegetables

In the deterministic risk analysis and the Monte Carlo analysis, the intake assumptions for the home gardener scenario are based on the data presented in the Handbook. The revised Handbook presents different intake rates for the homegrown food categories for “households who garden” and “households who farm.” The distributions of intakes used for the home gardeners came from the distributions for “households who garden” in the following tables: “Intake of Homegrown Exposed Vegetables,” “Intake of Homegrown Exposed Fruits,” and “Intake of Homegrown Root Vegetables.” The distributions of intakes used for the farmer came from the distributions for “households who farm” in the following tables: “Intake of Homegrown Exposed Vegetables,” “Intake of Homegrown Exposed Fruits,” and “Intake of Homegrown Root Vegetables.” The draft Handbook presents intakes for the separate categories for exposed fruits and vegetables. The exposure assumptions have been revised to reflect this change. The

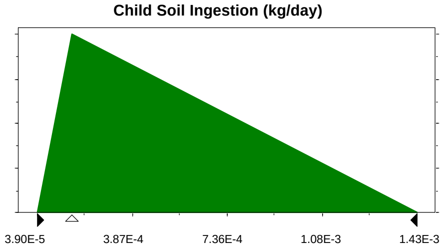
Table 5-2. Soil Ingestion Rate Assumptions

Scenario	Central Tendency	High End	Minimum	Likeliest	Maximum
Adult (kg/d)	5E-05	1.1E-04	5E-07	5E-05	4.8E-04
Child (kg/d)	1.65E-04	1.43E-03	3.9E-05	1.65E-04	1.4E-02

Adult



Child



distributions of intakes of beef and dairy products used for the farmer came from the distributions for “households who raise animals” in the following tables: “Intake of Homegrown Beef” and “Intake of Homegrown Dairy. ”

A fraction of this total intake is assumed to be actually home-produced. In this analysis, the home garden and agricultural field are assumed to be the contaminated area and, thus, the fractions that represent home-grown produce also represent the fraction of the dietary intake that is contaminated. These fractions are mean values and are used as a single value in the absence of additional data. This fraction assumed home-produced is presented in the Handbook in Table 12-71. The data from this table are presented here in Table 5-3.

The intake rates presented in the Handbook are presented in grams of fresh weight per day per kilogram of body weight. The equations used in this risk analysis require this intake to be converted to consumption rates for adults. This conversion is accomplished by using the 60 kg per individual average weight indicated in the Handbook for this purpose. For all organic compounds and most metals, these consumption rates remain in fresh (wet) weight equivalents for all dietary categories; however, for some metals, a dry weight consumption rate is required for the analysis for root vegetables and beef and dairy.

5.1.2.1 <u>Dry Weight Conversion</u>. The dry weight conversion factors are used to adjust the wet weight intakes for fruits, vegetables, root vegetables, beef, and dairy presented in the Handbook to dry weight for use with the bioconcentration or biotransfer factors required for this analysis. The dry weight consumption rate is needed for all compounds for fruits and exposed vegetables. The dry weights for root vegetables are used for all metals and those for beef and

Table 5-3. Fraction of Dietary Item Home-Produced

Dietary Item	Fraction Home-Produced Consumed by Households That Garden	Fraction Home-Produced Consumed by Households That Farm
Exposed Vegetables	0.233	0.420
Exposed Fruit	0.116	0.328
Root Vegetables	0.106	0.173
Beef	NA	0.319
Dairy	NA	0.254

NA = Not applicable.

dairy are used only for cadmium, selenium, and mercury. The same dietary weighting factors used in the estimation of ϒp (Section 4.5.1) were used for the dry weight conversions.

The following equation was used to convert the WW food consumption rate to a DW basis.

$$C_{DW} = C_{WW} * (1 - F_{MOISTURE}) \tag{5-1}$$

where

C_{DW} = consumption in dry weight
C_{WW} = consumption in wet weight
$F_{MOISTURE}$ = fraction moisture.

The dry weight conversions for these dietary categories are presented in Table 5-4.

The dry weight conversions for dairy products is the most complex due to the number of items included in the category. These items and their fraction moisture content are presented in Table 5-5.

The consumption rates used for adult home gardeners and farmers in the deterministic analysis are the 50th and 95th percentile values from the distribution of values presented in the Handbook. The parameter values for fruits and vegetables are presented in Table 5-6 and the values for beef and dairy are presented in Table 5-7.

Table 5-4. Moisture Content of Food Items Used for Dry Weight Conversions

Food Category	Fraction Moisture Content
Fruits	0.76
Exposed Vegetables	0.92
Root Vegetables	0.87
Beef	0.72
Dairy Products	0.76

Table 5-5. Dairy Intake Rates for Those Food Categories That Have Moisture Content Data

Food Category[a]	Food Intake Rate (g/d)	% Moisture	Weight[b]	Weighted % Moisture
Butter	5.2	15.87	0.06	0.9522
Cheddar Cheese	11.2	36.75	0.14	5.145
Colby, Washed Curd, Monterey Jack	2.5	38.2	0.03	1.146
Parmesan	0.6	17.66	0.007	0.12362
Swiss	1.5	37.21	0.02	0.7442
Cream	1.9	53.75	0.02	1.075
Blue	0.2	42.41	0.002	0.08482
Cottage Cheese	1.6	79.31	0.02	1.5862
Lowfat, Plain Milk (1%)	25.8	90.8	0.32	29.056
Skim, Plain Milk	29.7	90.8	0.37	33.596
Total Dairy Intake	**80.2**			73.50904
Weighted Percent Moisture				74

[a] Only those food categories for which moisture contents were available were included.
[b] Weighted by intake fraction.

Table 5-6. Parameter Values for Adult Consumption of Fruits and Vegetables

Dietary Item	Home Gardener		Farmer	
	Central	High End	Central	High End
Exposed Fruits (kg DW/d)	0.0127	0.0721	0.0188	0.0883
Exposed Vegetables (kg DW/d)	0.0040	0.0247	0.00625	0.0309
Root Vegetables				
(kg DW/d) metals	0.00513	0.0277	0.00672	0.0348
(kg WW/d) organics	0.04044	0.2184	0.05298	0.2748

Table 5-7. Parameter Values for Adult Farmer Consumption of Beef and Dairy Products

Dietary Item	Farmer	
	Central	High End
Beef		
(kg DW/d) metals	0.0312	0.128
(kg WW/d) organics	0.110	0.451
Dairy Products		
(kg DW/d) metals	0.174	0.634
(kg WW/d) organics	0.726	2.64

5.1.3 Monte Carlo Products

The distribution of consumption rate values for home-produced fruits and vegetables by home gardeners and farmers used in the Monte Carlo analysis are presented in Tables 5-8 through 5-15. The distributions of data used in the probabilistic analysis for home-produced beef and dairy for farmers are presented in Tables 5-16 and 5-17.

Table 5-8. Assumption: Farmer Fruit Intake (kg/d)

Continuous Range		Relative Probability
0	0.001	0.01
0	0.004	0.04
0	0.01	0.05
0.01	0.01	0.15
0.01	0.0188	0.25
0.019	0.0453	0.25
0.045	0.0721	0.15
0.072	0.0883	0.05
0.088	0.2265	0.05
Total Relative Probability		1.00

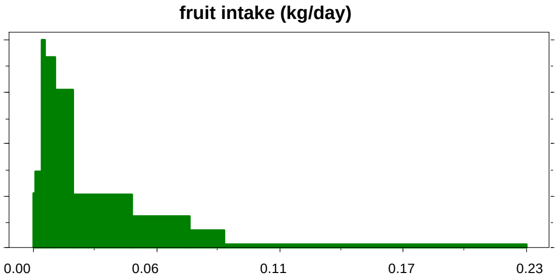


Table 5-9. Assumption: Home Gardener Fruit Intake (kg/d)

Continuous Range		Relative Probability
0.0000	0.0006	0.01
0.0006	0.0023	0.04
0.0023	0.0037	0.05
0.0037	0.0065	0.15
0.0065	0.0127	0.25
0.0127	0.0250	0.25
0.0250	0.0492	0.15
0.0492	0.0721	0.05
0.0721	0.1861	0.04
0.1861	0.4688	0.01
Total Relative Probability		1.00

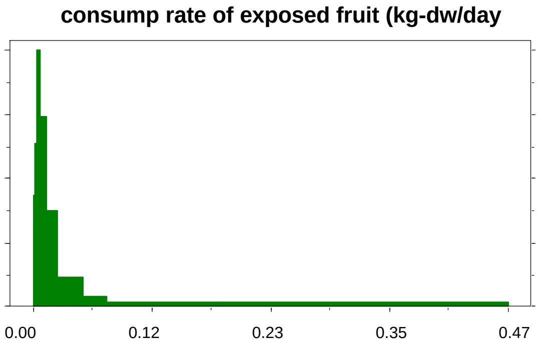


Table 5-10. Assumption: Farmer Exposed Vegetable Intake (kg/d)

Continuous Range		Relative Probability
0.0000	0.0008	0.05
0.0008	0.0017	0.05
0.0017	0.0029	0.15
0.0029	0.0063	0.25
0.0063	0.0127	0.25
0.0127	0.0272	0.15
0.0272	0.0309	0.05
0.0309	0.0467	0.04
0.0467	0.0602	0.01
Total Relative Probability		1.00

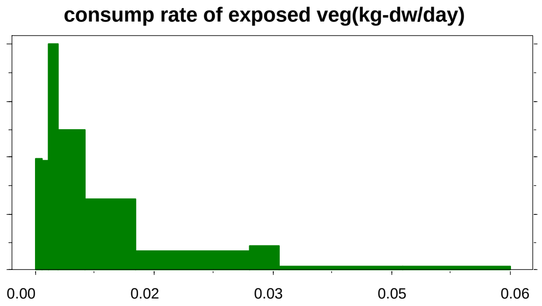


Table 5-11. Assumption: Home Gardener Exposed Vegetable Intake (kg/d)

Continuous Range		Relative Probability
0.0000	0.0000	0.01
0.0000	0.0004	0.04
0.0004	0.0008	0.05
0.0008	0.0019	0.15
0.0019	0.0040	0.25
0.0040	0.0089	0.25
0.0089	0.0164	0.15
0.0164	0.0247	0.05
0.0247	0.0467	0.04
0.0467	0.0933	0.01
Total Relative Probability		1.00

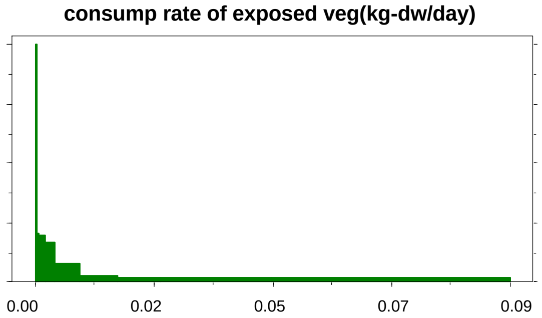


Table 5-12. Assumption: Farmer Root Vegetable Intake (kg-DW/d)

Continuous Range		Relative Probability
0.0000	0.0008	0.01
0.0008	0.0012	0.04
0.0012	0.0014	0.05
0.0014	0.0028	0.15
0.0028	0.0067	0.25
0.0067	0.0141	0.25
0.0141	0.0237	0.15
0.0237	0.0348	0.05
0.0348	0.0568	0.04
0.0568	0.0585	0.01
Total Relative Probability		1.00

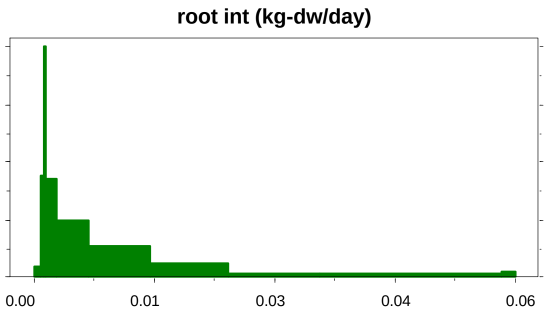


Table 5-13. Assumption: Farmer Root Vegetable Intake (kg-WW/day)

Continuous Range		Relative Probability
0	0.01	0.01
0.01	0.01	0.04
0.01	0.01	0.05
0.01	0.02	0.15
0.02	0.05	0.25
0.05	0.11	0.25
0.11	0.19	0.15
0.19	0.27	0.05
0.27	0.45	0.04
0.45	0.46	0.01
Total Relative Probability		1.00

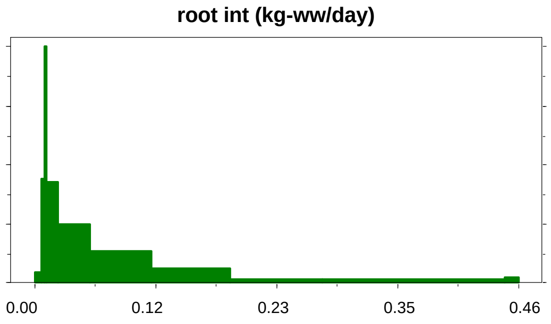


Table 5-14. Assumption: Home Gardener Root Vegetable Intake (kg-DW/d)

Continuous Range		Relative Probability
0.0000	0.0000	0.01
0.0000	0.0003	0.04
0.0003	0.0009	0.05
0.0009	0.0020	0.15
0.0020	0.0051	0.25
0.0051	0.0114	0.25
0.0114	0.0214	0.15
0.0214	0.0277	0.05
0.0277	0.0568	0.04
0.0568	0.0974	0.01
Total Relative Probability		1.00

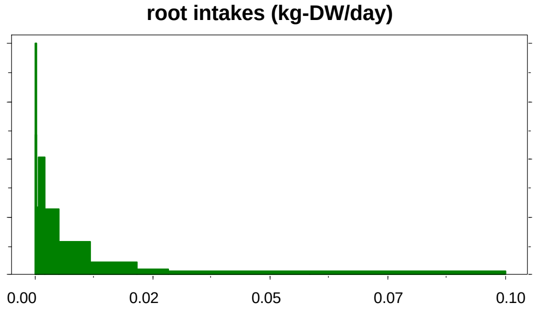


Table 5-15. Assumption: Home Gardener Root Vegetable Intake (kg-WW/d)

Continuous Range		Relative Probability
0.0000	0.0003	0.01
0.0003	0.0022	0.04
0.0022	0.0070	0.05
0.0070	0.0155	0.15
0.0155	0.0404	0.25
0.0404	0.0900	0.25
0.0900	0.1686	0.15
0.1686	0.2184	0.05
0.2184	0.4482	0.04
0.4482	0.7680	0.01
Total Relative Probability		1.00

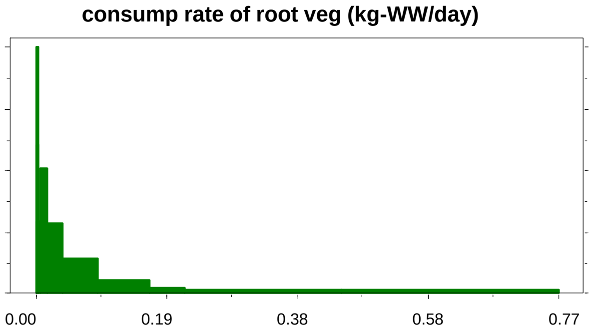


Table 5-16. Assumption: Farmer Beef Intake (kg-DW/d)

Continuous Range		Relative Probability
0.0000	0.0110	0.01
0.0110	0.0233	0.04
0.0233	0.0398	0.05
0.0398	0.0624	0.15
0.0624	0.1098	0.25
0.1098	0.2088	0.25
0.2088	0.3234	0.15
0.3234	0.4506	0.05
0.4506	0.7500	0.04
0.7500	1.1640	0.01
Total Relative Probability		1.00

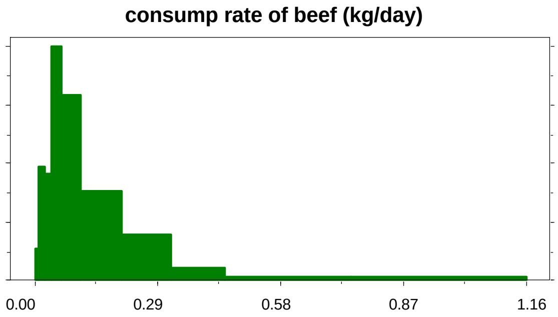
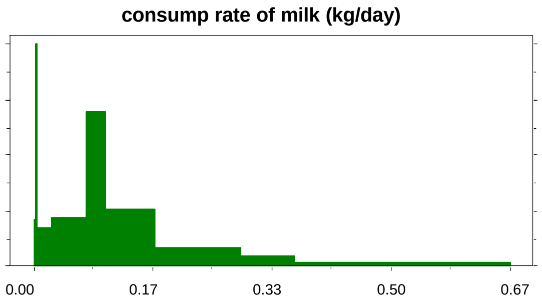


Table 5-17. Assumption: Farmer Dairy Intake (kg-WW/d)

Continuous Range		Relative Probability
0.0000	0.0238	0.01
0.0238	0.0442	0.04
0.0442	0.1908	0.05
0.1908	0.5436	0.15
0.5436	0.7260	0.25
0.7260	1.2240	0.25
1.2240	2.0940	0.15
2.0940	2.6400	0.05
2.6400	4.8060	0.04
4.8060	6.6600	0.01
Total Relative Probability		1.00



5.1.4 Fish Intake

There is a dichotomy in behaviors in fish ingestion, not a continuum. Most fish ingestion is represented by the distribution of ingestion rates presented in the 1996 Handbook for households that fish (recreational fishers). However, there are also specific subgroups, especially Native American subsistence fishers for whom this range is not adequate. The description of the population to be protected is essential for the appropriate evaluation of this pathway. This is especially important for all wastes having constituents that significantly bioaccumulate in fish (e.g., PCBs) or are biotransformed to more toxic forms (e.g., mercury) as significant constituents.

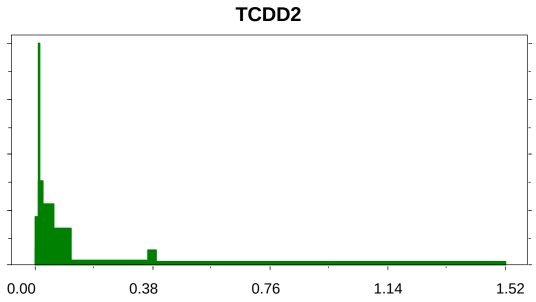
The intake rates for home-caught fish for recreational fishers were obtained from Table 12-25 in the Handbook, "Intake of Home Caught Fish (g/kg-day) - Midwest." This table presents intake rates for households that fish. The Midwest regional data were selected for ingestion rates for home-caught fish because the Midwest is the only region without a coastline, and the values for home-caught fish, therefore, should be restricted to freshwater species. This region also is an area where CKD may be applied as a soil supplement and an area with a Native American subsistence fisher population. As recommended above, an average body weight of 60 kg was used to calculate daily consumption from the ingestion rates presented in the tables. The fraction of fish consumed reported to be home caught is 0.113. This fraction is a mean quantity and is used as a single value in the absence of additional data at this time. The values used for this parameter in the deterministic analysis are presented in Table 5-18. The distribution of values used for the ingestion of home-caught fish in the probabilistic analysis are presented in Table 5-19.

Table 5-18. Parameter Values for Fisher Consumption of Home-Caught Fish

Dietary Item	Fisher	
	Central	High End
Fish (kg/d)	0.0618	0.394

Table 5-19. Assumption: Fisher Fish Intake (kg/d)

Continuous Range		Relative Probability
0.0000	0.0049	0.01
0.0049	0.0118	0.04
0.0118	0.0136	0.05
0.0136	0.0283	0.15
0.0283	0.0618	0.25
0.0618	0.1170	0.25
0.1170	0.3660	0.15
0.3660	0.3936	0.05
0.3936	0.9660	0.04
0.9660	1.5180	0.01
0.0118		1.00



5.1.5 Dietary Intakes for Children

This risk analysis provides a preliminary conservative approach for addressing exposure to children. The consumption rates for children of various ages must be keyed to the body weight for the age group. In the Handbook, ingestion rates for all dietary items are presented by the following age groups: 1 to 2, 3 to 5, 6 to 11, and 12 to 19 years. The Handbook also presents a body weight distribution chart for males and females ages 6 to 11 months and in 1-year increments thereafter to age 19. In order to obtain average body weights for use with the dietary intake tables, body weights for both sexes for each year of age are needed. The average body weights provided in the Handbook are presented in Table 5-20.

Table 5-20. Average Body Weights for Children by Age (kg)

	1 to 2		**3 to 5**			**6 to 11**						**12 to 19**							
Sex	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Male	11.8	13.6	15.7	17.8	19.8	23	25	28.2	31.1	36.4	40.3	44.2	49.9	57.1	61	67.1	66.7	71.1	71.7
Female	10.8	13	14.9	17	19.6	22.1	25	27.9	31.9	36.1	41.8	46.4	50.9	54.8	55.1	58.1	59.6	59	60.2

The body weights for both males and females in each year of the age range are averaged to obtain the average body weight for each age group presented in the intake distribution tables. These average weight values are presented in Table 5-21.

Table 5-21. Average Body Weights for Age Ranges

Age Range (Yr)	Weight (kg)
1 to 2	12.3
3 to 5	17.5
6 to 11	30.7
12 to 19	58.3

This average body weight (kg) for the age groups is used to estimate the daily consumption rate distributions (kg/d) for the age groups from the intake rate distributions (kg diet/kg body weight-day) presented in the Handbook. This approach will yield a distribution of consumption rates for children in each age range. However, children may be any age range during the period of exposure and may not remain in a single age range throughout the selected exposure duration. For long exposure durations, some type of weighted average ingestion rate may be used: however, this may not be appropriate for shorter exposure durations. In this probabilistic analysis that uses variable consumption rates and variable exposure durations for children, the age range with the highest distribution of consumption rates is selected for use. This distribution of consumption rates is used for all children for all exposure durations. This is a conservative assumption for exposure durations larger than the age ranges used. For all dietary items except milk the age range with the highest intake is 12 to 19 years. For dairy products the age range with the highest consumption rate is 6 to 11 years. In these cases the exposure is overestimated for all durations greater than 7 years (7.3 years is the median exposure duration). Thus, exposure is overestimated for all exposure durations greater than 5 years. Options for combining consumption rates and exposure durations for growing children are important for all dietary items. This issue is under continuing development. The consumption rates used in the deterministic risk analysis are presented in Table 5-22.

An adjustment for body weight is also required for the carcinogen slope factor (CSF) to be appropriate for children. The Handbook suggests that a body weight adjustment be made for any subpopulation with an average body weight different from the standard 70-kg body weight assumption used in calculating the CSF. The recommended correction factor is

$$CF = (BW_S / BW_I)^{1/3} \tag{5-2}$$

Table 5-22. Parameter Values for Child Farmer Consumption of Dietary Items

Dietary Item	Age Range	Central	High End
Exposed Fruit (kg DW/d)	12- 19	0.00854	0.0670
Exposed Vegetables (kg DW/d)	12- 19	0.00289	0.0166
Root Vegetables (kg DW/d) metals (kg WW/d) organics	12-19	0.00418 0.0329	0.0245 0.194
Beef (kg DW/d) metals (kg WW/d) organics	12-19	0.0250 0.088	0.059 0.210
Dairy Products (kg DW/d) metals (kg WW/d) organics	6-11	0.0876 0.365	0.212 0.365

DW = Dry weight.
WW = Whole weight.

Note: The same dry weight conversion factors applied for root vegetables, beef, and dairy products are applied for children also.

where

CF = correction factor
BW_S = body weight of subpopulation
BW_I = body weight used in developing CSF.

This factor is presented in Table 5-23 for each age range.

Table 5-23. Body Weight Correction Factors for Child Scenario Age Ranges

Age Range (yr)	Weights (kg)	Correction Factor
1 to 2	12.3	0.56
3 to 5	17.5	0.63
6 to 11	30.7	0.76
12 to 19	58.3	0.94

This factor has been applied as recommended in the Handbook to all carcinogens in this risk assessment as described below. No adjustments are needed for noncarcinogens.
.

$$CSF_A = CF \; x \; CSF_I \tag{5-3}$$

where

CSF_A = adjusted CSF
CSF_I = CSF in IRIS.

The distributions of data used in the Monte Carlo analysis for home-produced dietary items for children are presented in Tables 5-24 through 5-28.

Dairy intake for children uses a different set of values than all other intake parameters. All data for other intake parameters are from the tables of intakes of home-produced food items. The data for dairy intake for children are from the Handbook's Table 11-2. This table presents intake of total dairy products by age groups. The largest consumption rate that is selected for use in this analysis is for the 6- to 11-year-old age group. These data represent per capita intake rates and are not limited to home-produced products. In the absence of other data sources on home-produced dairy products, it is recommended that these data be used. The home-produced products section does give a fraction of home-produced dairy items consumed that can be used to develop a distribution for use in the analysis. The distribution of values used for the ingestion of child dairy intake in the probabilistic analysis is presented in Table 5-29.

5.2 Exposure Durations

Data for exposure duration are obtained from the distributions presented for population mobility (Chapter 14.3 of the Handbook). There are data for numerous categories of residents. The population mobility distribution for farmers will be used for the farmer scenario. All other categories (resident, home gardener, and fisher) will use the distribution of data for rural residents presented in Table 14-155 of the Handbook, "Total Residence Time, t (years), Corresponding to Selected Values of R(t) by Housing Category." For children, the exposure duration will change from using only 6 years' exposure duration to using the distribution of values presented in Table 14-159 of the Handbook, "Descriptive Statistics for Both Genders by Current Age." These data are relatively constant over childhood and can be adapted for use as a general distribution of values for children up to age 18. Table 5-30 presents estimated mobility data for children based upon current age.

Table 5-24. Assumption: Child of Farmer Fruit Intake (kg-DW/d)

Continuous Range		Relative Probability
0.0000	0.0012	0.01
0.0012	0.0017	0.04
0.0017	0.0036	0.05
0.0036	0.0057	0.15
0.0057	0.0085	0.25
0.0085	0.0318	0.25
0.0318	0.0478	0.15
0.0478	0.0670	0.05
0.0670	0.0827	0.05
Total Relative Probability		1.00

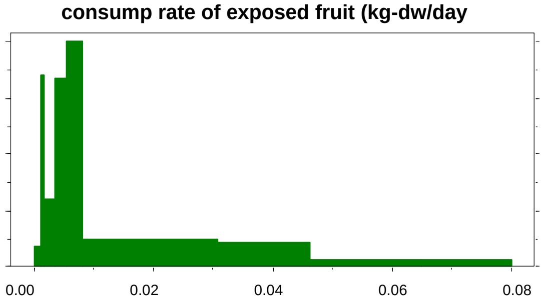


Table 5-25. Assumption: Child of Farmer Exposed Vegetable Intake (kg-DW/d)

Continuous Range		Relative Probability
0.0000	0.0001	0.01
0.0001	0.0006	0.04
0.0006	0.0013	0.05
0.0013	0.0029	0.15
0.0029	0.0064	0.25
0.0064	0.0103	0.25
0.0103	0.0166	0.15
0.0166	0.0250	0.05
Total Relative Probability		1.00

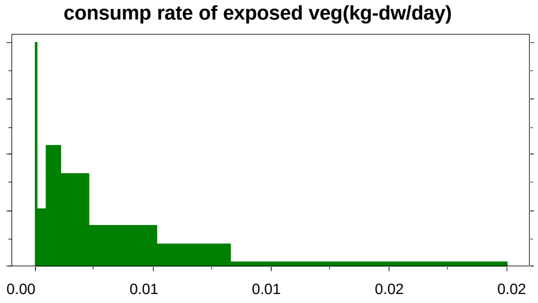


Table 5-26. Assumption: Child of Farmer Root Vegetable Intake (kg-WW/d)

Continuous Range		Relative Probability
0.0000	0.0004	0.01
0.0004	0.0005	0.04
0.0005	0.0040	0.05
0.0040	0.0157	0.15
0.0157	0.0329	0.25
0.0329	0.0799	0.25
0.0799	0.1318	0.15
0.1318	0.1936	0.05
0.1936	0.2991	0.05
Total Relative Probability		1.00

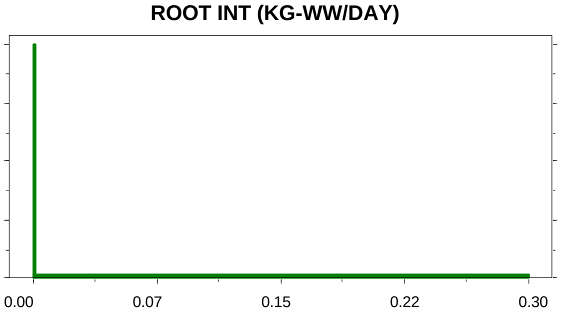


Table 5-27. Assumption: Child of Farmer Root Vegetable Intake (kg-DW/d)

Continuous Range		Relative Probability
0.0000	0.0001	0.01
0.0001	0.0001	0.04
0.0001	0.0005	0.05
0.0005	0.0020	0.15
0.0020	0.0042	0.25
0.0042	0.0101	0.25
0.0101	0.0167	0.15
0.0167	0.0245	0.05
0.0245	0.0379	0.05
Total Relative Probability		1.00

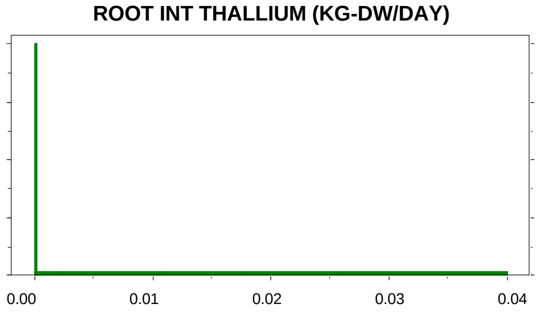


Table 5-28. Assumption: Child of Farmer Beef Intake (kg/d)

Continuous Range		Relative Probability
0.0000	0.02	0.01
0.02	0.03	0.04
0.03	0.03	0.05
0.03	0.05	0.15
0.05	0.09	0.25
0.09	0.14	0.25
0.14	0.21	0.15
0.21	0.21	0.05
0.21	0.25	0.05
Total Relative Probability		1.00

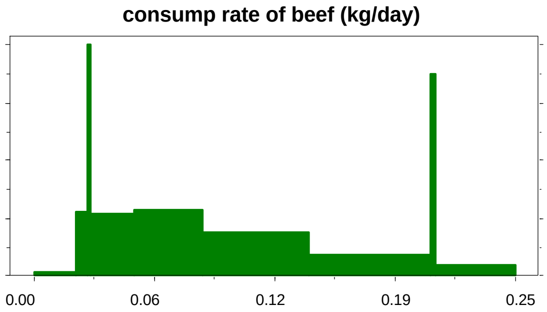


Table 5-29. Assumption: Child of Farmer Dairy Intake (kg/d)

Continuous Range		Relative Probability
0.0000	0.06	0.05
0.06	0.11	0.05
0.11	0.21	0.15
0.21	0.36	0.25
0.36	0.57	0.25
0.57	0.78	0.15
0.78	0.88	0.05
0.88	1.12	0.04
1.12	1.92	0.01
Total Relative Probability		1.00

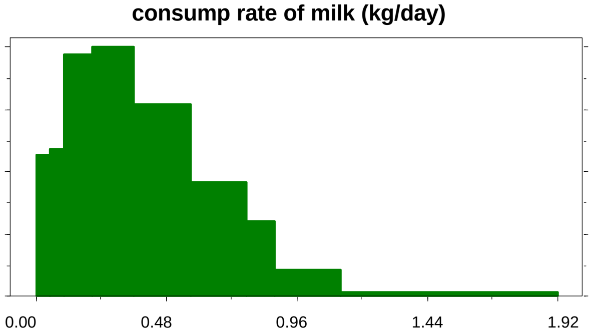


Table 5-30. Descriptive Statistics for Population Mobility for Children by Current Age

	Residential Occupancy Period (yr)					
	Percentile					
Current Age (yr)	**25**	**50**	**75**	**90**	**95**	**99**
3	3	5	8	13	17	22
6	4	7	10	15	18	22
9	5	8	12	16	18	22
12	5	9	13	16	18	23
15	5	8	12	16	18	23
18	4	7	11	16	19	23
Average	**4.3**	**7.3**	**11**	**15.3**	**18**	**22.5**

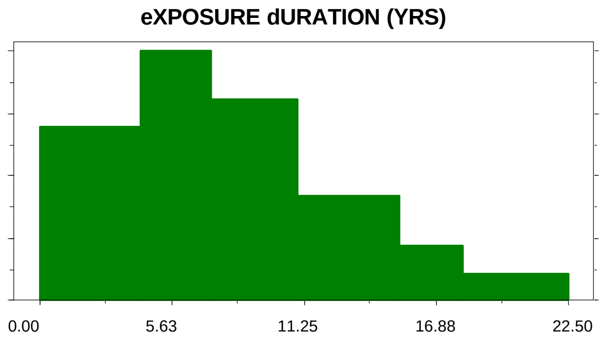


Table 5-31 presents the values used for exposure duration for all scenarios in the deterministic analysis. The distribution of values used for exposure duration in the probabilistic analysis are presented in Tables 5-32 and 5-33.

Table 5-31. Exposure Duration Values Used in Deterministic Risk Analysis

Receptor Scenario	Central Tendency (yr)	High End (yr)
Farmer	10	58.4
Home Gardener	3.3	32.3
Fisher	3.3	32.3
Child	7.3	18

Table 5-32. Assumption: Farmer Exposure Duration (yr)

Continuous Range		Relative Probability
0.0000	2.40	0.25
2.40	10.00	0.25
10.00	26.70	0.25
26.70	48.30	0.15
48.30	58.40	0.10
Total Relative Probability		1.00

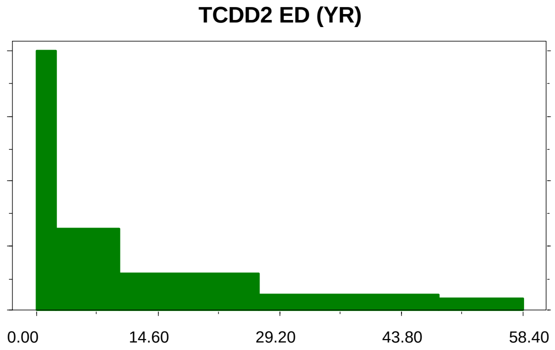
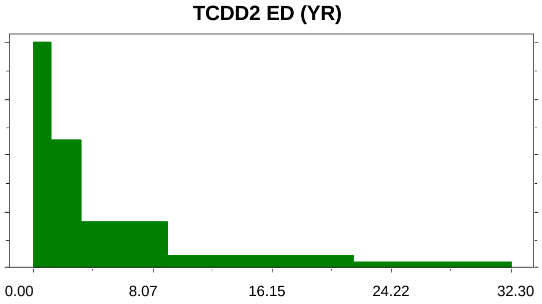


Table 5-33. Assumption: Home Gardener and Fisher Exposure Duration (yr)

Continuous Range		Relative Probability
0.0000	1.2	0.25
1.2	3.30	0.25
3.30	9.10	0.25
9.10	21.70	0.15
21.70	32.30	0.10
Total Relative Probability		1.00



6.0 Lead Exposure Evaluated with IEUBK Model

Human health risk assessment for lead is unique. Instead of developing a health benchmark in the traditional manner, all identified sources of lead exposure (including background) are used to predict blood lead (PbB) levels in the exposed individuals. The predicted PbB levels are compared to a target PbB. PbB levels have long been used as an index of body lead burdens and as an indicator of potential health effects.

The Integrated Exposure Uptake Biokinetic Model (IEUBK) (U.S. EPA, 1994a) was developed to predict PbB levels for an individual child or a population of children. The model was specifically designed to evaluate lead exposure in young children (birth to 7 years of age) because this age group is known to be highly sensitive to lead exposure. The pharmacokinetic relationships in the IEUBK model, in fact, are only valid for 0- to 7-year-olds.

The IEUBK model integrates lead exposures from diet, soil, dust, drinking water, and air and also considers elimination of lead from the body. The model uses standard age-weighted exposure parameters and its simulations represent chronic exposure and do not incorporate the variability in consumption patterns and media concentrations on a seasonal or daily basis. The IEUBK model simulates uptake, distribution within the body, and elimination of lead from the body. The uptake portion of the model takes into consideration two mechanisms of absorption of lead: saturable and nonsaturable. Elimination of lead is modeled through several routes: urine, gastrointestinal excretion, and sloughing of epidermal tissue, including hair and nails.

6.1 Exposure Factors

6.1.1 Inhalation and Drinking Waters

For inhalation of ambient air and ingestion of drinking water the Version 99d of the Integrated Exposure Uptake Biokinetic (IEUBK) model default parameters are used. These default parameters are presented in Table 6-1. These routes of exposure were not considered in the final risk analysis for other CKD constituents.

6.1.2 Dietary Intake

The dietary intake assumptions (homegrown vegetables, fruits, and roots) for children from the 1997 Exposure Factors Handbook are used in this analysis in order to make lead exposures from these sources comparable to all other constituents in CKD. There are no data in the EFH for the ingestion of homegrown beef and dairy products for children in this age group.

Table 6-1. Default Parameters Used in the IEUBK Blood Lead Model

Parameter	Default Value
Air lead concentration	0.100 µg/m^3
Indoor air percentage of outdoor air	30%
Drinking water lead concentration	4 µg/L

Therefore, beef and dairy ingestion pathways were not considered in the lead analysis. In the lead analysis, which is limited to children under the age of 7, it is not appropriate to use ingestion rates for older children for these parameters. For other constituents, beef ingestion rates for children 12 to 19 years old and dairy ingestion rates for children 6 to 11 years old were used.

The dietary concentrations of lead were estimated using the deterministic and probabilistic methodologies.

Table 6-2 compares the age-specific ingestion rates for lead in food products used in this analysis and the default dietary ingestion rates provided in the IEUBK blood-lead model. The 95th percentile concentrations of lead in exposed fruits and vegetables are used to derive the estimated media concentrations for the Monte Carlo analysis. These concentrations were used to estimate daily intake of lead in the diet of children assuming ingestion at central tendency ingestion rates as defined for the CKD multipathway analysis. The results of this analysis indicate that the estimated quantity of ingested lead is below the background dietary assumptions in the IEUBK model. This analysis demonstrates that lead exposures from diet do not contribute significantly to the total lead exposure of children of farmers who use CKD as a liming agent. Therefore, the CKD specific dietary inputs are not used in the remaining portion of this analysis.

Table 6-2. Ingestion Rates Used for Children in CKD Risk Analysis Compared to IEUBK Lead Model Default Values

Dietary Item	CKD Multipathway (50th and 95th Percentile)		IEUBK Lead Model Default Values
Root ingestion (gWW/day)	4.18 gDW/day 32.4 gWW/day 17.3 % homegrown	Diet 4.05 µg/d of lead	Diet 5.5 to 7.0 µg/d of lead
Exposed vegetable ingestion (gWW/day)	2.89 gDW/day 32.8 gWW/day 42% homegrown		
Exposed fruit ingestion	8.5 gDW/day 56 gWW/day 32.8 % homegrown		

6.1.3 Ingestion of Soil

The most important pathway for lead is soil and dust ingestion by children age 7 years and under. This pathway has been extensively researched in the development of the IEUBK model. A soil ingestion profile was developed to reflect soil ingestion patterns for narrower age ranges of children within in the 0- to 7-year-old age group. The same studies were considered in developing the age-specific ingestion rates for the IEUBK model as were considered in the development of the overall soil ingestion rates recommended for children 7 years and younger in the EFH. The IEUBK soil ingestion rate data reflect the child's age, activity pattern, and the total accessible dust and soil in the environment. The documentation of the IEUBK model points out that the mean value for soil ingestion is not subject to the bias caused by short-term studies in which the usual quantities of soil ingested are very low but there is occasional ingestion of a much larger quantity. Thus, the mean rate is judged to be a more meaningful measure of soil ingestion. These default parameters are presented in Table 6-3.

The blood lead concentrations were estimated using the default intake rates presented in IEUBK model and the 95th percentile media concentration determined in the Monte Carlo analysis. The IEUBK soil concentration distribution is presented in Table 6-4. Default IEUBK soil ingestion rates differ from those used in this analysis to estimate risk from other hazardous constituents in CKD. Soil ingestion rates used for other constituents are presented in Section 5.0 of the background document

Table 6-3. IEUBK Default Soil and Dust Intake Rates for Children 0 to 7 Years Old

Age Range (yr)	Soil Ingestion Rate (mg/d)
0.5-1	85
1-2	135
2-3	135
3-4	135
4-5	100
5-6	90
6-7	85

Table 6-4. Lead Concentrations in Soil from Monte Carlo Analysis

Percentile	Lead Soil Conc. (mg/kg)
0	0.10
5	1.03
10	1.87
15	2.90
20	4.05
25	5.16
30	6.26
35	7.34
40	8.50
45	9.83
50	11.35
55	13.21
60	15.45
65	18.43
70	22.48
75	28.99
80	39.13
85	54.88
90	78.51
95	128.13
100	721.49

The resultant blood lead concentrations estimated using the lead exposures estimated in this assessment have been added to the national geometric mean blood lead concentration in children ages 0 to 7 based on national average background concentrations of lead (i.e., using the default parameters in the IEUBK model), and the total blood lead level has been compared to a threshold value of 10 µg Pb/dL. Adverse health effects from lead exposure have been observed to occur at or below this level. The blood lead levels that correspond to the 95th percentile concentration of lead in soil and the child soil ingestion rates have been estimated using the IEUBK model. These results are presented in Table 6-5.

Table 6-5. Blood Lead Levels (µg/dL) Estimated Using IEUBK Default Soil Intake Rates 95th Percentile Soil Lead Concentration (128 mg/kg)

Age Range (yr)	95th Percentile Soil Concentration (128.1 mg/kg)
0.5-1	3.3
1-2	3.5
2-3	3.3
3-4	3.1
4-5	2.7
5-6	2.4
6-7	2.2
Probability of Blood Lead Level over 10 µg/dL	0.43 %
Mean Blood Lead Level	2.9

7.0 Risk Assessment Results

This section of the report describes the results of the deterministic and probabilistic risk assessment for each scenario. The risk assessment includes individual risk for the following receptor scenarios: home gardener, farmer, child of the farmer, and fisher. For each scenario the summary results tables for the deterministic analysis for metals are presented first. These results are followed by the confirming results of the probabilistic analysis.

The equations used in the evaluations of these scenarios and the values for the exposure parameters used in the equations are presented in Appendix A. The compound-specific data required in the risk assessment are presented in Appendix B.

The media concentrations and corresponding risk for each pathway and in all scenarios for the maximum double high end combination deterministic risk are presented in Appendix F.

7.1 Results for Metal Constituents

The results of the deterministic risk analysis for metals show increased cancer risk in the adult farmer scenario for arsenic (Risk= 2E-05) and increased hazard quotient in the child of farmer for thallium (HQ= 4). The two high-end parameter variations that produced the increased cancer risk for arsenic in the adult farmer are high arsenic concentration in CKD and long exposure duration in the farmer. The probabilistic analysis showed an increased cancer risk of 1E-05 at the 95th percentile in the farmer scenario for arsenic. The probabilistic analysis showed that the HQ for thallium in the child of farmer scenario exceeded 1 beginning at the 85th percentile. In a Monte Carlo analysis, combinations of variables are selected randomly from the distribution of values that are defined for the analysis. The values that are more probable are thus selected more frequently than less probable values in the distribution. This random selection process is repeated for at least 1,000 iterations of the analysis to ensure that a stable distribution of results is generated. These results are used by EPA to confirm the results of the deterministic risk analysis.

Metals Showing Increased
Cancer Risk (CR) or Hazard Quotient (HQ)

Scenario	Metal	CR or HQ
Farmer	Arsenic	CR = 2 E-5
Child	Thallium	HQ = 4

The deterministic risk analysis results for metals exposure in each scenario are presented in Tables 7-1 through 7-4. The results of the probabilistic analysis for the metals showing the potential for excess risk in the deterministic analysis are presented in Tables 7-5 through 7-8.

Table 7-1. Increased Hazard Quotient (HQ) or Cancer Risk (CR) to Home Gardener from Metals in CKD Used as an Agricultural Supplement

High-End Parameters Varied[a]	**Nickel (HQ)**	**Silver (HQ)**	**Thallium (I) (HQ)**	**Antimony (HQ)**	**Arsenic (CR)**	**Barium (HQ)**	**Beryllium (HQ)**	**Cadmium (HQ)**	**Chromium VI (HQ)**	**Selenium (HQ)**
Central Tendency	0.00008	0.00001	0.001	0.00009	1.E-08	0.0007	0.00002	0.0050	0.00004	0.000005
Single High-End Variation										
Long Exposure	0.00008	0.00001	0.001	0.00008	1.E-07	0.0006	0.00002	0.0040	0.00004	0.000005
Exposed Veg. Intake	0.0002	0.00004	0.001	0.0003	2.E-08	0.001	0.00003	0.0100	0.00006	0.000010
Root Veg.Intake	0.0001	0.00002	0.001	0.0001	1.E-08	0.0008	0.00002	0.0060	0.00005	0.000008
Fruit Intake	0.0003	0.00005	0.001	0.0003	3.E-08	0.002	0.00003	0.0100	0.00007	0.000010
Application Rate	0.0001	0.00002	0.001	0.0001	2.E-08	0.001	0.00003	0.0070	0.00007	0.000008
Application Frequency	0.0001	0.00002	0.001	0.0001	2.E-08	0.001	0.00003	0.0080	0.00007	0.000008
Constituent Conc.	0.0003	0.00006	0.03	0.001	7.E-08	0.002	0.0002	0.0300	0.0001	0.000040
Tilling Depth	0.0001	0.00001	0.001	0.0001	1.E-08	0.0008	0.00003	0.0060	0.00004	0.000006
Double High-End Variation										
Exposed Veg. Intake/Long Exposure	0.0002	0.00004	0.001	0.0002	2.E-07	0.001	0.00002	0.0100	0.00006	0.000010
Root Veg. Intake/Long Exposure	0.0001	0.00001	0.001	0.00009	1.E-07	0.0007	0.00002	0.0050	0.00005	0.000008
Fruit Intake/Long Exposure	0.0003	0.00005	0.001	0.0002	3.E-07	0.002	0.00003	0.0100	0.00007	0.000010
Application Rate/Long Exposure	0.0001	0.00002	0.001	0.0001	2.E-07	0.0009	0.00003	0.0070	0.00006	0.000008
Application Frequency/Long Exposure	0.0001	0.00002	0.001	0.0001	2.E-07	0.001	0.00003	0.0080	0.00007	0.000008
Constituent Conc./Long Exposure	0.0003	0.00006	0.03	0.0009	7.E-07	0.002	0.0001	0.0300	0.0001	0.000030
Tilling Depth/Long Exposure	0.0001	0.00001	0.001	0.00009	1.E-07	0.0008	0.00003	0.0060	0.00004	0.000005
Exposed Veg. Intake/Root Veg. Intake	0.0002	0.00004	0.001	0.0003	2.E-08	0.002	0.00004	0.0100	0.00006	0.000010
Exposed Veg. Intake/ Fruit Intake	0.0003	0.00007	0.002	0.0005	4.E-08	0.003	0.00005	0.0200	0.00008	0.000020

(continued)

Table 7-1. (continued)

High-End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Exposed Veg. Intake/ Application Rate	0.0003	0.00006	0.002	0.0004	4.E-08	0.003	0.00005	0.0100	0.0001	0.000020
Exposed Veg. Intake/Application Frequency	0.0003	0.00006	0.002	0.0004	4.E-08	0.003	0.00006	0.0200	0.0001	0.000020
Exposed Veg. Intake/ Constituent Conc.	0.0006	0.0001	0.03	0.003	2.E-07	0.005	0.0002	0.0800	0.0002	0.000060
Exposed Veg. Intake/Tilling Depth	0.0003	0.00004	0.001	0.0003	2.E-08	0.003	0.00005	0.0100	0.00006	0.000010
Root Veg. Intake/Fruit Intake	0.0003	0.00005	0.001	0.0003	3.E-08	0.002	0.00003	0.0100	0.00007	0.000010
Root Veg. Intake/ Application Rate	0.0002	0.00003	0.001	0.0002	2.E-08	0.001	0.00003	0.0070	0.00008	0.000010
Root Veg. Intake/Application Frequency	0.0002	0.00003	0.001	0.0002	2.E-08	0.001	0.00003	0.0080	0.00008	0.000010
Root Veg. Intake/Constituent Conc.	0.0003	0.00007	0.03	0.001	8.E-08	0.002	0.0002	0.0400	0.0001	0.000050
Root Veg. Intake/Tilling Depth	0.0001	0.00002	0.001	0.0001	1.E-08	0.0009	0.00003	0.0060	0.00005	0.000009
Fruit Intake/Application Rate	0.0004	0.00008	0.002	0.0005	5.E-08	0.004	0.00005	0.0200	0.0001	0.000020
Fruit Intake/Application Frequency	0.0004	0.00008	0.002	0.0005	5.E-08	0.004	0.00006	0.0200	0.0001	0.000020
Fruit Intake/Constituent Conc.	0.0008	0.0002	0.04	0.004	2.E-07	0.007	0.0003	0.1000	0.0002	0.000070
Fruit Intake/Tilling Depth	0.0003	0.00006	0.001	0.0004	3.E-08	0.003	0.00005	0.0200	0.00008	0.000010
Appplication Rate/ Application Frequency	0.0002	0.00003	0.002	0.0002	3.E-08	0.002	0.00005	0.0100	0.0001	0.000010
Appplication Rate/Constituent Conc.	0.0005	0.0001	0.05	0.002	1.E-07	0.003	0.0002	0.0400	0.0002	0.000050
Appplication Rate/Tilling Depth	0.0002	0.00002	0.001	0.0002	2.E-08	0.001	0.00004	0.0090	0.00007	0.000009
Appplication Frequency/ Constituent Conc.	0.0005	0.0001	0.05	0.002	1.E-07	0.003	0.0003	0.0500	0.0002	0.000040
Appplication Frequency/Tilling Depth	0.0002	0.00002	0.001	0.0002	2.E-08	0.001	0.00004	0.0090	0.00007	0.000008
Constituent Conc./Tilling Depth	0.0003	0.00007	0.03	0.001	7.E-08	0.002	0.0002	0.0300	0.0001	0.000040

[a] Listed parameters are varied to high-end values 1 or 2 at a time; all other parameters remain at central tendency values.

Table 7-2. Increased Hazard Quotient (HQ) or Cancer Risk (CR) to Farmer from Metals in CKD Used as an Agricultural Supplement

High-End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Central Tendency	0.0006	0.0004	0.009	0.0003	5.E-07	0.003	0.00005	0.01	0.0002	0.00003
Single High-End Variation										
Long Exposure	0.0006	0.0004	0.009	0.0003	3.E-06	0.002	0.00005	0.01	0.0002	0.00003
Beef intake	0.002	0.0005	0.07	0.0004	6.E-07	0.003	0.00008	0.01	0.0006	0.00004
Dairy Intake	0.001	0.001	0.02	0.0004	2.E-06	0.004	0.00005	0.01	0.0004	0.0001
Exposed Veg. Intake	0.0008	0.0005	0.01	0.0006	6.E-07	0.006	0.00007	0.03	0.0002	0.00004
Root Veg. Intake	0.0006	0.0005	0.009	0.0003	5.E-07	0.003	0.00005	0.02	0.0002	0.00004
Fruit Intake	0.001	0.0005	0.01	0.001	7.E-07	0.008	0.0001	0.05	0.0003	0.00005
CKD Application Rate	0.001	0.0008	0.01	0.0004	8.E-07	0.004	0.00006	0.03	0.0003	0.00006
CKD Application Frequency	0.001	0.0007	0.02	0.0004	8.E-07	0.005	0.00007	0.03	0.0003	0.00006
Constituent Conc.	0.002	0.002	0.3	0.003	3.E-06	0.008	0.0003	0.1	0.0005	0.0002
Small Tilling Depth	0.0008	0.0004	0.009	0.0003	5.E-07	0.003	0.00006	0.02	0.0002	0.00004
Soil Intake	0.0006	0.0004	0.01	0.0003	5.E-07	0.003	0.00007	0.01	0.0002	0.00004
Double High-End Variation										
Beef Intake/Long Exposure	0.002	0.0005	0.07	0.0004	3.E-06	0.002	0.00007	0.01	0.0006	0.00004
Dairy Intake/Long Exposure	0.001	0.001	0.02	0.0003	9.E-06	0.003	0.00005	0.01	0.0004	0.0001
Exposed Veg. Intake/Long Exposure	0.0008	0.0005	0.01	0.0006	3.E-06	0.005	0.00007	0.03	0.0002	0.00004
Root Veg. Intake/Long Exposure	0.0006	0.0005	0.009	0.0003	3.E-06	0.002	0.00005	0.02	0.0002	0.00004
Fruit Intake/Long Exposure	0.001	0.0005	0.01	0.0009	4.E-06	0.008	0.0001	0.05	0.0003	0.00005
Application Rate/Long Exposure	0.0009	0.0007	0.01	0.0004	5.E-06	0.004	0.00006	0.03	0.0002	0.00006

(continued)

Table 7-2. (continued)

High-End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Application Frequency/Long Exposure	0.001	0.0007	0.02	0.0004	5.E-06	0.004	0.00007	0.03	0.0003	0.00006
Constituent Conc./Long Exposure	0.002	0.002	0.2	0.003	***2.E-05***	0.007	0.0003	0.09	0.0005	0.0002
Small Tilling Depth/Long Exposure	0.0008	0.0004	0.009	0.0003	3.E-06	0.003	0.00006	0.02	0.0002	0.00003
Soil Ingestion/Long Exposure	0.0006	0.0004	0.01	0.0003	3.E-06	0.002	0.00007	0.01	0.0002	0.00004
Beef Intake/Dairy Intake	0.003	0.001	0.08	0.0004	2.E-06	0.004	0.00008	0.01	0.0008	0.0001
Beef Intake/Exposed Veg. Intake	0.003	0.0005	0.08	0.0007	7.E-07	0.006	0.0001	0.03	0.0006	0.00005
Beef Intake/Root Vegetable Intake	0.003	0.0005	0.07	0.0004	6.E-07	0.003	0.00008	0.02	0.0006	0.00004
Beef Intake/Fruit Intake	0.003	0.0006	0.08	0.001	8.E-07	0.008	0.0001	0.05	0.0006	0.00005
Beef Intake/Application Rate	0.003	0.0008	0.1	0.0006	1.E-06	0.004	0.0001	0.03	0.0008	0.00007
Beef Intake/Application Frequency	0.004	0.0007	0.1	0.0006	1.E-06	0.005	0.0001	0.03	0.0008	0.00007
Beef Intake/Constituent Conc.	0.007	0.002	***2***	0.004	4.E-06	0.009	0.0006	0.1	0.0010	0.0002
Beef Intake/Small Tilling Depth	0.003	0.0005	0.08	0.0004	6.E-07	0.004	0.0001	0.02	0.0006	0.00005
Beef Intake/Soil Intake	0.003	0.0005	0.08	0.0004	6.E-07	0.003	0.0001	0.01	0.0006	0.00004
Dairy Intake/Exposed Vegetable Intake	0.002	0.001	0.02	0.0007	2.E-06	0.006	0.00007	0.03	0.0004	0.0001
Dairy Intake/Root Vegetable Intake	0.001	0.001	0.02	0.0004	2.E-06	0.004	0.00005	0.02	0.0004	0.0001
Dairy Intake/Fruit Intake	0.002	0.001	0.02	0.001	2.E-06	0.009	0.0001	0.05	0.0005	0.0001
Dairy Intake/Application Rate	0.003	0.002	0.03	0.0005	2.E-06	0.005	0.00006	0.03	0.0007	0.0001
Dairy Intake/Application Frequency	0.003	0.002	0.03	0.0005	2.E-06	0.006	0.00007	0.03	0.0007	0.0001
Dairy Intake/Constituent Conc.	0.005	0.007	0.5	0.004	***1.E-05***	0.01	0.0003	0.1	0.0010	0.0006
Dairy Intake/Tilling Depth	0.001	0.002	0.02	0.0004	2.E-06	0.005	0.00006	0.02	0.0004	0.0001
Dairy Intake/Soil Intake	0.001	0.001	0.02	0.0004	2.E-06	0.004	0.00007	0.01	0.0004	0.0001

(continued)

Table 7-2. (continued)

High-End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Exposed Veg. Intake/Root Veg. Intake	0.0009	0.0005	0.01	0.0007	6.E-07	0.006	0.00007	0.03	0.0002	0.00005
Exposed Veg. Intake/Fruit Intake	0.001	0.0006	0.01	0.001	8.E-07	0.01	0.0001	0.07	0.0003	0.00006
Exposed Veg. Intake/Application Rate	0.001	0.0009	0.02	0.001	9.E-07	0.008	0.0001	0.05	0.0003	0.00008
Exposed Veg. Intake/Application Frequency	0.001	0.0008	0.02	0.001	9.E-07	0.009	0.0001	0.06	0.0003	0.00008
Exposed Veg. Intake/Constituent Conc.	0.003	0.002	0.3	0.007	4.E-06	0.02	0.0006	0.2	0.0006	0.0002
Exposed Veg. Intake/Tilling Depth	0.001	0.0005	0.01	0.0007	6.E-07	0.007	0.00009	0.04	0.0002	0.00005
Exposed Veg. Intake/Soil Intake	0.0009	0.0005	0.01	0.0006	6.E-07	0.006	0.00009	0.03	0.0003	0.00004
Root Veg. Intake/Fruit Intake	0.001	0.0005	0.01	0.001	7.E-07	0.008	0.0001	0.06	0.0003	0.00005
Root Veg. Intake/Application Rate	0.001	0.0008	0.01	0.0005	8.E-07	0.004	0.00006	0.03	0.0003	0.00007
Root Veg. Intake/Application Frequency	0.001	0.0007	0.02	0.0005	8.E-07	0.005	0.00007	0.03	0.0003	0.00007
Root Veg. Intake/Constituent Conc.	0.002	0.002	0.3	0.004	3.E-06	0.009	0.0003	0.1	0.0005	0.0002
Root Veg. Intake/Tilling Depth	0.0009	0.0005	0.009	0.0004	5.E-07	0.004	0.00006	0.02	0.0002	0.00005
Root Veg. Intake/Soil Intake	0.0007	0.0005	0.01	0.0003	5.E-07	0.003	0.00007	0.02	0.0002	0.00004
Fruit Intake/Application Rate	0.002	0.0009	0.02	0.002	1.E-06	0.01	0.0001	0.09	0.0004	0.00009
Fruit Intake/Application Frequency	0.002	0.0008	0.02	0.001	1.E-06	0.01	0.0001	0.09	0.0004	0.00009
Fruit Intake/Constituent Conc.	0.004	0.003	0.4	0.01	4.E-06	0.02	0.0008	0.3	0.0007	0.0002
Fruit Intake/Tilling Depth	0.001	0.0006	0.01	0.001	7.E-07	0.01	0.0001	0.07	0.0003	0.00007
Fruit Intake/Soil Intake	0.001	0.0005	0.01	0.001	7.E-07	0.008	0.0001	0.05	0.0003	0.00005
Application Rate/Application Frequency	0.002	0.001	0.02	0.0008	1.E-06	0.007	0.0001	0.04	0.0004	0.0001
Application Rate/Constituent Conc.	0.004	0.003	0.4	0.007	5.E-06	0.01	0.0005	0.1	0.0008	0.0003
Application Rate/Tilling Depth	0.001	0.0008	0.01	0.0007	8.E-07	0.005	0.00009	0.03	0.0003	0.00006

(continued)

Table 7-2. (continued)

High-End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Application Rate/Soil Intake	0.001	0.0008	0.02	0.0005	8.E-07	0.004	0.00008	0.03	0.0003	0.00007
Application Frequency/Constituent Conc.	0.004	0.003	0.5	0.007	5.E-06	0.01	0.0006	0.2	0.0008	0.0003
Application Frequency/Tilling Depth	0.001	0.0008	0.02	0.0007	8.E-07	0.005	0.0001	0.03	0.0003	0.00006
Application Frequency/Soil Intake	0.001	0.0007	0.02	0.0005	8.E-07	0.005	0.0001	0.03	0.0003	0.00007
Constituent Conc./Tilling Depth	0.002	0.002	0.3	0.004	3.E-06	0.009	0.0005	0.1	0.0005	0.0002
Constituent Conc./Soil Intake	0.002	0.002	0.3	0.004	3.E-06	0.009	0.0004	0.1	0.0006	0.0002
Soil Intake/Tilling Depth	0.0009	0.0004	0.01	0.0004	5.E-07	0.004	0.00008	0.02	0.0002	0.00005

[a] Listed parameters are varied to high-end values 1 or 2 at a time; all other parameters remain at central tendency values.

Note: Shaded and italicized bolded entries indicate cases where increased cancer risk exceeds 1E-05 or Hazard Quotient exceeds 1 for noncarcinogens.

Table 7-3. Increased Hazard Quotient (HQ) or Cancer Risk (CR) to Child of Farmer from Metals in CKD Used as an Agricultural Supplement

High-End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (C R)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Central Tendency	0.0018	0.00057	0.053	0.00048	7.E-07	0.0057	0.00000042	0.019	0.0012	0.0001
Single High-End Variation										
Long Exposure	0.0018	0.00046	0.053	0.00047	1.E-06	0.0046	0.00022	0.018	0.0012	0.0001
Beef intake	0.0023	0.00058	0.073	0.00052	7.E-07	0.0057	0.00023	0.019	0.0013	0.0001
Dairy Intake	0.0023	0.0011	0.058	0.00051	1.E-06	0.0063	0.00022	0.019	0.0013	0.0002
Exposed Veg. Intake	0.002	0.0006	0.054	0.00073	7.E-07	0.0073	0.00024	0.026	0.0012	0.0001
Root Veg. Intake	0.0018	0.00057	0.053	0.0005	7.E-07	0.0057	0.00022	0.021	0.0012	0.0001
Fruit Intake	0.0023	0.00065	0.055	0.0013	8.E-07	0.012	0.00028	0.063	0.0013	0.0002
CKD Application Rate	0.0033	0.00091	0.085	0.00095	1.E-06	0.0073	0.00033	0.034	0.0024	0.0003
CKD Application Frequency	0.0034	0.0008	0.096	0.00095	1.E-06	0.0084	0.00033	0.035	0.0024	0.0003
Constituent Conc.	0.0073	0.0023	**1.6**	0.0062	4.E-06	0.015	0.0012	0.12	0.0037	0.0009
Small Tilling Depth	0.003	0.00057	0.053	0.00061	7.E-07	0.006	0.00023	0.02	0.0012	0.0001
Adult Soil intake	0.0018	0.00057	0.053	0.00048	7.E-07	0.0057	0.00022	0.019	0.0012	0.0001
Child Soil intake	0.0048	0.00061	0.11	0.0011	1.E-06	0.011	0.001	0.039	0.0032	0.0003
Double High-End Variation										
Beef Intake/Long Exposure	0.0023	0.00047	0.073	0.0005	1.E-06	0.0046	0.00023	0.018	0.0013	0.0001
Dairy Intake/Long Exposure	0.0023	0.0011	0.058	0.00049	2.E-06	0.0052	0.00022	0.018	0.0013	0.0002
Exposed Veg. Intake/Long Exposure	0.002	0.00049	0.054	0.00063	1.E-06	0.0063	0.00024	0.026	0.0012	0.0001
Root Veg. Intake/Long Exposure	0.0018	0.00046	0.053	0.00049	1.E-06	0.0046	0.00022	0.019	0.0012	0.0001
Fruit Intake/Long Exposure	0.0023	0.00054	0.055	0.0012	2.E-06	0.0098	0.00028	0.052	0.0013	0.0002

(continued)

Table 7-3. (continued)

High-End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (C R)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Application Rate/Long Exposure	0.0032	0.0008	0.085	0.00084	2.E-06	0.0072	0.00023	0.023	0.0023	0.0003
Application Frequency/Long Exposure	0.0033	0.0008	0.086	0.00084	2.E-06	0.0084	0.00033	0.034	0.0024	0.0003
Constituent Conc./Long Exposure	0.0073	0.0022	**1.6**	0.0061	8.E-06	0.014	0.0012	0.12	0.0037	0.0008
Small Tilling Depth/Long Exposure	0.003	0.00047	0.053	0.00059	1.E-06	0.006	0.00023	0.02	0.0012	0.0001
Adult Soil intake/Long Exposure	0.0018	0.00046	0.053	0.00047	1.E-06	0.0046	0.00022	0.018	0.0012	0.0001
Child Soil intake/Long Exposure	0.0048	0.0005	0.11	0.00097	2.E-06	0.011	0.001	0.038	0.0032	0.0003
Beef Intake/Dairy Intake	0.0028	0.0011	0.078	0.00055	1.E-06	0.0063	0.00023	0.019	0.0014	0.0002
Beef Intake/Exposed Veg. Intake	0.0025	0.00061	0.074	0.00077	7.E-07	0.0073	0.00025	0.026	0.0013	0.0001
Beef Intake/Root Vegetable Intake	0.0023	0.00058	0.073	0.00054	7.E-07	0.0058	0.00024	0.021	0.0013	0.0001
Beef Intake/Fruit Intake	0.0028	0.00066	0.075	0.0013	8.E-07	0.012	0.00029	0.063	0.0014	0.0002
Beef Intake/Application Rate	0.0037	0.00093	0.13	0.001	1.E-06	0.0073	0.00035	0.034	0.0026	0.0003
Beef Intake/Application Frequency	0.0038	0.00082	0.14	0.001	1.E-06	0.0084	0.00035	0.035	0.0026	0.0003
Beef Intake/Constituent Conc.	0.0093	0.0023	2.1	0.0066	5.E-06	0.015	0.0013	0.12	0.004	0.0010
Beef Intake/Small Tilling Depth	0.0035	0.00059	0.073	0.00065	7.E-07	0.006	0.00025	0.02	0.0013	0.0001
Beef Intake/Adult Soil Ingestion	0.0023	0.00058	0.073	0.00052	7.E-07	0.0057	0.00023	0.019	0.0013	0.0001
Beef Intake/Child Soil Ingestion	0.0053	0.00062	0.13	0.0011	1.E-06	0.011	0.001	0.039	0.0033	0.0003
Dairy Intake/Exposed Vegetable Intake	0.0025	0.0011	0.059	0.00076	1.E-06	0.0079	0.00024	0.026	0.0013	0.0002
Dairy Intake/Root Vegetable Intake	0.0023	0.0011	0.058	0.00053	1.E-06	0.0063	0.00022	0.021	0.0013	0.0002
Dairy Intake/Fruit Intake	0.0028	0.0011	0.06	0.0013	1.E-06	0.012	0.00028	0.063	0.0014	0.0002
Dairy Intake/Application Rate	0.0038	0.0021	0.09	0.00099	2.E-06	0.0087	0.00033	0.034	0.0026	0.0003
Dairy Intake/Application Frequency	0.0038	0.0021	0.1	0.00099	2.E-06	0.0097	0.00033	0.035	0.0026	0.0003

(continued)

Table 7-3. (continued)

High-End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (C R)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Dairy Intake/Constituent Conc.	0.0093	0.0053	**1.7**	0.0064	7.E-06	0.017	0.0012	0.12	0.0041	0.0011
Dairy Intake/Tilling Depth	0.0036	0.0011	0.058	0.00063	1.E-06	0.0065	0.00023	0.02	0.0013	0.0002
Dairy Intake/Adult Soil Ingestion	0.0023	0.0011	0.058	0.00051	1.E-06	0.0063	0.00022	0.019	0.0013	0.0002
Dairy Intake/Child Soil Ingestion	0.0053	0.0011	0.12	0.0011	2.E-06	0.011	0.001	0.039	0.0033	0.0004
Exposed Veg. Intake/Root Veg. Intake	0.002	0.00061	0.054	0.00075	7.E-07	0.0073	0.00024	0.028	0.0012	0.0002
Exposed Veg. Intake/Fruit Intake	0.0025	0.00068	0.056	0.0015	9.E-07	0.013	0.0003	0.07	0.0013	0.0002
Exposed Veg. Intake/Application Rate	0.0035	0.00097	0.086	0.0013	1.E-06	0.0097	0.00035	0.05	0.0025	0.0003
Exposed Veg. Intake/Application Frequency	0.0036	0.00086	0.096	0.0013	1.E-06	0.011	0.00036	0.051	0.0025	0.0003
Exposed Veg. Intake/Constituent Conc.	0.0078	0.0024	**1.6**	0.0086	5.E-06	0.02	0.0013	0.19	0.0037	0.0010
Exposed Veg. Intake/Tilling Depth	0.0032	0.00061	0.054	0.00086	7.E-07	0.0086	0.00025	0.037	0.0012	0.0001
Exposed Veg. Intake/Adult Soil Ingestion	0.002	0.0006	0.054	0.00073	7.E-07	0.0073	0.00024	0.026	0.0012	0.0001
Exposed Veg. Intake/Child Soil Ingestion	0.005	0.00064	0.11	0.0013	1.E-06	0.012	0.001	0.046	0.0032	0.0003
Root Veg. Intake/Fruit Intake	0.0024	0.00065	0.055	0.0013	8.E-07	0.012	0.00028	0.065	0.0013	0.0002
Root Veg. Intake/Application Rate	0.0033	0.00092	0.085	0.00098	1.E-06	0.0074	0.00033	0.035	0.0025	0.0003
Root Veg. Intake/Application Frequency	0.0034	0.00081	0.096	0.00098	1.E-06	0.0086	0.00033	0.037	0.0025	0.0003
Root Veg. Intake/Constituent Conc.	0.0074	0.0023	**1.6**	0.0064	4.E-06	0.015	0.0012	0.13	0.0037	0.0010
Root Veg. Intake/Tilling Depth	0.0031	0.00058	0.053	0.00063	7.E-07	0.0061	0.00023	0.022	0.0012	0.0001
Root Veg. Intake/Adult Soil Ingestion	0.0018	0.00057	0.053	0.0005	7.E-07	0.0057	0.00022	0.021	0.0012	0.0001
Root Veg. Intake/Child Soil Ingestion	0.0048	0.00061	0.11	0.0011	1.E-06	0.011	0.001	0.041	0.0032	0.0003
Fruit Intake/Application Rate	0.0041	0.0011	0.088	0.0017	1.E-06	0.016	0.00042	0.095	0.0026	0.0003
Fruit Intake/Application Frequency	0.0043	0.00097	0.098	0.0017	1.E-06	0.017	0.00042	0.1	0.0026	0.0003

(continued)

Table 7-3. (continued)

High-End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (C R)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Fruit Intake/Constituent Conc.	0.0091	0.0028	**1.6**	0.015	5.E-06	0.032	0.0016	0.38	0.0039	0.0010
Fruit Intake/Tilling Depth	0.0036	0.00065	0.055	0.0015	8.E-07	0.013	0.00031	0.073	0.0013	0.0002
Fruit Intake/Adult Soil Ingestion	0.0023	0.00065	0.055	0.0013	8.E-07	0.012	0.00028	0.063	0.0013	0.0002
Fruit Intake/Child Soil Ingestion	0.0053	0.00069	0.12	0.0019	1.E-06	0.017	0.0011	0.083	0.0033	0.0004
Appplication Rate/Application Frequency	0.0061	0.0012	0.15	0.0014	2.E-06	0.013	0.00045	0.047	0.0037	0.0004
Appplication Rate/Constituent Conc.	0.013	0.0044	**2.9**	0.011	7.E-06	0.028	0.0022	0.18	0.007	0.0014
Appplication Rate/Tilling Depth	0.0045	0.00091	0.085	0.0011	1.E-06	0.0096	0.00035	0.036	0.0024	0.0003
Appplication Rate/Adult Soil Ingestion	0.0033	0.00091	0.085	0.00095	1.E-06	0.0073	0.00033	0.034	0.0024	0.0003
Appplication Rate/Child Soil Ingestion	0.0073	0.00096	0.14	0.0013	2.E-06	0.012	0.002	0.054	0.0054	0.0006
Appplication Frequency/Constituent Conc.	0.013	0.0034	**3.1**	0.011	7.E-06	0.028	0.0023	0.19	0.007	0.0014
Appplication Frequency/Tilling Depth	0.0048	0.00091	0.096	0.0011	1.E-06	0.011	0.00045	0.036	0.0024	0.0003
Appplication Frequency/Adult Soil Ingestion	0.0034	0.0008	0.096	0.00095	1.E-06	0.0084	0.00033	0.035	0.0024	0.0003
Appplication Frequency/Child Soil Ingestion	0.0074	0.00086	0.14	0.0013	2.E-06	0.022	0.002	0.055	0.0054	0.0006
Constituent Conc./Tilling Depth	0.0094	0.0023	**1.6**	0.0083	4.E-06	0.016	0.0022	0.15	0.0037	0.0009
Constituent Conc./Adult Soil Ingestion	0.0073	0.0023	**1.6**	0.0062	4.E-06	0.015	0.0012	0.12	0.0037	0.0009
Constituent Conc./Child Soil Ingestion	0.012	0.0025	**3.6**	0.012	7.E-06	0.035	0.01	0.26	0.0097	0.0022
Tilling Depth/Adult Soil Ingestion	0.003	0.00057	0.053	0.00061	7.E-07	0.006	0.00023	0.02	0.0012	0.0001
Tilling Depth/Child Soil Ingestion	0.006	0.00062	0.11	0.0012	1.E-06	0.012	0.002	0.04	0.0032	0.0003
Adult Soil Ingestion /Child Soil Ingestion	0.0048	0.00061	0.11	0.0011	1.E-06	0.011	0.001	0.039	0.0032	0.0003

[a] Listed parameters are varied to high-end values 1 or 2 at a time; all other parameters remain at central tendency values.

Note: Shaded and italicized bolded entries indicate cases where increased cancer risk exceeds 1E-05 or hazard quotient exceeds 1 for noncarcinogens.

Table 7-4. Increased Hazard Quotient (HQ) or Cancer Risk (CR) to Fisher from Metals in CKD Used as an Agricultural Supplement

High End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Central Tendency	0.00000001	NA	0.00009	NA	4.E-11	NA	0.00000008	0.00002	0.000000	0.000002
Single High-End Variation										
Long Exposure	0.00000001	NA	0.00009	NA	4.E-10	NA	0.00000008	0.00002	0.000000	0.000002
Fish Intake	0.00000007	NA	0.0005	NA	3.E-10	NA	0.0000005	0.0001	0.000001	0.00001
Application Rate	0.00000002	NA	0.0001	NA	7.E-11	NA	0.0000001	0.00003	0.000000	0.000004
Application Frequency	0.00000002	NA	0.0001	NA	7.E-11	NA	0.0000001	0.00003	0.000000	0.000004
Constituent Conc.	0.00000004	NA	0.003	NA	3.E-10	NA	0.0000006	0.0001	0.000000	0.00001
Tilling Depth	0.00000001	NA	0.00009	NA	4.E-11	NA	0.0000001	0.00002	0.000000	0.000002
Double High-End Variation										
Fish Intake/Long Exposure	0.00000006	NA	0.0005	NA	3.E-09	NA	0.0000005	0.0001	0.000001	0.00001
Application Rate/Long Exposure	0.00000002	NA	0.0001	NA	7.E-10	NA	0.0000001	0.00002	0.000000	0.000003
Application Frequency/Long Exposure	0.00000002	NA	0.0001	NA	7.E-10	NA	0.0000001	0.00003	0.000000	0.000004
Constituent Con./Long Exposure	0.00000003	NA	0.002	NA	3.E-09	NA	0.0000006	0.0001	0.000000	0.00001
Tilling Depth/Long Exposure	0.00000001	NA	0.00009	NA	4.E-10	NA	0.0000001	0.00002	0.000000	0.000002
Fish Intake/Application Rate	0.00000010	NA	0.0009	NA	4.E-10	NA	0.0000008	0.0002	0.000001	0.00002
Fish Intake/Application Frequency	0.00000010	NA	0.0009	NA	4.E-10	NA	0.0000009	0.0002	0.000001	0.00002
Fish Intake/Constituent Conc.	0.00000020	NA	0.02	NA	2.E-09	NA	0.000004	0.0007	0.000002	0.00008
Fish Intake/Tilling Depth	0.00000008	NA	0.0006	NA	3.E-10	NA	0.0000007	0.0001	0.000001	0.00001
Application Rate/Application Frequency	0.00000003	NA	0.0002	NA	1.E-10	NA	0.0000002	0.00004	0.000000	0.000006
Application Rate/Constituent Conc.	0.00000005	NA	0.004	NA	5.E-10	NA	0.0000009	0.0002	0.000001	0.00002

(continued)

Table 7-4. (continued)

High End Parameters Varied[a]	Nickel (HQ)	Silver (HQ)	Thallium (I) (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium VI (HQ)	Selenium (HQ)
Application Rate/Tilling Depth	0.00000002	NA	0.0001	NA	7.E-11	NA	0.0000002	0.00003	0.000000	0.000004
Application Frequency/Constituent Conc.	0.00000006	NA	0.004	NA	5.E-10	NA	0.000001	0.0002	0.000001	0.00002
Application Frequency/Tilling Depth	0.00000002	NA	0.0001	NA	7.E-11	NA	0.0000002	0.00004	0.000000	0.000004
Constituent Conc./Tilling Depth	0.00000005	NA	0.003	NA	3.E-10	NA	0.0000008	0.0001	0.000000	0.00001

[a] Listed parameters are varied to high end values 1 or 2 at a time; all other parameters remain at central tendency values.

Note: Shaded and italicized bolded entries indicate cases where increased cancer risk exceeds 1E-05 or hazard quotient exceeds 1 for noncarcinogens.

Table 7-5. Increased Hazard Quotient (HQ) or Cancer Risk (CR) to Home Gardener from Metals in CKD Used as an Agricultural Supplement, Monte Carlo Results

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
0	0.0000	0.0000	0.0000	0.0000	6.5E-12	0.0000	0.00000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0001	0.0000	4.6E-10	0.0001	0.00000	0.0005	0.0000	0.0000
10	0.0000	0.0000	0.0002	0.0000	1.1E-09	0.0003	0.00000	0.0008	0.0000	0.0000
15	0.0000	0.0000	0.0003	0.0000	1.7E-09	0.0004	0.00000	0.0010	0.0000	0.0000
20	0.0000	0.0000	0.0005	0.0000	2.6E-09	0.0005	0.00001	0.0010	0.0000	0.0000
25	0.0000	0.0000	0.0006	0.0000	3.5E-09	0.0007	0.00001	0.0020	0.0000	0.0000
30	0.0000	0.0000	0.0008	0.0000	5.0E-09	0.0008	0.00001	0.0030	0.0000	0.0000
35	0.0000	0.0000	0.0010	0.0001	6.7E-09	0.0009	0.00001	0.0030	0.0000	0.0000
40	0.0000	0.0000	0.0010	0.0001	8.5E-09	0.0010	0.00001	0.0040	0.0000	0.0000
45	0.0001	0.0000	0.0010	0.0001	1.1E-08	0.0010	0.00001	0.0050	0.0000	0.0000

Table 7-5. (continued)

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
50	0.0001	0.0000	0.0020	0.0001	1.4E-08	0.0010	0.00001	0.0060	0.0001	0.0000
55	0.0001	0.0000	0.0020	0.0001	1.9E-08	0.0020	0.00001	0.0060	0.0001	0.0000
60	0.0001	0.0000	0.0030	0.0002	2.3E-08	0.0020	0.00001	0.0070	0.0001	0.0000
65	0.0001	0.0000	0.0030	0.0002	2.9E-08	0.0020	0.00001	0.0090	0.0001	0.0000
70	0.0001	0.0000	0.0040	0.0003	3.5E-08	0.0030	0.00002	0.0100	0.0001	0.0000
75	0.0001	0.0000	0.0050	0.0004	4.8E-08	0.0030	0.00002	0.0100	0.0001	0.0000
80	0.0001	0.0000	0.0080	0.0005	6.2E-08	0.0030	0.00003	0.0200	0.0001	0.0000
85	0.0002	0.0000	0.0100	0.0008	8.9E-08	0.0040	0.00004	0.0200	0.0001	0.0000
90	0.0002	0.0001	0.0300	0.0010	1.3E-07	0.0060	0.00005	0.0300	0.0001	0.0000
95	0.0003	0.0001	0.0700	0.0020	2.3E-07	0.0090	0.00008	0.0500	0.0002	0.0000

(continued)

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
100	0.0010	0.0006	0.4000	0.0300	3.5E-06	0.0500	0.00030	0.5000	0.0009	0.0003

Table 7-6. Increased Hazard Quotient (HQ) or Cancer Risk (CR) to Farmer from Metals in CKD Used as an Agricultural Supplement, Monte Carlo Results

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
0	0.0000	0.0000	0.0004	0.0000	9.E-12	0.0000	0.00000	0.0000	0.0000	0.0000
5	0.0002	0.0000	0.0030	0.0000	1.E-08	0.0006	0.00001	0.0020	0.0001	0.0000
10	0.0002	0.0000	0.0050	0.0000	3.E-08	0.0010	0.00001	0.0030	0.0001	0.0000
15	0.0002	0.0001	0.0090	0.0001	6.E-08	0.0020	0.00001	0.0040	0.0001	0.0000
20	0.0003	0.0001	0.0100	0.0001	9.E-08	0.0020	0.00001	0.0050	0.0002	0.0000
25	0.0003	0.0001	0.0200	0.0001	1.E-07	0.0030	0.00002	0.0070	0.0002	0.0000
30	0.0004	0.0001	0.0200	0.0001	2.E-07	0.0030	0.00002	0.0090	0.0002	0.0000
35	0.0004	0.0001	0.0300	0.0002	3.E-07	0.0040	0.00002	0.0100	0.0002	0.0000
40	0.0005	0.0002	0.0300	0.0003	3.E-07	0.0040	0.00002	0.0100	0.0003	0.0000
45	0.0006	0.0002	0.0400	0.0004	5.E-07	0.0050	0.00002	0.0100	0.0003	0.0000

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
50	0.0006	0.0003	0.0400	0.0005	6.E-07	0.0060	0.00003	0.0200	0.0003	0.0000
55	0.0007	0.0003	0.0600	0.0006	8.E-07	0.0060	0.00003	0.0200	0.0004	0.0000
60	0.0008	0.0004	0.0700	0.0007	1.E-06	0.0080	0.00004	0.0300	0.0004	0.0000
65	0.0009	0.0005	0.0900	0.0009	1.E-06	0.0090	0.00004	0.0300	0.0005	0.0001
70	0.0010	0.0006	0.1000	0.0010	2.E-06	0.0100	0.00005	0.0400	0.0005	0.0001

(continued)

Table 7-6. (continued)

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
75	0.0010	0.0008	0.1000	0.0010	2.E-06	0.0100	0.00006	0.0500	0.0006	0.0001
80	0.0010	0.0009	0.2000	0.0020	3.E-06	0.0100	0.00007	0.0600	0.0007	0.0001
85	0.0020	0.0010	0.4000	0.0020	5.E-06	0.0200	0.00009	0.0800	0.0008	0.0001
90	0.0020	0.0020	0.8000	0.0040	7.E-06	0.0200	0.00010	0.1000	0.0010	0.0001
95	0.0030	0.0020	***2.0000***	0.0100	***1.E-05***	0.0300	0.00020	0.2000	0.0010	0.0003
100	0.0100	0.0200	***20.0000***	0.1000	***1.E-04***	0.3000	0.00070	0.9000	0.0060	0.0010

Note: Shaded and italicized bolded entries indicate cases where increased cancer risk exceeds 1E-05 or Hazard Quotient exceeds 1 for noncarcinogens.

Table 7-7. Increased Hazard Quotient (HQ) or Cancer Risk (CR) to Child of Farmer from Metals in CKD Used as an Agricultural Supplement, Monte Carlo Results

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
0	0.0001	0.0000	0.0026	0.0000	9.4E-09	0.0000	0.00001	0.0001	0.0001	0.0000
5	0.0004	0.0000	0.0135	0.0000	6.0E-08	0.0010	0.00005	0.0024	0.0004	0.0000
10	0.0005	0.0000	0.0220	0.0001	1.5E-07	0.0022	0.00007	0.0038	0.0005	0.0000
15	0.0007	0.0001	0.0364	0.0001	2.4E-07	0.0032	0.00009	0.0056	0.0007	0.0000
20	0.0009	0.0001	0.0505	0.0001	3.1E-07	0.0040	0.00011	0.0067	0.0008	0.0000
25	0.0010	0.0001	0.0661	0.0002	3.8E-07	0.0048	0.00012	0.0084	0.0010	0.0000
30	0.0012	0.0001	0.0842	0.0003	4.5E-07	0.0058	0.00013	0.0102	0.0011	0.0000
35	0.0013	0.0001	0.1041	0.0004	5.8E-07	0.0067	0.00021	0.0124	0.0012	0.0001
40	0.0015	0.0002	0.1222	0.0006	6.8E-07	0.0076	0.00021	0.0146	0.0013	0.0001
45	0.0016	0.0002	0.1456	0.0007	8.1E-07	0.0084	0.00023	0.0171	0.0014	0.0001

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
50	0.0017	0.0003	0.1712	0.0008	9.8E-07	0.0100	0.00025	0.0211	0.0016	0.0001
55	0.0019	0.0003	0.2239	0.0010	1.1E-06	0.0112	0.00031	0.0272	0.0018	0.0001
60	0.0022	0.0004	0.2788	0.0013	1.3E-06	0.0122	0.00033	0.0330	0.0021	0.0001
65	0.0025	0.0005	0.3360	0.0015	1.6E-06	0.0135	0.00038	0.0408	0.0024	0.0001
70	0.0029	0.0007	0.4109	0.0017	1.8E-06	0.0154	0.00045	0.0474	0.0026	0.0002
75	0.0034	0.0008	0.5572	0.0020	2.2E-06	0.0173	0.00053	0.0556	0.0030	0.0002

(continued)

Table 7-7. (continued)

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
80	0.0040	0.0010	0.8192	0.0027	2.6E-06	0.0203	0.00063	0.0675	0.0034	0.0003
85	0.0049	0.0011	***1.3740***	0.0037	3.4E-06	0.0249	0.00078	0.0953	0.0041	0.0004
90	0.0058	0.0013	***2.7790***	0.0065	4.6E-06	0.0329	0.00109	0.1246	0.0048	0.0005
95	0.0081	0.0023	***7.1123***	0.0134	7.7E-06	0.0515	0.00210	0.1703	0.0064	0.0008
100	0.0350	0.0138	***49.3701***	0.1121	***3.0E-05***	0.1473	0.00863	0.6012	0.0163	0.0054

Note: Shaded and italicized bolded entries indicate cases where increased cancer risk exceeds 1E-05 or Hazard Quotient exceeds 1 for noncarcinogens

Table 7-8. Increased Hazard Quotient (HQ) or Cancer Risk (CR) to Fisher from Metals in CKD Used as an Agricultural Supplement, Monte Carlo Results

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
0	NA	NA	0.0000	NA	1.3E-14	NA	0.00000	0.000000	0.000000	0.000000
5	NA	NA	0.0000	NA	1.1E-12	NA	0.00000	0.000001	0.000000	0.000000
10	NA	NA	0.0000	NA	2.4E-12	NA	0.00000	0.000002	0.000000	0.000000
15	NA	NA	0.0000	NA	4.0E-12	NA	0.00000	0.000003	0.000000	0.000000
20	NA	NA	0.0000	NA	7.1E-12	NA	0.00000	0.000004	0.000000	0.000000
25	NA	NA	0.0001	NA	1.0E-11	NA	0.00000	0.000005	0.000000	0.000000
30	NA	NA	0.0001	NA	1.4E-11	NA	0.00000	0.000007	0.000000	0.000001
35	NA	NA	0.0001	NA	1.8E-11	NA	0.00000	0.000009	0.000000	0.000001
40	NA	NA	0.0001	NA	2.5E-11	NA	0.00000	0.000010	0.000000	0.000001
45	NA	NA	0.0001	NA	3.3E-11	NA	0.00000	0.000010	0.000000	0.000001
50	NA	NA	0.0002	NA	4.5E-11	NA	0.00000	0.000020	0.000000	0.000001
55	NA	NA	0.0002	NA	6.2E-11	NA	0.00000	0.000020	0.000000	0.000002
60	NA	NA	0.0003	NA	7.8E-11	NA	0.00000	0.000030	0.000000	0.000002
65	NA	NA	0.0004	NA	1.1E-10	NA	0.00000	0.000030	0.000000	0.000003
70	NA	NA	0.0005	NA	1.5E-10	NA	0.00000	0.000040	0.000000	0.000004
75	NA	NA	0.0007	NA	2.1E-10	NA	0.00000	0.000050	0.000000	0.000005
80	NA	NA	0.0010	NA	2.8E-10	NA	0.00000	0.000060	0.000000	0.000007

Table 7-8. (continued)

Percentiles	Nickel (HQ)	Silver (HQ)	Thallium (HQ)	Antimony (HQ)	Arsenic (CR)	Barium (HQ)	Beryllium (HQ)	Cadmium (HQ)	Chromium (HQ)	Selenium (HQ)
										(continued)
85	NA	NA	0.0020	NA	4.3E-10	NA	0.00000	0.000090	0.000001	0.000010
90	NA	NA	0.0030	NA	6.4E-10	NA	0.00000	0.000100	0.000001	0.000010
95	NA	NA	0.0080	NA	1.4E-09	NA	0.00000	0.000300	0.000001	0.000020
100	NA	NA	0.0900	NA	1.8E-08	NA	0.00001	0.002000	0.000006	0.000400

7.2 Results for Dioxin Congener Constituents

The risk analysis for dioxin and furan congeners was conducted by modeling the fate, transport, and resulting risk of each congener independently and then combining these risks using the TEF methodology (U.S. EPA 1989) into a total Toxicity Equivalent Quotient (TEQ) risk for all of the congeners. The total TEQ risk for dioxins and furans showed a risk in the deterministic risk analysis for the farmer scenario of 1E-04 and for the child of farmer scenario of 6E-05. The high-end parameters that corresponded to the highest risk results were high congener concentrations and long exposure durations in both scenarios. The probabilistic risk analysis was conducted for each congener independently using the same methodology described for the metals. The TEQ for the farmer scenario exceeded a cancer risk of 1E-05 at the 60th percentile, and the TEQ for the child of farmer scenario exceeded this risk level at the 50th percentile. The summary results for the deterministic analysis for dioxin congeners are presented in Tables 7-9 through 7-12. The risk results show increased risk in the farmer and child of farmer scenarios for dioxins or furans.

Increased Cancer Risk (CR) from Dioxin and Furan Congeners (TEQ)

Scenario	TEQ
Farmer	CR =1 E- 04
Child of Farmer	CR = 6 E- 05

7.3 Results for the Ecological Risk Screening Analysis

The phytotoxicity and ecological risk to soil organisms are assessed by comparing the soil concentration levels at the risk-limiting concentrations and at the highest high-end estimated concentration to the phytotoxicity and ecological risk benchmarks presented in the sewage sludge document. These results are presented in Table 7-13.

Table 7-9. Increased Cancer Risk (CR) to Home Gardener from Dioxin and Furan Congeners in CKD Used as an Agricultural Supplement

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4, 5,7,8,9-	HxCDD , 1,2,3, 7,8,9-	OCDF, 1,2,3,4, 6,7,8,9-	HxCDD , 1,2,3, 4,7,8-	PeCDD, 1,2,3,7, 8-	TCDF, 2,3,7, 8-	HpCDF , 1,2,3,4, 7,8,9-	PeCDF, 2,3,4,7, 8-	PeCDF, 1,2,3,7, 8-	HxCDF , 1,2,3, 6,7,8-	HxCDD , 1,2,3, 6,7,8-	HxCDF, 2,3,4, 6,7,8-	HpCDF , 1,2,3,4, 6,7,8-	HxCDF , 1,2,3, 4,7,8-	HxCDF , 1,2,3, 7,8,9-	HpCDD , 1,2,3,4, 6,7,8,-	TEQ
Central Tendency	1.E-09	5.E-11	4.E-10	5.E-12	4.E-10	2.E-09	2.E-10	4.E-11	1.E-09	1.E-10	3.E-10	4.E-10	2.E-10	5.E-11	3.E-10	2.E-10	9.E-11	7.E-09
Single High End Variation																		
Long Exposure	1.E-08	5.E-10	4.E-09	4.E-11	4.E-09	1.E-08	2.E-09	4.E-10	1.E-08	1.E-09	3.E-09	4.E-09	2.E-09	5.E-10	3.E-09	2.E-09	8.E-10	6.E-08
Exposed Veg. Intake	2.E-09	7.E-11	5.E-10	5.E-12	4.E-10	2.E-09	3.E-10	5.E-11	1.E-09	2.E-10	4.E-10	5.E-10	3.E-10	6.E-11	3.E-10	3.E-10	1.E-10	9.E-09
Root Veg.Intake	2.E-09	7.E-11	5.E-10	5.E-12	5.E-10	2.E-09	3.E-10	5.E-11	1.E-09	1.E-10	3.E-10	5.E-10	3.E-10	6.E-11	3.E-10	3.E-10	1.E-10	8.E-09
Fruit Intake	2.E-09	2.E-10	8.E-10	6.E-12	6.E-10	3.E-09	4.E-10	7.E-11	2.E-09	3.E-10	4.E-10	8.E-10	3.E-10	9.E-11	5.E-10	3.E-10	1.E-10	1.E-08
Application Rate	2.E-09	8.E-11	6.E-10	7.E-12	6.E-10	2.E-09	4.E-10	6.E-11	2.E-09	2.E-10	4.E-10	6.E-10	3.E-10	7.E-11	4.E-10	3.E-10	1.E-10	1.E-08
Application Frequency	2.E-09	9.E-11	7.E-10	8.E-12	6.E-10	3.E-09	4.E-10	6.E-11	2.E-09	2.E-10	5.E-10	7.E-10	4.E-10	8.E-11	5.E-10	4.E-10	1.E-10	1.E-08
Constituent Conc.	8.E-09	5.E-10	3.E-09	2.E-11	2.E-09	9.E-09	8.E-09	1.E-10	4.E-08	2.E-09	6.E-09	3.E-09	3.E-09	1.E-09	4.E-09	8.E-10	2.E-09	1.E-07
Tilling Depth	1.E-09	7.E-11	5.E-10	6.E-12	5.E-10	2.E-09	3.E-10	5.E-11	1.E-09	1.E-10	4.E-10	5.E-10	3.E-10	6.E-11	4.E-10	3.E-10	1.E-10	8.E-09
Double High End Variation																		
Exposed Veg. Intake/ Long Exposure	1.E-08	7.E-10	5.E-09	5.E-11	4.E-09	2.E-08	3.E-09	4.E-10	1.E-08	1.E-09	3.E-09	5.E-09	3.E-09	5.E-10	3.E-09	3.E-09	9.E-10	8.E-08
Root Veg. Intake/ Long Exposure	2.E-08	7.E-10	5.E-09	5.E-11	4.E-09	2.E-08	3.E-09	4.E-10	1.E-08	1.E-09	3.E-09	5.E-09	2.E-09	5.E-10	3.E-09	2.E-09	1.E-09	8.E-08
Fruit Intake/ Long Exposure	2.E-08	2.E-09	8.E-09	6.E-11	6.E-09	3.E-08	4.E-09	7.E-10	2.E-08	3.E-09	4.E-09	8.E-09	3.E-09	9.E-10	4.E-09	3.E-09	1.E-09	1.E-07
Application Rate/ Long Exposure	2.E-08	8.E-10	6.E-09	7.E-11	5.E-09	2.E-08	3.E-09	6.E-10	2.E-08	2.E-09	4.E-09	6.E-09	3.E-09	7.E-10	4.E-09	3.E-09	1.E-09	9.E-08
Application Frequency/ Long Exposure	2.E-08	8.E-10	6.E-09	7.E-11	6.E-09	2.E-08	4.E-09	6.E-10	2.E-08	2.E-09	5.E-09	6.E-09	3.E-09	8.E-10	4.E-09	3.E-09	1.E-09	1.E-07
Constituent Conc./ Long Exposure	8.E-08	5.E-09	3.E-08	1.E-10	2.E-08	8.E-08	7.E-08	1.E-09	4.E-07	2.E-08	5.E-08	3.E-08	3.E-08	1.E-08	4.E-08	8.E-09	2.E-08	9.E-07
Tilling Depth/ Long Exposure	1.E-08	7.E-10	5.E-09	6.E-11	5.E-09	2.E-08	3.E-09	5.E-10	1.E-08	1.E-09	4.E-09	5.E-09	3.E-09	6.E-10	3.E-09	3.E-09	1.E-09	8.E-08
Exposed Veg. Intake/ Root Veg. Intake	2.E-09	9.E-11	6.E-10	6.E-12	5.E-10	3.E-09	4.E-10	5.E-11	2.E-09	2.E-10	4.E-10	6.E-10	3.E-10	7.E-11	4.E-10	3.E-10	1.E-10	1.E-08
Exposed Veg. Intake/ Fruit Intake	2.E-09	2.E-10	1.E-09	7.E-12	7.E-10	4.E-09	6.E-10	8.E-11	3.E-09	3.E-10	5.E-10	1.E-09	4.E-10	1.E-10	5.E-10	4.E-10	1.E-10	1.E-08
Exposed Veg. Intake/ Application Rate	2.E-09	1.E-10	8.E-10	7.E-12	7.E-10	3.E-09	5.E-10	7.E-11	2.E-09	2.E-10	5.E-10	8.E-10	4.E-10	9.E-11	5.E-10	4.E-10	1.E-10	1.E-08
Exposed Veg. Intake/ Application Frequency	3.E-09	1.E-10	9.E-10	8.E-12	7.E-10	4.E-09	6.E-10	8.E-11	2.E-09	3.E-10	6.E-10	9.E-10	4.E-10	1.E-10	6.E-10	4.E-10	2.E-10	1.E-08
Exposed Veg. Intake/ Constituent Conc.	1.E-08	7.E-10	4.E-09	2.E-11	2.E-09	1.E-08	1.E-08	1.E-10	6.E-08	3.E-09	7.E-09	4.E-09	3.E-09	1.E-09	5.E-09	1.E-09	2.E-09	1.E-07

(continued)

Table 7-9. (continued)

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4, 5,7,8,9-	HxCDD, 1,2,3, 7,8,9-	OCDF, 1,2,3,4, 6,7,8,9-	HxCDD, 1,2,3, 4,7,8-	PeCDD, 1,2,3,7, 8-	TCDF, 2,3,7, 8-	HpCDF, 1,2,3,4, 7,8,9-	PeCDF, 2,3,4,7, 8-	PeCDF, 1,2,3,7, 8-	HxCDF, 1,2,3, 6,7,8-	HxCDD, 1,2,3, 6,7,8-	HxCDF, 2,3,4, 6,7,8-	HpCDF, 1,2,3,4, 6,7,8-	HxCDF, 1,2,3, 4,7,8-	HxCDF, 1,2,3, 7,8,9-	HpCDD, 1,2,3,4, 6,7,8,-	TEQ
Exposed Veg. Intake/ Tilling Depth	2.E-09	1.E-10	7.E-10	7.E-12	6.E-10	3.E-09	4.E-10	6.E-11	2.E-09	2.E-10	5.E-10	7.E-10	3.E-10	7.E-11	4.E-10	3.E-10	1.E-10	1.E-08
Root Veg. Intake/ Fruit Intake	3.E-09	2.E-10	1.E-09	7.E-12	7.E-10	3.E-09	5.E-10	8.E-11	3.E-09	3.E-10	5.E-10	1.E-09	4.E-10	1.E-10	5.E-10	4.E-10	1.E-10	1.E-08
Root Veg. Intake/ Application Rate	3.E-09	1.E-10	8.E-10	8.E-12	7.E-10	3.E-09	4.E-10	7.E-11	2.E-09	2.E-10	5.E-10	8.E-10	4.E-10	9.E-11	5.E-10	4.E-10	2.E-10	1.E-08
Root Veg. Intake/ Application Frequency	3.E-09	1.E-10	9.E-10	9.E-12	8.E-10	4.E-09	5.E-10	8.E-11	2.E-09	2.E-10	6.E-10	9.E-10	4.E-10	1.E-10	6.E-10	4.E-10	2.E-10	1.E-08
Root Veg. Intake/ Constituent Conc.	1.E-08	7.E-10	4.E-09	2.E-11	2.E-09	1.E-08	9.E-09	1.E-10	5.E-08	2.E-09	7.E-09	4.E-09	3.E-09	1.E-09	5.E-09	1.E-09	2.E-09	1.E-07
Root Veg. Intake/ Tilling Depth	2.E-09	1.E-10	7.E-10	7.E-12	6.E-10	3.E-09	3.E-10	6.E-11	2.E-09	2.E-10	4.E-10	7.E-10	3.E-10	8.E-11	4.E-10	3.E-10	1.E-10	1.E-08
Fruit Intake/ Application Rate	3.E-09	3.E-10	1.E-09	9.E-12	1.E-09	4.E-09	7.E-10	1.E-10	4.E-09	4.E-10	7.E-10	1.E-09	5.E-10	1.E-10	7.E-10	5.E-10	2.E-10	2.E-08
Fruit Intake/ Application Frequency	3.E-09	3.E-10	1.E-09	1.E-11	1.E-09	5.E-09	7.E-10	1.E-10	4.E-09	4.E-10	7.E-10	1.E-09	6.E-10	2.E-10	8.E-10	6.E-10	2.E-10	2.E-08
Fruit Intake/ Constituent Conc.	1.E-08	2.E-09	7.E-09	2.E-11	3.E-09	2.E-08	2.E-08	2.E-10	1.E-07	5.E-09	9.E-09	7.E-09	4.E-09	2.E-09	6.E-09	1.E-09	3.E-09	2.E-07
Fruit Intake/ Tilling Depth	2.E-09	3.E-10	1.E-09	9.E-12	9.E-10	4.E-09	5.E-10	1.E-10	3.E-09	3.E-10	6.E-10	1.E-09	4.E-10	1.E-10	6.E-10	4.E-10	2.E-10	2.E-08
Appplication Rate/ Application Frequency	3.E-09	1.E-10	1.E-09	1.E-11	1.E-09	4.E-09	6.E-10	1.E-10	3.E-09	3.E-10	7.E-10	1.E-09	6.E-10	1.E-10	7.E-10	6.E-10	2.E-10	2.E-08
Appplication Rate/ Constituent Conc.	1.E-08	8.E-10	5.E-09	2.E-11	2.E-09	1.E-08	1.E-08	2.E-10	7.E-08	3.E-09	9.E-09	5.E-09	4.E-09	2.E-09	6.E-09	1.E-09	3.E-09	1.E-07
Appplication Rate/ Tilling Depth	2.E-09	1.E-10	8.E-10	9.E-12	7.E-10	3.E-09	4.E-10	7.E-11	2.E-09	2.E-10	6.E-10	8.E-10	4.E-10	9.E-11	5.E-10	4.E-10	2.E-10	1.E-08
Appplication Frequency/ Constituent Conc.	1.E-08	9.E-10	6.E-09	3.E-11	3.E-09	2.E-08	1.E-08	2.E-10	7.E-08	3.E-09	9.E-09	6.E-09	5.E-09	2.E-09	7.E-09	1.E-09	3.E-09	2.E-07
Appplication Frequency/ Tilling Depth	2.E-09	1.E-10	9.E-10	1.E-11	9.E-10	3.E-09	5.E-10	8.E-11	2.E-09	2.E-10	6.E-10	9.E-10	5.E-10	1.E-10	6.E-10	5.E-10	2.E-10	1.E-08
Constituent Conc./ Tilling Depth	1.E-08	7.E-10	4.E-09	2.E-11	2.E-09	1.E-08	9.E-09	1.E-10	6.E-08	2.E-09	7.E-09	5.E-09	4.E-09	1.E-09	5.E-09	1.E-09	3.E-09	1.E-07

[a] Listed parameters are varied to high end values 1 or 2 at a time; all other parameters remain at central tendency values.

Table 7-10. Increased Cancer Risk (CR) to Farmer from Dioxin and Furan Congeners in CKD Used as an Agricultural Supplement

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4, 5,7,8,9-	HxCDD, 1,2,3, 7,8,9-	OCDF, 1,2,3,4, 6,7,8,9-	HxCDD, 1,2,3, 4,7,8-	PeCDD, 1,2,3,7, 8-	TCDF, 2,3,7,8-	HpCDF, 1,2,3,4, 7,8,9-	PeCDF, 2,3,4,7, 8-	PeCDF, 1,2,3,7, 8-	HxCDF, 1,2,3, 6,7,8-	HxCDD, 1,2,3, 6,7,8-	HxCDF, 2,3,4, 6,7,8-	HpCDF, 1,2,3,4, 6,7,8-	HxCDF, 1,2,3, 4,7,8-	HxCDF, 1,2,3, 7,8,9-	HpCDD, 1,2,3,4, 6,7,8,-	TEQ
Central Tendency	1.6E-07	4.3E-09	6.7E-08	8.2E-11	4.6E-08	2.3E-07	1.0E-08	3.0E-09	3.0E-07	7.7E-09	2.3E-08	5.9E-08	1.7E-08	1.6E-09	3.2E-08	1.9E-08	1.5E-09	9.8E-07
Single High End Variation																		
Long Exposure	9.1E-07	2.4E-08	3.8E-07	4.7E-10	2.6E-07	1.3E-06	5.8E-08	1.7E-08	1.7E-06	4.3E-08	1.3E-07	3.3E-07	9.5E-08	8.9E-09	1.8E-07	1.1E-07	8.6E-09	5.5E-06
Beef intake	8.5E-07	2.0E-08	2.7E-07	3.1E-10	1.9E-07	1.1E-06	3.3E-08	9.5E-09	1.3E-06	2.9E-08	1.0E-07	2.6E-07	8.1E-08	6.4E-09	1.5E-07	8.3E-08	6.4E-09	4.5E-06
Dairy Intake	4.4E-07	1.1E-08	2.0E-07	2.1E-10	1.3E-07	6.3E-07	3.0E-08	9.1E-09	8.7E-07	2.2E-08	6.6E-08	1.7E-07	4.6E-08	4.1E-09	8.9E-08	5.5E-08	3.6E-09	2.8E-06
Exposed Veg. Intake	1.7E-07	4.5E-09	6.8E-08	8.4E-11	4.7E-08	2.3E-07	1.1E-08	3.1E-09	3.0E-07	8.0E-09	2.4E-08	6.0E-08	1.7E-08	1.6E-09	3.2E-08	1.9E-08	1.6E-09	9.9E-07
Root Veg. Intake	1.7E-07	4.4E-09	6.8E-08	8.7E-11	4.7E-08	2.3E-07	1.1E-08	3.1E-09	3.0E-07	7.9E-09	2.4E-08	6.0E-08	1.7E-08	1.6E-09	3.2E-08	1.9E-08	1.6E-09	9.9E-07
Fruit Intake	1.7E-07	5.6E-09	7.1E-08	9.9E-11	4.9E-08	2.4E-07	1.3E-08	3.4E-09	3.1E-07	9.3E-09	2.5E-08	6.3E-08	1.8E-08	2.0E-09	3.3E-08	2.0E-08	1.8E-09	1.0E-06
CKD Application Rate	2.5E-07	6.5E-09	1.0E-07	1.2E-10	7.0E-08	3.4E-07	1.6E-08	4.6E-09	4.5E-07	1.2E-08	3.5E-08	8.9E-08	2.6E-08	2.4E-09	4.8E-08	2.9E-08	2.3E-09	1.5E-06
CKD Application Frequency	2.7E-07	7.2E-09	1.1E-07	1.4E-10	7.7E-08	3.7E-07	1.7E-08	5.0E-09	5.0E-07	1.3E-08	3.9E-08	9.8E-08	2.8E-08	2.6E-09	5.2E-08	3.2E-08	2.5E-09	1.6E-06
Constituent Conc.	1.2E-06	4.4E-08	5.4E-07	2.8E-10	1.9E-07	1.3E-06	3.5E-07	8.8E-09	1.2E-05	1.3E-07	4.5E-07	5.0E-07	2.2E-07	3.6E-08	4.5E-07	7.3E-08	3.2E-08	**1.8E-05**
Small Tilling Depth	1.9E-07	5.9E-09	8.7E-08	1.1E-10	6.2E-08	2.8E-07	1.3E-08	3.9E-09	3.8E-07	9.7E-09	3.1E-08	7.6E-08	2.2E-08	2.1E-09	4.1E-08	2.5E-08	2.1E-09	1.2E-06
Soil Intake	1.7E-07	4.4E-09	6.8E-08	9.7E-11	4.7E-08	2.3E-07	1.1E-08	3.1E-09	3.0E-07	7.9E-09	2.4E-08	6.0E-08	1.8E-08	1.7E-09	3.2E-08	2.0E-08	1.8E-09	1.0E-06
Double High End Variation																		
Beef Intake/ Long Exposure	4.8E-06	1.2E-07	1.5E-06	1.8E-09	1.1E-06	6.0E-06	1.8E-07	5.3E-08	7.2E-06	1.6E-07	5.7E-07	1.5E-06	4.5E-07	3.6E-08	8.3E-07	4.7E-07	3.6E-08	**2.5E-05**
Dairy Intake/ Long Exposure	2.5E-06	6.4E-08	1.1E-06	1.2E-09	7.6E-07	3.5E-06	1.7E-07	5.1E-08	4.9E-06	1.2E-07	3.7E-07	9.4E-07	2.6E-07	2.3E-08	5.0E-07	3.1E-07	2.0E-08	**1.6E-05**
Exposed Veg. Intake/ Long Exposure	9.3E-07	2.5E-08	3.8E-07	4.8E-10	2.6E-07	1.3E-06	6.2E-08	1.7E-08	1.7E-06	4.5E-08	1.3E-07	3.3E-07	9.7E-08	9.2E-09	1.8E-07	1.1E-07	8.9E-09	5.6E-06
Root Veg. Intake/ Long Exposure	9.3E-07	2.5E-08	3.8E-07	4.9E-10	2.6E-07	1.3E-06	5.9E-08	1.7E-08	1.7E-06	4.4E-08	1.3E-07	3.3E-07	9.7E-08	9.2E-09	1.8E-07	1.1E-07	9.0E-09	5.6E-06
Fruit Intake/ Long Exposure	9.6E-07	3.2E-08	4.0E-07	5.6E-10	2.8E-07	1.3E-06	7.0E-08	1.9E-08	1.7E-06	5.2E-08	1.4E-07	3.5E-07	1.0E-07	1.1E-08	1.9E-07	1.1E-07	1.0E-08	5.8E-06
Application Rate/ Long Exposure	1.4E-06	3.7E-08	5.7E-07	7.0E-10	3.9E-07	1.9E-06	8.9E-08	2.5E-08	2.5E-06	6.6E-08	2.0E-07	5.0E-07	1.4E-07	1.3E-08	2.7E-07	1.6E-07	1.3E-08	8.3E-06

Table 7-10. (continued)

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4, 5,7,8,9-	HxCDD, 1,2,3, 7,8,9-	OCDF, 1,2,3,4, 6,7,8,9-	HxCDD, 1,2,3, 4,7,8-	PeCDD, 1,2,3,7, 8-	TCDF, 2,3,7,8-	HpCDF, 1,2,3,4, 7,8,9-	PeCDF, 2,3,4,7, 8-	PeCDF, 1,2,3,7, 8-	HxCDF, 1,2,3, 6,7,8-	HxCDD, 1,2,3, 6,7,8-	HxCDF, 2,3,4, 6,7,8-	HpCDF, 1,2,3,4, 6,7,8-	HxCDF, 1,2,3, 4,7,8-	HxCDF, 1,2,3, 7,8,9-	HpCDD, 1,2,3,4, 6,7,8,-	TEQ
Application Frequency/ Long Exposure	1.5E-06	4.1E-08	6.3E-07	7.8E-10	4.3E-07	2.1E-06	9.7E-08	2.8E-08	2.8E-06	7.2E-08	2.2E-07	5.5E-07	1.6E-07	1.5E-08	2.9E-07	1.8E-07	1.4E-08	9.1E-06
Constituent Conc./ Long Exposure	6.7E-06	2.5E-07	3.1E-06	1.6E-09	1.1E-06	7.2E-06	1.9E-06	5.0E-08	6.9E-05	7.2E-07	2.6E-06	2.8E-06	1.2E-06	2.0E-07	2.5E-06	4.1E-07	1.8E-07	**1.0E-04**
Small Tilling Depth/ Long Exposure	1.1E-06	3.3E-08	4.8E-07	6.4E-10	3.5E-07	1.6E-06	7.0E-08	2.2E-08	2.1E-06	5.4E-08	1.7E-07	4.2E-07	1.2E-07	1.1E-08	2.3E-07	1.4E-07	1.2E-08	6.9E-06
Soil Ingestion/ Long Exposure	9.3E-07	2.5E-08	3.8E-07	5.5E-10	2.7E-07	1.3E-06	6.1E-08	1.7E-08	1.7E-06	4.4E-08	1.4E-07	3.4E-07	9.9E-08	9.6E-09	1.8E-07	1.1E-07	1.0E-08	5.6E-06
Beef Intake/ Dairy Intake	1.1E-06	2.7E-08	4.0E-07	4.4E-10	2.8E-07	1.5E-06	5.2E-08	1.6E-08	1.9E-06	4.3E-08	1.4E-07	3.7E-07	1.1E-07	9.0E-09	2.0E-07	1.2E-07	8.5E-09	6.3E-06
Beef Intake/ Exposed Veg. Intake	8.6E-07	2.1E-08	2.7E-07	3.2E-10	2.0E-07	1.1E-06	3.4E-08	9.5E-09	1.3E-06	2.9E-08	1.0E-07	2.6E-07	8.1E-08	6.5E-09	1.5E-07	8.4E-08	6.4E-09	4.5E-06
Beef Intake/ Root Vegetable Intake	8.6E-07	2.0E-08	2.7E-07	3.2E-10	2.0E-07	1.1E-06	3.3E-08	9.5E-09	1.3E-06	2.9E-08	1.0E-07	2.6E-07	8.1E-08	6.5E-09	1.5E-07	8.4E-08	6.5E-09	4.5E-06
Beef Intake/ Fruit Intake	8.6E-07	2.2E-08	2.8E-07	3.3E-10	2.0E-07	1.1E-06	3.5E-08	9.8E-09	1.3E-06	3.1E-08	1.0E-07	2.7E-07	8.2E-08	6.9E-09	1.5E-07	8.5E-08	6.7E-09	4.5E-06
Beef Intake/ Application Rate	1.3E-06	3.1E-08	4.1E-07	4.7E-10	2.9E-07	1.6E-06	5.0E-08	1.4E-08	2.0E-06	4.4E-08	1.6E-07	4.0E-07	1.2E-07	9.8E-09	2.2E-07	1.3E-07	9.6E-09	6.8E-06
Beef Intake/ Application Frequency	1.4E-06	3.4E-08	4.5E-07	5.2E-10	3.2E-07	1.8E-06	5.5E-08	1.6E-08	2.1E-06	4.9E-08	1.7E-07	4.4E-07	1.3E-07	1.1E-08	2.5E-07	1.4E-07	1.1E-08	7.4E-06
Beef Intake/ Constituent Conc.	6.2E-06	2.1E-07	2.2E-06	1.0E-09	8.1E-07	6.1E-06	1.1E-06	2.8E-08	5.3E-05	4.9E-07	2.0E-06	2.2E-06	1.0E-06	1.5E-07	2.1E-06	3.1E-07	1.4E-07	**7.8E-05**
Beef Intake/ Small Tilling Depth	1.0E-06	2.8E-08	3.5E-07	4.3E-10	2.6E-07	1.4E-06	4.0E-08	1.2E-08	1.6E-06	3.7E-08	1.3E-07	3.4E-07	1.1E-07	8.4E-09	1.9E-07	1.1E-07	8.7E-09	5.6E-06
Beef Intake/ Soil Intake	8.6E-07	2.0E-08	2.7E-07	3.3E-10	2.0E-07	1.1E-06	3.3E-08	9.6E-09	1.3E-06	2.9E-08	1.0E-07	2.7E-07	8.2E-08	6.6E-09	1.5E-07	8.4E-08	6.7E-09	4.5E-06
Dairy Intake/ Exposed Vegetable Intake	4.5E-07	1.1E-08	2.0E-07	2.1E-10	1.3E-07	6.3E-07	3.1E-08	9.2E-09	8.8E-07	2.2E-08	6.6E-08	1.7E-07	4.7E-08	4.2E-09	8.9E-08	5.5E-08	3.7E-09	2.8E-06
Dairy Intake/ Root Vegetable Intake	4.5E-07	1.1E-08	2.0E-07	2.1E-10	1.3E-07	6.3E-07	3.0E-08	9.2E-09	8.8E-07	2.2E-08	6.6E-08	1.7E-07	4.7E-08	4.2E-09	8.9E-08	5.5E-08	3.7E-09	2.8E-06
Dairy Intake/ Fruit Intake	4.5E-07	1.3E-08	2.0E-07	2.2E-10	1.4E-07	6.4E-07	3.2E-08	9.5E-09	8.9E-07	2.3E-08	6.7E-08	1.7E-07	4.8E-08	4.6E-09	9.0E-08	5.6E-08	3.9E-09	2.8E-06
Dairy Intake/ Application Rate	6.8E-07	1.7E-08	3.0E-07	3.1E-10	2.0E-07	9.6E-07	4.6E-08	1.4E-08	1.3E-06	3.3E-08	1.0E-07	2.5E-07	7.0E-08	6.3E-09	1.3E-07	8.3E-08	5.5E-09	4.2E-06
Dairy Intake/ Application Frequency	7.4E-07	1.9E-08	3.3E-07	3.4E-10	2.2E-07	1.0E-06	5.0E-08	1.5E-08	1.5E-06	3.6E-08	1.1E-07	2.8E-07	7.7E-08	6.9E-09	1.5E-07	9.1E-08	6.0E-09	4.6E-06
Dairy Intake/ Constituent Conc.	3.2E-06	1.2E-07	1.6E-06	6.9E-10	5.6E-07	3.6E-06	1.0E-06	2.7E-08	3.6E-05	3.7E-07	1.3E-06	1.4E-06	5.9E-07	9.4E-08	1.3E-06	2.1E-07	7.7E-08	**5.2E-05**
Dairy Intake/ Tilling Depth	5.3E-07	1.5E-08	2.6E-07	2.8E-10	1.8E-07	8.0E-07	3.6E-08	1.2E-08	1.1E-06	2.7E-08	8.6E-08	2.2E-07	6.0E-08	5.4E-09	1.1E-07	7.1E-08	4.9E-09	3.5E-06

(continued)

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4,5,7,8,9-	HxCDD, 1,2,3,7,8,9-	OCDF, 1,2,3,4,6,7,8,9-	HxCDD, 1,2,3,4,7,8-	PeCDD, 1,2,3,7,8-	TCDF, 2,3,7,8-	HpCDF, 1,2,3,4,7,8,9-	PeCDF, 2,3,4,7,8-	PeCDF, 1,2,3,7,8-	HxCDF, 1,2,3,6,7,8-	HxCDD, 1,2,3,6,7,8-	HxCDF, 2,3,4,6,7,8-	HpCDF, 1,2,3,4,6,7,8-	HxCDF, 1,2,3,4,7,8-	HxCDF, 1,2,3,7,8,9-	HpCDD, 1,2,3,4,6,7,8,-	TEQ
Dairy Intake/ Soil Intake	4.5E-07	1.1E-08	2.0E-07	2.2E-10	1.4E-07	6.3E-07	3.1E-08	9.2E-09	8.8E-07	2.2E-08	6.7E-08	1.7E-07	4.7E-08	4.3E-09	8.9E-08	5.5E-08	3.9E-09	2.8E-06
Exposed Veg. Intake/ Root Veg. Intake	1.7E-07	4.6E-09	6.8E-08	8.9E-11	4.7E-08	2.3E-07	1.1E-08	3.1E-09	3.0E-07	8.2E-09	2.4E-08	6.0E-08	1.8E-08	1.7E-09	3.2E-08	2.0E-08	1.6E-09	1.0E-06
Exposed Veg. Intake/ Fruit Intake	1.8E-07	5.8E-09	7.2E-08	1.0E-10	4.9E-08	2.4E-07	1.3E-08	3.4E-09	3.1E-07	9.5E-09	2.5E-08	6.4E-08	1.9E-08	2.1E-09	3.4E-08	2.1E-08	1.9E-09	1.1E-06
Exposed Veg. Intake/ Application Rate	2.6E-07	6.7E-09	1.0E-07	1.3E-10	7.1E-08	3.5E-07	1.7E-08	4.6E-09	4.6E-07	1.2E-08	3.6E-08	9.0E-08	2.6E-08	2.5E-09	4.9E-08	3.0E-08	2.4E-09	1.5E-06
Exposed Veg. Intake/ Application Frequency	2.8E-07	7.4E-09	1.1E-07	1.4E-10	7.8E-08	3.8E-07	1.8E-08	5.1E-09	5.0E-07	1.3E-08	3.9E-08	9.9E-08	2.9E-08	2.7E-09	5.3E-08	3.2E-08	2.6E-09	1.7E-06

(continued)

Table 7-10. (continued)

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4, 5,7,8,9-	HxCDD, 1,2,3, 7,8,9-	OCDF, 1,2,3,4, 6,7,8,9-	HxCDD, 1,2,3, 4,7,8-	PeCDD, 1,2,3,7, 8-	TCDF, 2,3,7,8-	HpCDF, 1,2,3,4, 7,8,9-	PeCDF, 2,3,4,7, 8-	PeCDF, 1,2,3,7, 8-	HxCDF, 1,2,3, 6,7,8-	HxCDD, 1,2,3, 6,7,8-	HxCDF, 2,3,4, 6,7,8-	HpCDF, 1,2,3,4, 6,7,8-	HxCDF, 1,2,3, 4,7,8-	HxCDF, 1,2,3, 7,8,9-	HpCDD, 1,2,3,4, 6,7,8,-	TEQ
Exposed Veg. Intake/ Constituent Conc.	1.2E-06	4.6E-08	5.5E-07	2.8E-10	2.0E-07	1.3E-06	3.7E-07	9.0E-09	1.2E-05	1.3E-07	4.6E-07	5.0E-07	2.2E-07	3.7E-08	4.5E-07	7.4E-08	3.4E-08	**1.8E-05**
Exposed Veg. Intake/ Tilling Depth	2.0E-07	6.0E-09	8.8E-08	1.2E-10	6.2E-08	2.9E-07	1.3E-08	4.0E-09	3.8E-07	1.0E-08	3.1E-08	7.7E-08	2.2E-08	2.1E-09	4.1E-08	2.5E-08	2.1E-09	1.3E-06
Exposed Veg. Intake/ Soil Intake	1.7E-07	4.5E-09	6.9E-08	9.9E-11	4.8E-08	2.3E-07	1.2E-08	3.2E-09	3.0E-07	8.2E-09	2.5E-08	6.1E-08	1.8E-08	1.8E-09	3.3E-08	2.0E-08	1.8E-09	1.0E-06
Root Veg. Intake/ Fruit Intake	1.8E-07	5.7E-09	7.2E-08	1.0E-10	4.9E-08	2.4E-07	1.3E-08	3.4E-09	3.1E-07	9.5E-09	2.5E-08	6.4E-08	1.8E-08	2.1E-09	3.4E-08	2.1E-08	1.9E-09	1.0E-06
Root Veg. Intake/ Application Rate	2.6E-07	6.7E-09	1.0E-07	1.3E-10	7.1E-08	3.5E-07	1.6E-08	4.6E-09	4.6E-07	1.2E-08	3.6E-08	9.0E-08	2.6E-08	2.5E-09	4.8E-08	3.0E-08	2.4E-09	1.5E-06
Root Veg. Intake/ Application Frequency	2.8E-07	7.4E-09	1.1E-07	1.4E-10	7.8E-08	3.8E-07	1.8E-08	5.1E-09	5.0E-07	1.3E-08	3.9E-08	9.9E-08	2.9E-08	2.7E-09	5.3E-08	3.2E-08	2.7E-09	1.6E-06
Root Veg. Intake/ Constituent Conc.	1.2E-06	4.5E-08	5.5E-07	2.9E-10	2.0E-07	1.3E-06	3.6E-07	9.0E-09	1.2E-05	1.3E-07	4.6E-07	5.0E-07	2.2E-07	3.7E-08	4.5E-07	7.3E-08	3.4E-08	**1.8E-05**
Root Veg. Intake/ Tilling Depth	2.0E-07	6.0E-09	8.8E-08	1.2E-10	6.2E-08	2.9E-07	1.3E-08	4.0E-09	3.8E-07	9.9E-09	3.1E-08	7.7E-08	2.2E-08	2.1E-09	4.1E-08	2.5E-08	2.2E-09	1.3E-06
Root Veg. Intake/ Soil Intake	1.7E-07	4.5E-09	6.9E-08	1.0E-10	4.8E-08	2.3E-07	1.1E-08	3.2E-09	3.0E-07	8.1E-09	2.4E-08	6.1E-08	1.8E-08	1.8E-09	3.3E-08	2.0E-08	1.9E-09	1.0E-06
Fruit Intake/ Application Rate	2.7E-07	8.5E-09	1.1E-07	1.5E-10	7.4E-08	3.6E-07	1.9E-08	5.1E-09	4.8E-07	1.4E-08	3.8E-08	9.6E-08	2.8E-08	3.1E-09	5.1E-08	3.1E-08	2.7E-09	1.6E-06
Fruit Intake/ Application Frequency	2.9E-07	9.4E-09	1.2E-07	1.6E-10	8.1E-08	4.0E-07	2.1E-08	5.6E-09	5.2E-07	1.5E-08	4.1E-08	1.0E-07	3.0E-08	3.4E-09	5.5E-08	3.4E-08	3.0E-09	1.7E-06
Fruit Intake/ Constituent Conc.	1.3E-06	5.8E-08	5.8E-07	3.3E-10	2.0E-07	1.4E-06	4.2E-07	9.9E-09	1.3E-05	1.6E-07	4.8E-07	5.3E-07	2.3E-07	4.6E-08	4.7E-07	7.7E-08	3.9E-08	**1.9E-05**
Fruit Intake/ Tilling Depth	2.1E-07	7.7E-09	9.2E-08	1.4E-10	6.5E-08	3.0E-07	1.5E-08	4.4E-09	4.0E-07	1.2E-08	3.3E-08	8.2E-08	2.4E-08	2.6E-09	4.3E-08	2.6E-08	2.5E-09	1.3E-06
Fruit Intake/ Soil Intake	1.8E-07	5.7E-09	7.2E-08	1.1E-10	5.0E-08	2.4E-07	1.3E-08	3.5E-09	3.1E-07	9.5E-09	2.6E-08	6.4E-08	1.9E-08	2.2E-09	3.4E-08	2.1E-08	2.1E-09	1.1E-06
Appplication Rate/ Application Frequency	4.2E-07	1.1E-08	1.7E-07	2.1E-10	1.2E-07	5.7E-07	2.6E-08	7.6E-09	7.5E-07	1.9E-08	5.9E-08	1.5E-07	4.3E-08	4.0E-09	8.0E-08	4.8E-08	3.8E-09	2.5E-06
Application Rate/ Constituent Conc.	1.8E-06	6.7E-08	8.3E-07	4.2E-10	2.9E-07	2.0E-06	5.3E-07	1.3E-08	1.9E-05	2.0E-07	6.9E-07	7.5E-07	3.3E-07	5.5E-08	6.8E-07	1.1E-07	4.9E-08	**2.7E-05**
Appplication Rate/ Tilling Depth	2.9E-07	8.5E-09	1.3E-07	1.6E-10	9.0E-08	4.2E-07	1.9E-08	5.7E-09	5.6E-07	1.4E-08	4.5E-08	1.1E-07	3.2E-08	3.0E-09	6.0E-08	3.6E-08	3.0E-09	1.8E-06
Appplication Rate/ Soil Intake	2.6E-07	6.6E-09	1.0E-07	1.5E-10	7.2E-08	3.5E-07	1.7E-08	4.7E-09	4.6E-07	1.2E-08	3.7E-08	9.1E-08	2.7E-08	2.6E-09	4.9E-08	3.0E-08	2.7E-09	1.5E-06
Application Frequency/ Constituent Conc.	2.0E-06	7.4E-08	9.1E-07	4.6E-10	3.2E-07	2.1E-06	5.8E-07	1.5E-08	2.0E-05	2.2E-07	7.6E-07	8.2E-07	3.6E-07	6.0E-08	7.4E-07	1.2E-07	5.4E-08	**3.0E-05**
Appplication Frequency/ Tilling Depth	3.2E-07	9.8E-09	1.4E-07	1.9E-10	1.0E-07	4.7E-07	2.1E-08	6.5E-09	6.3E-07	1.6E-08	5.1E-08	1.3E-07	3.7E-08	3.4E-09	6.7E-08	4.1E-08	3.4E-09	2.1E-06

(continued)

Table 7-10. (continued)

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4, 5,7,8,9-	HxCDD, 1,2,3, 7,8,9-	OCDF, 1,2,3,4, 6,7,8,9-	HxCDD, 1,2,3, 4,7,8-	PeCDD, 1,2,3,7, 8-	TCDF, 2,3,7,8-	HpCDF, 1,2,3,4, 7,8,9-	PeCDF, 2,3,4,7, 8-	PeCDF, 1,2,3,7, 8-	HxCDF, 1,2,3, 6,7,8-	HxCDD, 1,2,3, 6,7,8-	HxCDF, 2,3,4, 6,7,8-	HpCDF, 1,2,3,4, 6,7,8-	HxCDF, 1,2,3, 4,7,8-	HxCDF, 1,2,3, 7,8,9-	HpCDD, 1,2,3,4, 6,7,8,-	TEQ
Appplication Frequency/ Soil Intake	2.8E-07	7.3E-09	1.1E-07	1.6E-10	7.9E-08	3.8E-07	1.8E-08	5.2E-09	5.0E-07	1.3E-08	4.0E-08	9.9E-08	2.9E-08	2.8E-09	5.4E-08	3.3E-08	3.0E-09	1.7E-06
Constituent Conc./ Tilling Depth	1.4E-06	6.0E-08	7.0E-07	3.8E-10	2.6E-07	1.6E-06	4.2E-07	1.1E-08	1.6E-05	1.6E-07	6.0E-07	6.4E-07	2.8E-07	4.7E-08	5.7E-07	9.4E-08	4.4E-08	**2.3E-05**
Constituent Conc./ Soil Intake	1.2E-06	4.5E-08	5.5E-07	3.3E-10	2.0E-07	1.3E-06	3.7E-07	9.1E-09	1.2E-05	1.3E-07	4.7E-07	5.0E-07	2.2E-07	3.9E-08	4.6E-07	7.5E-08	3.8E-08	**1.8E-05**
Soil Intake/ Tilling Depth	2.0E-07	6.0E-09	8.8E-08	1.3E-10	6.3E-08	2.9E-07	1.3E-08	4.0E-09	3.8E-07	1.0E-08	3.2E-08	7.7E-08	2.3E-08	2.2E-09	4.2E-08	2.6E-08	2.4E-09	1.3E-06

[a] Listed parameters are varied to high end values 1 or 2 at a time; all other parameters remain at central tendency values.

Note: Shaded and italicized bolded entries indicate cases where increased cancer risk exceeds 1E-05 or Hazard Quotient exceeds 1 for noncarcinogens.

Table 7-11. Increased Cancer Risk (CR) to Child of Farmer from Dioxin and Furan Congeners in CKD Used as an Agricultural Supplement

High End Parameters Varied[a]	**TCDD, 2,3,7, 8-**	**OCDD, 1,2,3,4 , 5,7,8, 9-**	**HxCDD , 1,2,3, 7,8,9-**	**OCDF, 1,2,3,4 , 6,7,8, 9-**	**HxCDD , 1,2,3, 4,7,8-**	**PeCDD, 1,2,3,7, 8-**	**TCDF, 2,3,7, 8-**	**HpCDF , 1,2,3,4, 7,8,9-**	**PeCDF, 2,3,4,7, 8-**	**PeCDF, 1,2,3,7, 8-**	**HxCDF , 1,2,3, 6,7,8-**	**HxCDD , 1,2,3, 6,7,8-**	**HxCDF , 2,3,4, 6,7,8-**	**HpCDF , 1,2,3,4, 6,7,8-**	**HxCDF , 1,2,3, 4,7,8-**	**HxCDF , 1,2,3, 7,8,9-**	**HpCDD , 1,2,3,4, 6,7,8,-**	**TEQ**
Central Tendency	3.E-07	7.E-09	1.E-07	4.E-10	8.E-08	4.E-07	2.E-08	5.E-09	4.E-07	1.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06
Single High End Variation																		
Long Exposure	6.E-07	1.E-08	2.E-07	6.E-10	2.E-07	8.E-07	4.E-08	1.E-08	9.E-07	3.E-08	9.E-08	2.E-07	7.E-08	7.E-09	1.E-07	7.E-08	1.E-08	3.E-06
Beef intake	5.E-07	1.E-08	2.E-07	5.E-10	1.E-07	6.E-07	3.E-08	7.E-09	7.E-07	2.E-08	7.E-08	2.E-07	5.E-08	6.E-09	9.E-08	5.E-08	9.E-09	2.E-06
Dairy Intake	4.E-07	1.E-08	2.E-07	5.E-10	1.E-07	6.E-07	3.E-08	8.E-09	7.E-07	2.E-08	7.E-08	1.E-07	5.E-08	6.E-09	8.E-08	5.E-08	9.E-09	2.E-06
Exposed Veg. Intake	3.E-07	7.E-09	1.E-07	4.E-10	8.E-08	4.E-07	2.E-08	5.E-09	4.E-07	1.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06
Root Veg. Intake	3.E-07	7.E-09	1.E-07	4.E-10	8.E-08	4.E-07	2.E-08	5.E-09	4.E-07	1.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06
Fruit Intake	3.E-07	8.E-09	1.E-07	4.E-10	8.E-08	4.E-07	3.E-08	6.E-09	4.E-07	2.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06
CKD Application Rate	4.E-07	1.E-08	2.E-07	6.E-10	1.E-07	6.E-07	4.E-08	8.E-09	6.E-07	2.E-08	7.E-08	1.E-07	5.E-08	7.E-09	9.E-08	6.E-08	1.E-08	2.E-06
CKD Application Frequency	5.E-07	1.E-08	2.E-07	7.E-10	1.E-07	6.E-07	4.E-08	9.E-09	7.E-07	2.E-08	8.E-08	2.E-07	6.E-08	8.E-09	1.E-07	6.E-08	1.E-08	3.E-06
Constituent Conc.	2.E-06	7.E-08	8.E-07	1.E-09	3.E-07	2.E-06	8.E-07	2.E-08	2.E-05	2.E-07	9.E-07	8.E-07	5.E-07	1.E-07	8.E-07	1.E-07	2.E-07	**3.E-05**
Small Tilling Depth	3.E-07	9.E-09	1.E-07	6.E-10	1.E-07	5.E-07	3.E-08	7.E-09	5.E-07	2.E-08	6.E-08	1.E-07	5.E-08	6.E-09	7.E-08	5.E-08	1.E-08	2.E-06
Adult Soil intake	3.E-07	7.E-09	1.E-07	4.E-10	8.E-08	4.E-07	2.E-08	5.E-09	4.E-07	1.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06
Child Soil intake	4.E-07	9.E-09	1.E-07	9.E-10	1.E-07	5.E-07	4.E-08	9.E-09	5.E-07	2.E-08	8.E-08	1.E-07	6.E-08	9.E-09	9.E-08	6.E-08	2.E-08	2.E-06
Double High End Variation																		
Beef Intake/ Long Exposure	1.E-06	2.E-08	3.E-07	7.E-10	3.E-07	1.E-06	5.E-08	1.E-08	2.E-06	4.E-08	1.E-07	3.E-07	1.E-07	1.E-08	2.E-07	1.E-07	1.E-08	5.E-06
Dairy Intake/ Long Exposure	9.E-07	2.E-08	4.E-07	7.E-10	3.E-07	1.E-06	6.E-08	2.E-08	2.E-06	4.E-08	1.E-07	3.E-07	1.E-07	1.E-08	2.E-07	1.E-07	1.E-08	5.E-06
Exposed Veg. Intake/ Long Exposure	6.E-07	1.E-08	2.E-07	6.E-10	2.E-07	8.E-07	4.E-08	1.E-08	9.E-07	3.E-08	9.E-08	2.E-07	7.E-08	7.E-09	1.E-07	7.E-08	1.E-08	3.E-06
Root Veg. Intake/ Long Exposure	6.E-07	1.E-08	2.E-07	6.E-10	2.E-07	8.E-07	4.E-08	1.E-08	9.E-07	3.E-08	9.E-08	2.E-07	7.E-08	7.E-09	1.E-07	7.E-08	1.E-08	3.E-06
Fruit Intake/ Long Exposure	6.E-07	2.E-08	2.E-07	6.E-10	2.E-07	8.E-07	4.E-08	1.E-08	1.E-06	3.E-08	9.E-08	2.E-07	7.E-08	8.E-09	1.E-07	7.E-08	1.E-08	3.E-06

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4,5,7,8,9-	HxCDD, 1,2,3,7,8,9-	OCDF, 1,2,3,4,6,7,8,9-	HxCDD, 1,2,3,4,7,8-	PeCDD, 1,2,3,7,8-	TCDF, 2,3,7,8-	HpCDF, 1,2,3,4,7,8,9-	PeCDF, 2,3,4,7,8-	PeCDF, 1,2,3,7,8-	HxCDF, 1,2,3,6,7,8-	HxCDD, 1,2,3,6,7,8-	HxCDF, 2,3,4,6,7,8-	HpCDF, 1,2,3,4,6,7,8-	HxCDF, 1,2,3,4,7,8-	HxCDF, 1,2,3,7,8,9-	HpCDD, 1,2,3,4,6,7,8,-	TEQ
Application Rate/ Long Exposure	9.E-07	2.E-08	3.E-07	8.E-10	2.E-07	1.E-06	6.E-08	2.E-08	1.E-06	4.E-08	1.E-07	3.E-07	1.E-07	1.E-08	2.E-07	1.E-07	2.E-08	5.E-06
Application Frequency/ Long Exposure	1.E-06	2.E-08	4.E-07	9.E-10	3.E-07	1.E-06	7.E-08	2.E-08	2.E-06	4.E-08	2.E-07	3.E-07	1.E-07	1.E-08	2.E-07	1.E-07	2.E-08	5.E-06
Constituent Conc./ Long Exposure	4.E-06	2.E-07	2.E-06	2.E-09	7.E-07	4.E-06	1.E-06	3.E-08	4.E-05	4.E-07	2.E-06	2.E-06	8.E-07	2.E-07	2.E-06	3.E-07	2.E-07	**6.E-05**
Small Tilling Depth/ Long Exposure	7.E-07	2.E-08	3.E-07	8.E-10	2.E-07	1.E-06	5.E-08	1.E-08	1.E-06	3.E-08	1.E-07	3.E-07	9.E-08	9.E-09	2.E-07	9.E-08	2.E-08	4.E-06
Adult Soil intake/ Long Exposure	6.E-07	2.E-08	2.E-07	6.E-10	2.E-07	8.E-07	4.E-08	1.E-08	9.E-07	3.E-08	9.E-08	2.E-07	7.E-08	8.E-09	1.E-07	7.E-08	1.E-08	3.E-06

(continued)

Table 7-11. (continued)

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4,5,7,8,9-	HxCDD, 1,2,3,7,8,9-	OCDF, 1,2,3,4,6,7,8,9-	HxCDD, 1,2,3,4,7,8-	PeCDD, 1,2,3,7,8-	TCDF, 2,3,7,8-	HpCDF, 1,2,3,4,7,8,9-	PeCDF, 2,3,4,7,8-	PeCDF, 1,2,3,7,8-	HxCDF, 1,2,3,6,7,8-	HxCDD, 1,2,3,6,7,8-	HxCDF, 2,3,4,6,7,8-	HpCDF, 1,2,3,4,6,7,8-	HxCDF, 1,2,3,4,7,8-	HxCDF, 1,2,3,7,8,9-	HpCDD, 1,2,3,4,6,7,8,-	TEQ
Child Soil intake/ Long Exposure	7.E-07	2.E-08	3.E-07	1.E-09	2.E-07	9.E-07	6.E-08	1.E-08	1.E-06	3.E-08	1.E-07	2.E-07	9.E-08	1.E-08	1.E-07	9.E-08	2.E-08	4.E-06
Beef Intake/ Dairy Intake	6.E-07	1.E-08	2.E-07	5.E-10	2.E-07	8.E-07	4.E-08	1.E-08	9.E-07	3.E-08	9.E-08	2.E-07	7.E-08	7.E-09	1.E-07	7.E-08	1.E-08	3.E-06
Beef Intake/ Exposed Veg. Intake	5.E-07	1.E-08	2.E-07	5.E-10	1.E-07	6.E-07	3.E-08	7.E-09	7.E-07	2.E-08	7.E-08	2.E-07	5.E-08	6.E-09	9.E-08	5.E-08	9.E-09	2.E-06
Beef Intake/ Root Vegetable Intake	5.E-07	1.E-08	2.E-07	5.E-10	1.E-07	6.E-07	3.E-08	7.E-09	7.E-07	2.E-08	7.E-08	2.E-07	5.E-08	6.E-09	9.E-08	5.E-08	9.E-09	2.E-06
Beef Intake/ Fruit Intake	5.E-07	1.E-08	2.E-07	5.E-10	1.E-07	6.E-07	3.E-08	7.E-09	7.E-07	2.E-08	7.E-08	2.E-07	5.E-08	6.E-09	9.E-08	5.E-08	9.E-09	3.E-06
Beef Intake/ Application Rate	7.E-07	2.E-08	2.E-07	7.E-10	2.E-07	9.E-07	4.E-08	1.E-08	1.E-06	3.E-08	1.E-07	2.E-07	8.E-08	9.E-09	1.E-07	8.E-08	1.E-08	4.E-06
Beef Intake/ Application Frequency	8.E-07	2.E-08	3.E-07	8.E-10	2.E-07	1.E-06	5.E-08	1.E-08	1.E-06	3.E-08	1.E-07	2.E-07	9.E-08	1.E-08	1.E-07	9.E-08	2.E-08	4.E-06
Beef Intake/ Constituent Conc.	3.E-06	1.E-07	1.E-06	2.E-09	5.E-07	3.E-06	1.E-06	2.E-08	3.E-05	3.E-07	1.E-06	1.E-06	7.E-07	1.E-07	1.E-06	2.E-07	2.E-07	**4.E-05**
Beef Intake/ Small Tilling Depth	5.E-07	2.E-08	2.E-07	6.E-10	2.E-07	8.E-07	4.E-08	9.E-09	9.E-07	2.E-08	9.E-08	2.E-07	7.E-08	8.E-09	1.E-07	7.E-08	1.E-08	3.E-06
Beef Intake/ Adult Soil Ingestion	5.E-07	1.E-08	2.E-07	5.E-10	1.E-07	6.E-07	3.E-08	7.E-09	7.E-07	2.E-08	7.E-08	2.E-07	5.E-08	6.E-09	9.E-08	5.E-08	9.E-09	2.E-06
Beef Intake/ Child Soil Ingestion	6.E-07	1.E-08	2.E-07	1.E-09	2.E-07	7.E-07	5.E-08	1.E-08	8.E-07	3.E-08	1.E-07	2.E-07	7.E-08	1.E-08	1.E-07	8.E-08	2.E-08	3.E-06
Dairy Intake/ Exposed Vegetable Intake	4.E-07	1.E-08	2.E-07	5.E-10	1.E-07	6.E-07	3.E-08	8.E-09	7.E-07	2.E-08	7.E-08	1.E-07	5.E-08	6.E-09	8.E-08	5.E-08	9.E-09	2.E-06
Dairy Intake/ Root Vegetable Intake	4.E-07	1.E-08	2.E-07	5.E-10	1.E-07	6.E-07	3.E-08	8.E-09	7.E-07	2.E-08	7.E-08	1.E-07	5.E-08	6.E-09	8.E-08	5.E-08	9.E-09	2.E-06
Dairy Intake/ Fruit Intake	4.E-07	1.E-08	2.E-07	5.E-10	1.E-07	6.E-07	3.E-08	8.E-09	7.E-07	2.E-08	7.E-08	2.E-07	5.E-08	6.E-09	8.E-08	5.E-08	9.E-09	2.E-06
Dairy Intake/ Application Rate	6.E-07	2.E-08	2.E-07	7.E-10	2.E-07	8.E-07	5.E-08	1.E-08	1.E-06	3.E-08	1.E-07	2.E-07	7.E-08	9.E-09	1.E-07	8.E-08	1.E-08	4.E-06
Dairy Intake/ Application Frequency	7.E-07	2.E-08	3.E-07	8.E-10	2.E-07	9.E-07	5.E-08	1.E-08	1.E-06	3.E-08	1.E-07	2.E-07	8.E-08	9.E-09	1.E-07	9.E-08	2.E-08	4.E-06
Dairy Intake/ Constituent Conc.	3.E-06	1.E-07	1.E-06	2.E-09	5.E-07	3.E-06	1.E-06	2.E-08	3.E-05	3.E-07	1.E-06	1.E-06	6.E-07	1.E-07	1.E-06	2.E-07	2.E-07	**4.E-05**
Dairy Intake/ Tilling Depth	5.E-07	1.E-08	2.E-07	6.E-10	2.E-07	7.E-07	4.E-08	1.E-08	9.E-07	3.E-08	9.E-08	2.E-07	6.E-08	7.E-09	1.E-07	7.E-08	1.E-08	3.E-06
Dairy Intake/ Adult Soil Ingestion	4.E-07	1.E-08	2.E-07	5.E-10	1.E-07	6.E-07	3.E-08	8.E-09	7.E-07	2.E-08	7.E-08	1.E-07	5.E-08	6.E-09	8.E-08	5.E-08	9.E-09	2.E-06
Dairy Intake/ Child Soil Ingestion	5.E-07	1.E-08	2.E-07	1.E-09	2.E-07	7.E-07	5.E-08	1.E-08	8.E-07	3.E-08	9.E-08	2.E-07	7.E-08	1.E-08	1.E-07	7.E-08	2.E-08	3.E-06

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4,5,7,8,9-	HxCDD, 1,2,3,7,8,9-	OCDF, 1,2,3,4,6,7,8,9-	HxCDD, 1,2,3,4,7,8-	PeCDD, 1,2,3,7,8-	TCDF, 2,3,7,8-	HpCDF, 1,2,3,4,7,8,9-	PeCDF, 2,3,4,7,8-	PeCDF, 1,2,3,7,8-	HxCDF, 1,2,3,6,7,8-	HxCDD, 1,2,3,6,7,8-	HxCDF, 2,3,4,6,7,8-	HpCDF, 1,2,3,4,6,7,8-	HxCDF, 1,2,3,4,7,8-	HxCDF, 1,2,3,7,8,9-	HpCDD, 1,2,3,4,6,7,8,-	TEQ
Exposed Veg. Intake/ Root Veg. Intake	3.E-07	7.E-09	1.E-07	4.E-10	8.E-08	4.E-07	2.E-08	5.E-09	4.E-07	1.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06

(continued)

Table 7-11. (continued)

High End Parameters Varied[a]	TCDD, 2,3,7,8-	OCDD, 1,2,3,4,5,7,8,9-	HxCDD, 1,2,3,7,8,9-	OCDF, 1,2,3,4,6,7,8,9-	HxCDD, 1,2,3,4,7,8-	PeCDD, 1,2,3,7,8-	TCDF, 2,3,7,8-	HpCDF, 1,2,3,4,7,8,9-	PeCDF, 2,3,4,7,8-	PeCDF, 1,2,3,7,8-	HxCDF, 1,2,3,6,7,8-	HxCDD, 1,2,3,6,7,8-	HxCDF, 2,3,4,6,7,8-	HpCDF, 1,2,3,4,6,7,8-	HxCDF, 1,2,3,4,7,8-	HxCDF, 1,2,3,7,8,9-	HpCDD, 1,2,3,4,6,7,8,-	TEQ
Exposed Veg. Intake/ Fruit Intake	3.E-07	8.E-09	1.E-07	4.E-10	8.E-08	4.E-07	3.E-08	6.E-09	4.E-07	2.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06
Exposed Veg. Intake/ Application Rate	4.E-07	1.E-08	2.E-07	6.E-10	1.E-07	6.E-07	4.E-08	8.E-09	6.E-07	2.E-08	7.E-08	1.E-07	5.E-08	7.E-09	9.E-08	6.E-08	1.E-08	2.E-06
Exposed Veg. Intake/ Application Frequency	5.E-07	1.E-08	2.E-07	7.E-10	1.E-07	6.E-07	4.E-08	9.E-09	7.E-07	2.E-08	8.E-08	2.E-07	6.E-08	8.E-09	1.E-07	6.E-08	1.E-08	3.E-06
Exposed Veg. Intake/Constituent Conc.	2.E-06	7.E-08	8.E-07	1.E-09	3.E-07	2.E-06	8.E-07	2.E-08	2.E-05	2.E-07	9.E-07	8.E-07	5.E-07	1.E-07	8.E-07	1.E-07	2.E-07	**3.E-05**
Exposed Veg. Intake/ Tilling Depth	3.E-07	9.E-09	1.E-07	6.E-10	1.E-07	5.E-07	3.E-08	7.E-09	5.E-07	2.E-08	6.E-08	1.E-07	5.E-08	6.E-09	7.E-08	5.E-08	1.E-08	2.E-06
Exposed Veg. Intake/ Adult Soil Ingestion	3.E-07	7.E-09	1.E-07	4.E-10	8.E-08	4.E-07	2.E-08	5.E-09	4.E-07	1.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06
Exposed Veg. Intake/ Child Soil Ingestion	4.E-07	9.E-09	1.E-07	9.E-10	1.E-07	5.E-07	4.E-08	9.E-09	5.E-07	2.E-08	8.E-08	1.E-07	6.E-08	9.E-09	9.E-08	6.E-08	2.E-08	2.E-06
Root Veg. Intake/ Fruit Intake	3.E-07	8.E-09	1.E-07	4.E-10	8.E-08	4.E-07	3.E-08	6.E-09	4.E-07	2.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06
Root Veg. Intake/ Application Rate	4.E-07	1.E-08	2.E-07	6.E-10	1.E-07	6.E-07	4.E-08	8.E-09	6.E-07	2.E-08	7.E-08	1.E-07	5.E-08	7.E-09	9.E-08	6.E-08	1.E-08	2.E-06
Root Veg. Intake/ Application Frequency	5.E-07	1.E-08	2.E-07	7.E-10	1.E-07	6.E-07	4.E-08	9.E-09	7.E-07	2.E-08	8.E-08	2.E-07	6.E-08	8.E-09	1.E-07	6.E-08	1.E-08	3.E-06
Root Veg. Intake/ Constituent Conc.	2.E-06	7.E-08	8.E-07	1.E-09	3.E-07	2.E-06	8.E-07	2.E-08	2.E-05	2.E-07	9.E-07	8.E-07	5.E-07	1.E-07	8.E-07	1.E-07	2.E-07	**3.E-05**
Root Veg. Intake/ Tilling Depth	3.E-07	9.E-09	1.E-07	6.E-10	1.E-07	5.E-07	3.E-08	7.E-09	5.E-07	2.E-08	6.E-08	1.E-07	5.E-08	6.E-09	7.E-08	5.E-08	1.E-08	2.E-06
Root Veg. Intake/ Adult Soil Ingestion	3.E-07	7.E-09	1.E-07	4.E-10	8.E-08	4.E-07	2.E-08	6.E-09	4.E-07	1.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06
Root Veg. Intake/ Child Soil Ingestion	4.E-07	9.E-09	1.E-07	9.E-10	1.E-07	5.E-07	4.E-08	9.E-09	5.E-07	2.E-08	8.E-08	1.E-07	6.E-08	9.E-09	9.E-08	6.E-08	2.E-08	2.E-06
Fruit Intake/ Application Rate	4.E-07	1.E-08	2.E-07	6.E-10	1.E-07	6.E-07	4.E-08	9.E-09	7.E-07	2.E-08	7.E-08	2.E-07	6.E-08	7.E-09	9.E-08	6.E-08	1.E-08	2.E-06
Fruit Intake/ Application Frequency	5.E-07	1.E-08	2.E-07	7.E-10	1.E-07	6.E-07	4.E-08	9.E-09	7.E-07	3.E-08	8.E-08	2.E-07	6.E-08	8.E-09	1.E-07	6.E-08	1.E-08	3.E-06
Fruit Intake/ Constituent Conc.	2.E-06	8.E-08	9.E-07	1.E-09	3.E-07	2.E-06	8.E-07	2.E-08	2.E-05	3.E-07	9.E-07	8.E-07	5.E-07	1.E-07	8.E-07	1.E-07	2.E-07	**3.E-05**
Fruit Intake/ Tilling Depth	3.E-07	1.E-08	1.E-07	6.E-10	1.E-07	5.E-07	3.E-08	7.E-09	5.E-07	2.E-08	6.E-08	1.E-07	5.E-08	6.E-09	8.E-08	5.E-08	1.E-08	2.E-06
Fruit Intake/ Adult Soil Ingestion	3.E-07	8.E-09	1.E-07	4.E-10	8.E-08	4.E-07	3.E-08	6.E-09	4.E-07	2.E-08	5.E-08	1.E-07	4.E-08	5.E-09	6.E-08	4.E-08	8.E-09	2.E-06
Fruit Intake/ Child Soil Ingestion	4.E-07	1.E-08	1.E-07	9.E-10	1.E-07	5.E-07	4.E-08	9.E-09	5.E-07	2.E-08	8.E-08	1.E-07	6.E-08	9.E-09	9.E-08	6.E-08	2.E-08	2.E-06

High End Parameters Varied[a]	**TCDD, 2,3,7,8-**	**OCDD, 1,2,3,4,5,7,8,9-**	**HxCDD, 1,2,3,7,8,9-**	**OCDF, 1,2,3,4,6,7,8,9-**	**HxCDD, 1,2,3,4,7,8-**	**PeCDD, 1,2,3,7,8-**	**TCDF, 2,3,7,8-**	**HpCDF, 1,2,3,4,7,8,9-**	**PeCDF, 2,3,4,7,8-**	**PeCDF, 1,2,3,7,8-**	**HxCDF, 1,2,3,6,7,8-**	**HxCDD, 1,2,3,6,7,8-**	**HxCDF, 2,3,4,6,7,8-**	**HpCDF, 1,2,3,4,6,7,8-**	**HxCDF, 1,2,3,4,7,8-**	**HxCDF, 1,2,3,7,8,9-**	**HpCDD, 1,2,3,4,6,7,8,-**	**TEQ**
Application Rate/ Application Frequency	7.E-07	2.E-08	3.E-07	1.E-09	2.E-07	9.E-07	6.E-08	1.E-08	1.E-06	4.E-08	1.E-07	2.E-07	9.E-08	1.E-08	1.E-07	9.E-08	2.E-08	4.E-06

(continued)

Table 7-11. (continued)

High End Parameters Varied[a]	TCDD, 2,3,7, 8-	OCDD, 1,2,3,4 , 5,7,8, 9-	HxCDD , 1,2,3, 7,8,9-	OCDF, 1,2,3,4 , 6,7,8, 9-	HxCDD , 1,2,3, 4,7,8-	PeCDD, 1,2,3,7, 8-	TCDF, 2,3,7, 8-	HpCDF , 1,2,3,4, 7,8,9-	PeCDF, 2,3,4,7, 8-	PeCDF, 1,2,3,7, 8-	HxCDF , 1,2,3, 6,7,8-	HxCDD , 1,2,3, 6,7,8-	HxCDF , 2,3,4, 6,7,8-	HpCDF , 1,2,3,4, 6,7,8-	HxCDF , 1,2,3, 4,7,8-	HxCDF , 1,2,3, 7,8,9-	HpCDD , 1,2,3,4, 6,7,8,-	TEQ
Application Rate/ Constituent Conc.	3.E-06	1.E-07	1.E-06	2.E-09	5.E-07	3.E-06	1.E-06	2.E-08	3.E-05	4.E-07	1.E-06	1.E-06	7.E-07	2.E-07	1.E-06	2.E-07	3.E-07	**4.E-05**
Application Rate/ Tilling Depth	5.E-07	1.E-08	2.E-07	8.E-10	2.E-07	7.E-07	4.E-08	1.E-08	8.E-07	3.E-08	9.E-08	2.E-07	7.E-08	9.E-09	1.E-07	7.E-08	2.E-08	3.E-06
Application Rate/ Adult Soil Ingestion	4.E-07	1.E-08	2.E-07	6.E-10	1.E-07	6.E-07	4.E-08	8.E-09	6.E-07	2.E-08	7.E-08	1.E-07	5.E-08	7.E-09	9.E-08	6.E-08	1.E-08	2.E-06
Application Rate/ Child Soil Ingestion	6.E-07	1.E-08	2.E-07	1.E-09	2.E-07	8.E-07	7.E-08	1.E-08	8.E-07	3.E-08	1.E-07	2.E-07	9.E-08	1.E-08	1.E-07	9.E-08	3.E-08	3.E-06
Application Frequency/ Constituent Conc.	3.E-06	1.E-07	1.E-06	2.E-09	6.E-07	4.E-06	1.E-06	3.E-08	3.E-05	4.E-07	2.E-06	1.E-06	8.E-07	2.E-07	1.E-06	2.E-07	3.E-07	**5.E-05**
Application Frequency/ Tilling Depth	6.E-07	2.E-08	2.E-07	9.E-10	2.E-07	8.E-07	5.E-08	1.E-08	9.E-07	3.E-08	1.E-07	2.E-07	8.E-08	1.E-08	1.E-07	8.E-08	2.E-08	3.E-06
Application Frequency/ Adult Soil Ingestion	5.E-07	1.E-08	2.E-07	7.E-10	1.E-07	6.E-07	4.E-08	9.E-09	7.E-07	2.E-08	8.E-08	2.E-07	6.E-08	8.E-09	1.E-07	6.E-08	1.E-08	3.E-06
Application Frequency/ Child Soil Ingestion	6.E-07	2.E-08	2.E-07	2.E-09	2.E-07	8.E-07	7.E-08	2.E-08	8.E-07	4.E-08	1.E-07	2.E-07	9.E-08	2.E-08	1.E-07	1.E-07	3.E-08	4.E-06
Constituent Conc./ Tilling Depth	2.E-06	9.E-08	1.E-06	2.E-09	4.E-07	3.E-06	9.E-07	2.E-08	2.E-05	3.E-07	1.E-06	1.E-06	6.E-07	1.E-07	1.E-06	2.E-07	2.E-07	**3.E-05**
Constituent Conc./ Adult Soil Ingestion	2.E-06	7.E-08	8.E-07	1.E-09	3.E-07	2.E-06	8.E-07	2.E-08	2.E-05	2.E-07	9.E-07	8.E-07	5.E-07	1.E-07	8.E-07	1.E-07	2.E-07	**3.E-05**
Constituent Conc./ Child Soil Ingestion	3.E-06	9.E-08	1.E-06	3.E-09	5.E-07	3.E-06	1.E-06	3.E-08	2.E-05	4.E-07	2.E-06	1.E-06	7.E-07	2.E-07	1.E-06	2.E-07	4.E-07	**4.E-05**
Tilling Depth/ Adult Soil Ingestion	3.E-07	9.E-09	1.E-07	6.E-10	1.E-07	5.E-07	3.E-08	7.E-09	5.E-07	2.E-08	6.E-08	1.E-07	5.E-08	6.E-09	7.E-08	5.E-08	1.E-08	2.E-06
Tilling Depth/ Child Soil Ingestion	4.E-07	1.E-08	2.E-07	1.E-09	2.E-07	6.E-07	5.E-08	1.E-08	6.E-07	3.E-08	1.E-07	2.E-07	7.E-08	1.E-08	1.E-07	8.E-08	2.E-08	3.E-06
Adult Soil Ingestion A5/ Child Soil Ingestion	4.E-07	9.E-09	1.E-07	9.E-10	1.E-07	5.E-07	4.E-08	9.E-09	5.E-07	2.E-08	8.E-08	1.E-07	6.E-08	9.E-09	9.E-08	6.E-08	2.E-08	2.E-06

[a] Listed parameters are varied to high end values 1 or 2 at a time; all other parameters remain at central tendency values.

Note: Shaded and italicized bolded entries indicate cases where increased cancer risk exceeds 1E-05 or Hazard Quotient exceeds 1 for noncarcinogens.

Table 7-12. Increased Cancer Risk (CR) to Fisher from Dioxin and Furan Congeners in CKD Used as an Agricultural Supplement

High End Parameters Varied[a]	**TCDD, 2,3,7,8-**	**OCDD, 1,2,3,4,5,7,8,9-**	**HxCDD, 1,2,3,7,8,9-**	**OCDF, 1,2,3,4,6,7,8,9-**	**HxCDD, 1,2,3,4,7,8-**	**PeCDD, 1,2,3,7,8-**	**TCDF, 2,3,7,8-**	**HpCDF, 1,2,3,4,7,8,9-**	**PeCDF, 2,3,4,7,8-**	**PeCDF, 1,2,3,7,8-**	**HxCDF, 1,2,3,6,7,8-**	**HxCDD, 1,2,3,6,7,8-**	**HxCDF, 2,3,4,6,7,8-**	**HpCDF, 1,2,3,4,6,7,8-**	**HxCDF, 1,2,3,4,7,8-**	**HxCDF, 1,2,3,7,8,9-**	**HpCDD, 1,2,3,4,6,7,8,-**	**TEQ**
Central Tendency	4.E-10	1.E-14	8.E-11	3.E-15	9.E-11	7.E-10	9.E-11	1.E-12	4.E-10	4.E-11	7.E-11	8.E-11	5.E-11	1.E-12	6.E-11	5.E-11	3.E-12	2.E-09
Single High End Variation																		
Long Exposure	4.E-09	1.E-13	7.E-10	3.E-14	8.E-10	6.E-09	9.E-10	9.E-12	4.E-09	4.E-10	6.E-10	7.E-10	5.E-10	1.E-11	6.E-10	5.E-10	3.E-11	2.E-08
Fish Intake	3.E-09	8.E-14	5.E-10	2.E-14	6.E-10	4.E-09	6.E-10	6.E-12	3.E-09	3.E-10	4.E-10	5.E-10	3.E-10	8.E-12	4.E-10	3.E-10	2.E-11	1.E-08
Application Rate	7.E-10	2.E-14	1.E-10	5.E-15	1.E-10	1.E-09	1.E-10	2.E-12	6.E-10	6.E-11	1.E-10	1.E-10	8.E-11	2.E-12	1.E-10	8.E-11	4.E-12	3.E-09
Application Frequency	7.E-10	2.E-14	1.E-10	5.E-15	1.E-10	1.E-09	2.E-10	2.E-12	7.E-10	7.E-11	1.E-10	1.E-10	8.E-11	2.E-12	1.E-10	8.E-11	5.E-12	4.E-09
Constituent Conc.	3.E-09	1.E-13	6.E-10	1.E-14	4.E-10	4.E-09	3.E-09	3.E-12	2.E-08	7.E-10	1.E-09	7.E-10	6.E-10	3.E-11	9.E-10	2.E-10	6.E-11	3.E-08
Tilling Depth	5.E-10	2.E-14	1.E-10	4.E-15	1.E-10	8.E-10	1.E-10	1.E-12	5.E-10	5.E-11	9.E-11	1.E-10	7.E-11	2.E-12	8.E-11	7.E-11	4.E-12	3.E-09
Double High End Variation																		
Fish Intake/ Long Exposure	3.E-08	8.E-13	5.E-09	2.E-13	5.E-09	4.E-08	6.E-09	6.E-11	3.E-08	2.E-09	4.E-09	5.E-09	3.E-09	8.E-11	4.E-09	3.E-09	2.E-10	1.E-07
Application Rate/ Long Exposure	6.E-09	2.E-13	1.E-09	4.E-14	1.E-09	9.E-09	1.E-09	1.E-11	6.E-09	6.E-10	1.E-09	1.E-09	7.E-10	2.E-11	9.E-10	7.E-10	4.E-11	3.E-08
Application Frequency/ Long Exposure	7.E-09	2.E-13	1.E-09	5.E-14	1.E-09	1.E-08	1.E-09	2.E-11	7.E-09	6.E-10	1.E-09	1.E-09	8.E-10	2.E-11	1.E-09	8.E-10	5.E-11	3.E-08
Constituent Con./ Long Exposure	3.E-08	1.E-12	6.E-09	1.E-13	3.E-09	4.E-08	3.E-08	3.E-11	2.E-07	6.E-09	1.E-08	6.E-09	6.E-09	3.E-10	8.E-09	2.E-09	6.E-10	3.E-07
Tilling Depth/ Long Exposure	5.E-09	2.E-13	1.E-09	4.E-14	1.E-09	8.E-09	1.E-09	1.E-11	5.E-09	5.E-10	8.E-10	1.E-09	6.E-10	2.E-11	8.E-10	6.E-10	4.E-11	3.E-08
Fish Intake/ Application Rate	4.E-09	1.E-13	8.E-10	3.E-14	8.E-10	6.E-09	9.E-10	1.E-11	4.E-09	4.E-10	7.E-10	8.E-10	5.E-10	1.E-11	6.E-10	5.E-10	3.E-11	2.E-08
Fish Intake/ Application Frequency	5.E-09	1.E-13	8.E-10	3.E-14	9.E-10	7.E-09	1.E-09	1.E-11	4.E-09	4.E-10	7.E-10	8.E-10	5.E-10	1.E-11	7.E-10	5.E-10	3.E-11	2.E-08
Fish Intake/ Constituent Conc.	2.E-08	8.E-13	4.E-09	6.E-14	2.E-09	2.E-08	2.E-08	2.E-11	1.E-07	4.E-09	8.E-09	4.E-09	4.E-09	2.E-10	6.E-09	1.E-09	4.E-10	2.E-07
Fish Intake/ Tilling Depth	3.E-09	1.E-13	7.E-10	3.E-14	7.E-10	5.E-09	7.E-10	8.E-12	3.E-09	3.E-10	6.E-10	7.E-10	4.E-10	1.E-11	5.E-10	4.E-10	2.E-11	2.E-08
Appplication Rate/ Application Frequency	1.E-09	3.E-14	2.E-10	8.E-15	2.E-10	2.E-09	2.E-10	3.E-12	1.E-09	1.E-10	2.E-10	2.E-10	1.E-10	3.E-12	2.E-10	1.E-10	7.E-12	5.E-09
Appplication Rate/ Constituent Conc.	5.E-09	2.E-13	1.E-09	2.E-14	6.E-10	6.E-09	5.E-09	5.E-12	3.E-08	1.E-09	2.E-09	1.E-09	1.E-09	4.E-11	1.E-09	3.E-10	9.E-11	5.E-08
Appplication Rate/ Tilling Depth	8.E-10	3.E-14	2.E-10	6.E-15	2.E-10	1.E-09	2.E-10	2.E-12	8.E-10	7.E-11	1.E-10	2.E-10	1.E-10	2.E-12	1.E-10	1.E-10	6.E-12	4.E-09
Appplication Frequency/ Constituent Conc.	5.E-09	2.E-13	1.E-09	2.E-14	6.E-10	6.E-09	5.E-09	5.E-12	3.E-08	1.E-09	2.E-09	1.E-09	1.E-09	5.E-11	1.E-09	3.E-10	1.E-10	5.E-08
Appplication Frequency/ Tilling Depth	9.E-10	3.E-14	2.E-10	7.E-15	2.E-10	1.E-09	2.E-10	2.E-12	9.E-10	8.E-11	1.E-10	2.E-10	1.E-10	3.E-12	1.E-10	1.E-10	7.E-12	4.E-09

Constituent Conc./ Tilling Depth	4.E-09	2.E-13	8.E-10	1.E-14	5.E-10	5.E-09	4.E-09	4.E-12	2.E-08	8.E-10	2.E-09	9.E-10	8.E-10	4.E-11	1.E-09	2.E-10	8.E-11	4.E-08

[a] Listed parameters are varied to high end values 1 or 2 at a time; all other parameters remain at central tendency values.

Table 7-13. Range of Concentrations of Metals in Soils from Use of CKD as an Agricultural Soil Amendment Compared to Ecological Benchmarks for Soil and Phytotoxicity Limits[a]

Metal	Range of Soil Concentrations (mg/kg)	Sewage Sludge->Soil->Plant Reference Cumulative Application Rate of Pollutant for Application of Sewage Sludge to Agricultural Land (mg/kg)	Sewage Sludge->Soil->Soil Organism Reference Cumulative Application Rate of Pollutant for Application of Sewage Sludge to Agricultural Land (mg/kg)	Sewage Sludge->Soil->Soil Organism Predator Reference Cumulative Application Rate of Pollutant for Application of Sewage Sludge to Agricultural Land (mg/kg)
Lead	0.267 - 842	NA	NA	2,083
Mercury	0.00002-0.0769	NA	NA	NA
Nickel	0.0414 - 3.76	175	NA	NA
Silver	0.00009 - 0.0647	NA	NA	NA
Thallium	0.00552 - 24.13	NA	NA	NA
Antimony	0.00005 - 0.267	NA	NA	NA
Arsenic	0.00155 - 1.65	NA	NA	NA
Barium	0.0202 - 159	NA	NA	NA
Beryllium	0.00143 - 0.269	NA	NA	NA
Cadmium	0.00190 - 4.708	NA	NA	22
Chromium	0.0174 - 1.42	1,250	NA	NA
Selenium	0.0001 - 0.3940	NA	NA	NA

NA = Not available.

[a] Source: Technical Background Document for the Application of Sewage Sludge to Agricultural Fields.

The metals included in the probabilistic analysis were limited to antimony, arsenic, beryllium, cadmium, thallium and lead. (Note: These tables do not include mercury, which is considered independently using the methodology presented in the *Mercury Studies: Report to Congress* (U.S. EPA, 1996). The results for mercury are presented in Table 4-16.)

8.0 Risk-Based Concentration Limits

Risk-limiting concentrations for constituents of CKD have been established to be protective of human health. These levels are intended to ensure that risks do not exceed 1E-05 or HQs of 1 for any constituents in CKD used as agricultural lime substitute. These concentrations are estimated by assuming that all agricultural practice parameters (application rate, application frequency, and tilling depth) are high-end values and estimating the constituent concentration required to reach the target risk or HQ. These risk-based concentrations are estimated using the deterministic analysis and are confirmed by the probabilistic analysis.

8.1 Risk-Based Concentrations for Metals

The constituent concentrations estimated for metals in CKD using high-end agricultural practice parameters are presented in Table 8-1. These values were estimated to yield a maximum cancer risk of 1E-5 or a hazard quotient of 1 in either the farmer scenario or the child of farmer scenario. The risk or HQ was estimated by setting all agricultural practice parameters at high-end values and varying all exposure parameters to high-end values two at a time. The most conservative scenario (farmer or child of farmer) was used to set the risk-limiting concentration.

The estimated limiting concentrations in CKD were confirmed by including these concentrations as constants in the deterministic risk analysis with the agricultural practice parameters fixed at high-end values. These assumptions fix the soil concentrations at a single value. The soil and other media concentrations are presented in Table 8-2. Only exposure parameters remain to be varied either singly or doubly in the deterministic analysis. The results of this analysis are presented for the farmer and child of farmer scenarios in Tables 8-3 and 8-4. The resulting risk and HQ values are compared to the target risk limits (cancer risk = 1E-5; noncancer HQ =1). The lead value is derived in essentially the same manner except that it is based on a threshold blood lead level of 10 μg/dL and IEUBK default soil ingestion rates are used as described in Section 6.0. Results of the lead analysis are presented in Table 8-5.

The risk-limiting concentrations are also compared to the sampling data for each constituent to see how many times the sampled concentrations exceeded the risk-limiting concentrations. These data are presented in Figures 8-1 through 8-12.

Table 8-1. Risk-Limiting Concentrations for Metals in CKD

Constituent	Risk-Limiting Concentration (mg/kg)	Background Soil [b] Concentration (mg/kg)	Highest Measured Concentration (mg/kg)	Facilities Exceeding Limiting Concentration/ Total Facilities Measured
Lead	1500 [a]	13[c]	2620	14/63
Mercury	3	0.089	2.9	0
Nickel	9000	0.058[c]	55	0
Silver	900	0[c]	40.70	0
Thallium	15	0.26[c]	450	17/51
Antimony	895	20[d]	102	0
Arsenic	4	5.2[c]	80.7	51/60
Barium	2500	452[c]	900	0
Beryllium	870	0.65[c]	6.2	0
Cadmium	22	--[c]	44.9	7/61
Chromium VI	2889	37[c]	105.25	0
Selenium	6430	0.51[c]	102	0

[a] Based on direct ingestion of product by children.

[b] Represents the geometric mean of the data for the entire United States.

[c] Dragun, J., and A. Chiasson. 1991. *Elements in North American Soils.* HMCRI. Greenbelt, MD.

[d] Agency for Toxic Substances and Disease Registry. 1988. *Toxicological Profile for Lead*. Atlanta, GA.

Table 8-2. Metal Media Concentrations at the Risk-Limiting Concentration Levels

Constituent	Soil Concentration (mg/kg)	Fruit Concentration (mg/kg-DW)	Aboveground Vegetable Concentration (mg/kg-DW)	Belowground Vegetable Concentration (mg/kg)	Beef Concentration (mg/kg)	Milk Concentration (mg/kg)	Fish Concentration (mg/kg)
Lead	400	0.029	0.016	3.7	0.062	0.042	0.0134
Nickel	185	5.92	5.92	1.47	1.95	0.445	0.000345
Silver	3.60	1.44	1.44	0.360	0.05.63	0.614	NA
Thallium (I)	0.7	0.00284	0.00282	0.000280	0.0155	0.000684	0.000473
Antimony	2.23	0.447	0.447	0.0670	0.00638	0.000997	NA
Arsenic	0.0885	0.00318	0.00318	0.000706	0.000212	0.000825	6.07E-06
Barium	477	71.5	71.5	7.15	0.162	0.576	NA
Beryllium	200	2.01	2.01	0.300	0.1.24	0.000110	0.00754
Cadmium	4.52	1.64	1.64	0.288	0.00163	0.000177	0.00197
Chromium VI	58.3	0.441	0.439	0.262	0.190	0.0489	0.00131
Selenium	51.2	0.820	0.818	1.12	0.0902	0.129	0.258

NA = Not applicable.

Table 8-3. Cancer Risk to Farmer from Arsenic in CKD Applied as an Agricultural Supplement at Risk-Limiting Concentration

Parameters	Arsenic
Central Tendency	5.53E-07
Long Exposure	3.2E-06
Beef intake	6.8E-07
Dairy Intake	1.73E-06
Exposed Veg. Intake	6.5E-07
Root Veg. Intake	5.63E-07
Fruit Intake	7.66E-07
Soil Intake	5.69E-07
Beef Intake/ Long Exposure	3.93E-06
Dairy Intake/Long Exposure	1E-05
Exposed Veg. Intake/ Long Exposure	3.76E-06
Root Veg. Intake/Long Exposure	3.26E-06
Fruit Intake/ Long Exposure	4.43E-06
Soil Ingestion/Long Exposure	3.29E-06
Beef Intake/ Dairy Intake	1.86E-06
Beef Intake/ Exposed Veg. Intake	7.77E-07
Beef Intake/Root Vegetable Intake	6.9E-07
Beef Intake/Fruit Intake	8.93E-07
Beef Intake/Soil Intake	6.95E-07
Dairy Intake/Exposed Vegetable Intake	1.83E-06

Parameters	**Arsenic**
Dairy Intake/Root Vegetable Intake	1.74E-06
Dairy Intake/Fruit Intake	1.94E-06
Dairy Intake/ Soil Intake	1.75E-06
Exposed Veg. Intake/ Root Veg. Intake	6.6E-07
Exposed Veg. Intake/ Fruit Intake	8.63E-07
Exposed Veg. Intake/Soil Intake	6.65E-07
Root Veg. Intake/Fruit Intake	7.76E-07
Root Veg. Intake/Soil Intake	5.79E-07
Fruit Intake/Soil Intake	7.82E-07
Maximum Risk	**1.E-05**

Table 8-4. Hazard Quotient or Risk to Child of Farmer from Thallium and Cadmium in CKD Applied as an Agricultural Supplement at Risk-Limiting Concentrations

Parameters	Thallium (I)	Cadmium
Central Tendency	0.43	0.21
Long Exposure	0.43	0.21
Beef intake	0.63	0.22
Dairy Intake	0.46	0.22
Exposed Veg. Intake	0.44	0.38
Root Veg. Intake	0.43	0.23
Fruit Intake	0.44	0.73
Adult Soil intake	0.43	0.21
Child Soil intake	0.83	0.51
Beef Intake/ Long Exposure	0.63	0.21
Dairy Intake/Long Exposure	0.46	0.21
Exposed Veg. Intake/ Long Exposure	0.44	0.38
Root Veg. Intake/Long Exposure	0.43	0.23
Fruit Intake/ Long Exposure	0.44	0.73
Adult Soil intake/Long Exposure	0.43	0.21
Child Soil intake/Long Exposure	0.83	0.41
Beef Intake/ Dairy Intake	0.66	0.22
Beef Intake/ Exposed Veg. Intake	0.64	0.39
Beef Intake/Root Vegetable Intake	0.63	0.23
Beef Intake/Fruit Intake	0.64	0.74
Beef Intake/Adult Soil Ingestion	0.63	0.22
Beef Intake/Child Soil Ingestion	1	0.52
Dairy Intake/Exposed Vegetable Intake	0.47	0.39
Dairy Intake/Root Vegetable Intake	0.46	0.23
Dairy Intake/Fruit Intake	0.47	0.74

(continued)

Table 8-4. (continued)

Parameters	Thallium (I)	Cadmium
Dairy Intake/Adult Soil Ingestion	0.46	0.22
Dairy Intake/Child Soil Ingestion	0.86	0.52
Exposed Veg. Intake/ Root Veg. Intake	0.44	0.4
Exposed Veg. Intake/ Fruit Intake	0.44	0.9
Exposed Veg. Intake/Adult Soil Ingestion	0.44	0.38
Exposed Veg. Intake/Child Soil Ingestion	0.84	0.68
Root Veg. Intake/Fruit Intake	0.44	0.75
Root Veg. Intake/Adult Soil Ingestion	0.43	0.23
Root Veg. Intake/Child Soil Ingestion	0.83	0.53
Fruit Intake/Adult Soil Ingestion	0.44	0.73
Fruit Intake/Child Soil Ingestion	0.84	1
Adult Soil Ingestion /Child Soil Ingestion	0.83	0.51
Maximum Risk	**1.0**	**1.0**

Table 8-5. Blood Lead Levels (µg/dL) Estimated Using IEUBK Default Soil Intake Rates at Limiting Soil Lead Concentration (400 mg/kg)

Age Range (years)	**Blood Pb (µg/dL)**
0.5-1	6.3
1-2	7.1
2-3	6.6
3-4	6.3
4-5	5.3
5-6	4.5
6-7	4.0
Probability of Blood Lead Level over 10 µg/dL	10.61 %
Mean Blood Lead Level	5.7

Figure 8-1 Risk Limiting Concentration Compared to Measured Concentrations for Lead (mg/kg)

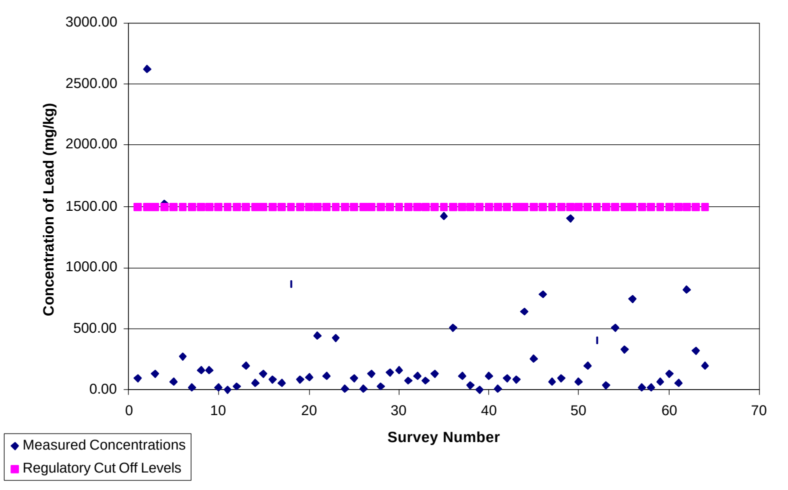


Figure 8 - 2 Risk Limiting Concentration Compared to Measured Concentrations for Mercury (mg/kg)

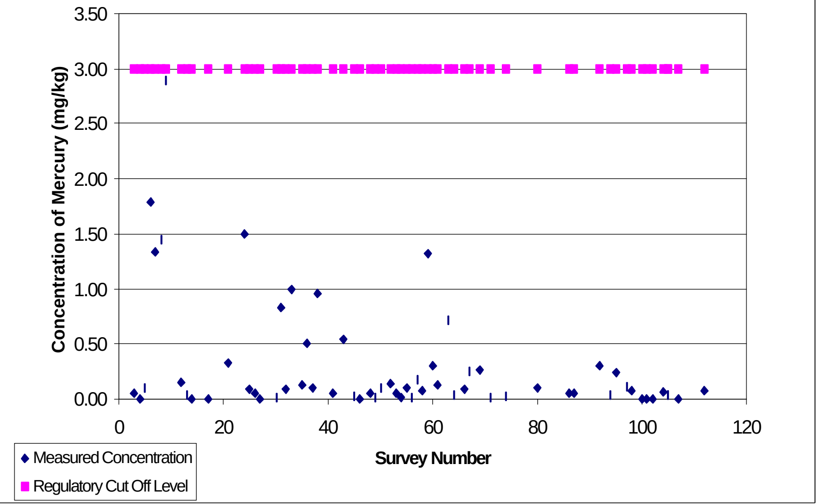


Figure 8- 3 Risk Limiting Concentration Compared to Measured Concentrations for Nickel (mg/kg)

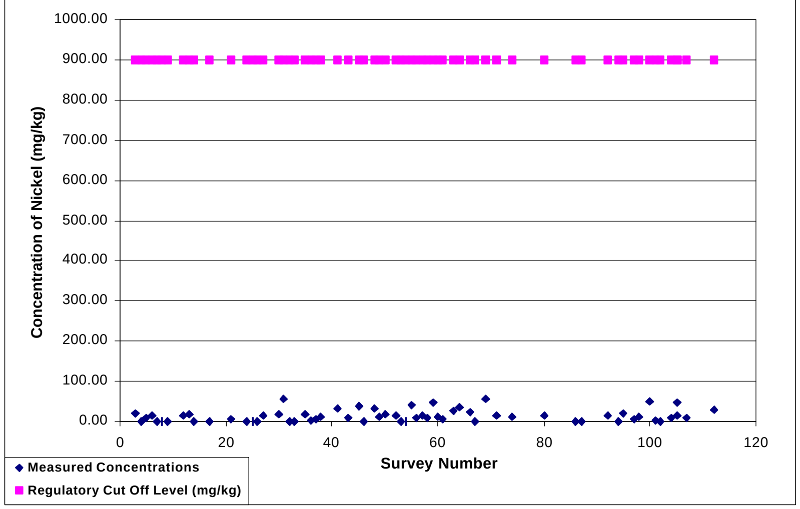
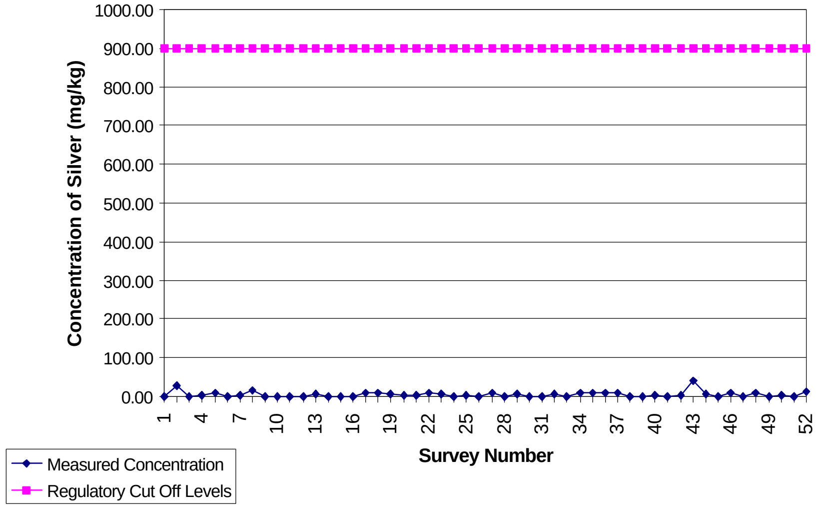


Figure 8 - 4 Risk Limiting Concentration Compared to Measured Concentrations for Silver (mg/kg)



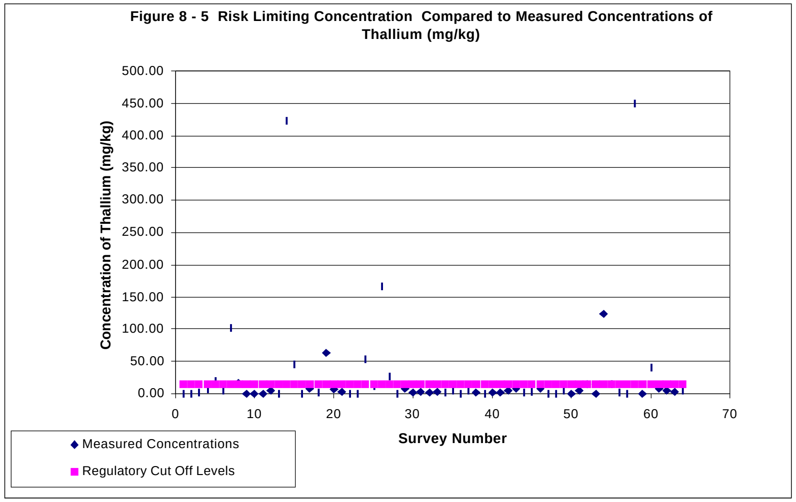


Figure 8 - 5 Risk Limiting Concentration Compared to Measured Concentrations of Thallium (mg/kg)

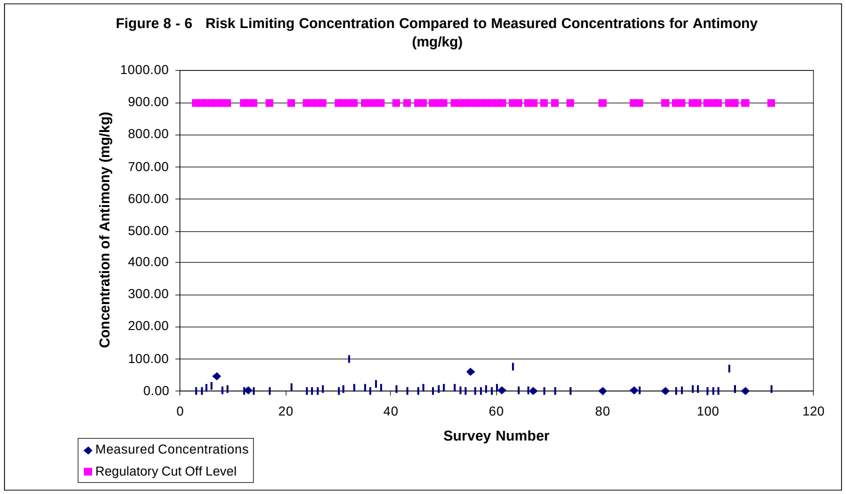


Figure 8 - 6 Risk Limiting Concentration Compared to Measured Concentrations for Antimony (mg/kg)

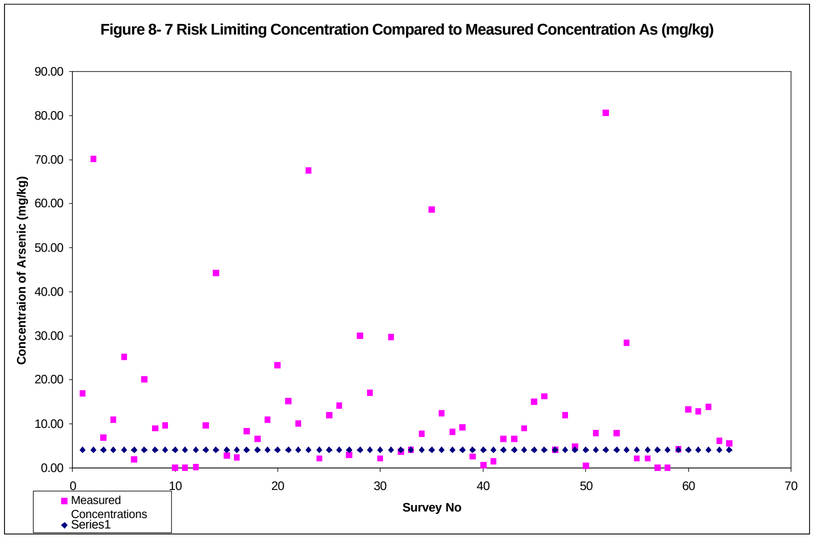


Figure 8- 7 Risk Limiting Concentration Compared to Measured Concentration As (mg/kg)

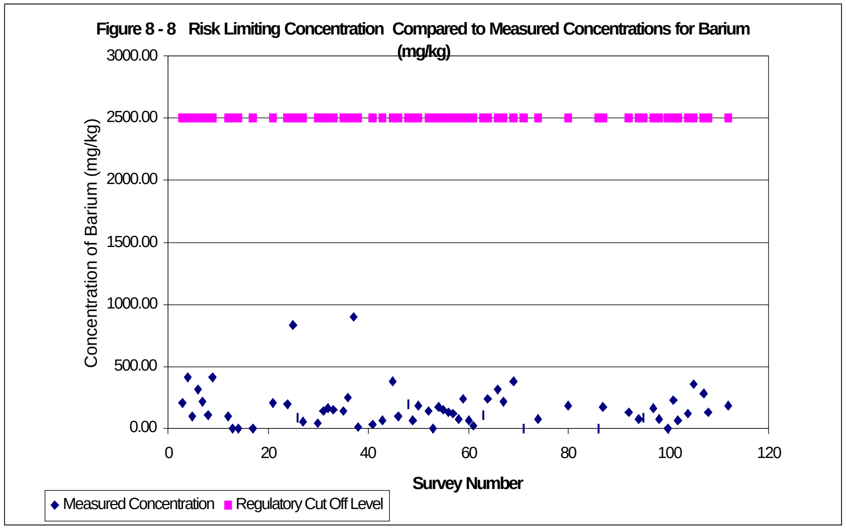


Figure 8 - 8 Risk Limiting Concentration Compared to Measured Concentrations for Barium (mg/kg)

Figure 8 - 9 Regulatory Cut Off Levels Compared to Measured Concentrations for Beryllium (mg/kg)

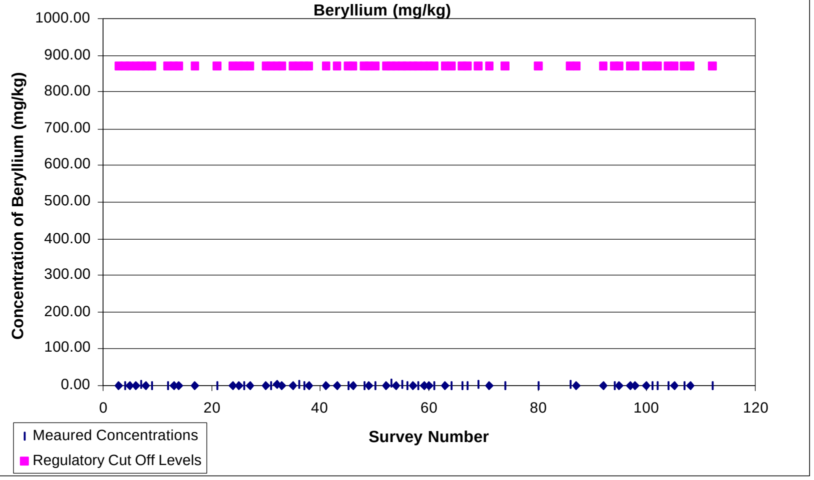


Figure 8- 10 Risk Limiting Concentration Compared to Measured Concentrations for Cd (mg/kg)

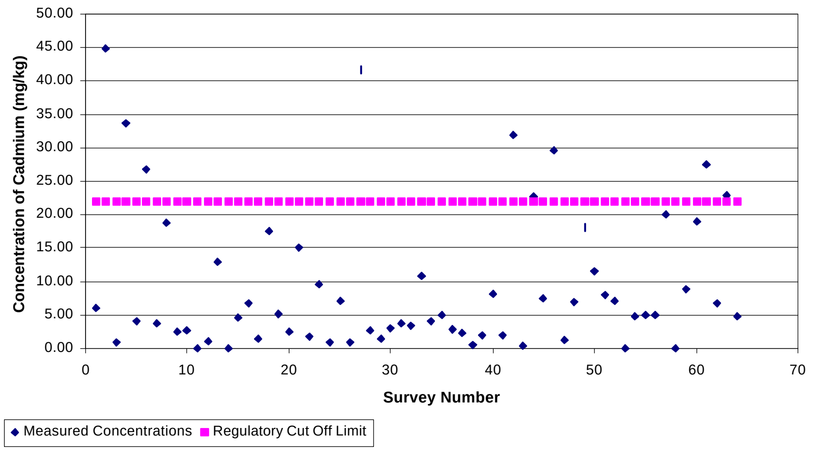


Figure 8 - 11 Risk Limiting Concentration Levels Compared to Measured Concentrations of Chromium (mg/kg)

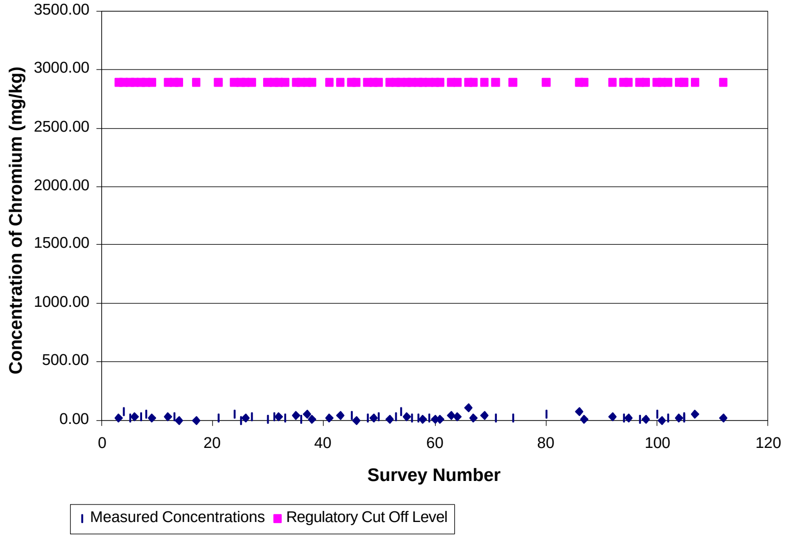
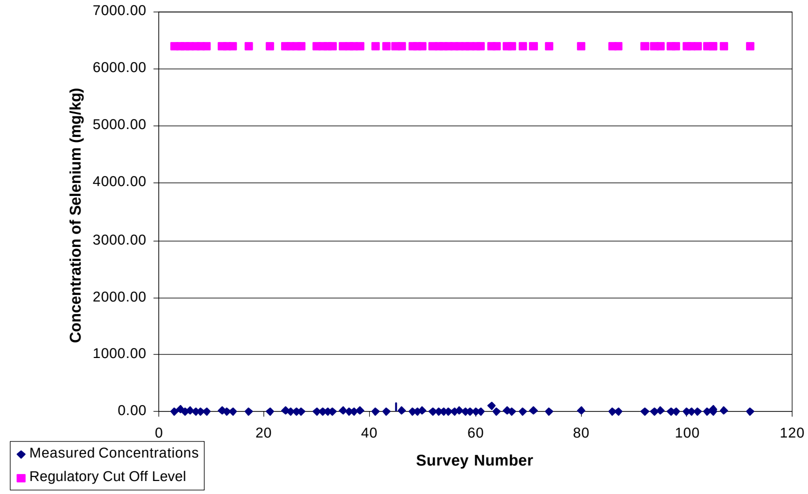


Figure 8 - 12 Risk Limiting Concentration Compared to Measured Concentrations for Selenium (mg/kg)



8.2 Risk-Based Concentration Limits for Dioxin and Furan Congeners

The process for setting risk-based concentration limits is relatively straightforward for the metal constituents. However, unlike metals, dioxins are comprised of multiple individual dioxin and furan congeners. It is not possible to set a limiting value for each dioxin or furan congener individually because insufficient congener-specific toxicity testing data are available. The available data indicate that, although the biochemical mechanism that leads to the toxic response resulting from exposure to dioxins is not known in detail, a strong structure-activity relationship (SAR) and a mechanistic basis for toxic effects have been identified. The SAR is assumed to be sufficiently strong that estimates of the long-term toxicity of minimally tested congeners of chlorinated dibenzodioxins (CDDs) and chlorinated dibenzofurans (CDFs) can be inferred on the basis of available information. This process has led to the development of toxicity equivalency factors (TEFs) for converting levels to CDDs /CDFs into “equivalent” amounts of 2,3,7,8-TCDD. The process takes into account the distribution of CDD/CDF congeners or homologues and their likely relative toxicity. The TEF values are still considered to be interim in nature and are subject to periodic updating. The Technical Panel of the Risk Assessment Forum recommends the use of this method to assess human health risks posed by mixtures of CDDs andCDFs until the data gaps are filled (U.S. EPA, 1989).

For this analysis, concentrations for each congener in CKD are measured individually and specific fate and transport parameters are provided. Each congener is modeled independently. The TEF methodology is then used to sum the risk from each congener to produce a single risk value as a 2,3,7,8-TCDD equivalent. In order to establish a regulatory limit using the TEF methodology, a profile of congeners in CKD must be assumed. The relative concentrations of congeners in the 14 samples of CKD analyzed for this study were compared to each other and to soil background concentrations in North America. No obvious pattern of congener distribution was observed among the samples. These profiles are presented in Figure 8-13. The profile of congener distribution for soil background in North America was, therefore, assumed as the default profile for CKD in order to establish cutoff levels for CKD. The background soil concentration data are presented in Table 8-6.

Based on EPA’s risk modeling, the estimated total indirect cancer risks for the farmer scenario from the average North American soil background concentrations of dioxins and furans in the environment is approximately 1E-05. The average TEQ background concentration of dioxin and furan congeners in soil is 8 ppt. Therefore, limiting concentrations in CKD have been established to ensure that, when CKD is applied at the high application rates and frequency, the resulting soil concentrations, as measured in TEQ, are equal to background soil levels. If the distribution of congeners in CKD is assumed to be the same as the distribution in soil, the TEQ concentration of dioxins and furans in CKD applied as an agricultural soil amendment can be backcalculated to be 40 ppt when high-end agricultural practice parameters (application rate and frequency) are assumed. This methodology was used to estimate the soil TEQ concentrations for the 15 sets of sampling data. The estimated soil TEQ concentrations exceed background in only the three samples identified above the proposed limit. These confirming data are presented in Tables 8-7 and 8-8. Figure 8-14 shows the facility TEQ compared to the regulatory cutoff level.

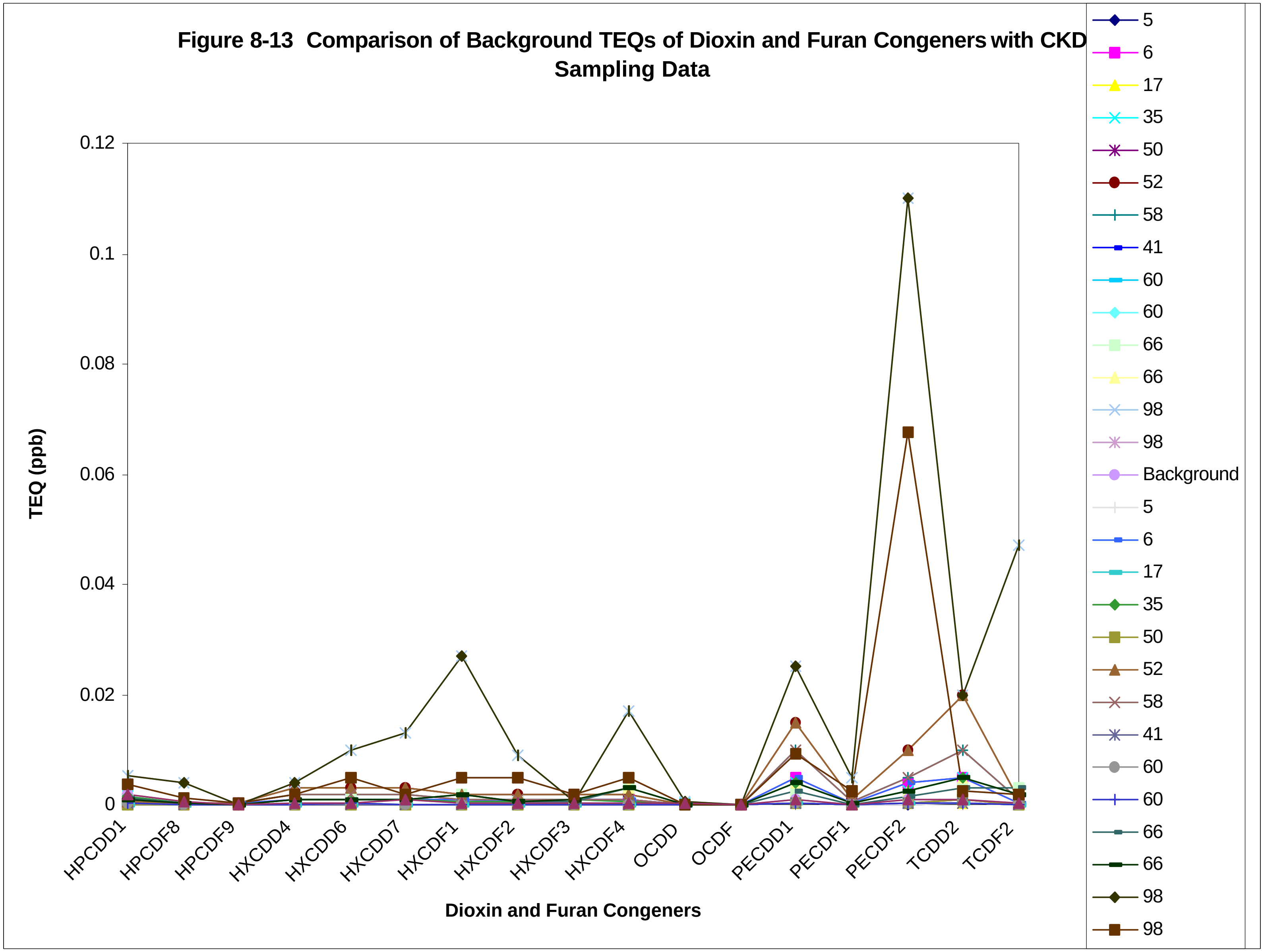


Figure 8-13 Comparison of Background TEQs of Dioxin and Furan Congeners with CKD Sampling Data

Table 8-6. Soil Background Levels Compared to Concentrations of Dioxin Congeners in CKD

Congener	**Background Soil Concentration[a] (ppt)**
1,2, 3, 4, 6, 7,8- Heptachlorodibenzodioxin	0.194
1, 2, 3, 4, 6, 7, 8-Heptachlorodibenzofuran	0.047
1, 2, 3, 4, 7, 8, 9-Heptachlorodibenzofuran	0.00188
1, 2, 3, 4, 7, 8-Hexachlorodibenzodioxin	0.00188
1, 2, 3, 6, 7, 8-Hexachlorodibenzodioxin	0.004
1, 2, 3, 7, 8, 9-Hexachlorodibenzodioxin	0.009
1, 2, 3, 7, 8, 9-Hexachlorodibenzofuran	0.00188
2, 3, 4, 6, 7, 8-Hexachlorodibenzofuran	0.00188
1, 2, 3, 6, 7, 8-Hexachlorodibenzofuran	0.00188
1,2, 3, 4, 7, 8-Hexachlorodibenzofuran	0.002
Octachlorodibenzodioxin	0.237
Octachlorodibenzofuran	0.0302
1, 2, 3, 7, 8-Pentachlorodibenzodioxin	0.00188
1, 2, 3, 7, 8-Pentachlorodibenzofuran	0.00331
2, 3, 4, 7, 8-Pentachlorodibenzofuran	0.00188
2, 3, 7, 8-Tetrachlorodibenzodioxin	0.00088
2, 3, 7, 8-Tetrachlorodibenzofuran	0.00159
Total TEF (ppt)	**8**

[a] U.S. Environmental Protection Agency. 1994c. *Estimating Exposure to Dioxin-Like Compounds*. EPA/600/6-88/005B. Office of Research and Development, Washington, DC. June.

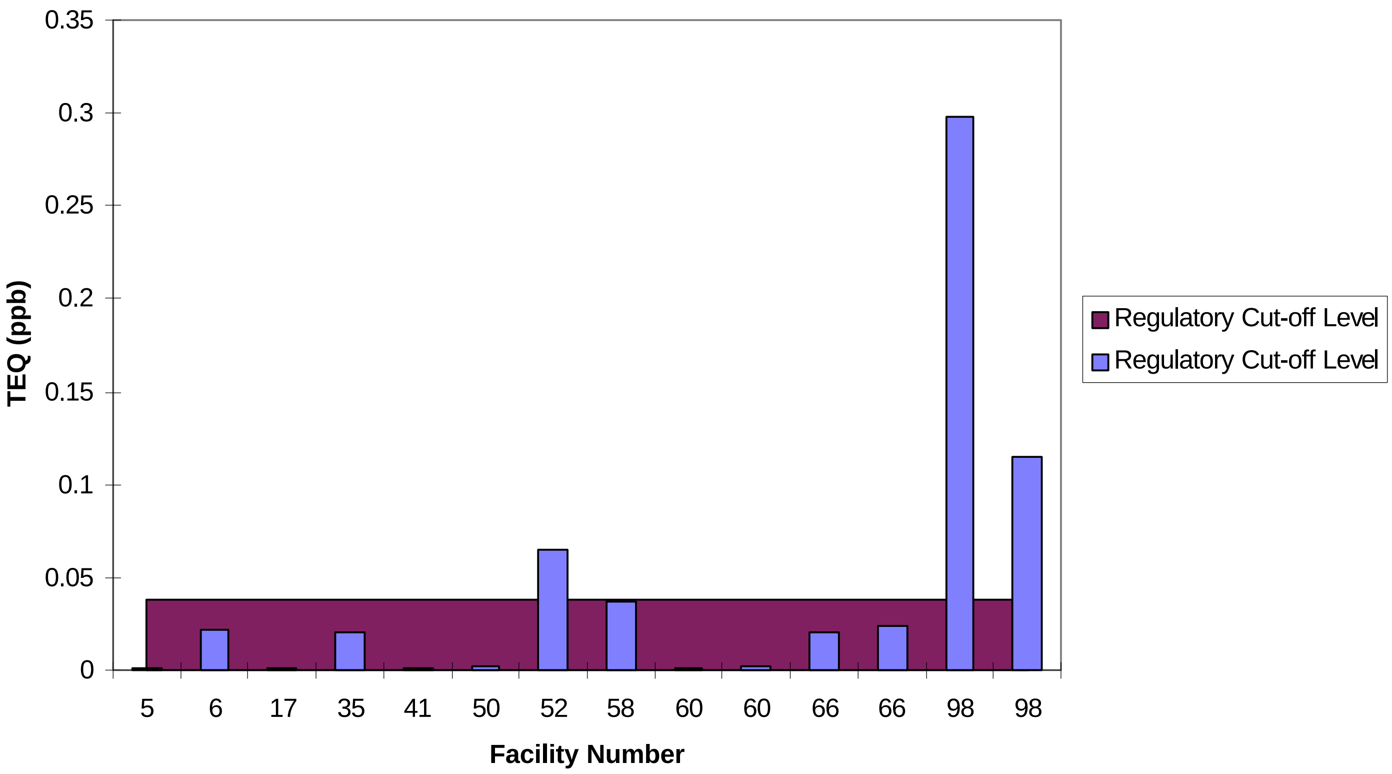
Table 8-7. Dioxin TEQ for CKD Product by Sample Number

Congener	Sample Number													
	5	6	17	35	50	52	58	41	60	60	66	66	98	98
TCDD, 2,3,7,8-	0.000335	0.005	0.000335	0.005	0.000912	0.02	0.01	0.000335	0.000335	0.000335	0.003	0.005	0.02	0.002479
OCDD, 1,2,3,4,5,7,8,9-	2.48E-06	0.00004	2.48E-06	0.00037	6.74E-06	0.00005	0.00002	4.98E-05	6.74E-06	6.74E-06	0.00015	0.00012	0.00063	0.000135
HxCDD, 1,2,3,7,8,9-	3.35E-05	0.001	3.35E-05	0.0008	9.12E-05	0.003	0.002	3.35E-05	9.12E-05	9.12E-05	0.0008	0.0008	0.013	0.001832
OCDF, 1,2,3,4,6,7,8,9-	9.12E-07	0.00003	9.12E-07	0.00001	2.48E-06	0.00003	0.00002	2.48E-06	9.12E-07	9.12E-07	0.00001	0.00001	0.00004	1.83E-05
HxCDD, 1,2,3,4,7,8-	3.35E-05	0.001	3.35E-05	0.0008	9.12E-05	0.003	0.002	3.35E-05	9.12E-05	9.12E-05	0.0008	0.0008	0.004	0.001832
PeCDD, 1,2,3,7,8-	0.000168	0.005	0.000168	0.004	0.000456	0.015	0.01	0.000168	0.000168	0.000456	0.0025	0.004	0.025	0.009158
TCDF, 2,3,7,8-	1.23E-05	0.0003	3.35E-05	0.002	9.12E-05	0.001	0.0008	9.12E-05	1.23E-05	9.12E-05	0.003	0.002	0.047	0.001832
HpCDF,1,2,3,4,7,8,9-	3.35E-06	0.0002	3.35E-06	0.0001	9.12E-06	0.0003	0.0002	3.35E-06	3.35E-06	3.35E-06	0.00008	0.0001	0.00008	0.000183
PeCDF, 2,3,4,7,8-	6.17E-05	0.004	0.000168	0.0025	0.000168	0.01	0.005	0.000168	0.000168	0.000168	0.0015	0.0025	0.11	0.067668
PeCDF, 1,2,3,7,8-	6.17E-06	0.0004	1.68E-05	0.00025	1.68E-05	0.001	0.0005	1.68E-05	1.68E-05	4.56E-05	0.00015	0.00025	0.005	0.002489
HxCDF, 1,2,3,6,7,8-	1.23E-05	0.0005	1.23E-05	0.0005	1.23E-05	0.002	0.0008	3.35E-05	3.35E-05	3.35E-05	0.0005	0.0005	0.009	0.004979
HxCDD, 1,2,3,6,7,8-	3.35E-05	0.001	3.35E-05	0.0008	9.12E-05	0.003	0.002	3.35E-05	0.000248	0.000248	0.0008	0.0008	0.01	0.004979
HxCDF, 2,3,4,6,7,8-	3.35E-05	0.0008	3.35E-05	0.0005	9.12E-05	0.002	0.001	9.12E-05	3.35E-05	3.35E-05	0.003	0.003	0.017	0.004979
HpCDF,1,2,3,4,6,7,8-	3.35E-06	0.0001	1.23E-06	0.0003	3.35E-06	0.0002	0.0001	9.12E-06	3.35E-06	9.12E-06	0.0004	0.0004	0.004	0.001353
HxCDF, 1,2,3,4,7,8-	1.23E-05	0.0008	1.23E-05	0.0005	3.35E-05	0.002	0.001	3.35E-05	3.35E-05	9.12E-05	0.002	0.002	0.027	0.004979
HxCDF, 1,2,3,7,8,9-	3.35E-05	0.001	3.35E-05	0.0008	3.35E-05	0.002	0.001	1.23E-05	1.23E-05	3.35E-05	0.0005	0.0008	0.0005	0.001832
HpCDD, 1,2,3,4,6,7,8,-	9.12E-06	0.0002	9.12E-06	0.0016	2.48E-05	0.0005	0.0002	0.000183	0.000183	0.000183	0.0012	0.0008	0.0054	0.003679
Total TEQ (ppt)	**0.795042**	**21.37**	**0.930756**	**20.83**	**2.13418**	**65.08**	**36.64**	**1.298043**	**1.440786**	**1.921275**	**20.39**	**23.88**	**297.65**	**114.4036**

Table 8-8. Dioxin TEQ for Soil from Application of CKD as an Agricultural Soil Amendment by Facility Number High Application Rate/ High Application Frequency

Constituent	CAS No.	Facility Number													
		5	6	17	35	50	52	58	41	60	60	66	66	98	98
TCDD, 2,3,7,8-	1746-01-6	5.3E-08	8.0E-07	5.3E-08	8.0E-07	1.5E-07	3.2E-06	1.6E-06	5.3E-08	5.3E-08	5.3E-08	4.8E-07	8.0E-07	3.2E-06	4.0E-07
OCDD	3268-87-9	6.2E-10	1.0E-08	6.2E-10	9.3E-08	1.7E-09	1.3E-08	5.0E-09	1.3E-08	1.7E-09	1.7E-09	3.8E-08	3.0E-08	1.6E-07	3.4E-08
HxCDD, 1,2,3,7,8,9-	19408-74-3	7.2E-09	2.2E-07	7.2E-09	1.7E-07	2.0E-08	6.5E-07	4.3E-07	7.2E-09	2.0E-08	2.0E-08	1.7E-07	1.7E-07	2.8E-06	3.9E-07
OCDF,	39001-02-0	2.4E-10	8.0E-09	2.4E-10	2.7E-09	6.6E-10	8.0E-09	5.3E-09	6.6E-10	2.4E-10	2.4E-10	2.7E-09	2.7E-09	1.1E-08	4.9E-09
HxCDD, 1,2,3,4,7,8-	39227-28-6	8.0E-09	2.4E-07	8.0E-09	1.9E-07	2.2E-08	7.1E-07	4.8E-07	8.0E-09	2.2E-08	2.2E-08	1.9E-07	1.9E-07	9.5E-07	4.4E-07
PeCDD, 1,2,3,7,8-	40321-76-4	3.4E-08	1.0E-06	3.4E-08	8.0E-07	9.2E-08	3.0E-06	2.0E-06	3.4E-08	3.4E-08	9.2E-08	5.0E-07	8.0E-07	5.0E-06	1.8E-06
TCDF, 2,3,7,8-	51207-31-9	2.1E-09	5.0E-08	5.6E-09	3.4E-07	1.5E-08	1.7E-07	1.3E-07	1.5E-08	2.1E-09	1.5E-08	5.0E-07	3.4E-07	7.9E-06	3.1E-07
HpCDF,1,2,3,4,7,8,9-	55673-89-7	7.3E-10	4.4E-08	7.3E-10	2.2E-08	2.0E-09	6.6E-08	4.4E-08	7.3E-10	7.3E-10	7.3E-10	1.7E-08	2.2E-08	1.7E-08	4.0E-08
PeCDF, 2,3,4,7,8-	57117-31-4	1.3E-08	8.2E-07	3.4E-08	5.1E-07	3.4E-08	2.0E-06	1.0E-06	3.4E-08	3.4E-08	3.4E-08	3.1E-07	5.1E-07	2.3E-05	1.4E-05
PeCDF, 1,2,3,7,8-	57117-41-6	1.2E-09	7.9E-08	3.3E-09	4.9E-08	3.3E-09	2.0E-07	9.8E-08	3.3E-09	3.3E-09	9.0E-09	2.9E-08	4.9E-08	9.8E-07	4.9E-07
HxCDF, 1,2,3,6,7,8-	57117-44-9	2.8E-09	1.8E-07	2.8E-09	1.1E-07	7.6E-09	4.5E-07	2.3E-07	7.6E-09	7.6E-09	2.1E-08	4.5E-07	4.5E-07	6.1E-06	1.1E-06
HxCDD, 1,2,3,6,7,8-	57653-85-7	7.2E-09	2.2E-07	7.2E-09	1.7E-07	2.0E-08	6.5E-07	4.3E-07	7.2E-09	5.3E-08	5.3E-08	1.7E-07	1.7E-07	2.2E-06	1.1E-06
HxCDF, 2,3,4,6,7,8-	60851-34-5	2.7E-09	1.1E-07	2.7E-09	1.1E-07	2.7E-09	4.4E-07	1.7E-07	7.3E-09	7.3E-09	7.3E-09	1.1E-07	1.1E-07	2.0E-06	1.1E-06
HpCDF,1,2,3,4,6,7,8-	67562-39-4	7.3E-10	2.2E-08	2.7E-10	6.6E-08	7.3E-10	4.4E-08	2.2E-08	2.0E-09	7.3E-10	2.0E-09	8.7E-08	8.7E-08	8.7E-07	3.0E-07
HxCDF, 1,2,3,4,7,8-	70648-26-9	7.1E-09	1.7E-07	7.1E-09	1.1E-07	1.9E-08	4.2E-07	2.1E-07	1.9E-08	7.1E-09	7.1E-09	6.4E-07	6.4E-07	3.6E-06	1.1E-06
HxCDF, 1,2,3,7,8,9-	72918-21-9	7.3E-09	2.2E-07	7.3E-09	1.7E-07	7.3E-09	4.4E-07	2.2E-07	2.7E-09	2.7E-09	7.3E-09	1.1E-07	1.7E-07	1.1E-07	4.0E-07
HpCDD,1,2,3,4,6,7,8,-	99999-99-9	2.3E-09	5.1E-08	2.3E-09	4.1E-07	6.3E-09	1.3E-07	5.1E-08	4.6E-08	4.6E-08	4.6E-08	3.0E-07	2.0E-07	1.4E-06	9.3E-07
Total TEQ (ppt)		0.15	4	0.18	4	0.40	**13**	7	0.26	0.30	0.39	4	5	**60**	**24**

Figure 8-14 Facility TEQ Compared to Regulatory Cut Off Level



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Appendix A

Equations Used in Risk Assessment Modeling

Table A-1.1. Constituent Concentration Due to Erosion in Buffer Field

All Exposure Scenario

$$C_{BF} = \frac{SL_{BF} \ x \ C_F \ x \ ER}{ks_{BF} \ x \ M_{BF}}$$

Parameter	Definition	Central Tendency	High End
C_{BF}	Constituent concentation in the buffer field (mg/kg)		
$SL_{F,BF}$	Soil load delivered to buffer field for material orginating from source field (kg/yr)	Calculated (see Equation A-1.2.)	
C_F	Source field constituent concentration (mg/kg)	Chemical-specific	
ks_{BF}	Constituent loss constant for buffer field (1/yr)	Calculated (see Equation A-1.6.)	
M_{BF}	Mass of soil in mixing depth of buffer field (kg)	Calculated (see Equation A-1.14.)	

Description

This equation is used to calculate the constituent concentration in the buffer field as a result of erosion from the source field. Buffer field is located in the area existing between the source field and the surface water body.

Table A-1.2. Soil Load Delivered to Buffer Field for Material Originating from Source Field

All Exposure Scenarios

$$SL_{F,BF} = X_{e,F} \ x \ A_B \ x \ (1 - SD_{SB}) \ x \left(\frac{A_{BF}}{A_F + A_{BF}} \right)$$

Parameter	Definition	Central Tendency	High End
$SL_{F,BF}$	Soil load delivered to buffer field for material originating from source field (kg/yr)		
$X_{e,F}$	Unit soil loss from source field (kg/m^2-yr)	Calculated (see Table A-1.3.)	
A_F	Area of source field (m^2)	Ag field = 2,000,000 Home garden = 5,100	
SD_{SB}	Sub-basins ediment delivery ratio (unitless)	Calculated (see Table A-1.5.)	
A_{BF}	Area of buffer field (m^2)	Calculated (see Table A-1.4.)	

Description

This equation is used to calculate the load of eroded soil originating from the source field of interest that is deposited onto the buffer field.

Table A-1.3. Universal Soil Loss Equation (USLE) for the Source Field

All Exposure Scenarios

$$X_{e,F} = R_F \times K_F \times LS_F \times C_F \times P_F \times \frac{907.18}{4047}$$

Parameter	**Definition**	**Central Tendency**	**High End**
$X_{e,F}$	Unit soil loss from the source field (kg/m^2/yr)		
R_F	USLE rainfall (or erosivity) factor (1/yr)	Alpena, MI = 50 Holly Hills, SC = 350 Ravena, NY = 125	
K_F	USLE erodibility factor (ton/acre)	Alpena, MI = 0.23 Holly Hills, SC = 0.52 Ravena, NY = 0.19	
LS_F	USLE length-slope factor (unitless)	1.5	
C_F	USLE cover management factor (unitless)	0.5	
P_F	USLE supporting practice factor (unitless)	1	
907.18	Conversion factor (kg/ton)		
4047	Conversion factor (m^2/acre)		

Description

This equation calculates the soil loss rate from the source field, using the Universal Soil Loss Equation; the result is used in the soil erosion load equation.

Table A-1.4. Buffer Field Area

All Exposure Scenarios			
$A_{BF} = d_b \ x \ \sqrt{A_F}$			
Parameter	**Definition**	**Central Tendency**	**High End**
A_{BF}	Area of buffer field (m^2)		
d_b	Distance between field source and waterbody side-length of buffer field (m)	300	75
A_F	Area of source field of interest (m^2)	Ag. Field = 2,000,000 Home garden = 5,100	

Table A-1.5. Sub-basin Sediment Delivery Ratio

All Exposure Scenarios

$$SD_{SB} = a \; x \; (A_F + A_{BF})^{-b}$$

Parameter	Definition	Central Tendency	High End
SD_{SB}	Sub-basin sediment delivery ratio for sub-basin (unitless)		
a	Empirical intercept coefficient	Depends on sub-basin area; see table below	
A_{BF}	Area of buffer field (m^2)	Calculated (see Table A-1.4.)	
A_F	Area of source field of interest (m^2)	Ag. field = 2,000,000 Home garden = 5,100	
b	Empirical slope coefficient	0.125	

Description

This equation calculates the sediment delivery ratio for the sub-basin; the result is used in the soil erosion load equation.

Values for Empirical Intercept Coefficient, a

Sub-basin (A_F+A_{BF})	"a" coefficient (unitless)
$\leq$ 0.1	2.1
1	1.9
10	1.4
100	1.2
1,000	0.6
1 sq. mile = 2.59x10^6 m^2	

Table A-1.6. Constituent Loss Constant

All Exposure Scenarios

$$ks_{BF} = ksl_{BF} + kse_{BF} + ksr_{BF} + ksg_{BF} + ksv_{BF}$$

Parameter	Definition	Central Tendency	High End
ks_{BF}	Constituent loss constant due to all processes for the buffer field (1/yr)		
ksl_{BF}	Constituent loss constant due to leaching (1/yr)	Calculated (see Table A-1.7.)	
kse_{BF}	Constituent loss constant due to soil erosion (1/yr)	Calculated (see Table A-1.10.)	
ksr_{BF}	Constituent loss constant due to surface runoff (1/yr)	Calculated (see Table A-1.12.)	
ksg_{BF}	Constituent loss constant due to degradation (1/yr)	Chem. Specific (App. B of Background Document)	
ksv_{BF}	Constituent loss constant due to volatilization (1/yr)	Calculated (see Table A-1.13.)	

Description

This equation calculates the constitutent loss constant, which accounts for the loss of constituent from soil by several mechanisms.

Table A-1.7. Constituent Loss Constant Due to Leaching

All Exposure Scenarios

$$ksl_{BF} = \frac{P + I - R - E_v}{\theta\ x\ Z_{BF}\ x\ [1.0 + (BD\ x\ Kd_s / \theta)]}$$

Parameter	Definition	Central Tendency	High End
ksl_{BF}	Constituent loss constant for buffer field due to leaching (1/yr)		
P	Average annual precipitation (cm/yr)	Alpena, MI = 73.2 Holly Hill, SC = 131.6 Ravena, NY = 90.9	
I	Average annual irrigation (cm/yr)	0	
R	Average annual runoff (cm/yr)	Alpena, MI = 19.1 Holly Hill, SC = 12.7 Ravena, NY = 25.4	
E_v	Average annual evapotranspiration (cm/yr)	Alpena, MI = 25.6 Holly Hill, SC = 46.1 Ravena, NY = 31.8	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table A-1.8.)	
Z_{BF}	Soil depth of buffer field from which leaching removal occurs - untilled (cm)	2.5	
BD	Soil bulk density (g/cm^3)	1.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix B of Background Document)	

Description

This equation calculates the constituent loss constant due to leaching from soil.

Table A-1.8. Soil Volumetric Water Content

All Exposure Scenarios			
$\theta = \theta_s \left[\frac{q}{K_s} \right]^{\left(\frac{1}{2b+3}\right)}$			
Parameter	**Definition**	**Central Tendency**	**High End**
θ	Soil volumetric water content (mL/cm^3)		
θ_s	Soil saturated volumetric water content (mL/cm^3)	0.43	
q	Average annual recharge rate (cm/yr)	Calculated (see Table A-1.9.)	
K_s	Saturated hydraulic conductivity (cm/yr)	808	
b	Soil-specific exponent representing water retention (unitless)	5.4	

Table A-1.9. Average Annual Recharge

<table>
<tr><th colspan="4">All Exposure Scenarios</th></tr>
<tr><td colspan="4">$$q = P + I - E_v - R_f$$</td></tr>
<tr><th>Parameter</th><th>Definition</th><th>Central Tendency</th><th>High End</th></tr>
<tr><td>q</td><td>Average annual recharge rate (cm/yr)</td><td colspan="2"></td></tr>
<tr><td>P</td><td>Average annual precipitation (cm/yr)</td><td colspan="2">Alpena, MI = 73.2
Holly Hill, SC = 131.6
Ravena, NY = 90.9</td></tr>
<tr><td>I</td><td>Average annual irrigation (cm/yr)</td><td colspan="2">0</td></tr>
<tr><td>E_v</td><td>Average annual evapotranspiration (cm/yr)</td><td colspan="2">Alpena, MI = 25.6
Holly Hill, SC = 46.1
Ravena, NY = 31.8</td></tr>
<tr><td>R_f</td><td>Average annual runoff (cm/yr)</td><td colspan="2">Alpena, MI = 19.1
Holly Hill, SC = 12.7
Ravena, NY = 25.4</td></tr>
</table>

Table A-1.10. Constituent Loss Constant Due to Erosion

All Exposure Scenarios

$$kse_{BF} = \frac{0.1 \ x \ ER \ x \ X_{e,BF} \ x \ SD_{SB}}{BD \ x \ Z_{BF}} \ x \ \left(\frac{Kd_s \ x \ BD}{\theta + (Kd_s \ x \ BD)} \right)$$

Parameter	Definition	Central Tendency	High End
kse_{BF}	Constituent loss constant for buffer field due to soil erosion (1/yr)		
$X_{e,BF}$	Unit soil loss for buffer field ($kg/m^2/yr$)	Calculated (see Table A-1.11.)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table A-1.8.)	
Z_{BF}	Soil mixing depth for buffer field - untilled (cm)	2.5	
BD	Soil bulk density (g/cm^3)	1.5	
Kd_s	Soil-water partition coefficient (mL/g)	Chemical-specific (see Appendix B of Background Document)	
SD_{SB}	Sediment delivery ratio for the sub-basin (unitless)	Calculated (see Table A-1.5).	
ER	Constituent enrichment ratio (unitless)	Organics = 3 Metals = 1	

Table A-1.11. Universal Soil Loss Equation (USLE) for Buffer Field

All Exposure Scenarios

$$X_{e,BF} = R_{BF} \ x \ K_{BF} \ x \ LS_{BF} \ x \ C_{BF} \ x \ P_{BF} \ x \ \frac{907.18}{4047}$$

Parameter	Definition	Central Tendency	High End
$X_{e,BF}$	Unit soil loss for buffer field (kg/m^2 -yr)		
R_{BF}	USLE rainfall factor (1/yr)	Alpena, MI = 50 Holly Hill, SC = 350 Ravena, NY = 125	
K_{BF}	USLE erodibility factor (ton/acre)	Alpena, MI = 0.23 Holly Hill, SC = 0.52 Ravena, NY = 0.19	
LS_{BF}	USLE length-slope factor (unitless)	1.5	
C_{BF}	USLE cover factor (unitless)	0.5	
P_{BF}	USLE erosion control practice factor (unitless)	1.0	
907.18	Units conversion factor (kg/ton)		
4047	Units conversion factor (m^2/acre)		

Description

This equation is used to calculate the soil loss rate from the buffer field using the Universal Soil Loss Equation; the result is used in the soil erosion load equation.

Table A-1.12. Constituent Loss Constant Due to Runoff

All Exposure Scenarios

$$ksr_{BF} = \frac{R}{\theta \, x \, Z_{BF}} \, x \left(\frac{1}{1 + (Kd_s \, x \, BD / \theta)} \right)$$

Parameter	Definition	Central Tendency	High End
ksr_{BF}	Constituent loss constant for buffer field due to runoff (1/yr)		
R	Average annual runoff (cm/yr)	Alpena, MI = 19.1 Holly Hill, SC = 12.7 Ravena, NY = 25.4	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table A-1.8.)	
Z_{BF}	Soil mixing depth of buffer field - untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix B of Background Document)	
BD	Soil bulk density (g/cm^3)	1.5	

Description

This equation calculates the constituent loss constant due to runoff from soil.

Table A-1.13. Constituent Loss Constant Due to Volatilization

All Exposure Scenarios

$$ksv_{BF} = \left[\frac{3.1536x10^{7}\ x\ H}{Z_{BF}\ x\ Kd_{s}\ x\ R\ x\ T\ x\ BD}\right] x \left[0.482\ x\ u^{0.78}\ x \left(\frac{\mu_{a}}{\rho_{a}\ x\ D_{a}}\right)^{-0.67} x \left(\sqrt{\frac{4\ x\ A_{BF}}{\pi}}\right)^{-0.11}\right]$$

Parameter	Definition	Central Tendency	High End
ksv_{BF}	Constituent loss constant for buffer field due to volatilization (1/yr)		
$3.1536x10^{7}$	Conversion constant (s/yr)		
H	Henry's law constant (atm-m^3/mol)	Chemical-specific (see Appendix B of Background Document)	
Z_{BF}	Soil mixing depth of buffer field - untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix B of Background Document)	
R	Universal gas constant (atm-m^3/mol-K)	$8.205x10^{-5}$	
T	Ambient air temperature (K)	Alpena, MI = 279.1 Holly Hill, SC = 291.3 Ravena, NY = 282	
BD	Soil bulk density (g/cm^3)	1.5	
u	Average annual windspeed (m/s)	Alpena, MI = 4.1 Holly Hill, SC = 4.1 Ravena, NY = 5.1	
μ_a	Viscosity of air (g/cm-s)	$1.81x10^{-4}$	
ρ_a	Density of air (g/cm^3)	$1.2x10^{-3}$	
D_a	Diffusivity of constituent in air (cm^2/s)	Chemical-specific (see Appendix B of Background Document)	
A_{BF}	Surface area of buffer field (m^2)	Calculated (see Table A-1.4.)	

Description

This equation calculates the constituent loss constant due to volatilization from soil.

Table A-1.14. Mass of Soil in Mixing Depth of Buffer Field

All Exposure Scenarios

$$M_{BF} = Z_{BF} \ x \ A_{BF} \ x \ BD \ x \ 10$$

Parameter	Definition	Central Tendency	High End
M_{BF}	Mass of soil in mixing depth of buffer field (kg)		
Z_{BF}	Soil mixing depth for buffer field - untilled (cm)	2.5	
A_{BF}	Area of buffer field (m^2)	Calculated (see Table A-1.4.)	
BD	Soil bulk density (g/cm^3)	1.5	
10	Units conversion factor (cm^2 - kg/m^2 -g)		

Description

This equation is used to calculate the total mass of soil in the buffer field that will be mixing with the mass of eroded material.

Table A-2.1. Total Load to Waterbody

Subsistence Fisher Scenario

$$L_T = L_R + L_E$$

Parameter	Definition	Central Tendency	High End
L_T	Total constituent load to the waterbody (g/yr)		
L_R	Runoff load from pervious surfaces (g/yr)	Calculated (see Table A-2.2.)	
L_E	Soil erosion load (g/yr)	Calculated (see Table A-2.3.)	

Description

This equation calculates the total average waterbody load from runoff and erosion loads.

Table A-2.2. Pervious Runoff Load to Waterbody

Subsistence Fisher Scenario

$$L_R = R \ x \ (A_{BF} \ x \ C_{BF} + A_F \ x \ C_F) \ x \ \frac{BD}{\theta + Kd_s \ x \ BD} \ x \ 0.01$$

Parameter	Definition	Central Tendency	High End
L_R	Pervious surface runoff load (g/yr)		
R	Average annual surface runoff (cm/yr)	Alpena, MI – 19.1 Holly Hill, SC = 12.7 Ravena, NY = 25.4	
BD	Soil bulk density (g/cm^3)	1.5	
A_{BF}	Area of buffer field (m^2)	Calculated (see Table A-1.4.)	
C_{BF}	Constituent concentration in buffer field (mg/kg)	Calculated (see Table A-1.1.)	
A_F	Area of source field (m^2)	Ag field = 2,000,000 Home garden = 5,000	
C_F	Constituent concentration in surce field (mg/kg)	Chemical specific	
Kd_s	Soil-water partition coefficient (L/kg) or (cm^3/g)	Chemical specific (see Appendix B of Background Document)	
0.01	Units conversion factor (kg-cm^2/mg-m^2)		
θ	Volumetric soil water content (cm^3/cm^3)	Calculated (see Table A-1.8.)	

Description

This equation calculates the average runoff load to the waterbody from pervious soil surfaces in the sub-basin.

Table A-2.3. Erosion Load to Waterbody

Subsistence Fisher Scenario

$$L_E = [(X_{e,F}\ x\ A_F\ x\ C_F) + (X_{e,BF}\ x\ A_{BF}\ x\ C_{BF})]\ x\ SD_{SB}\ x\ ER\ \frac{Kd_s\ x\ BD}{\theta + Kd_s\ x\ BD}\ x\ 0.001$$

Parameter	Definition	Central Tendency	High End
L_E	Constituent load via soil erosion load (g/yr)		
$X_{e,WF}$	Unit soil loss from the source field (kg/m^2/yr)	Calculated (see Table A-1.3.)	
A_F	Source field area (m^2)	Ag field = 2,000,000 Home garden = 5,100	
C_F	Source field constituent concentration (mg/kg)	Chemical specific (see Appendix B of Background Document)	
$X_{e,BF}$	Unit soil loss for buffer field (kg/m^2 -yr)	Calculated (see Table A-1.11.)	
A_{BF}	Buffer field area (m^2)	Calculated (see Table A-1.4.)	
C_{BF}	Constituent concentration in the buffer field (mg/kg)	Calculated (see Table A-1.1.)	
SD_{SB}	Sediment delivery ratio for sub-basin (unitless)	Calculated (see Table A-1.5.)	
ER	Soil enrichment ratio (unitless)	Organics = 3 Metals = 1	
Kd_s	Soil-water partition coefficient (L/kg) or (cm^3/g)	Chemical specific (see Appendix B of Background Document)	
BD	Soil bulk density (g/cm^3)	1.5	
θ	Volumetric soil water content (cm^3/cm^3)	Calculated (see Table A-1.8)	
0.001	Units conversion factor (g/mg)		

Description

This equation calculates the load to the waterbody resulting from soil erosion.

Table A-2.4. Total Waterbody Concentration

Subsistence Fisher Scenario

$$C_{wtot} = \frac{L_T}{Vf_x \ x \ f_{water} + k_{wt} \ x \ WA_w \ x \ (d_w + d_b)}$$

Parameter	Definition	Input Value
C_{wtot}	Total water body concentration, including water column and bed sediment (mg/L) or (g/(m^3)	
L_T	Total chemical load into waterbody, including runoff and erosion (g/yr)	Calculated (see Table A-2.1.)
Vf_x	Average volumetric flow rate through water body (m^3/yr)	$3x10^8$
f_{water}	Fraction of total water body constituent concentration that occurs in the water column (unitless)	Calculated (see Table A-2.5.)
k_{wt}	Overall total waterbody dissipation rate constant (1/yr)	Calculated (see Table A-2.6.)
WA_w	Waterbody surface area (m^2)	$1.0x10^6$
d_w	Depth of water column (m)	0.64
d_b	Depth of upper benthic layer (m)	0.03

Description

This equation calculates the total waterbody concentration, including both the water column and the bed sediment.

Table A-2.5. Fraction in Water Column and Benthic Sediment

Subsistence Fisher Scenario

$$f_{water} = \frac{(1 + Kd_{sw} \ x \ TSS \ x \ 10^{-6}) \ x \ d_w / \ d_z}{(1 + Kd_{sw} \ x \ TSS \ x \ 10^{-6}) \ x \ d_w / d_z + (\theta_{bs} + Kd_{bs} \ x \ BS) \ x \ d_b \ / d_z}$$

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

Parameter	Definition	Central Tendency	High End
f_{water}	Fraction of total waterbody constituent concentration that occurs in the water column (unitless)		
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	Chemical specific (see Appendix B of Background Document)	
TSS	Total suspended solids (mg/L)	80	
10^{-6}	Conversion factor (kg/mg)		
d_w	Depth of the water column (m)	0.64	
d_z	Total waterbody depth (m)	Calculated (d_w+d_b)	
d_b	Depth of the upper benthic layer (m)	0.03	
θ_{bs}	Bed sediment porosity (L_{water}/L)	0.6	
Kd_{bs}	Bed sediment/sediment pore water partition coefficient (L/kg) or (g/cm^3)	Chemical-specific (see Appendix B of Background Document)	
BS	Bed sediment concentration (g/cm^3)	1.0	
f_{benth}	Fraction of total waterbody constituent concentration that occurs in the benthic sediment (unitless)		

Description

These equations calculate the fraction of total waterbody concentration occurring in the water column and the bed sediments.

Table A-2.6. Overall Total Waterbody Dissipation Rate Constant

Subsistence Fisher Scenario

$$k_{wt} = f_{water} \; x \; k_v + k_b$$

Parameter	Definition	Central Tendency	High End
k_{wt}	Overall total waterbody dissipation rate constant (1/yr)		
f_{water}	Fraction of total waterbody constituent concentration that occurs in the water column	Calculated (see Table A-2.5.)	
k_v	Water column volatilization rate constant (1/yr)	Calculated (see Table A-2-7.)	
k_b	Benthic burial rate constant (1/yr)	Calculated (see Table A-2.10.)	

Description

This equation calculates the overall dissipation rate of constituent in surface water due to volatilization and benthic burial.

Table A-2.7. Water Column Volatilization Loss Rate Constant

Subsistence Fisher Scenario

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

Parameter	Definition	Central Tendency	High End
k_v	Water column volatilization rate constant (1/yr)		
K_v	Overall transfer rate (m/yr)	Calculated (see Table A-2.8.)	
d_z	Total waterbody depth (m)	Calculated (d_w+d_b)	
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	Chemical specific (see Appendix B of Background Document)	
TSS	Total suspended solids (mg/L)	80	
10^{-6}	Conversion factor (kg/mg)		

Description

This equation calculates the water column constituent loss due to volatilization.

Table A-2.8. Overall Transfer Rate

Subsistence Fisher Scenario

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

Parameter	Definition	Central Tendency	High End
K_v	Overall transfer rate (m/yr)		
K_L	Liquid phase transfer coefficient (m/yr)	Calculated (see Table A-2.9.)	
K_G	Gas phase transfer coefficient (m/yr) – flowing stream or river	36,500	
H	Henry's Law constant (atm-m^3/mol)	Chemical specific (see Appendix B of Background Document)	
R	Universal gas constant (atm-m^3/mol-K)	8.205×10^{-5}	
T_k	Waterbody temperature (K)	298	
θ	Temperature correction factor (unitless)	1.026	

Description

This equation calculates the overall transfer rate of constituent from the liquid and gas phases in surface water.

Table A-2.9. Liquid Phase Transfer Coefficient

Subsistence Fisher Scenario			
- Flowing stream or river $$K_L = \sqrt{\frac{10^{-4}\ x\ D_w\ x\ u}{d_z}}\ x\ 3.15\ x\ 10^7$$			
Parameter	**Definition**	**Central Tendency**	**High End**
K_L	Liquid phase transfer coefficient (m/yr)		
D_w	Diffusivity of chemical in water (cm^2/s)	Chemical specific (see Appendix B of Background Document)	
u	Current velocity (m/s)	0.7	
d_z	Total waterbody depth (m)	Calculated (d_w+d_b)	
$3.15x10^7$	Conversion constant (s/yr)		
10^{-4}	Units conversion factor (m^2/cm^2)		
Description			
This equation calculates the transfer rate of constituent from the liquid phase for a flowing system.			

Table A-2.10. Benthic Burial Rate Constant

Subsistence Fisher Scenario

$$k_b = f_{benth} \ x \ \left(\frac{W_b}{d_b} \right)$$

Parameter	Definition	Central Tendency	High End
k_b	Benthic burial rate constant (1/yr)		
f_{benth}	Fraction of total waterbody constituent concentration that occurs in the benthic sediment	Calculated (see Table A-2.5.)	
W_b	Burial rate (m/yr)	Calculated (see Table A-2.11.)	
d_b	Depth of upper benthic sediment layer (m)	0.03	

Description

This equation calculates the water column constituent loss due to burial in benthic sediment.

Table A-2-11. Benthic Burial Rate Constant

Subsistence Fisher Scenario

$$W_b = W_{dep} \ x \ \left(\frac{TSS \ x \ 10^{-6}}{BS} \right)$$

Parameter	Definition	Central Tendency	High End
W_b	Benthic burial rate constant (m/yr)		
W_{dep}	Deposition rate to bottom sediment (m/yr)	Calculated (see Table A-2.12.)	
TSS	Total suspended solids (mg/L)	80	
10^{-6}	Units conversion factor (kg/mg)		
BS	Bed sediments concentration (kg/L)	1	

Description

This equation is used to determine the loss of constituent from the benthic sediment layer.

Table A-2.12. Deposition Rate to Bottom Sediment

Subsistence Fisher Scenario

$$W_{dep} = \left(\frac{X_{e,SB} \ x \ A_{SB} \ x \ SD_{SB} \ x \ 1000 - Vf_x \ x \ TSS}{WA_w \ x \ TSS} \right)$$

Parameter	Definition	Central Tendency	High End
W_{dep}	Deposition rate to bottom sediment (m/yr)		
$X_{e,SB}$	Unit soil loss from the sub-basin (kg/m^2/yr)	Calculated (see Table A-2.13.)	
A_{SB}	Area of sub-basin (m^2)	Calculated (see Table A-2.24.)	
SD_{SB}	Sub-basin sediment delivery ratio (unitless)	Calculated (see Table A-1.5.)	
Vf_x	Average volumetric flow rate (m^3/yr)	3.0×10^8	
TSS	Total suspended solids (g/m^3)	80	
1000	Units conversion factor (g/kg)		
WA_w	Waterbody surface area (m^2)	1×10^6	

Description

This equation is used to determine the loss of constituent from the waterbody as it deposits onto the benthic sediment.

Table A-2.13. Universal Soil Loss Equation (USLE) for the Sub-Basin

All Exposure Scenarios

$$X_{e,SB} = R_{SB} \ x \ K_{SB} \ x \ LS_{SB} \ x \ C_{SB} \ x \ P_{SB} \ x \ \frac{907.18}{4{,}047}$$

Parameter	Definition	Central Tendency	High End
$X_{e,SB}$	Unit soil loss from the sub-basin (kg/m^2-yr)		
R_{SB}	USLE rainfall factor (1/yr)	Alpena, MI = 50 Holly Hill, SC = 350 Ravena, NY = 125	
K_{SB}	USLE erodibility factor (ton/acre)	Alpena, MI = 0.23 Holly Hill, SC = 0.52 Ravena, NY = 0.19	
LS_{SB}	USLE length-slope factor (unitless)	1.5	
C_{SB}	USLE cover factor (unitless)	0.5	
P_{SB}	USLE erosion control practice factor (unitless)	1.0	
907.18	Units conversion factor (kg/ton)		
4,047	Units conversion factor (m^2/acre)		

Description

This equation is used to calculate the soil loss rate from the sub-basin using the Universal Soil Loss Equation.

Table A-2.14. Sub-basin Area

Subsistence Fisher Scenario

$$A_{SB} = A_F + A_{BF}$$

Parameter	Definition	Central Tendency	High End
A_{SB}	Area of Sub-basin		
A_F	Area of source field of interest (m^2)	Ag. Field = 2,000,000 Home garden = 5,100	
A_{BF}	Area of buffer field (m^2)	Calculated (see Table A-1.4.)	

Description

This equation is used to calculate the area of the sub-basin.

Table A-2.15. Total Water Column Concentration

Subsistence Fisher Scenario

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

Parameter	Definition	Central Tendency	High End
C_{wt}	Total concentration in water column (mg/L)		
f_{water}	Fraction of total water body constituent concentration that occurs in the water column (unitless)	Calculated (see Table A-2.5.)	
C_{wtot}	Total water concentration in surface water system, including water column and bed sediment (mg/L)	Calculated (see Table A-2.4.)	
d_b	Depth of upper benthic layer (m)	0.03	
d_w	Depth of the water column (m)	0.64	

Description

This equation calculates the total water column concentration of constituent; this includes both dissolved constituent and constituent sorbed to suspended solids.

Table A-2.16. Dissolved Water Concentration

Subsistence Fisher Scenario

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

Parameter	**Definition**	**Central Tendency**	**High End**
C_{dw}	Dissolved phase water concentration (mg/L)		
C_{wt}	Total concentration in water column (mg/L)	Calculated (see TableA-2.15.)	
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	Chemical specific (see Appendix B of Background Document)	
10^{-6}	Units conversion factor (kg/mg)		
TSS	Total suspended solids (mg/L)	80	

Description

This equation calculates the concentration of constituent dissolved in the water column.

Table A-2.17. Concentration Sorbed to Bed Sediment

Subsistence Fisher Scenario

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

Parameter	Definition	Central Tendency	High End
C_{bs}	Concentration sorbed to bed sediments (mg/kg)		
f_{benth}	Fraction of total waterbody constituent concentration that occurs in the bed sediment (unitless)	Calculated (see Table A-2-5.)	
C_{wtot}	Total water concentration in surface water system, including water column and bed sediment (mg/L)	Calculated (see Table A-2.4.)	
d_w	Total depth of water column (m)	0.64	
d_b	Depth of the upper benthic layer (m)	0.03	
θ_{bs}	Bed sediment porosity (unitless)	0.6	
Kd_{bs}	Bed sediment/sediment pore water partition coefficient (L/kg)	Chemical specific (see Appendix B of Background Document)	
BS	Bed sediment concentration (kg/L)	1.0	

Description

This equation calculates the concentration of constituent sorbed to bed sediments.

Table A-2.18. Fish Concentration from Dissolved Water Concentration

Subsistence Fisher Scenario

$$C_{fish} = C_{dw} \; x \; BCF$$

Parameter	Definition	Central Tendency	High End
C_{fish}	Fish concentration (mg/kg)		
C_{dw}	Dissolved water concentration (mg/L)	Calculated (see Table A-2.16.)	
BCF	Bioconcentration factor (L/kg)	Chemical specific (see Appendix B of Background Document)	

Description

This equation calculates fish concentration from dissolved water concentration using a bioconcentration factor.

Table A-2.19. Fish Concentration from Dissolved Water Concentration

Subsistence Fisher Scenario

$$C_{fish} = C_{wt} \times BAF$$

Parameter	Definition	Central Tendency	High End
C_{fish}	Fish concentration (mg/kg)		
C_{wt}	Dissolved water concentration (mg/L)	Calculated (see Table A-2.15.)	
BAF	Bioconcentration factor (L/kg)	Chemical specific (see Appendix B of Background Document)	

Description

This equation calculates fish concentration from dissolved water concentration using a bioconcentration factor.

Table A-2.21. Fish Concentration from Bottom Sediment Concentration

Subsistence Fisher Scenario

$$C_{fish} = \frac{C_{BS} \; x \; BSAF \; x \; f_{lipid}}{OC_{BS}}$$

Parameter	Definition	Central Tendency	High End
C_{fish}	Fish concentration (mg/kg)		
C_{BS}	Dissolved water concentration (mg/L)	Calculated (see Table A-2.17.)	
BSAF	Biota to sediment accumulation factor (L/kg)	Chemical specific (see Appendix B of Background Document)	
f_{lipid}	Fish lipid content (fraction)	0.05	
OC_{BS}	Fraction organic carbon in bed sediment (unitless)	2.34×10^{-3}	6.88×10^{-3}

Description

This equation calculates fish concentration from bottom sediment concentration using a bioaccumulation factor.

Table A-3.1. Exposed Vegetables Concentration Due to Direct Deposition

Farmer and Home Gardener Scenarios

$$Pd = \frac{D_{dep}\ x\ D_v\ x\ 315.36)\ x\ Rp\ x\ [(1.0 - \exp(-kp\ x\ Tp)]}{Yp\ x\ kp}$$

Parameter	Definition	Central Tendency	High End
Pd	Concentration in plant due to direct deposition (mg/kg) or (µg/g)		
D_{dep}	Dry deposition of particles ($g/m^2/yr$)	Modeled (see Appendix E)	
315.36	Units conversion factor (mg-m-s/µg-cm-yr)		
Rp	Interception fraction of edible portion of plant (dimensionless)	0.074	
kp	Plant surface loss coefficient (1/yr)	18	
Tp	Length of plant exposure to deposition of edible portion of plant, per harvest (yrs)	0.16	
Yp	Yield or standing crop biomass of the edible portion of the plant (kg DW/m^2)	3	

Description

This equation calculates the contaminant concentration in exposed vegetation due to wet and dry deposition of contaminant on the plant surface.

Table A-3.2. Exposed Vegetables Concentration Due to Air-to-Plant Transfer

Farmer and Home Gardener Scenarios

$$Pv = \frac{Cv \ x \ Bv \ x \ VG_{ag}}{\rho_a}$$

Parameter	Definition	Default Value
Pv	Concentration of pollutant in the plant due to air-to-plant transfer (mg/kg) or (μg/g)	
Cv	Air concentration of vapor (μg/m^3)	Waste management scenario-specific
Bv	Air-to-plant biotransfer factor ([mg pollutant/kg plant tissue DW]/[μg pollutant/g air])	Chemical-specific (see Appendix B)
VG_{ag}	Empirical correction factor for exposed vegetables (dimensionless)	0.01
ρ_a	Density of air (g/cm^3)	1.2×10^{-3}

Description

This equation calculates the contaminant concentration in exposed vegetation due to direct uptake of vapor phase contaminants into the plant leaves.

Table A-3.3. Exposed Vegetables Concentration Due to Root Uptake

Farmer and Home Gardener Scenarios

$$Pr = Sc \times Br$$

Parameter	Definition	Central Tendency	High End
Pr	Concentration of pollutant in the plant due to direct uptake from soil (mg/kg)		
Sc	Average soil concentration of pollutant over exposure duration (mg/kg)	Calculated (see Table A-1.1)	
Br	Plant-soil bioconcentration factor for exposed vegetables [µg/g DW]/[µg/g soil]	Chemical-specific (see Appendix B)	

Description

This equation calculates the contaminant concentration in exposed vegetation due to direct uptake of contaminants from soil.

Table A-3.4. Exposed Fruit Concentration Due to Direct Deposition

Farmer and Home Gardener Scenarios

$$Pd = \frac{D_{dep}\ x\ D_v\ x\ 315.36)\ x\ Rp\ x\ [(1.0 - \exp(-kp\ x\ Tp)]}{Yp\ x\ kp}$$

Parameter	Definition	Central Tendency	High End
Pd	Concentration in plant due to direct deposition (mg/kg) or (µg/g)		
D_{dep}	Dry deposition of particles (g/m^2/yr)	Modeled (see Appendix ?)	
315.36	Units conversion factor (mg-m-s/µg-cm-yr)		
Rp	Interception fraction of edible portion of plant (dimensionless)	0.01	
kp	Plant surface loss coefficient (1/yr)	18	
Tp	Length of plant exposure to deposition of edible portion of plant, per harvest (yrs)	0.16	
Yp	Yield or standing crop biomass of the edible portion of the plant (kg DW/m^2)	0.12	

Description

This equation calculates the contaminant concentration in exposed fruit due to wet and dry deposition of contaminant on the plant surface.

Table A-3.5. Exposed Fruit Concentration Due to Air-to-Plant Transfer

Farmer and Home Gardener Scenarios

$$Pv = \frac{Cv \ x \ Bv \ x \ VG_{ag}}{\rho_a}$$

Parameter	Definition	Default Value
Pv	Concentration of pollutant in the plant due to air-to-plant transfer (mg/kg) or (µg/g)	
Cv	Air concentration of vapor (µg/m^3)	Waste management scenario-specific
Bv	Air-to-plant biotransfer factor ([mg pollutant/kg plant tissue DW]/[µg pollutant/g air])	Chemical-specific (see Appendix B)
VG_{ag}	Empirical correction factor for exposed vegetables (dimensionless)	0.01
ρ_a	Density of air (g/cm^3)	1.2 x 10^{-3}

Description

This equation calculates the contaminant concentration in exposed fruit due to direct uptake of vapor phase contaminants into the plant leaves.

Table A-3.6. Exposed Fruit Concentration Due to Root Uptake

Farmer and Home Gardener Scenarios

$$Pr = Sc \ x \ Br$$

Parameter	Definition	Central Tendency	High End
Pr	Concentration of pollutant in the plant due to direct uptake from soil (mg/kg)		
Sc	Average soil concentration of pollutant over exposure duration (mg/kg)	Calculated (see Table A-1.1)	
Br	Plant-soil bioconcentration factor for exposed vegetables [µg/g DW]/[µg/g soil]	Chemical-specific (see Appendix B)	

Description

This equation calculates the contaminant concentration in exposed fruit due to direct uptake of contaminants from soil.

Table A-3.7. Root Vegetable Concentration Due to Root Uptake

Farmer and Home Gardener Scenarios

$$Pr_{bg} = \frac{Sc \ x \ RCF}{Kd_s} \qquad (organics)$$

$$Pr_{bg} = Sc \ x \ B_r \qquad (metals)$$

Parameter	Definition	Central Tendency	High End
Pr_{bg}	Concentration of pollutant in belowground plant parts due to root uptake (mg/kg)		
Sc	Soil concentration of pollutant (mg/kg)	Calculated (see Table E-1.1)	
RCF	Ratio of concentration in roots to concentration in soil pore water ([mg pollutant/kg plant tissue FW] /[µg pollutant/mL pore water])	Chemical-specific (see Appendix B)	
B_r	Soil to plant biotransfer factor for root vegetables (µg pollutant/g plant tissue DW)/(mg pollutant/ g soil)	Chemical-specific (see Appendix B)	
Kd_s	Soil-water partition coefficient (mL/g)	Chemical-specific (see Appendix B)	

Description

This equation calculates the contaminant concentration in root vegetables due to uptake from the soil water.

Table A-4.1. Beef Concentration Due to Plant and Soil Ingestion

Farmer Scenario

$$A_{beef} = (\Sigma F \ x \ Qp_i \ x \ P_i + Qs \ x \ Sc) \ x \ Ba_{beef}$$

Parameter	Definition	Central Tendency	High End
A_{beef}	Concentration of pollutant in beef (mg/kg)		
F	Fraction of plant grown on contaminated soil and eaten by the animal (dimensionless)	1	
Qp_i	Quantity of plant eaten by the animal each day (kg plant tissue DW/day)		
	- beef grain	0.47	
	- beef silage	2.5	
	- beef forage	8.8	
P_i	Total concentration of pollutant in each plant species eaten by the animal (mg/kg) = Pd + Pv + Pr	Calculated (see Tables A-4.3, A-4.4, A-4.5)	
Qs	Quantity of soil eaten by the foraging animal (kg soil/day)	0.5	
Sc	Soil concentration (mg/kg)	Calculated (see Table E.1.1)	
Ba_{beef}	Biotransfer factor for beef (d/kg)	Chemical-specific (see Appendix B)	

Description

This equation calculates the concentration of contaminant in beef from ingestion of forage, silage, grain, and soil.

Table A-4.2. Milk Concentration Due to Plant and Soil Ingestion

Farmer Scenario

$$A_{milk} = (\Sigma F \ x \ Qp_i \ x \ P_i + Qs \ x \ Sc) \ x \ Ba_{milk}$$

Parameter	Definition	Central Tendency	High End
A_{milk}	Concentration of pollutant in milk (mg/kg)		
F	Fraction of plant grown on contaminated soil and eaten by the animal (dimensionless)	1	
Qp_i	Quantity of plant eaten by the animal each day (kg plant tissue DW/day) - grain - silage - forage	 3.0 4.1 13.2	
P_i	Total concentration of pollutant in each plant species eaten by the animal (mg/kg) = Pd + Pv + Pr	Calculated (see Tables A-4.3, A-4.4, A-4.5)	
Qs	Quantity of soil eaten by the foraging animal (kg soil/day)	0.4	
Sc	Soil concentration (mg/kg)	Calculated (see Table E-1.1)	
Ba_{milk}	Biotransfer factor for milk (day/kg)	Chemical-specific (see Appendix B)	

Description

This equation calculates the concentration of contaminant in milk from ingestion of forage, silage, grain, and soil.

Table A-4.3. Forage (Pasture Grass/Hay) Concentration Due to Direct Deposition

Farmer Scenario

$$Pd = \frac{(D_{dep}) \ x \ Rp \ x \ [(1.0 - \exp(-kp \ x \ Tp)]}{Yp \ x \ kp}$$

Parameter	Definition	Central Tendency	High End
Pd	Concentration in plant due to direct deposition (mg/kg) or (μg/g)		
D_{dep}	Dry deposition of particles (g/m^2/yr	Modeled (see Appendix E)	
Rp	Interception fraction of edible portion of plant (dimensionless) - forage	0.5	
kp	Plant surface loss coefficient (1/yr)	18	
Tp	Length of the plant exposure to deposition of edible portion of plant per harvest (yrs) - forage	0.12	
Yp	Yield or standing crop biomass of the edible portion of the plant (kg DW/m^2)	0.24	
315.36	Units conversion (mg-m-s/μg-on-yr)		

Description

This equation calculates the contaminant concentration in the plant due to dry particle deposition of contaminant on the plant surface.

Table A-4.4. Forage (Pasture Grass/Hay) Concentration Due to Air-to-Plant Transfer

Farmer Scenario

$$Pv = \frac{Cv \ x \ Bv \ x \ VG_{ag}}{\rho_a}$$

Parameter	Definition	Central Tendency	High End
Pv	Concentration of pollutant in the plant due to air-to-plant transfer (mg/kg)		
Cv	Vapor phase air concentration of pollutant in air due to direct emissions (µg pollutant/m^3)	Modeled (see Appendix E)	
Bv	Air-to-plant biotransfer factor ([mg pollutant/kg plant tissue DW]/[µg [pollutant/g air])	Chemical-specific (see Appendix B)	
VG_{ag}	Empirical correction factor (dimension less)	1.0	
ρ_a	Density of air (g/cm^3)	1.2×10^{-3}	

Description

This equation calculates the contaminant concentration in the plant due to direct uptake of vapor phase contaminants into the plant leaves.

Table A-4.5. Forage/Silage/Grain Concentraton Due to Root Uptake

Farmer Scenario

$$Pr = Sc \times Br$$

Parameter	Definition	Default Value
Pr	Concentration of pollutant in the plant due to direct uptake from soil (mg/kg)	
Sc	Average soil concentration of pollutant over exposure duration (mg/kg)	Calculated (see Table A-1.1)
Br	Plant-soil bioconcentraton factor plant [µg/g DW]/[µg/g soil]	Chemical-specific (see Appendix B)

Description

This equation calculates the contaminant concentration in the plant due to direct uptake of contaminants from soil.

Table A-5.1. Contaminant Intake from Soil

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

Parameter	Description	Values
I_{soil}	Daily intake of contaminant from soil (mg/d)	
Sc	Average soil concentration of pollutant over exposure duration (mg/kg)	calculated (see Appendix A)
CR_{soil}	Consumption rate of soil (kg/d)	varies
F_{soil}	Fraction of consumed soil contaminated (unitless)	1

Description

This equation calculates the daily intake of contaminant from soil consumption. The soil concentration will vary with each scenario, and the soil consumption rate varies for children and adults.

Table A-5.2. Contaminant Intake from Exposed Vegetable Intake

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

Parameter	Description	Values
I_{ag}	Daily intake of contaminant from exposed vegetables (mg/kg Fw)	
Pd	Concentration in exposed vegetables due to deposition (mg/kg Dw)	calculated (see Appendix A)
Pv	Concentration in exposed vegetables due to air-to-plant transfer (mg/kg Dw)	calculated (see Appendix A)
Pr	Concentration in exposed vegetables due to root uptake (mg/kg Dw)	calculated (see Appendix A)
CR_{ag}	Consumption rate of exposed vegetables (kg Dw/d)	varies
F_{ag}	Fraction of exposed vegetables contaminated (unitless)	varies

Description

This equation calculates the daily intake of contaminate from ingestion of exposed vegetables. The consumption rate varies for children and adults. The contaminated fraction and the concentration in exposed vegetables will vary with each scenario.

Table A-5.3. Contaminant Intake from Exposed Fruit Intake

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

Parameter	Description	Values
I_{ef}	Daily intake of contaminant from exposed fruit (mg/kg Fw)	
Pd	Concentration in exposed fruit due to deposition (mg/kg Dw)	calculated
Pv	Concentration in exposed fruit due to air-to-plant transfer (mg/kg Dw)	calculated (see Appendix A)
Pr	Concentration in exposed fruit due to root uptake (mg/kg Dw)	calculated (see Appendix A)
CR_{ag}	Consumption rate of exposed fruit (kg Dw/d)	varies
F_{ag}	Fraction of exposed fruit contaminated (unitless)	varies

Description

This equation calculates the daily intake of contaminate from ingestion of exposed fruit. The consumption rate varies for children and adults. The contaminated fraction and the concentration in exposed fruit will vary with each scenario.

Table A-5.4. Contaminant Intake from Root Vegetable Intake

$$I_{ev} = Pr_{bg} \cdot CR_{rv} \cdot F_{rv}$$

Parameter	Description	Values
I_{rv}	Daily intake of contaminant from root vegetables for dioxins (mg/kg Fw); metals (mg/kg Dw)	
Pr_{rv}	Concentration in root vegetables due to deposition for dioxins (mg/kg Fw); metals (mg/kg Dw)	calculated (see Appendix A)
CR_{rv}	Consumption rate of root vegetables for dioxins (kg Fw/d); metals (kg Dw/d)	varies
F_{rv}	Fraction of root vegetables contaminated (unitless)	varies

Description

This equation calculates the daily intake of contaminate from ingestion of exposed vegetables. The consumption rate varies for children and adults. The contaminated fraction and the concentration in exposed vegetables will vary with each scenario.

Table A-5.5. Contaminant Intake from Beef and Milk

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

Parameter	Description	Values
I_i	Daily intake of contaminant from animal tissue *i* (mg/d)	
A_i	Concentration in animal tissue *i* (mg/kg Fw) - for Dioxins and (mg/kg Dw) - for Cadmium	calculated (see Appendix A)
CR_i	Consumption rate of animal tissue *i* (kg Fw/d) - for Dioxins and (Kg Dw/d) - for Cadmium	varies
F_i	Fraction of animal tissue *i* contaminated (unitless)	varies

Description

This equation calculates the daily intake of contaminate from ingestion of animal tissue (where the "*i*" in the above equation refers to beef and milk). The consumption rate varies for children and adults and for the type of animal tissue.

Table A-5.6. Contaminant Intake from Fish

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

Parameter	Description	Values
I_{fish}	Daily intake of contaminant from fish (mg/d)	
C_{fish}	Concentration in fish (mg/kg)	calculated (see Appendix A)
CR_{fish}	Consumption rate of fish (kg/d)	varies
F_{fish}	Fraction of fish contaminated (unitless)	varies

Description

This equation calculates the daily intake of contaminate from ingestion of fish.

Table A-5.7. Total Daily Intake

Adult and Child Home Gardener

$$I = I_{soil} + I_{ev} + I_{ef} + I_{rv}$$

Farmer

$$I = I_{soil} + I_{ev} + I_{beef} + I_{milk} + I_{ef} + I_{rv}$$

Fisher

$$I = I_{fish}$$

Parameter	Description	Values
I	Total daily intake of contaminant (mg/d)	
I_{soil}	Daily intake of contaminant from soil (mg/d)	calculated (see Appendix A-5.1)
I_{ev}	Daily intake of contaminant from exposed vegetables	calculated (see Appendix A-5.2)
I_{ef}	Daily intake of contaminant from exposed fruit (mg/d)	calculated (see Appendix A-5.3)
I_{rv}	Daily intake of contaminant from root vegetables	calculated (see Appendix A-5.4)
I_{beef}, I_{milk}	Daily intake of contaminant from animal tissue (mg/d)	calculated (see Appendix A-5.5)
I_{fish}	Daily intake of contaminant from fish (mg/d)	calculated (see Appendix A-5.6)

Description

This equation calculates the daily intake of contaminant on a pathway by pathway basis.

Table A-5.7. (Continued) Total Daily Intake

$$I = I_{soil} + I_{ev} + I_{beef} + I_{milk} + I_{fish} + I_{ef} + I_{rv}$$

Parameter	Description	Values
I	Total daily intake of contaminant (mg/d)	
I_{soil}	Daily intake of contaminant from soil (mg/d)	calculated (see Table A-5.1)
I_{ev}	Daily intake of contaminant from exposed vegetables (mg/d)	calculated (see Table A-5.2)
I_{ef}	Daily intake of contaminant from exposed fruit (mg/d)	calculated (see Table A-5.3)
I_{rv}	Daily intake of contaminant from root vegetables fruit (mg/d)	calculated (see Table A-5.4)
I_{beef}, I_{milk}	Daily intake of contaminant from animal tissue (mg/d)	calculated (see Table A-5.5)
I_{fish}	Daily intake of contaminant from fish (mg/d)	calculated (see Table A-5.6)

Description

This equation calculates the daily intake of contaminate via all indirect pathways.

Table A-5.8. Individual Cancer Risk: Carcinogens

$$Cancer\ Risk = \frac{I \cdot ED \cdot EF \cdot CSF}{BW \cdot AT \cdot 365}$$

Parameter	Description	Values
Cancer Risk	Individual lifetime cancer risk (unitless)	
I	Total daily intake of contaminant (mg/d)	calculated (see Table A-5.6)
ED	Exposure duration (yr)	varies
EF	Exposure frequency (day/yr)	350
BW	Body weight (kg)	adult: 70 child: varies
AT	Averaging time (yr)	70
365	Units conversion factor (day/yr)	
CSF	Oral cancer slope factor (per mg/kg/d)	chemical-specific

Description

This equation calculates the individual cancer risk from indirect exposure to carcinogenic chemicals. The body weight varies for the child and the adult. The exposure duration varies for different scenarios.

Table A-5.9. Hazard Quotient: Noncarcinogens

$$HQ = \frac{I}{BW \cdot RfD}$$

Parameter	Description	Values
HQ	Hazard quotient (unitless)	
I	Total daily intake of contaminant (mg/d)	calculated (see Table A-5.6)
BW	Body weight (kg)	adult: 70 child: varies
RfD	Reference Dose (mg/kg/d)	chemical-specific

Description

This equation calculates the hazard quotient for indirect exposure to noncarcinogenic chemicals. The body weight varies for the child and the adult.

Table A-5.10 Total Cancer Risk for Farmer Scenario: Carcinogens

$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$

Parameter	Definition	Values
Total Cancer Risk	Total individual lifetime cancer risk for all chemicals (unitless)	
Cancer Risk$_i$	Individual lifetime cancer risk for chemical carcinogen I (unitless)	calculated (see Table A-5.7)

Description

For carcinogens, cancer risks are added across all carcinogenic chemicals.

Table A-5.11 Hazard Index for Specific Organ Effects for Farmer Scenario: Noncarcinogens

$$HI_j = \sum_i HQ_i$$

Parameter	Definition	Values
Hi_j	Hazard index for specific organ effect j (unitless)	
HQ_i	Hazard quotient for chemical I with specific organ effect j (unitless)	calculated (see Table A-5.9)

Description
For noncancer health effects, hazard quotients are added across chemicals when they target the same organ to calculate an overall hard index.

Table A-6.1 Inhalation Cancer Risk for Individual Chemicals from Unit Risk Factor: Carcinogens

$$Cancer\ Risk = C_a \bullet URF$$

Parameter	Description	Values
Cancer Risk	Individual Lifetime cancer risk (unitless)	
C_a	Concentration in air (μg/m^3)	calculated (see Appendix F)
UFR	Inhalation Unit Risk Factor (per μg/m^3)	chemical-specific

Description

This equation calculates the inhalation cancer risk for individual constituents using the Unit Risk Factor.

Table A-6.2. Inhalation Cancer Risk for Individual Chemicals from Carcinogenic Slope Factor: Carcinogens

$$Cancer\ Risk = ADI \bullet CSF_{inh}$$

$$ADI = \frac{C_a \bullet IR \bullet ET \bullet EF \bullet ED \bullet 0.001\ mg/\mu g}{BW \bullet AT \bullet 365\ day/yr}$$

Parameter	Description	Values
Cancer Risk	Individual lifetime cancer risk (unitless)	
ADI	Average daily intake via inhalation (mg/kg/day)	
IR	Inhalation rate (m^3/hr)	calculated
ET	Exposure time (hr/day)	24
EF	Exposure frequency (day/yr)	350
BW	Body weight (kg)	Adult = 70 Child = varies
AT	Averaging time (yr)	70
CSF_{inh}	Inhalation Carcinogenic slope Factor (per mg/kg/day)	chemical-specific

Description
This equation calculates the inhalation cancer risk for individual constituents using the Carcinogenic Slope Factor.

Table A-6.3. Inhalation Hazard Quotient for Individual Chemicals: Noncarcinogens

$$HQ = \frac{C_a \bullet 0.001\ mg/\mu g}{RfC}$$

Parameter	Description	Values
HQ	Hazard quotient (unitless)	
C_a	Concentration in air ($\mu g/m^3$)	calculated (see Appendix F)
RfC	Reference concentration (mg/m^3)	chemical-specific

Description

This equation calculates the inhalation hazard quotient for individual constituents.

Table A-6.4 Total Inhalation Cancer Risk: Carcinogens

$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$

Parameter	Definition	Values
Total Cancer Risk	Total individual lifetime cancer risk for all chemicals (unitless)	
Cancer Risk_i	Individual lifetime cancer risk for chemical carcinogen I (unitless)	calculated (see Tables A-6.1, A-6.2)

Description

For carcinogens, cancer risks are added across all carcinogenic chemicals.

Table A-6.5   Hazard Index for Inhalation: Noncarcinogens

$$HI_{inh} = \sum_{i} HQ_i$$

Parameter	Definition	Values
Hi_{inh}	Hazard index for inhalation (unitless)	
HQ_i	Hazard quotient for chemical I (unitless)	calculated (see Table A-6.3)

Description

For noncancer health effects, hazard quotients are added across chemicals when the same organ to calculate an overall hazard index.

Appendix B

Physical & Chemical Properties Data for Constituents of Concern

Table B-1.1. Chemical-Specific Inputs for TCDD 2,3,7,8-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	5.5E-1	1
Koc	Soil Adsorbtion Coefficient (ml/g)	2.7E+6	1
Kow	Octanol-water partition coefficient (unitless)	4.4E+6	1
VP	Vapor Pressure (atm)	9.7E-13	1
SOl	Water solubility (ml/g)	1.9E-5	1
MW	Molecular Weight (g/mol)	322	1
H	Henry's Law Constant (atm-m^3/mol)	1.6E-5	1
D_a	Diffusivity in air (cm^2/sec)	4.7E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	6.1E+4	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	3.9E+3	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	5.6E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	7.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	1.0E-2	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	1.11	4
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	1.27	4
BSAF	Fish biota to sediment accumulation factor (unitless)	9.0E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	156,000	6
RfD	Reference Dose (mg/kg/day)	NA	
URF	Unit Risk Factor (per µg/m^3)	NA	
RfC	Reference Concentration (mg/m^3)	NA	

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.2. Chemical-Specific Inputs for TCDF 2,3,7,8-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	7.1E-1	1
Koc	Soil Adsorbtion Coefficient (ml/g)	2.1E+6	1
Kow	Octanol-water partition coefficient (unitless)	3.4E+6	1
VP	Vapor Pressure (atm)	1.2E-11	1
SOl	Water solubility (ml/g)	4.2E-4	1
MW	Molecular Weight (g/mol)	306	1
H	Henry's Law Constant (atm-m^3/mol)	8.6E-6	1
D_a	Diffusivity in air (cm^2/sec)	4.8E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	8.1E+4	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	3.2E+3	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	6.5E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	1.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	3.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.92	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	0.46	7
BSAF	Fish biota to sediment accumulation factor (unitless)	9.0E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.1	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.3. Chemical-Specific Inputs for PeCDD 1,2,3,7,8-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	2.6E-1	1
K_{oc}	Soil Adsorbtion Coefficient (ml/g)	2.7E+6	1
K_{ow}	Octanol-water partition coefficient (unitless)	4.4E+6	1
VP	Vapor Pressure (atm)	1.2E-12	1
SOl	Water solubility (ml/g)	1.2E-4	1
MW	Molecular Weight (g/mol)	356.4	1
H	Henry's Law Constant (atm-m^3/mol)	6.2E-6	1
Da	Diffusivity in air (cm2/sec)	4.5E-2	1
Dw	Diffusivity in water (cm2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	1.2E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	3.9E+3	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	5.6E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)1	6E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	1E-2	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	1.11	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	1.27	7
BSAF	Fish biota to sediment accumulation factor (unitless)	9E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.5	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.4. Chemical-Specific Inputs for

PeCDF 1,2,3,7,8-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2E-1	1
Koc	Soil Adsorbtion Coefficient (ml/g)	3.8E+6	1
Kow	Octanol-water partition coefficient (unitless)	6.2E+6	1
VP	Vapor Pressure (atm)	3.6E-12	1
SOl	Water solubility (ml/g)	2.4E-4	1
MW	Molecular Weight (g/mol)	340.4	1
H	Henry's Law Constant (atm-m3/mol)	6.2E-6	1
Da	Diffusivity in air (cm2/sec)	4.6E-2	1
Dw	Diffusivity in water (cm2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	4.6E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	5.1E+3	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	4.6E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	1.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	2.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	1.20	4
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	2.50	4
BSAF	Fish biota to sediment accumulation factor (unitless)	9E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.05	1

[1] Pork biotransfer factor set equal to beef biotransfer.

Table B-1.5. Chemical-Specific Inputs for PeCDF 2,3,4,7,8-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	3.0E-1	1
Koc	Soil Adsorbtion Coefficient (ml/g)	5.1E+6	1
Kow	Octanol-water partition coefficient (unitless)	8.3E+6	1
VP	Vapor Pressure (atm)	4.3E-12	1
SOl	Water solubility (ml/g)	2.4E-4	1
MW	Molecular Weight (g/mol)	340.4	1
H	Henry's Law Constant (atm-m^3/mol)	6.2E-6	1
D_a	Diffusivity in air (cm^2/sec)	4.6E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	4.6E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	6.4E+3	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	3.9E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	5.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	9.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	1.20	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	2.50	7
BSAF	Fish biota to sediment accumulation factor (unitless)	9E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.5	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.6. Chemical-Specific Inputs for HxCDD 1,2,3,4,7,8-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	7E-2	1
Koc	Soil Adsorbtion Coefficient (ml/g)	3.8E+7	1
Kow	Octanol-water partition coefficient (unitless)	6.2E+7	1
VP	Vapor Pressure (atm)	1.3E-13	1
SOl	Water solubility (ml/g)	4.4E-6	1
MW	Molecular Weight (g/mol)	390.9	1
H	Henry's Law Constant (atm-m^3/mol)	1.2E-5	1
D_a	Diffusivity in air (cm^2/sec)	4.3E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	4.5E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	3.0E+4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	1.2E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	3.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	6.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.85	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	1.46	7
BSAF	Fish biota to sediment accumulation factor (unitless)	4E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.1	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.7. Chemical-Specific Inputs for

HxCDD 1,2,3,6,7,8

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.0E-2	1
Koc	Soil Adsorbtion Coefficient (ml/g)	1.2E+7	1
Kow	Octanol-water partition coefficient (unitless)	2.0E+7	1
VP	Vapor Pressure (atm)	4.7E-14	1
SOl	Water solubility (ml/g)	4.4E-6	1
MW	Molecular Weight (g/mol)	390.9	1
H	Henry's Law Constant (atm-m^3/mol)	1.2E-5	1
D_a	Diffusivity in air (cm^2/sec)	4.3E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	4.5E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	1.3E+4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	2.3E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	3.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	5.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.99	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	1.62	7
BSAF	Fish biota to sediment accumulation factor (unitless)	4E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.1	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B.1-8. Chemical-Specific Inputs for HxCDD 1,2,3,7,8,9-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	2E-2	1
Koc	Soil Adsorbtion Coefficient (ml/g)	1.2E+7	1
Kow	Octanol-water partition coefficient (unitless)	2.0E+7	1
VP	Vapor Pressure (atm)	6.4E-14	1
SOl	Water solubility (ml/g)	4.4E-6	1
MW	Molecular Weight (g/mol)	390.9	1
H	Henry's Law Constant (atm-m^3/mol)	1.2E-5	1
D_a	Diffusivity in air (cm^2/sec)	4.3E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	4.5E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	1.3E+4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	2.3E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	3E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	6E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.50	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	1.05	7
BSAF	Fish biota to sediment accumulation factor (unitless)	4E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEF	Toxicity Equivalency Factor	0.1	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.9. Chemical-Specific Inputs for HxCDF 1,2,3,4,7,8

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	6.0E-2	1
Koc	Soil Adsorbtion Coefficient (ml/g)	1.2E+7	1
Kow	Octanol-water partition coefficient (unitless)	2.0E+7	1
VP	Vapor Pressure (atm)	3.2E-13	1
SOl	Water solubility (ml/g)	1.3E-5	1
MW	Molecular Weight (g/mol)	347.9	1
H	Henry's Law Constant (atm-m^3/mol)	1.4E-5	1
D_a	Diffusivity in air (cm^2/sec)	4.4E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	1.5E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	1.3E+4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	2.3E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	4.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	7.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.86	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	1.89	7
BSAF	Fish biota to sediment accumulation factor (unitless)	4E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.1	1

[1] Pork biotransfer factor set equal to beek biotransfer factor.

Table B-1.10. Chemical-Specific Inputs for

HxCDF 1,2,3,6,7,8-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	6.0E-2	1
Koc	Soil Adsorbtion Coefficient (ml/g)	1.2E+7	1
Kow	Octanol-water partition coefficient (unitless)	2.0E+7	1
VP	Vapor Pressure (atm)	2.9E-13	1
SOl	Water solubility (ml/g)	1.8E-5	1
MW	Molecular Weight (g/mol)	374.9	1
H	Henry's Law Constant (atm-m^3/mol)	6.1E-6	1
D_a	Diffusivity in air (cm^2/sec)	4.4E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	1.5E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	1.3E+4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	2.3E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	3.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	6.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.73	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	1.68	7
BSAF	Fish biota to sediment accumulation factor (unitless)	4E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.1	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.11. Chemical-Specific Inputs for HxCDF 1,2,3,7,8,9

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	1.1E-1	1
Koc	Soil Adsorbtion Coefficient (ml/g)	1.2E+7	1
Kow	Octanol-water partition coefficient (unitless)	2.0E+7	1
VP	Vapor Pressure (atm)	3.7E-13	1
SOl	Water solubility (ml/g)	1.3E-5	1
MW	Molecular Weight (g/mol)	374.9	1
H	Henry's Law Constant (atm-m^3/mol)	1.0E-5	1
D_a	Diffusivity in air (cm^2/sec)	1.3-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	1.5E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	1.3E+4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	2.3E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	3.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	6.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.73	4
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	1.68	4
BSAF	Fish biota to sediment accumulation factor (unitless)	4E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.1	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.12. Chemical-Specific Inputs for HxCDF 2,3,4,6,7,8-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	7.0E-2	1
Koc	Soil Adsorbtion Coefficient (ml/g)	1.2E+7	1
Kow	Octanol-water partition coefficient (unitless)	2.0E+7	1
VP	Vapor Pressure (atm)	2.6E-13	1
SOl	Water solubility (ml/g)	1.3E-5	1
MW	Molecular Weight (g/mol)	374.9	1
H	Henry's Law Constant (atm-m^3/mol)	1.0E-5	1
D_a	Diffusivity in air (cm^2/sec)	4.4E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	1.5E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	1.3E4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	2.3E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	3.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	5.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.39	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	0.54	7
BSAF	Fish biota to sediment accumulation factor (unitless)	4E-2	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.1	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.13. Chemical-Specific Inputs for HpCDD 1,2,3,4,6,7,8

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	2E-2	1
Koc	Soil Adsorbtion Coefficient (ml/g)	9.8E+7	1
Kow	Octanol-water partition coefficient (unitless)	1.6E+8	1
VP	Vapor Pressure (atm)	4.2E-14	1
SOl	Water solubility (ml/g)	2.4E-6	1
MW	Molecular Weight (g/mol)	425.3	1
H	Henry's Law Constant (atm-m^3/mol)	7.5E-6	1
D_a	Diffusivity in air (cm^2/sec)	4.1E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	3.5E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	6.2E+4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	7.1E-4	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	6E-3	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	1E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.22	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	0.98	7
BSAF	Fish biota to sediment accumulation factor (unitless)	5E-3	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.01	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.14. Chemical-Specific Inputs for HpCDF 1,2,3,4,6,7,8-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.0E-2	1
Koc	Soil Adsorbtion Coefficient (ml/g)	4.9E+7	1
Kow	Octanol-water partition coefficient (unitless)	7.9E+7	1
VP	Vapor Pressure (atm)	1.8E-13	1
SOl	Water solubility (ml/g)	1.4E-6	1
MW	Molecular Weight (g/mol)	409.3	1
H	Henry's Law Constant (atm-m^3/mol)	5.3E-5	1
D_a	Diffusivity in air (cm^2/sec)	4.2E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	4.4E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	3.7E+4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	1.1E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	6.0E-3	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	1.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.18	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	0.68	7
BSAF	Fish biota to sediment accumulation factor (unitless)	5E-3	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.01	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.15. Chemical-Specific Inputs for HpCDF 1,2,3,4,7,8,9

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	3.0E-2	1
Koc	Soil Adsorbtion Coefficient (ml/g)	4.9E+7	1
Kow	Octanol-water partition coefficient (unitless)	7.9E+7	1
VP	Vapor Pressure (atm)	1.4E-13	1
SOl	Water solubility (ml/g)	1.4E-6	1
MW	Molecular Weight (g/mol)	409.3	1
H	Henry's Law Constant (atm-m^3/mol)	5.3E-5	1
D_a	Diffusivity in air (cm^2/sec)	4.2E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	4.4E+5	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	3.7E+4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	1.1E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	1.0E-2	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	3.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.16	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	0.49	7
BSAF	Fish biota to sediment accumulation factor (unitless)	5E-3	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factor	0.01	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.16. Chemical-Specific Inputs for OCDD 1,2,3,4,5,7,8,9

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	2.0E-4	1
Koc	Soil Adsorbtion Coefficient (ml/g)	2.4E+7	1
Kow	Octanol-water partition coefficient (unitless)	3.9E+7	1
VP	Vapor Pressure (atm)	1.1E-15	1
SOl	Water solubility (ml/g)	7.4E-8	1
MW	Molecular Weight (g/mol)	460.8	1
H	Henry's Law Constant (atm-m^3/mol)	7.0E-9	1
D_a	Diffusivity in air (cm^2/sec)	3.9E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	8.6E+6	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	2.1E+4	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	1.6E-3	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	8.0E-3	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	1.0E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.04	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	0.47	7
BSAF	Fish biota to sediment accumulation factor (unitless)	$1x10^{-4}$	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEF	Toxicity Equivalency Factor	0.0001	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.17. Chemical-Specific Inputs for OCDF 1,2,3,4,6,7,8,9-

Parameter	Definition	Value	Ref
Chemical/Physical Properties			
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	2E-3	1
Koc	Soil Adsorbtion Coefficient (ml/g)	3.9E+8	1
Kow	Octanol-water partition coefficient (unitless)	6.3E+8	1
VP	Vapor Pressure (atm)	4.9E-15	1
SOl	Water solubility (ml/g)	1.2E-6	1
MW	Molecular Weight (g/mol)	444.8	1
H	Henry's Law Constant (atm-m^3/mol)	1.9E-6	1
D_a	Diffusivity in air (cm^2/sec)	4.0E-2	1
D_w	Diffusivity in water (cm^2/sec)	8.0E-6	2
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	1.3E+6	24
RCF	Root concentration factor ([µg pollutant/g plant tissue FW]/[µg pollutant/g soil water])	1.8E+5	1
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	3.2E-4	3
Ba_{beef}/Ba_{pork}	Biotransfer factor for beef (day/kg)[1]	5E-3	23
Ba_{milk}	Biotransfer factor for milk (day/kg)	1E-3	5
BCF_{chick}	Biconcentration factor for TCDD-TEQ in thigh meat (unitless)	0.07	7
BCF_{egg}	Biconcentration factor for TCDD-TEQ in eggs (unitless)	0.30	7
BSAF	Fish biota to sediment accumulation factor (unitless)	1E-4	1
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	6.0E-1	5
Health Benchmarks			
TEQ	Toxicity Equivalency Factors	0.001	1

[1] Pork biotransfer factor set equal to beef biotransfer factor.

Table B-1.18. Chemical-Specific Inputs for Antimony

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		2	9
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		2	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		2	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables leafy vegetables forage / grain/ silage	0.03 0.2 0.2	12 12 12
Ba_{beef}	Biotransfer factor for beef (day/kg)		0.001	12
Ba_{milk}	Biotransfer factor for milk (day/kg)		0.0001	12
Ba_{pork}	Biotransfer factor for pork (day/kg)		0.001	13
BCF	Fish bioconcentration factor (L/kg)		0	14
BAF	Fish bioaccumulation factor (L/kg)		NA	
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.2	15
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		NA	
RfD	Reference Dose (mg/kg/day)		0.0004	16
URF	Unit Risk Factor (per µg/m^3)		NA	
RfC	Reference Concentration (mg/m^3)		NA	

Table B-1.19. Chemical-Specific Inputs for Arsenic

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		29	17
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		29	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		29	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables leafy vegetables forage / grain/ silage	0.008 0.036 0.06	18 18 18
Ba_{beef}	Biotransfer factor for beef (day/kg)		0.002	12
Ba_{milk}	Biotransfer factor for milk (day/kg)		0.006	12
Ba_{pork}	Biotransfer factor for pork (day/kg)		0.002	13
BCF	Fish bioconcentration factor (L/kg)		18	14
BAF	Fish bioaccumulation factor (L/kg)		NA	
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.2	15
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		1.75	16
RfD	Reference Dose (mg/kg/day)		0.0003	16
URF	Unit Risk Factor (per µg/m^3)		0.0043	16
RfC	Reference Concentration (mg/m^3)		NA	

Table B-1.20. Chemical-Specific Inputs for Barium

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		8,265	25
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		8,265	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		8,265	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	rootvegetables leafy vegetables forage / grain/ silage	0.015 0.15 0.15	12 12 12
Ba_{beef}	Biotransfer factor for beef (day/kg)		1.5e-4	12
Ba_{milk}	Biotransfer factor for milk (day/kg)		3.5e-4	12
Ba_{pork}	Biotransfer factor for milk (day/kg)		1.5e-4	13
BCF	Fish bioconcentration factor (L/kg)		NA	
BAF	Fish bioaccumulation factor (L/kg)		NA	9
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.6	21
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		NA	
RfD	Reference Dose (mg/kg/day)		0.07	16
URF	Unit Risk Factor (per µg/m^3)		NA	
RfC	Reference Concentration (mg/m^3)		0.0005	6

Table B-1.21. Chemical-Specific Inputs for Beryllium

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		4,600	17
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		4,600	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		4,600	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables leafy vegetables forage / silage/ grain	0.0015 0.01 0.01	12 12 12
Ba_{beef}	Biotransfer factor for beef (day/kg)		0.001	12
Ba_{milk}	Biotransfer factor for milk (day/kg)		9e-7	12
Ba_{pork}	Biotransfer factor for pork (day/kg)		0.001	13
BCF	Fish bioconcentration factor (L/kg)		95	14
BAF	Fish bioaccumulation factor (L/kg)		NA	
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.6	21
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		4.3	16
RfD	Reference Dose (mg/kg/day)		0.005	16
URF	Unit Risk Factor (per µg/m^3)		0.0024	16
RfC	Reference Concentration (mg/m^3)		NA	

Table B-1.22. Chemical-Specific Inputs for Cadmium

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		120	17
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		120	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		120	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables	0.064	18
		leafy vegetables	0.36	18
		forage / silage/ grain	0.14	18
Ba_{beef}	Biotransfer factor for beef (day/kg)		0.0004	5
Ba_{milk}	Biotransfer factor for milk (day/kg)		0.0001	5
Ba_{pork}	Biotransfer factor for pork (day/kg)		6e-4	5
BCF	Fish bioconcentration factor (L/kg)		32	14
BAF	Fish bioaccumulation factor (L/kg)		NA	
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.6	21
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		NA	
RfD	Reference Dose (mg/kg/day)		1e-3 soil 5e-4 water	16
URF	Unit Risk Factor (per µg/m^3)		0.0018	16
RfC	Reference Concentration (mg/m^3)		NA	

Table B-1.23. Chemical-Specific Inputs for Chromium III

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		3.32E+6	26
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		3.32E+6	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		3.32E+6	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables	0.0045	12
		leafy vegetables	0.0075	12
		forage / silage/ grain	0.0075	12
Ba_{beef}	Biotransfer factor for beef (day/kg)		5.5E-3	12
Ba_{milk}	Biotransfer factor for milk (day/kg)		0.0015	12
Ba_{pork}	Biotransfer factor for pork (day/kg)		5.5E-3	13
BCF	Fish bioconcentration factor (L/kg)		3	14
BAF	Fish bioaccumulation factor (L/kg)		NA	
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.6	21
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		NA	
RfD	Reference Dose (mg/kg/day)		1	16
URF	Unit Risk Factor (per µg/m^3)		NA	
RfC	Reference Concentration (mg/m^3)		NA	

Table B-1.24. Chemical-Specific Inputs for Chromium VI

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		19	17
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		19	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		19	11
Transfer Factors				
B_r	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables	0.0045	12
		leafy vegetables	0.0075	12
		forage / silage /grain	0.0075	12
Ba_{beef}	Biotransfer factor for beef (day/kg)		0.0055	12
Ba_{milk}	Biotransfer factor for milk (day/kg)		0.0015	12
Ba_{pork}	Biotransfer factor for pork (day/kg)		0.0055	13
BCF	Fish bioconcentration factor (L/kg)		3	14
BAF	Fish bioaccumulation factor (L/kg)		NA	
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.6	21
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		NA	
RfD	Reference Dose (mg/kg/day)		0.005	16
URF	Unit Risk Factor (per µg/m^3)		0.012	16
RfC	Reference Concentration (mg/m^3)		NA	

Table B-1.25. Chemical-Specific Inputs for Lead

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		2.8E+5	20
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		2.8E+5	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		2.8E+5	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables leafy vegetables forage / silage/ grain	9.0E-3 1.3E-5 1.3E-5	12 12 12
Ba_{beef}	Biotransfer factor for beef (day/kg)		3E-4	12
Ba_{milk}	Biotransfer factor for milk (day/kg)		2.5E-4	12
Ba_{pork}	Biotransfer factor for pork (day/kg)		3e-4	13
BCF	Fish bioconcentration factor (L/kg)		NA	
BAF	Fish bioaccumulation factor (L/kg)		8	14
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.6	21
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		NA	
RfD	Reference Dose (mg/kg/day)		NA	
URF	Unit Risk Factor (per µg/m^3)		NA	
RfC	Reference Concentration (mg/m^3)		NA	

Table B-1.26. Chemical-Specific Inputs for Nickel

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		21	17
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		21	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		21	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables	0.008	18
		leafy vegetables	0.032	18
		forage / silage/ grain	0.11	18
Ba_{beef}	Biotransfer factor for beef (day/kg)		0.006	12
Ba_{milk}	Biotransfer factor for milk (day/kg)		0.001	12
Ba_{pork}	Biotransfer factor for pork (day/kg)		0.006	13
BCF	Fish bioconcentration factor (L/kg)		4	14
BAF	Fish bioaccumulation factor (L/kg)		NA	
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.6	21
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		NA	
RfD	Reference Dose (mg/kg/day)		0.02	16
URF	Unit Risk Factor (per µg/m^3)		2.4E-4	16
RfC	Reference Concentration (mg/m^3)		NA	

Table B-1.27. Chemical-Specific Inputs for Selenium

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		5	17
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		5	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		5	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables leafy vegetables forage/ silage/ grain	0.022 0.016 0.006	18
Ba_{beef}	Biotransfer factor for beef (day/kg)		0.0076	5
Ba_{milk}	Biotransfer factor for milk (day/kg)		0.0451	5
Ba_{pork}	Biotransfer factor for pork (day/kg)		0.63	5
BCF	Fish bioconcentration factor (L/kg)		88	14
BAF	Fish bioaccumulation factor (L/kg)		NA	
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.2	15
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		NA	
RfD	Reference Dose (mg/kg/day)		0.005	16
URF	Unit Risk Factor (per µg/m^3)		NA	
RfC	Reference Concentration (mg/m^3)		NA	

Table B-1.28. Chemical-Specific Inputs for Silver

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		0.4	9
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		0.4	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		0.4	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables	0.1	12
		leafy vegetables	0.4	12
		forage/ silage/ grain	0.4	12
Ba_{beef}	Biotransfer factor for beef (day/kg)		0.003	12
Ba_{milk}	Biotransfer factor for milk (day/kg)		0.02	12
Ba_{pork}	Biotransfer factor for pork (day/kg)		0.003	13
BCF	Fish bioconcentration factor (L/kg)		0	14
BAF	Fish bioaccumulation factor (L/kg)		NA	
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.6	21
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		NA	
RfD	Reference Dose (mg/kg/day)		0.005	16
URF	Unit Risk Factor (per µg/m^3)		NA	
RfC	Reference Concentration (mg/m^3)		NA	

Table B-1.29. Chemical-Specific Inputs for Thallium (I)

Parameter	Definition		Value	Ref
Chemical/Physical Properties				
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)		0	8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)		71	17
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)		71	10
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)		71	11
Transfer Factors				
Br	Soil-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g soil])	root vegetables leafy vegetables forag/ silage/ grain	0.0004 0.004 0.004	12 12 12
Ba_{beef}	Biotransfer factor for beef (day/kg)		0.04	12
Ba_{milk}	Biotransfer factor for milk (day/kg)		0.002	12
Ba_{pork}	Biotransfer factor for pork (day/kg)		0.04	13
BCF	Fish bioconcentration factor (L/kg)		67	14
BAF	Fish bioaccumulation factor (L/kg)		NA	
Other Parameters				
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)		0.6	21
Health Benchmarks				
CSF	Cancer Slope Factor (per mg/kg/day)		NA	
RfD	Reference Dose (mg/kg/day)		8E-5	19
URF	Unit Risk Factor (per µg/m^3)		NA	
RfC	Reference Concentration (mg/m^3)		NA	

Appendix C

PRELIMINARY DRAFT SENSITIVITY ANALYSIS FOR CEMENT KILN DUST USED AS AGRICULTURAL SOIL AMENDMENT

1.0 SUMMARY

RTI performed a sensitivity analysis to evaluate the parameters used in the risk analysis for the use of cement kiln dust (CKD) as an agricultural supplement. This analysis will be used to identify the risk drivers to be varied in the final high end risk analysis. The parameters determined to be risk drivers by this analysis are listed below in Table 1 in decreasing order of impact for each scenario.

2.0 WASTE STREAM CHARACTERIZATION

The waste stream characterization was provided by the EPA Work Assignment Manager from the 1992 Portland Cement Survey and 1993 EPA Sampling, and 1992 3007 Data, and 1994 Comments Data (U.S. EPA 1996). These data included constituent concentrations for metals and dioxin congeners and preliminary estimates for rates of application to agricultural fields. The chemical analysis data are presented in Table 2 for metals and Table 3 for dioxin congeners.

Table 1 Potential Risk Drivers for Each Receptor Scenario

Preliminary Draft Sensitivity Analysis - April 8, 1997

Home Gardener		Subsistence Farmer		Subsistence Fisher		Child of Subsistence Farmer	
Parameter	Risk Ratio	Parameter	Risk Ratio	Parameter	Risk Ratio	Parameter	Risk Ratio
Concentration	269-21	Concentration	344-22	Concentration	125	Concentration	326-21
Exposure duration	15-1	Exposure duration	24-1	Area of waterbody	50	Meteorologic location	4-1
Intake of vegetables	6-2	Intake of milk	7-1	USLE cover factor	14	Application rate	3-2
Application rate	3-2	Intake of beef	5-1	Soil FeOX	12	Application frequency	2
Application frequency	3-2	Intake of vegetables	3-2	Intake of fish	11	Tilling depth	2-1
Tilling depth	3-1	Application rate	3-2	USLE length-slope	5		
Intake of root vegetables	2-1	Application frequency	3-2	USLE factor erodibility	3		
		Meteorologic location	3-1	Application rate	2		
		Tilling depth	2-1	Field size	2		
		Intake of root vegetables	2-1	Application frequency	2		
				USLE factor erosivity/ rainfall	2		

Table 2. Median, 5TH and 95TH Percentile Concentration of Metals in CKD

Metal	5th Percentile (mg/kg)	Median (mg/kg)	95th Percentile (mg/kg)	Background Soil Conc[a] (mg/kg)	Reference
Silver	0.35	3	15	0	b
Arsenic	1.5	9	59	5.2	b
Barium	16	137	410	452	b
Beryllium	0.18	1	4	.065	b
Cadmium	0.89	5	32	--	b
Chromium	9	26	75	37	b
Mercury	0.01	0.1	1	0.058	b
Nickel	5	15	49	13	b
Lead	14	113	1346	20	c
Antimony	0.23	5	64	0.51	b
Selenium	0.50	6	37	0.26	b
Thallium	0.50	5	146	0	b

[a] Represents the geometric mean of the data for the entire U.S.

b Dragun, J; and A. Chiasson. 1991 *Elements in North American Soils.* HMCRI. Greenbelt, MD

c Agency for Toxic Substances and Disease Registry. 1988. Toxicological Profile for Lead. Atlanta, GA.

Table 3. Median and 95th Percentile Concentration of Dioxin Congeners in CKD

Congener	All Measurements (ppb)			Background
	5th P. Conc	Median Conc.	95th P. Conc.	Soil Conc. Range
(1)Heptachlorodibenzodioxin	0.0009	0.02	0.428	0.194
(8)Heptachlorodibenzofuran	0.00025	0.01	0.228	0.047
(9)Heptachlorodibenzofuran	0.00034	0.008	0.0235	0.00188
(4)Hexachlorodibenzodioxin	0.00034	0.008	0.0335	0.00188
(6)Hexachlorodibenzodioxin	0.00034	0.008	0.0674	0.004
(7)Hexachlorodibenzodioxin	0.00034	0.008	0.065	0.009
(1)Hexachlorodibenzofuran	0.00012	0.0065	0.1269	0.00188
(2)Hexachlorodibenzofuran	0.00012	0.005	0.06386	0.00188
(3)Hexachlorodibenzofuran	0.00012	0.005	0.01891	0.00188
(4)Hexachlorodibenzofuran	0.00034	0.0065	0.09186	0.002
Octochlorodibenzodioxin	0.0025	0.0449	0.461	0.096
Octochlorodibenzofuran	0.00091	0.01	0.0335	0.0231
(1)Pentachlorodibenzodioxin	0.00034	0.0065	0.037	0.00188
(1)Pentachlorodibenzofuran	0.00025	0.004	0.06736	0.00331
(2)Pentachlorodibenzofuran	0.00025	0.004	0.1650	0.00188
Tetrachlorodibenzodioxin	0.00034	0.00274	0.02	0.00081
Tetrachlorodibenzo furan	0.00012	0.0055	0.184	0.00139

The variation in constituent concentration has the greatest risk ratio in all scenarios. In all scenarios the risk ratio exceeds 100 for many constituents. Source variation is dependent upon independent chemical analysis of samples from 14 facilities for dioxins and 63 facilities for metals.

3.0 SOURCE CHARACTERIZATION

The application of CKD as a liming agent is assumed only to occur in areas near active cement kilns generating large quantities of CKD with initial soil pH less than 6. Potentially appropriate sites were established using a generalized soils map of North America. This soils map is based on information compiled in 1968 by the United States Department of Agriculture (Hunt, 1974). It broadly segregates soil types into generally acidic, transitional and generally alkaline groupings. Only areas with a potential for having generally acidic soils were considered appropriate for amendment with CKD. A listing of cement kiln locations (U.S. EPA, 1996a) was then used to identify facilities in or near the areas with acid soil. Meteorologic conditions were a secondary consideration in selecting sites for the initial screening risk assessment. However, for the sensitivity analysis meteorologic conditions were the primary consideration in selecting locations. All cement kiln sites in areas with acid soil and with meteorologic data ready for use in the ISC3 model were ranked according to rainfall potential. The following sites were selected to represent the range of meteorologic conditions (based upon rainfall) expected to occur in areas where CKD may be applied as an agricultural soil amendment.:

High Rainfall location - Miami, FL
Median rainfall location - Indianapolis, IN
Low Rainfall location - Alpena, MI

3.1 Field size

The size of the area source is also required for the source characterization. In this analysis the area of the source is the size of the agricultural field or home garden where CKD is incorporated. The variation in field size is determined from the Census of Agriculture: 1982, 1987, 1992. The average farm size in the states with acid soils and operating cement kilns. The variation in field size is determined from these data.

Table 4. Field Size Distribution for States With Cement Kilns and Potentially Acid Soils

State	Farms (number)	Land in farms (acres)	Average size of farm (acres)	Average size of farm (m^2
Tennessee	75076	11169086	149	602982.14
Pennsylvania	44870	7189541	160	647497.6
Maryland	13037	2223476	171	692013.06
West Virginia	17020	3267188	192	776997.12
Virginia	42222	8297011	197	797231.42
Ohio	70711	14247969	201	813418.86
Michigan	46562	10088170	217	878168.62
Maine	5776	1258297	218	882215.48
South Carolina	20242	4472569	221	894356.06
Alabama	37905	8450823	223	902449.78
New York	32306	7458015	231	934824.66
Georgia	40759	10025581	246	995527.56
Indiana	62778	15618831	249	1007668.1
Missouri	98082	28546875	291	1177636.3
Florida	35204	10766077	306	1238339.2
Mississippi	31998	10188362	318	1286901.5
Arkansas	43937	14127711	322	1303088.9
Iowa	96543	31346565	325	1315229.5
Illinois	77610	27250340	351	1420447.9

Median -	902449.78
95th Percentile -	1325751.3
5th Percentile -	643046.05

Additional source characterization parameters include the rate and frequency of application and the depth of incorporation (i.e., tilling). RTI contacted Dr. Terry Logan of Ohio State University to verify the rate and frequency of application of CKD on the advise of Rufus Chaney of the U.S. Department of Agriculture. Dr. Logan recommended a minimum rate of application of 2 tons/acre/application (U.S. EPA 1993c) based upon economic considerations and a maximum rate of 5 tons/acre per application. Dr. Logan confirmed that commonly application of liming agents are made once every 3 to 4 years. Values of 2, 3 and 4 years are used in this sensitivity analysis. Tilling depth values are assumed to be 10, 15 and 20 cm based upon common tilling disc sizes (RTI, 1996). The bulk density of CKD was estimated to be 1.5 g/cm^3 , the same as loose Portland cement this value was not varied in the analysis (Perry and Green, 1984). All application parameters are assumed identical for the home garden and the agricultural field. The lifetime of the agricultural field or home garden where these processes occurred was assumed to be 40 years. The need for lime for soil pH adjustment does not diminish over time and may increase with the addition of large quantities of nitrogen fertilizer (Christenson et al., 1981). Dr. Logan stated that the use of CKD as a liming agent could be expected to continue for extended periods (approaching 100 years) for a field and steady state conditions could be assumed to be present.

Table 5. Values used in Sensitivity Analysis for Application of CKD as an Agricultural Amendment

Parameter	**Low**	**Central**	**High**
Application Rate (tons/acre [a])	2	3	5
Frequency of Application (per years[a])	2	3	5
Tilling depth (cm [b])	10	15	20
Bulk density CKD (tonne/m^3 [c])	1.5	1.5	1.5
Lifetime of field (years [d])	40	40	40

[a] *Lime for Michigan Soils: Extension Bulletin E-471*

[b] Technical Background Document for the Hazardous Waste Identification Rule.

[c] *Perry's Chemical Engineers' Handbook, Sixth Edition*

[d] U.S. EPA, 1996. *Exposure Factors Handbook - Draft Report.*

Factors that change the effective concentration of constituents in soil, (e.g., application rate, application frequency) have risk ratios of four or less for all constituents and scenarios .

4.0 AIR EMISSIONS MODELING

Constituents of cement kiln dust may be released into the air from the agricultural field by volatilization or by emission of particulate matter. For this analysis, volatile emissions from the agricultural field were estimated using the soil partitioning model based upon the equations presented in Jury et al. (1983; 1984; and 1990). Particulate emissions were estimated from two types of releases: emissions due to wind erosion and emissions due to agricultural tilling.

Particulate emissions due to wind erosion were modeled assuming that the agricultural field is not covered by continuous vegetation or snow and that the surface soils have an unlimited reservoir of erodible surface particles. These assumptions are most reasonable in the case of loose sandy soils that do not form a surface crust or sites at which the surface soil is regularly disturbed. Thus, during the growing season or during periods of snow cover this model over predicts emission of particulate due to wind erosion. The duration and effectiveness of vegetative cover and/or the duration of snow cover may be considered in future analyses. The factor for estimating emission of particles due to wind erosion was obtained from U.S. EPA (1985a):

$$E_{wind} = 0.036 \bullet (1 - V) \bullet \left(\frac{u}{u_t} \right)^3 \bullet f(x)$$

where

E_{wind} = emissions of PM_{10} from wind erosion ($g/m^2/s$)
V = vegetative cover (fraction)
u = mean wind speed (m/s)
u_t = threshold wind speed (m/s),
f(x) = function of roughness height.

This empirical equation only estimates the emission of respirable particulate matter (PM_{10}) from the site and is not applicable for emission of larger particles. The emission of larger particles is not of importance for emission due to wind erosion.

During agricultural tilling particulate matter created from loosening and pulverizing the soils released into the atmosphere as the soil is dropped to the surface. The emission factor used to estimate tilling emissions in this analysis is based on the factor presented in U.S. EPA (1985b):

$$E_{at} = 5.38 \bullet K_{at} \bullet S^{0.6} \bullet N_{op} \bullet CF$$

where

E_{at} = emissions of soil (PM_{10} or PM_{30}) from agricultural tilling ($g/m^2/s$),
K_{at} = I particle size multiplier to adjust results to PM_{10} or PM_{30} (unitless),
S = silt content of soil (%), N_{op} is the number of operations per day (d^{-1}),
and
CF = conversion factor ([d•g•ha]/[s•kg•m^2]).

It was assumed for the initial analysis that tilling occurs for 1 month (730 hours) distributed throughout the year. The range of tilling time may vary within an order of magnitude from this value. All the variables used to estimate inhalation risk for farmers and their children are high. No risk in excess of E-6 was estimated for any constituent of total waste stream. Thus this pathway was not considered in the sensitivity analysis.

The variation silt content of the soils are shown in Table 6. Silt content of soils usually varies from 3 percent for sandy soils to 87 percent for silt soils. The silt content of soils expected to be present in the geographic locations where CKD may be used as an agricultural soil amendment are presented in Table 6.

Table 6. Silt Content Values for Sensitivity Analysis

Silt Content Parameter	Percent Silt Content
High	87
Median	60
Low	50

Modeling of particulate and volatile emissions is limited to releases from the agricultural field. Emissions from other sources such as storing, transporting, loading, and unloading the cement kiln dust were neglected in this analysis because exposures from these short term activities are minimal in comparison to continuous releases from the agricultural field.

ISC3 was used to estimate the average air concentration of particulate and vapor. ISC3 is the air dispersion and deposition model developed by EPA for use in indirect exposure modeling. It is a Gaussian plume model theat is applicable in simple, intermediate, and complex terrain areas. This model can simulate both wet and dry deposition and plume depletion. However, for CKD wet deposition of particles and vapors were not considered. In this sensitivity analysis only onsite receptors are evaluated..

The *Guideline on Air Quality Models* (U.S. EPA, 1993) recommends that 5 years of appropriate meteorologic data be used for making long-term estimates of ambient air concentrations and deposition rates. Five years of hourly observations of surface and upper air parameters from the National Weather Service Station near the facilities on interest have been obtained form the National Climatic Data Center or downloaded from the OAQPS-TTN. The data include:

- windspeed
- wind direction
- ambient temperature
- cloud cover
- day and nighttime (twice daily) measured mixing heights (upper air parameter).

Additional meteorologic observation elements are required for deposition calculation, including:

- precipitation type
- precipitation amount
- station pressure
- anemometer height.

Meteorologic factors are considered dependent variables in the analysis and are linked to the geographic location of the cement kiln. ISC3 is the primary model where variation in meteorologic data and source size are considered. These factors are also incorporated in other portions of the indirect exposure model but they must be correlated to the variations in ISC3. In the sensitivity analysis the meteorologic conditions were of greatest concern in the farmer scenario where the risk ratio is 3 for a constituent of concern (thallium) and the field size is most important to the subsistence fisher scenario where the risk ratio is also 3 for thallium.

4.0 SOIL PROPERTIES AND SOIL EROSION PARAMETERS

The variability in soil parameters is evaluated using taxonomic descriptions of soils and soil map units presented in a 1967 compilation of soil Great Groups, Orders, and Suborders Map of the United States (USGS, 1970). This general soils map was used in conjunction with specific county soils data from the Patriot database (U.S. EPA, 1993b) and selected U.S. Department of Agriculture soil surveys available for counties in these regions. For the sensitivity analysis the range of variability n soil parameters is assumed to occur at a single central tendency meteorologic location. The soil parameters values evaluated in the sensitivity analysis are presented in Table 7.

Table 7 Soil Parameters Evaluated in the Sensitivity Analysis

Soil Parameter	5th Percentile	50th Percentile	95th Percentile	Reference
Soil bulk density	1.3	1.4	1.5	MUIR Database, USDA
Soil Foc	0.002	0.01	0.015	MUIR Database, USDA
Total soil porosity	0.49	0.43	0.38	Patriot Database
Liquid filled porosity	0.27	0.20	0.09	Patriot Database
Air porosity	0.22	0.23	0.29	Patriot Database
pH	5.6	6.0	7.2	MUIR Database, USDA

Soil Parameter	5th Percentile	50th Percentile	95th Percentile	Reference
Amorphous FeOX	0.01	0.31	1.11	Brady (1978)
Natural organic matter	1.0	2.0	5.0	MUIR Database, USDA

Soil parameters are used in the soil partitioning equations were used to determine losses through leaching, runoff, and/or volatilization for dioxin and furan compounds and metals using equations presented in Jury et al. (1983, 1984, and 1990). In addition, metals partitioning is performed using the MINTEQ model. All equations used to estimate fate and transport of CKD constituents in the environment were presented in Appendix A of the initial risk assessment document. The parameters in the Jury equations and MINTEQ model are varied uniformly in the remaining portions of the model. The chemical-specific data used in this analysis are presented in Appendix B of that document. The variation in chemical concentration data are obtained from the data presented in Section 2.0.

4.1 Metals Speciation and Partitioning

Metals speciation was determined through MINTEQA2 modeling using soil parameter data, meteorologic data, and chemical concentration data identified in the previous sections.

The soil-water distribution coefficients (K_d s) for selected metals (i.e., Ag^+, Ba^{2+}, Cd^{2+}, Hg^{2+}, Ni^{2+}, and Pb^{2+}) were calculated using the MINTEQ aqueous speciation model. The model used for these calculations is an updated version of MINTEQA2 obtained from Allison Geoscience Consultants, Inc. Due to the poorly understood geochemistry for Tl^+, As^{3+}, Se^{6+}, and Cr^{6+} , the K_ds for these four metals were determined using an empirical pH-dependent adsorption relationship. It is assumed that Be adsorption can be conservatively approximated by that of its fellow Group II-A element Ba, and the Kd values computed for Ba are used for Be as well.

4.2 Soil Erosion to the Waterbody

The total load to the waterbody (L_T) is the sum of the constituent load via erosion (L_E) and the constituent load from pervious runoff (L_R). The total load to the waterbody is used to estimate risk to the subsistence and/or recreational fisher from the ingestion of fish. The estimation of L_E requires the calculation of a weighted average constituent concentration in watershed soils based on the eroded soil contribution ($S_{c,erode}$), and the L_R term requires the calculation of a weighted average constituent concentration based on the pervious runoff contribution ($S_{c,run}$). The weighted average constituent concentration represents the effective watershed soil concentration based on contributions from the subbasin and the remainder of the watershed. Most important, the weighted average concentration accounts for the differences in constituent concentrations in the different areas within the watershed. The calculation of L_T requires constituent concentrations for each of the following areas within the watershed: the source (LTU), the receptor site, the buffer and surrounding area, and the watershed area outside the drainage subbasin. For the watershed soils outside the subbasin, it is assumed that constituents reach the watershed solely via air deposition (i.e., no erosion component) (Beaulieu, 1996). In the CKD analysis, however, no contribution to the total waterbody concentration is assumed for areas outside the subbasin. The subbasin is assumed to consist of only the agricultural field and the intervening area (the area between the agricultural field and the waterbody(Beaulieu, 1996).

The USLE factors used for the estimation of soil erosion to the nearest waterbody are presented in Table 8.

Table 8 USLE Parameter Values for Sensitivity Analysis

Parameter	5th Percentile	50th Percentile	95th Percentile	Reference
Area of waterbody (m^2)	46,000	1,000,000	21,000,000	a
USLE factor -rainfall/erosivity (1/yr)	75	90	120	b
USLE factor erdodibility	0.1	0.3	0.6	b
USLE factor length-slope	0.2	1.5	2	b
USLE cover factor	.005	0.15	0.5	b
Distance to waterbody	75	150	250	a

a Technical Support Document for the Hazardous Waste Identification Rule: Risk Assessment for Human and Ecological Receptors

b Technical Guide Notice, Notice #116, Water Erosion Prediction Section, USDA, Natural Resources Conservation Service, Michigan State Office

The values supplied by the State of Michigan were used in this sensitivity analysis. The values covered a wide range of soil erosion conditions and are applicable in areas where CKD may potentially be used as a liming agent. Additional information from other areas may be required for more site specific input for the final risk analysis.

6.0 ESTIMATION OF METALS AND DIOXIN CONCENTRATIONS IN PLANTS

The plant-soil bioconcentration factor (Br) accounts for the uptake of constituent from soil and the subsequent transport of constituent to the plant tissue. The factor is defined as the ratio of the constituent concentration in the plant to constituent concentration in the soil. The

Br factors are a function of the constituent's bioavailability in the soil. Bioconcentration factors for metal constituents of CKD were obtained from the literature (U.S. EPA, 1992; U.S. EPA, 1996; and Baes et al., 1984). Empirical correlations were used to estimate transfer of dioxins to plant tissue. These factors were not considered variable for the sensitivity analysis.

Direct soil transfer to plants through rainsplash is considered in the sensitivity analysis. Empirical data collected by Dreicer and Whicker (1984) was used to develop the equation used to estimate the ratio of the plant concentration to the soil concentration on a dry weight basis. However, this ratio only applies to exposed vegetation and vegetation no higher than 40 cm above the soil surface.

$$P_R = C_F * 0.05$$

Where

P_R = Concentration in plant due to rainsplash transport mechanism (µg/g DW-plant)
C_F = Source field constituent concentration (mg/kg DW-soil)

The effect of rainsplash on risk or hazard quotient is a risk ratio of approximately 2 for the home gardener and subsistence farmer scenario. It appears to be appropriate to add this additional exposure to the forage and leafy vegetable pathways for use in the subsistence farmer and home gardener scenarios.

7.0 OTHER DIETARY EXPOSURES TO CKD APPLIED AS A SOIL AMENDMENT

The ingestion rates for food items considered in the risk analysis are presented in Table 9. These factors are from the 1996 Exposure Factors Handbook.

Intake variation is most important to the subsistence fisher scenario (risk ration >10) where there is the greatest difference in intake quantity. Intake is still important but less important for other food items (risk ration< 7) in all cases.

Table 9. Dietary Ingestion Exposure Factors Used in CKD Risk Assessment

Exposure Factor	5th Percentile (Adult) Exposure Factors Handbook 1996	50th Percentile (Adult) Exposure Factors Handbook 1996	95th Percentile (Adult) Exposure Factors Handbook 1996	Child Exposure Factors Handbook 1996
Soil ingestion (mg/d)	50	50	50	165
Aboveground produce (DW) ingestion (g/d)	10	20	81.9	NA
Root vegetable (WW) ingestion (g/d)	11	40	169	NA
Fish, ingestion (fisher scenarios) (g/d)	13.62	59	170	NA
Beef, ingestion (g/d)	27.9	98	323	NA
Milk, ingestion (g/d)	190.8	726	2094	NA

8.0 RISK ESTIMATIONS FOR SUBSISTENCE FARMER, HOME GARDENER, AND SUBSISTENCE FISHER

The risk assessment includes the receptor scenarios: subsistence farmer, subsistence fisher, home gardener, and child of the subsistence farmer. All receptors ingest contaminated soil. Exposure through the ingestion of contaminated drinking water is not considered in any scenario.

Risks in the subsistence farmer scenario may occur through the ingestion of plants grown on amended soil and beef and milk products from animals ingesting vegetation grown on fields amended with CKD. Beef and milk may be expected to be most conservative categories of animal products because they have the highest lipid content of all meats and dairy products. Also, the biotransfer factors for these dietary items are evaluated most thoroughly. Other meat products (lamb, poultry, and pork) are less completely assessed and are assumed to have biotransfer factors no greater than those established for beef and milk. The addition of these other dietary items will increase human exposure because the additional dietary items are not assumed to replace any of the beef and/or milk in the current assumptions. The beef and milk biotransfer factors for all constituents are not varied in the sensitivity analysis only the intake of these products.

The subsistence fisher scenario estimates risk through the ingestion of fish taken from a waterbody adjacent to fields amended with CKD. For the sensitivity analysis the waterbody is assumed to be a stream 75 meters to 250 meters from the agricultural field. The area of the agricultural field is varied as noted in the previous section.. The constituents may reach the stream from the agricultural field through soil erosion or be windblown. Windblown deposition is estimated to be the same as the onsite deposition because the contribution to the constituent loading due to air deposition to the waterbody is expected to be low with respect the constituent loading due to soil erosion. The soil erosion from the agricultural field to the adjacent water body is modeled using the integrated setting approach (Beaulieu, 1996) developed for the petroleum refining listing decision nongroundwater risk analysis and presented in the Background Document for the Interim Notice of Data Availability for the Petroleum Refining Listing Decision. This procedure remains unchanged from the initial risk assessment.

The results of the sensitivity analysis are presented in terms of the risk ratio. The risk ratio is the ratio of the risk estimated using the high end parameter to the risk estimated using the low ind parameter. The higher the risk ratio the greater the effect of the variability of the parameter. If there is no effect from varying the parameter over the range, the risk ratio is one.

The results are presented for each constituent the
Table 10 - Subsistence farmer
Table 11 - Home gardener
Table 12 - Subsistence fisher
Table 13 - Child of subsistence farmer

Table 10 Results of Sensitivity Analysis for Home Gardener Scenario

	Risk Ratio											
Parameter	Dioxin (TEQ)	Mercury	Nickel	Silver	Thallium	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Selenium
Met Location	1	1	1	1	1	1	1	1	1	1	1	1
Field size	1	1	1	1	1	1	1	1	1	1	1	1
Concentration	222	193	9	51	269	194	41	21	21	47	8	57
Application rate	2	3	3	3	3	3	3	2	2	2	3	2
Application frequency	2	1	2	2	2	3	2	2	2	2	2	2
Bulk Density	1	1	1	1	1	1	1	1	1	1	1	1
Silt Content of Soil	1	1	1	1	1	1	1	1	1	1	1	1
Tilling Depth	2	1	2	2	3	2	1	2	2	2	2	2
Soil parameters, other	2	3	1	1	1	1	1	1	1	1	1	1
Exposure duration	15	1	1	1	1	1	15	1	15	1	1	1
Intake of vegetables	3	2	4	5	2	6	4	6	3	5	3	2
Intake of root vegetables	2	7	2	2	1	2	2	2	2	2	3	6

Table 11 Results of Sensitivity Analysis for Subsistence Farmer Scenario

	Risk Ratio											
Parameter	Dioxin (TEQ)	Mercury	Nickel	Silver	Thallium	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Selenium
Met Location	3	1	1	1	3	1	3	1	1	1	3	6
Field size	1	1	1	1	1	1	1	1	1	1	1	1
Concentration	272	133	10	39	302	344	40	25	22	27	8	72
Application rate	2	2	2	2	2	2	3	3	3	3	3	2
Application frequency	2	2	2	2	2	2	2	2	2	3	2	2
Bulk Density	1	1	1	1	1	1	1	1	1	1	1	1
Silt Content of Soil	1	1	1	1	1	1	1	1	1	1	1	1
Tilling Depth	2	1	2	2	2	2	2	2	2	3	2	2
Soil parameters, other	1	0	1	1	1	1	1	1	1	1	1	1
Exposure duration	24	1	1	1	1	1	24	1	24	1	1	1
Intake of beef	3	1	2	1	5	1	1	1	2	1	2	1
Intake of milk	4	1	3	7	2	1	7	2	1	1	3	4
Intake of vegetables	1	2	2	1	1	5	1	3	4	5	1	1
Intake of root vegetables	1	6	1	1	1	2	1	2	2	2	2	3

Table 12 Results of Sensitivity Analysis for Subsistence Fisher Scenario

	Risk Ratio											
Parameter	Dioxin (TEQ)	Mercury	Nickel	Silver	Thallium	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Selenium
Met Location	1	1	1	NA	1	NA	1	NA	1	1	1	1
Field size	2	2	1	NA	3	NA	2	NA	2	2	2	2
Concentration	235	125	10	NA	250	NA	42	NA	21	33	10	50
Application rate	2	3	3	NA	3	NA	2	NA	2	3	2	4
Application frequency	2	2	1	NA	2	NA	2	NA	2	2	2	3
Bulk Density	1	1	1	NA	1	NA	1	NA	1	1	1	1
Silt Content of Soil	1	1	1	NA	1	NA	1	NA	1	1	1	1
Tilling Depth	1	1	0	NA	0	NA	1	NA	0	0	0	1
Soil parameters, other	0	0	1	NA	1	NA	1	NA	1	1	1	1
soil pH	1	1	1	NA	1	NA	1	NA	0	0	2	2
soil FeOX	1	12	1	NA	1	NA	1	NA	1	1	1	2
Soil NOM	1	1	1	NA	1	NA	1	NA	1	0	1	1
Area of water body	1	50	1	NA	1	NA	1	NA	1	1	1	1
Area of watershed	1	1	1	NA	1	NA	1	NA	1	1	1	1
USLE factor rainfall/erosivity	2	2	1	NA	1	NA	1	NA	2	2	1	1
USLE factor erodibility	6	4	5	NA	2	NA	1	NA	5	4	1	1
USLE length-slope factor	11	5	3	NA	2	NA	1	NA	7	5	1	1
USLE cover factor	101	14	15	NA	3	NA	2	NA	30	17	2	2
Exposure duration	15	1	1	NA	1	NA	15	NA	15	1	1	1
Intake of fish	12	11	15	NA	12	NA	13	NA	12	12	10	12

Table 13 Results of Sensitivity Analysis for Child Scenario

	Risk Ratio											
Parameter	Dioxin (TEQ)	Mercury	Nickel	Silver	Thallium	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Selenium
Met Location	3	1	1	1	4	1	3	1	1	1	3	3
Field size	1	1	1	1	1	1	1	1	1	1	1	1
Concentration	275	182	9	48	326	262	40	28	21	38	9	94
Application rate	3	2	2	3	2	3	3	3	2	2	2	2
Application frequency	2	2	2	2	2	2	2	2	2	2	2	2
Bulk Density	1	1	1	1	1	1	1	1	1	1	1	1
Silt Content of Soil	1	1	1	1	1	1	1	1	1	1	1	1
Tilling Depth	2	1	2	1	2	2	2	2	2	2	2	2
Soil parameters, other	1	0	1	1	1	1	1	1	1	1	1	1

Not all chemicals modeled are of concern in each scenario. Although, the risk ratio may be high for a particular chemical the risk or hazard quotient may be so low that there is no need to consider the chemical in any future risk analysis, in spite of the high risk ratios. Dioxins are of concern in all scenarios and should be modeled in all scenarios in the final risk analysis. For the metals, however, not all constituents need be included in the final analysis. Table 14 presents the metals of concern for each scenario. All metals are included in the analysis if the value of the risk or HQ are within 2 orders of magnitude of a level of concern. This assures that no constituent of concern is omitted from future modeling, however, unnecessary resources are not expended.

Table 14 Metals of Concern for Exposure Scenario and Parameters Driving Risk

Scenario	Metal	Parameters
Subsistence Fisher	Mercury	Field size Concentration Application rate Soil parameters, other soil FeOX Area of waterbody USLE erodiblity factor USLE Length-slope factor USLE Cover factor Intake of fish
Subsistence Farmer	Thallium Antimony Arsenic Beryllium Cadmium	Meteorologic location Concentration Application rate Application frequency Tilling depth Intake of beef Intake of milk Intake of vegetables Intake of root vegetables
Home Gardener	Antimony Arsenic Beryllium	Concentration Application rate Application frequency Tilling depth Intake of vegetables Intake of root vegetables

Scenario	Metal	Parameters
Child	Thallium Antimony Arsenic Beryllium Cadmium	Meteorologic location Concentration Application rate Application frequency Tilling depth
None	Nickel Silver Barium Chromium Selenium	None

Mercury is the only metal constituent of concern in the subsistence fisher scenario. The modeling of this metal in the final risk assessment is the only case where soil parameters are identified as risk drivers and must be varied in the analysis. The distribution of these parameters within geographic areas and among geographic areas should be considered. The variation in the amorphous iron oxide (FeOX) results in the greatest risk ratio of all soil parameters. In addition, the variation in the size of the waterbody and the intake of fish were also identified.

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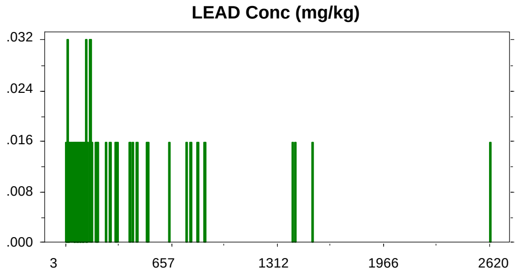
APPENDIX D
CONSTITUENT CONCENTRATION DATA

The following tables present the sampling and analysis data that are used in the Monte Carlo simulations for the probabilistic risk analysis. These data are the measurements obtained during the Agency's 1992 and 1993 sampling study. The data set includes a total of 45 CKD samples from 20 different facilities, 10 that burn hazardous waste and 10 that do not.

APPENDIX D
CONCENTRATION INPUT DATA FOR MONTE CARLO ANALYSIS

Sampling Data for Lead

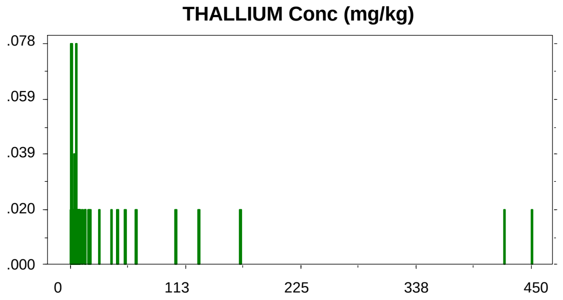
Assumption: LEAD Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	3.12	0.015873
	Single point	5.90	0.015873
	Single point	7.69	0.015873
	Single point	14.00	0.015873
	Single point	16.20	0.015873
	Single point	20.00	0.031746
	Single point	22.00	0.015873
	Single point	24.10	0.015873
	Single point	28.50	0.015873
	Single point	36.30	0.015873
	Single point	40.60	0.015873
	Single point	53.50	0.015873
	Single point	57.20	0.015873
	Single point	59.50	0.015873
	Single point	62.10	0.015873
	Single point	62.50	0.015873
	Single point	63.00	0.015873
	Single point	65.00	0.015873
	Single point	73.20	0.015873
	Single point	77.56	0.015873
	Single point	80.80	0.015873
	Single point	81.50	0.015873
	Single point	86.00	0.015873
	Single point	94.00	0.015873
	Single point	95.37	0.015873
	Single point	97.00	0.015873
	Single point	97.75	0.015873
	Single point	103.00	0.015873
	Single point	110.00	0.015873
	Single point	112.00	0.015873
	Single point	113.00	0.015873
	Single point	114.90	0.015873
	Single point	127.50	0.015873
	Single point	131.00	0.031746
	Single point	131.90	0.015873
	Single point	134.00	0.015873
	Single point	140.00	0.015873
	Single point	157.00	0.031746



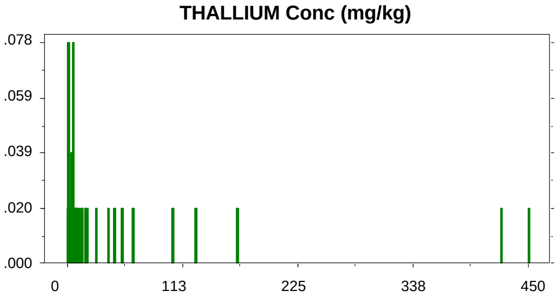
Assumption: LEAD Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	164.00	0.015873
	Single point	192.83	0.015873
	Single point	197.00	0.015873
	Single point	200.00	0.015873
	Single point	255.00	0.015873
	Single point	275.00	0.015873
	Single point	315.50	0.015873
	Single point	324.50	0.015873
	Single point	400.00	0.015873
	Single point	420.00	0.015873
	Single point	441.00	0.015873
	Single point	508.00	0.015873
	Single point	510.00	0.015873
	Single point	642.00	0.015873
	Single point	745.00	0.015873
	Single point	777.00	0.015873
	Single point	819.00	0.015873
	Single point	863.00	0.015873
	Single point	1400.00	0.015873
	Single point	1420.00	0.015873
	Single point	1521.25	0.015873
	Single point	2620.00	0.015873
Total Relative Probability			1.000000

Sampling Data for Thallium

Assumption: THALLIUM Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.44	0.019608
	Single point	0.50	0.078431
	Single point	1.17	0.019608
	Single point	1.40	0.019608
	Single point	1.50	0.019608
	Single point	1.60	0.019608
	Single point	1.70	0.019608
	Single point	1.75	0.019608
	Single point	2.10	0.019608
	Single point	2.16	0.019608
	Single point	2.30	0.019608
	Single point	2.50	0.019608
	Single point	2.92	0.019608
	Single point	3.40	0.019608
	Single point	3.70	0.039216
	Single point	4.00	0.019608
	Single point	4.39	0.019608
	Single point	4.70	0.019608
	Single point	5.00	0.078431
	Single point	5.12	0.019608
	Single point	5.20	0.019608
	Single point	5.85	0.019608
	Single point	6.65	0.019608
	Single point	6.70	0.019608
	Single point	8.12	0.019608
	Single point	8.20	0.019608
	Single point	8.42	0.019608
	Single point	8.44	0.019608
	Single point	8.90	0.019608
	Single point	11.03	0.019608
	Single point	14.60	0.019608
	Single point	15.30	0.019608
	Single point	17.30	0.019608
	Single point	19.37	0.019608
	Single point	27.50	0.019608
	Single point	40.75	0.019608
	Single point	45.55	0.019608
	Single point	52.90	0.019608
	Single point	63.60	0.019608
	Single point	103.00	0.019608
	Single point	125.00	0.019608
	Single point	166.00	0.019608
	Single point	423.50	0.019608

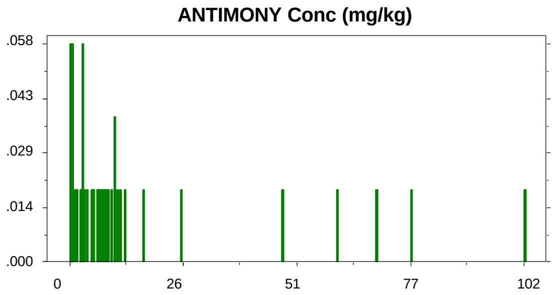


Assumption: THALLIUM Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	450.00	0.019608
Total Relative Probability			1.000000



Sampling Data for Antimony

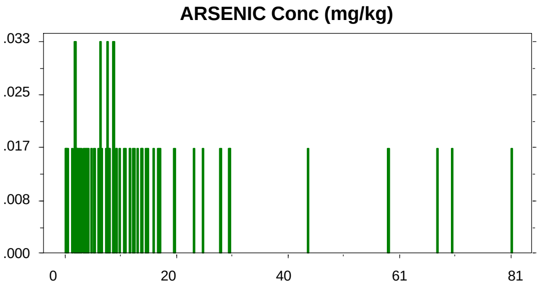
Assumption: ANTIMONY Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.09	0.019231
	Single point	0.10	0.019231
	Single point	0.16	0.019231
	Single point	0.30	0.019231
	Single point	0.40	0.019231
	Single point	0.42	0.057692
	Single point	0.47	0.019231
	Single point	0.50	0.057692
	Single point	0.56	0.019231
	Single point	0.75	0.019231
	Single point	1.40	0.019231
	Single point	1.50	0.019231
	Single point	2.50	0.019231
	Single point	2.65	0.019231
	Single point	2.75	0.019231
	Single point	3.00	0.057692
	Single point	3.02	0.019231
	Single point	3.20	0.019231
	Single point	3.85	0.019231
	Single point	5.10	0.019231
	Single point	5.30	0.019231
	Single point	5.40	0.019231
	Single point	6.25	0.019231
	Single point	6.60	0.019231
	Single point	6.70	0.019231
	Single point	6.90	0.019231
	Single point	7.45	0.019231
	Single point	7.82	0.019231
	Single point	8.20	0.019231
	Single point	8.30	0.019231
	Single point	8.40	0.019231
	Single point	8.80	0.019231
	Single point	9.30	0.019231
	Single point	10.00	0.019231
	Single point	10.10	0.038462
	Single point	10.90	0.019231
	Single point	11.35	0.019231
	Single point	12.40	0.019231
	Single point	16.45	0.019231
	Single point	25.00	0.019231
	Single point	47.67	0.019231
	Single point	60.00	0.019231
	Single point	68.78	0.019231



Assumption: ANTIMONY Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	76.67	0.019231
	Single point	102.00	0.019231
Total Relative Probability			1.000000

Sampling Data for Arsenic

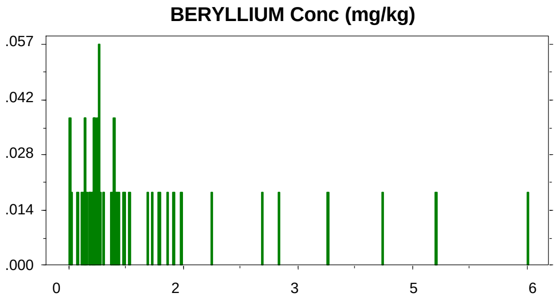
Assumption: ARSENIC Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.26	0.016667
	Single point	0.50	0.016667
	Single point	0.62	0.016667
	Single point	1.50	0.016667
	Single point	1.95	0.016667
	Single point	2.10	0.033333
	Single point	2.15	0.016667
	Single point	2.20	0.016667
	Single point	2.25	0.016667
	Single point	2.50	0.016667
	Single point	2.74	0.016667
	Single point	3.00	0.016667
	Single point	3.70	0.016667
	Single point	4.00	0.016667
	Single point	4.02	0.016667
	Single point	4.30	0.016667
	Single point	5.00	0.016667
	Single point	5.60	0.016667
	Single point	6.20	0.016667
	Single point	6.60	0.033333
	Single point	6.65	0.016667
	Single point	6.90	0.016667
	Single point	7.70	0.016667
	Single point	8.00	0.033333
	Single point	8.12	0.016667
	Single point	8.30	0.016667
	Single point	9.00	0.033333
	Single point	9.10	0.016667
	Single point	9.53	0.016667
	Single point	9.60	0.016667
	Single point	10.00	0.016667
	Single point	10.97	0.016667
	Single point	11.00	0.016667
	Single point	11.90	0.016667
	Single point	12.00	0.016667
	Single point	12.40	0.016667
	Single point	12.80	0.016667
	Single point	13.18	0.016667
	Single point	14.00	0.016667
	Single point	14.20	0.016667
	Single point	15.00	0.016667
	Single point	15.20	0.016667



Assumption: ARSENIC Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	16.30	0.016667
	Single point	16.90	0.016667
	Single point	17.20	0.016667
	Single point	20.10	0.016667
	Single point	23.40	0.016667
	Single point	25.13	0.016667
	Single point	28.40	0.016667
	Single point	29.80	0.016667
	Single point	30.00	0.016667
	Single point	44.20	0.016667
	Single point	58.50	0.016667
	Single point	67.50	0.016667
	Single point	70.20	0.016667
	Single point	80.70	0.016667
Total Relative Probability			1.000000

Sampling Data for Beryllium

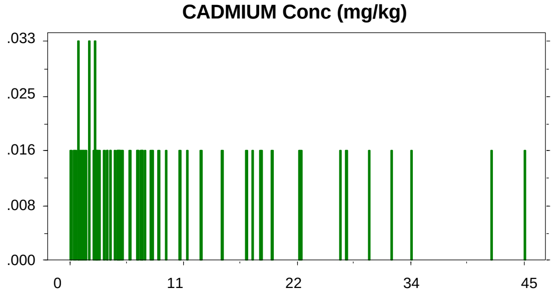
Assumption: BERYLLIUM Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.10	0.037736
	Single point	0.12	0.018868
	Single point	0.22	0.018868
	Single point	0.27	0.018868
	Single point	0.30	0.018868
	Single point	0.30	0.037736
	Single point	0.32	0.037736
	Single point	0.34	0.018868
	Single point	0.37	0.018868
	Single point	0.38	0.018868
	Single point	0.39	0.018868
	Single point	0.41	0.018868
	Single point	0.42	0.018868
	Single point	0.43	0.037736
	Single point	0.44	0.037736
	Single point	0.45	0.018868
	Single point	0.47	0.037736
	Single point	0.50	0.056604
	Single point	0.51	0.018868
	Single point	0.55	0.018868
	Single point	0.56	0.018868
	Single point	0.65	0.018868
	Single point	0.67	0.018868
	Single point	0.70	0.037736
	Single point	0.72	0.018868
	Single point	0.75	0.018868
	Single point	0.77	0.018868
	Single point	0.83	0.018868
	Single point	0.85	0.018868
	Single point	0.90	0.018868
	Single point	1.15	0.018868
	Single point	1.20	0.018868
	Single point	1.29	0.018868
	Single point	1.30	0.018868
	Single point	1.40	0.018868
	Single point	1.50	0.018868
	Single point	1.60	0.018868
	Single point	2.00	0.018868
	Single point	2.67	0.018868
	Single point	2.90	0.018868
	Single point	3.54	0.018868
	Single point	4.27	0.018868



Assumption: BERYLLIUM Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	5.00	0.018868
	Single point	6.20	0.018868
Total Relative Probability			1.000000

Sampling Data for Cadmium

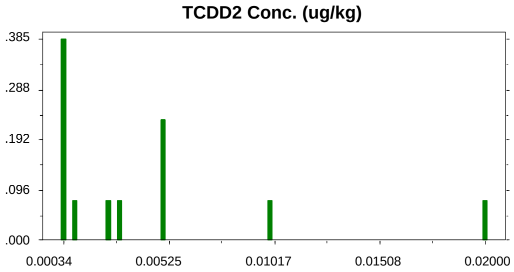
Assumption: CADMIUM Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.06	0.016393
	Single point	0.41	0.016393
	Single point	0.62	0.016393
	Single point	0.89	0.032787
	Single point	0.90	0.016393
	Single point	1.10	0.016393
	Single point	1.20	0.016393
	Single point	1.40	0.016393
	Single point	1.46	0.016393
	Single point	1.70	0.016393
	Single point	2.00	0.032787
	Single point	2.31	0.016393
	Single point	2.50	0.032787
	Single point	2.68	0.016393
	Single point	2.70	0.016393
	Single point	2.82	0.016393
	Single point	3.00	0.016393
	Single point	3.40	0.016393
	Single point	3.70	0.016393
	Single point	3.80	0.016393
	Single point	4.00	0.016393
	Single point	4.08	0.016393
	Single point	4.53	0.016393
	Single point	4.77	0.016393
	Single point	4.80	0.016393
	Single point	4.90	0.016393
	Single point	4.95	0.016393
	Single point	5.00	0.016393
	Single point	5.20	0.016393
	Single point	6.00	0.016393
	Single point	6.67	0.016393
	Single point	6.75	0.016393
	Single point	7.00	0.016393
	Single point	7.11	0.016393
	Single point	7.17	0.016393
	Single point	7.40	0.016393
	Single point	8.00	0.016393
	Single point	8.15	0.016393
	Single point	8.80	0.016393
	Single point	9.55	0.016393
	Single point	10.85	0.016393
	Single point	11.60	0.016393



Assumption: CADMIUM Conc (mg/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	13.00	0.016393
	Single point	15.10	0.016393
	Single point	17.50	0.016393
	Single point	18.00	0.016393
	Single point	18.80	0.016393
	Single point	18.92	0.016393
	Single point	20.00	0.016393
	Single point	22.68	0.016393
	Single point	22.90	0.016393
	Single point	26.80	0.016393
	Single point	27.40	0.016393
	Single point	29.60	0.016393
	Single point	31.88	0.016393
	Single point	33.71	0.016393
	Single point	41.70	0.016393
	Single point	44.90	0.016393
Total Relative Probability			1.000000

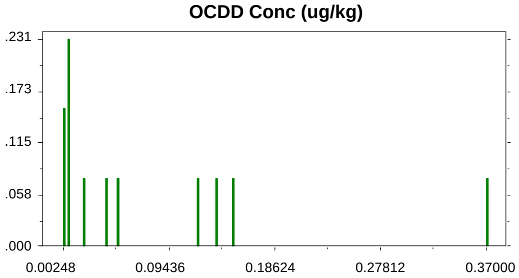
Sampling Data for TCDD

Assumption: TCDD2 Conc. (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00034	0.384615
	Single point	0.00091	0.076923
	Single point	0.00248	0.076923
	Single point	0.00300	0.076923
	Single point	0.00500	0.230769
	Single point	0.01000	0.076923
	Single point	0.02000	0.076923
Total Relative Probability			1.000000



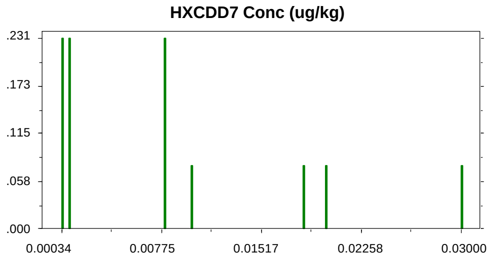
Sampling Data for OCDD

Assumption: OCDD Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00248	0.153846
	Single point	0.00674	0.230769
	Single point	0.02000	0.076923
	Single point	0.04000	0.076923
	Single point	0.04979	0.076923
	Single point	0.05000	0.076923
	Single point	0.12000	0.076923
	Single point	0.13534	0.076923
	Single point	0.15000	0.076923
	Single point	0.37000	0.076923
Total Relative Probability			1.000000



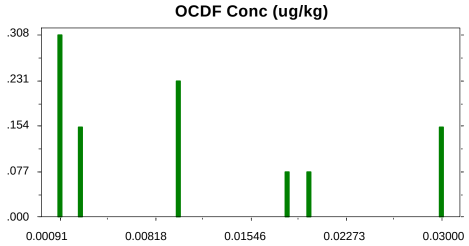
Sampling Data for HXCDD7 Conc (ug/kg)

Assumption: HXCDD7 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00034	0.230769
	Single point	0.00091	0.230769
	Single point	0.00800	0.230769
	Single point	0.01000	0.076923
	Single point	0.01832	0.076923
	Single point	0.02000	0.076923
	Single point	0.03000	0.076923
Total Relative Probability			1.000000



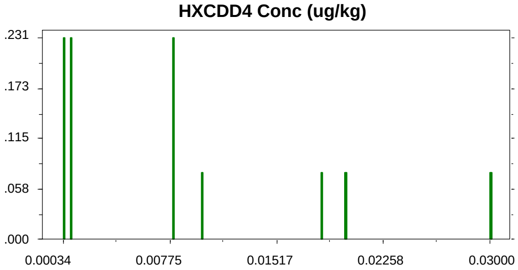
Sampling Data for OCDF Conc (ug/kg)

Assumption: OCDF Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00091	0.307692
	Single point	0.00248	0.153846
	Single point	0.01000	0.230769
	Single point	0.01832	0.076923
	Single point	0.02000	0.076923
	Single point	0.03000	0.153846
Total Relative Probability			1.000000



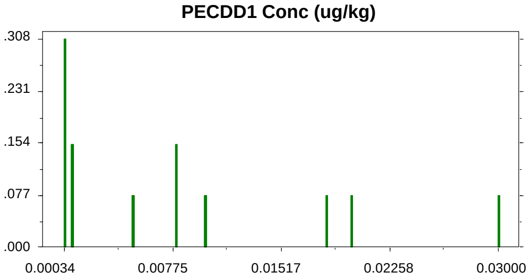
Sampling Data for HxCDD4 Conc (ug/kg)

Assumption: HXCDD4 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00034	0.230769
	Single point	0.00091	0.230769
	Single point	0.00800	0.230769
	Single point	0.01000	0.076923
	Single point	0.01832	0.076923
	Single point	0.02000	0.076923
	Single point	0.03000	0.076923
Total Relative Probability			1.000000



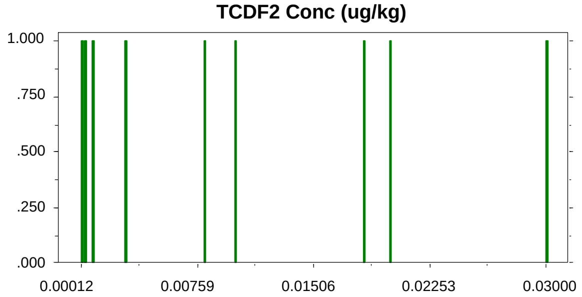
Sampling Data for PeCDD1 Conc (ug/kg)

Assumption: PECDD1 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00034	0.307692
	Single point	0.00091	0.153846
	Single point	0.00500	0.076923
	Single point	0.00800	0.153846
	Single point	0.01000	0.076923
	Single point	0.01832	0.076923
	Single point	0.02000	0.076923
	Single point	0.03000	0.076923
Total Relative Probability			1.000000



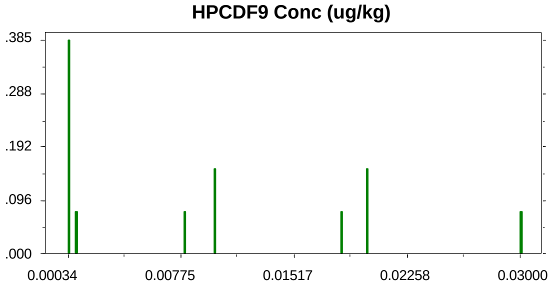
Sampling Data for TCDF2 Conc (ug/kg)

Assumption: TCDF2 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00012	1.000000
	Single point	0.00034	1.000000
	Single point	0.00091	1.000000
	Single point	0.00300	1.000000
	Single point	0.00800	1.000000
	Single point	0.01000	1.000000
	Single point	0.01832	1.000000
	Single point	0.02000	1.000000
	Single point	0.03000	1.000000
Total Relative Probability			9.000000



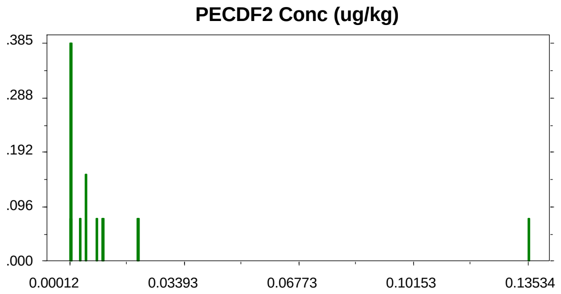
Sampling Data for HpCDF9 Conc (ug/kg)

Assumption: HPCDF9 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00034	0.384615
	Single point	0.00091	0.076923
	Single point	0.00800	0.076923
	Single point	0.01000	0.153846
	Single point	0.01832	0.076923
	Single point	0.02000	0.153846
	Single point	0.03000	0.076923
Total Relative Probability			1.000000



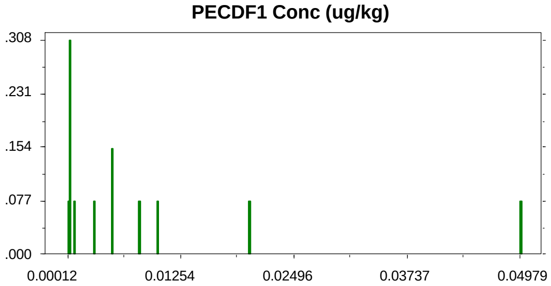
Sampling Data for PeCDF2 Conc (ug/kg)

Assumption: PECDF2 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00012	0.076923
	Single point	0.00034	0.384615
	Single point	0.00300	0.076923
	Single point	0.00500	0.153846
	Single point	0.00800	0.076923
	Single point	0.01000	0.076923
	Single point	0.02000	0.076923
	Single point	0.13534	0.076923
Total Relative Probability			1.000000



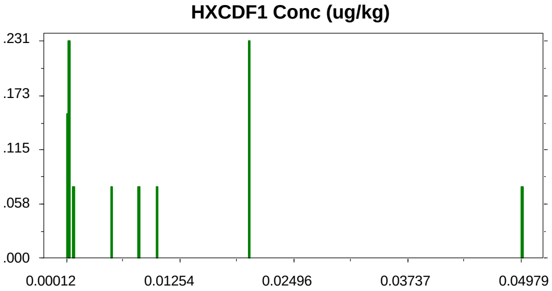
Sampling Data for PeCDF1 Conc (ug/kg)

Assumption: PECDF1 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00012	0.076923
	Single point	0.00034	0.307692
	Single point	0.00091	0.076923
	Single point	0.00300	0.076923
	Single point	0.00500	0.153846
	Single point	0.00800	0.076923
	Single point	0.01000	0.076923
	Single point	0.02000	0.076923
	Single point	0.04979	0.076923
Total Relative Probability			1.000000



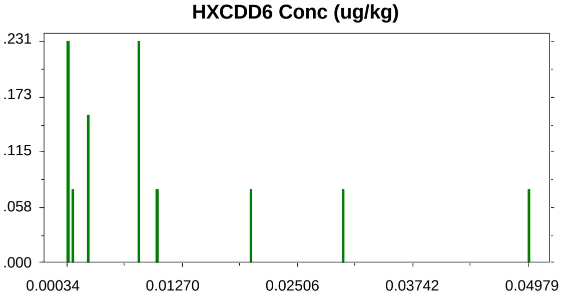
Sampling Data for HxCDF1 Conc (ug/kg)

Assumption: HXCDF1 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00012	0.153846
	Single point	0.00034	0.230769
	Single point	0.00091	0.076923
	Single point	0.00500	0.076923
	Single point	0.00800	0.076923
	Single point	0.01000	0.076923
	Single point	0.02000	0.230769
	Single point	0.04979	0.076923
Total Relative Probability			1.000000



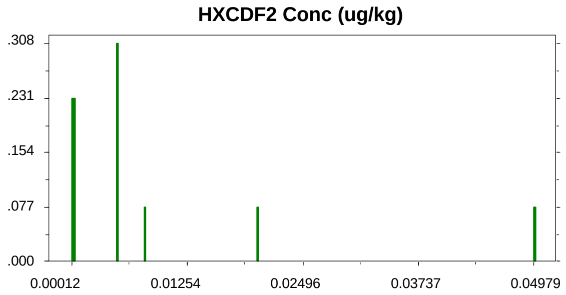
Sampling Data for HxCDD6 Conc (ug/kg)

Assumption: HXCDD6 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00034	0.230769
	Single point	0.00091	0.076923
	Single point	0.00248	0.153846
	Single point	0.00800	0.230769
	Single point	0.01000	0.076923
	Single point	0.02000	0.076923
	Single point	0.03000	0.076923
	Single point	0.04979	0.076923
Total Relative Probability			1.000000



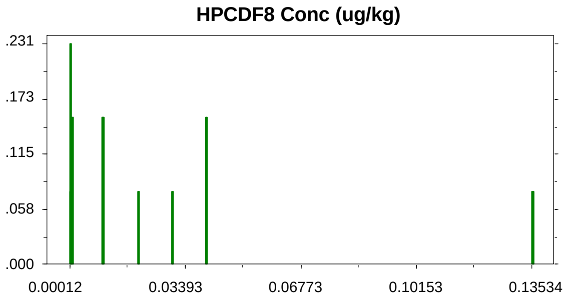
Sampling Data for HxCDF2 Conc (ug/kg)

Assumption: HXCDF2 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00012	0.230769
	Single point	0.00034	0.230769
	Single point	0.00500	0.307692
	Single point	0.00800	0.076923
	Single point	0.02000	0.076923
	Single point	0.04979	0.076923
Total Relative Probability			1.000000



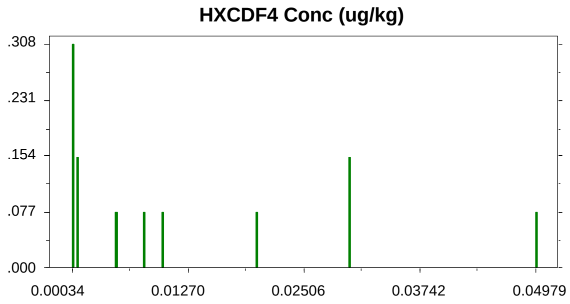
Sampling Data for HpCDF8 Conc (ug/kg)

Assumption: HPCDF8 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00012	0.076923
	Single point	0.00034	0.230769
	Single point	0.00091	0.153846
	Single point	0.01000	0.153846
	Single point	0.02000	0.076923
	Single point	0.03000	0.076923
	Single point	0.04000	0.153846
	Single point	0.13534	0.076923
Total Relative Probability			1.000000



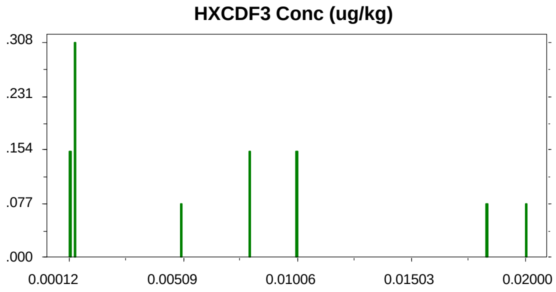
Sampling Data for HxCDF4 Conc (ug/kg)

Assumption: HXCDF4 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00034	0.307692
	Single point	0.00091	0.153846
	Single point	0.00500	0.076923
	Single point	0.00800	0.076923
	Single point	0.01000	0.076923
	Single point	0.02000	0.076923
	Single point	0.03000	0.153846
	Single point	0.04979	0.076923
Total Relative Probability			1.000000



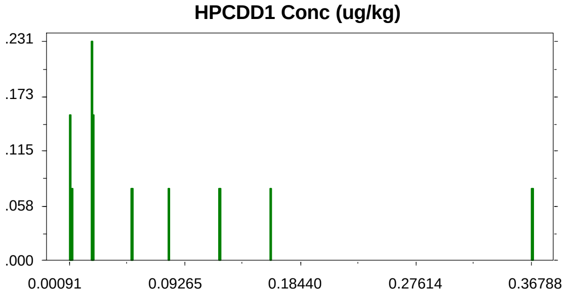
Sampling Data for HxCDF3 Conc (ug/kg)

Assumption: HXCDF3 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00012	0.153846
	Single point	0.00034	0.307692
	Single point	0.00500	0.076923
	Single point	0.00800	0.153846
	Single point	0.01000	0.153846
	Single point	0.01832	0.076923
	Single point	0.02000	0.076923
Total Relative Probability			1.000000



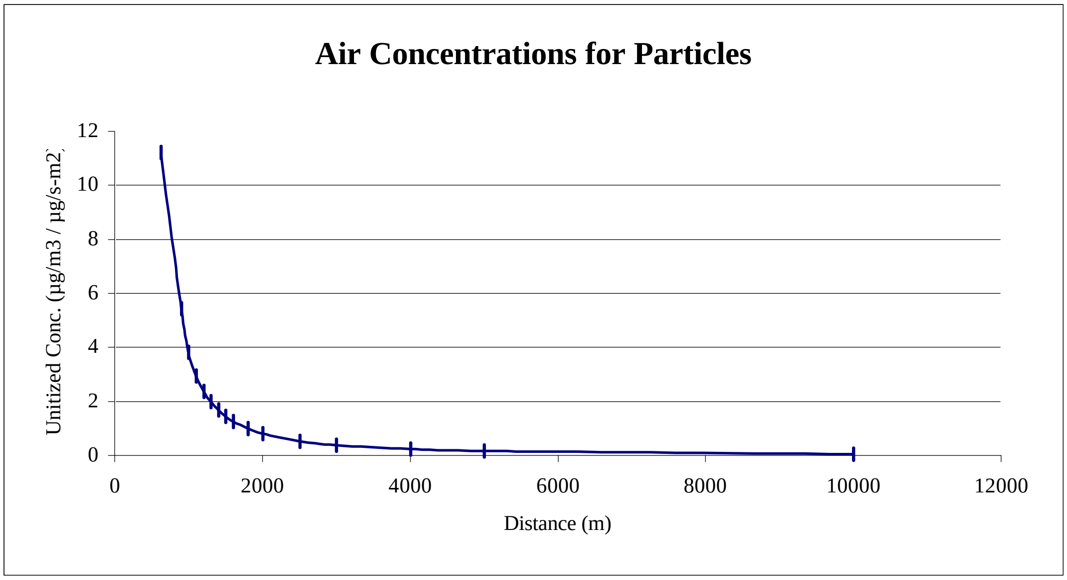
Sampling Data for HpCDD1 Conc (ug/kg)

Assumption: HPCDD1 Conc (ug/kg)			
Custom distribution with parameters:			Relative Prob.
	Single point	0.00091	0.153846
	Single point	0.00248	0.076923
	Single point	0.01832	0.230769
	Single point	0.02000	0.153846
	Single point	0.05000	0.076923
	Single point	0.08000	0.076923
	Single point	0.12000	0.076923
	Single point	0.16000	0.076923
	Single point	0.36788	0.076923
Total Relative Probability			1.000000

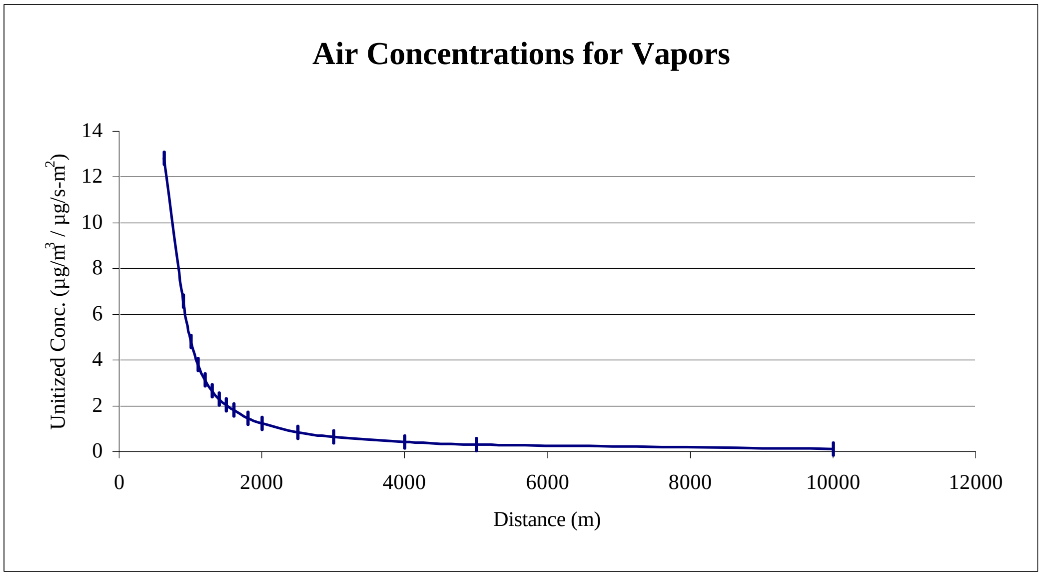


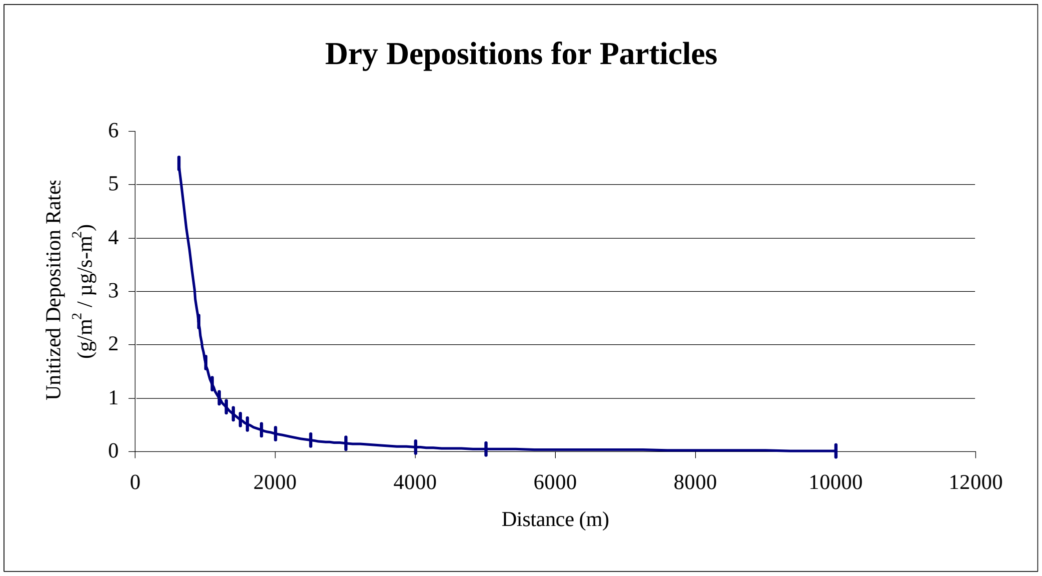
APPENDIX E
AIR MODELING PROFILES FOR LAND BASED AREA SOURCES

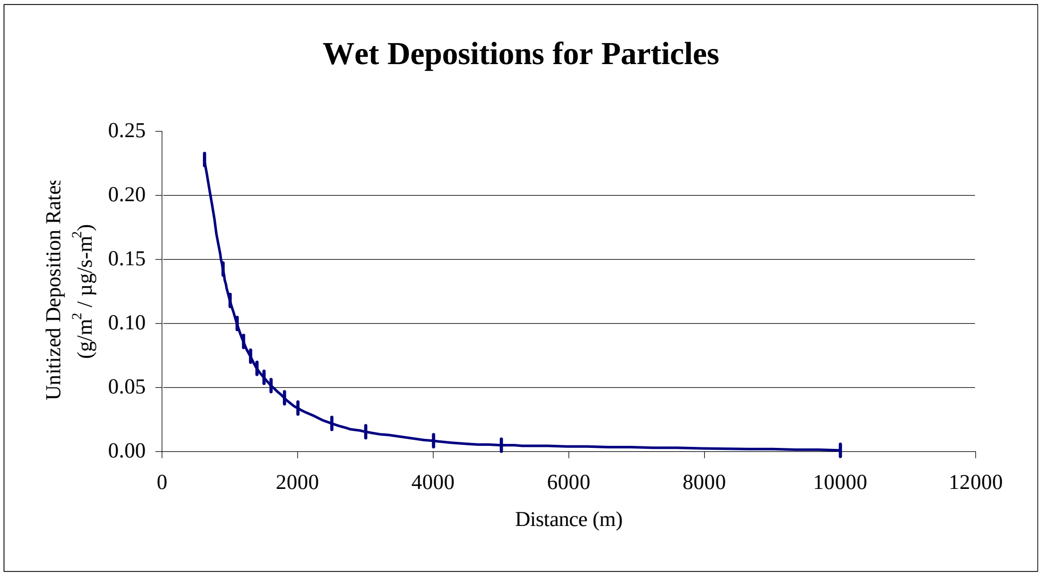
The following pages present the graphical representation of the air modeling results for a large land based unit. These graphs show the exponential decline in air concentration and deposition of particles and vapors as the distance from the source increases. This trend is true of all area sources. These graphs show the diminishing returns modeling air deposition over very large areas such as a entire watershed because the preponderance of deposition is within the area closest to the unit, i.e., the subbasin. The air deposition of particles and vapors and air concentrations within the subbasin and the waterbody are assumed to be equal to onsite deposition and concentrations in this analysis in order to be conservative.

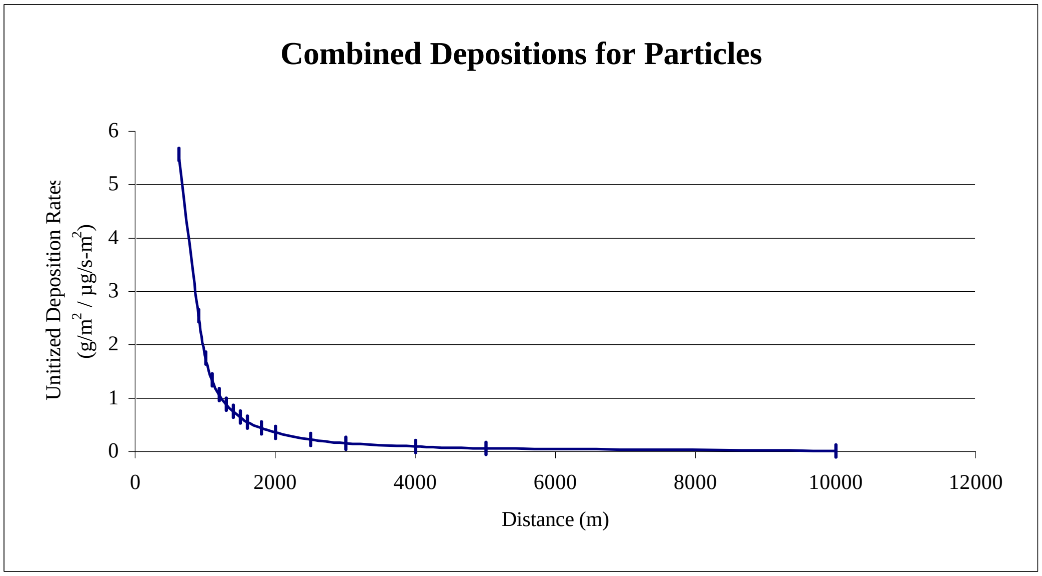


Air Concentrations for Particles
Unitized Conc. (µg/m3 / µg/s-m2)
12
10
8
6
4
2
0
0
2000
4000
6000
8000
10000
12000
Distance (m)


Air Concentrations for Vapors
Unitized Conc. (µg/m^3 / µg/s-m^2)
14
12
10
8
6
4
2
0
0
2000
4000
6000
8000
10000
12000
Distance (m)


Dry Depositions for Particles
Unitized Deposition Rates
(g/m2 / µg/s-m2)
6
5
4
3
2
1
0
0
2000
4000
6000
8000
10000
12000
Distance (m)


Wet Depositions for Particles
Unitized Deposition Rates
(g/m2 / µg/s-m2)
0.25
0.20
0.15
0.10
0.05
0.00
0
2000
4000
6000
8000
10000
12000
Distance (m)


Combined Depositions for Particles
Unitized Deposition Rates
(g/m^2 / μg/s-m^2)
6
5
4
3
2
1
0
0
2000
4000
6000
8000
10000
12000
Distance (m)

PEER REVIEW

Draft Risk Assessment for Cement Kiln Dust Used as an Agricultural Soil Amendment
Draft Report
EPA Reference DW12938494-01-0

Organized By:

Cooperative State Research Education and Extension Service Technical Committee W-170

Co-Chairs:	G.M. Pierzynski, Kansas State University G.F. Vance, University of Wyoming
Administrative Advisor:	Lee Sommers, Colorado State University
CSREES Representative:	Maurice Horton, U.S. Department of Agriculture

Submitted To:

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By:

PRC Committee Co-Chairs

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G.F. Vance, University of Wyoming
A.L. Page, University of California, Riverside

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William Jury	University of California, Riverside	Soil Physics, Jury Equations
Shiou Kuo	Washington State University	Soil Chemistry, Metal Bioavailability
Albert Page	University of California, Riverside	Soil Chemistry, Metal Bioavailability
Gary Pierzynski	Kansas State University	Soil Chemistry, Metal Bioavailability
George Vance	University of Wyoming	Soil Organic Chemistry

Summary

The Peer Review Committee (PRC) was given five objectives for their review of the EPA Risk Assessment for the Use of Cement Kiln Dust as an Agricultural Liming Agent:

1) Review and comment on the assumptions used for application practices including application rate and frequency, duration of application and depth of incorporation. Provide advice on alternate, more appropriate parameters.

2) Plant soil bioaccumulation factors (Br) for metals were obtained from the Technical Support Document for Land Application of Sewage Sludge. Evaluate the use of these Br values for assessing risks from agricultural use of CKD. Discuss any alternative, more appropriate Br factors

3) Evaluate and comment on the use of: a) MINTEQ modeling to determine metals speciation; b) Jury equations to determine dioxin and metal partitioning in soil; and c) the ISCST3 model for air dispersion and deposition.

4) Comment on how phytotoxicity and ecological risk are addressed in the analysis. Provide recommendations on appropriate alternative method(s).

5) Evaluate and comment on the uncertainty/variability analysis conducted in support of the point risk estimates.

In the review process, a thorough editing of all aspects of the document was completed and is provided for the benefit of the EPA

The PRC commends the EPA for producing the risk assessment as there is a strong need for the information that is presented. The procedures that were followed were sufficiently rigorous for the task at hand. The use of the deterministic approach supplemented by the probabilistic approach is the appropriate methodology for this situation. In general, the probabilistic approach was supportive of the deterministic approach, which lends credibility to the overall risk assessment.

The PRC concluded that the intent of the document was not explicitly stated nor was it inherently obvious after the review was completed. Analogies are drawn to the *Technical Support Document for the Land Application of Sewage Sludge*, but that document had a clear purpose in setting regulatory limits on application rates for sewage sludge and contaminants. No such conclusions are made in the CKD risk assessment. Similarly, the CKD risk assessment is not a risk assessment methodology or guidance document.

Four receptor scenarios were considered for a number of inorganic contaminants and dioxins. A serious deficiency is the lack of presentation of a screening procedure that was used to select the chemicals of concern and the receptor scenarios. Several potentially important omissions include B, Co, Cu, Mo, and Zn. If these or other contaminants were considered, the identity of those substances should be presented along with the rationale for their elimination from further consideration. Likewise, all receptor scenarios that were considered should be presented along with the rationale for their elimination from further consideration. For example, the risk assessment indicates that Pb may be a problem, which suggests that a pathway considering the conversion of CKD-amended land to residential use should be considered.

Objective 1:

The assumptions used for application practices including application rate and frequency, duration of application, and depth of incorporation for acidic soils are generally correct. The risk assessment needs to take into account the real possibility that the CKD application rate may be high enough to raise the soil pH above 7.0. Assumptions on the distribution of soils that would be candidates for CKD applications were not correct. There is a large area of soils that would be candidates for CKD applications that were not considered in the risk assessment. This problem is a result of using out-dated soils information at too large of a scale. More recent soil classification information applied on a smaller scale would help correct this deficiency. Similarly, the assumption limiting the use of CKD to within 20 miles of the point of application seems arbitrary and excludes many areas that are reasonable sites for CKD application.

Objective 2

The use of plant soil bioconcentration factors (Br) for assessing the risk from agricultural liming use of CKD is acceptable. The only realistic alternative would be the use of uptake slopes, but it is recognized that there is not sufficient data for this type of analysis.

The PRC felt that the use of Br factors from the *Technical Support Document for Land Application of Sewage Sludge* was not appropriate, but admits that there are few alternatives. The matrix for sewage sludge would be completely different than CKD due to the presence of organic materials and other constituents that may act as metal adsorbents. The EPA is encouraged to take the required steps to gather the data that is needed to calculate Br values from CKD amended soils. The EPA is also encouraged to investigate the use of data for materials that are more similar to CKD than sewage sludges, such as coal fly ashes, wood ash, or flue-gas desulfurization by-products.

Objective 3:

It is difficult to evaluate the use of MINTEQ modeling to determine metals speciation. Some of the K_d values for metals were estimated with MINTEQ (Ag, Ba, Be, Cd, Hg, Ni) , some were based on empirical relationships (As, Cr, Se, Tl), and for others (Pb, Sb) it is not clear how K_d values were obtained. It is clear that some of the assumptions that were used in the modeling are questionable. In particular, the emphasis on iron oxides as adsorbents is unrealistic for the elements considered with MINTEQ, but would seem more realistic for elements that exist as oxyanions (As, Cr, Se) for which empirical relationships were used. The net effect is difficult to ascertain but it would seem likely that the approach used would under predict K_d values, and therefore over predict risk, if the appropriate input data were used. It is also concluded that site-specific soil parameters were not risk drivers, although the rationale for this statement is not clearly presented.

The use of the Jury equations to determine dioxin and metal partitioning in soil is justifiable. Some errors were found, as noted in the specific comments.

The use of the ISCST3 Gaussian-plume model for air dispersion and deposition seems appropriate. The simulations are conducted with standard software that was not available to the PRC members. While the outcome cannot be verified by actual measurements, in this case, model simulation is appropriate because there is no other reliable way of estimating. The assumptions used in developing the exposure scenarios and selecting input data to calculate fluxes and concentrations were in general cautious. The end result of parameter estimation would therefore be conservative. If there is fault with this estimation, it would have to be on the potential of overestimating concentrations of airborne substances due to volatilization, wind erosion, and tillage operations. As a result, the subsequent calculations on vapor adsorption and foliar deposition of dioxin and metals could be overestimated. The authors report that many parameters such as soil texture and size of the application field had no significant effect on the outcome, which indicated that concentration estimates of airborne pollutants would remain essentially a function of the CKD application rates.

Objective 4:

The PRC concluded that the methods for assessing phytotoxicity and ecological risk are inadequate. The use of benchmarks from the *Technical Support Document for Land Application of Sewage Sludge* is not appropriate. The PRC recommends a literature review for ecological benchmarks of ecological risk assessments for metals from various sources and dioxins. The information presented should be summarized in a table to facilitate the comparison with soil contaminant concentrations from this risk assessment. There have been a number of ecological risk assessments performed for metal contaminated sites that can be used as a guide for ecological benchmarks for soil and phytotoxicity.

Objective 5

Descriptions and discussions of the Monte Carlo simulations were scattered throughout the document, making it difficult to get a comprehensive picture on how the simulations were run. As the computational algorithms for Monte Carlo simulations are relatively straightforward, the usefulness of the results are entirely dependent on the appropriate selection of parameters and the range and distribution of the data. With few exceptions, the simulations seemed reasonable. The presentation of the results could be improved in places, as noted in the specific comments.

Recommendations

1) Clarify the intent of the document.

2) Present a complete list of receptor scenarios and rationale for selecting the four scenarios for further development.

3) Present rationale for selecting chemicals of concern.

4) Include list of abbreviations and glossary.

5) Correct deficiencies with Jury equations and any associated problems.

6) Update soils information.

7) Provide suitable limits for metals and organic chemicals in CKD and for the lifetime of applications.

8) Use suitable approach for ecological risk assessment and repeat ecological risk assessment.

7) Review editorial comments and make changes as necessary.

Table of Contents

Detailed Review

Although an analysis of uses of CKD is important, it should be stated up front that the risk assessments conducted for this document are specific to application of CKD as a liming material and not for any other purpose. The title may need to be changed to read "Draft Risk Assessment for Cement Kiln Dust Used as a Soil Liming Amendment."

This is one of many risk assessment documents produced by EPA. The PRC hopes that the authors will participate in recent efforts by EPA to standardize the presentation.

Several formatting changes and additions will help the presentation of material. A list of abbreviations is a critical need. A glossary would be helpful to some readers. Please identify the subsections in the table of contents and check page numbers for accuracy. Provide a list of figures and improve the table captions so that they are self-explanatory.

There are several potentially important omissions in the risk assessment. One is handling, processing, storage and transport of CKD and the assumption that there is negligible risk from these activities. The handling issues are indirectly related to agricultural operations, but are important and potentially a substantial risk. The dusts can be quite caustic and difficult to handle. Salinity/sodicity issues can also be a problem, particularly for germination. Timing of CKD applications, management practices, and weather can be important variables. Preventing negative outcomes from the use of CKD is in everyone's best interest.

In the summary section there was a brief description of the Monte Carlo simulation method and its limitations. In the main text of the document, the discussions of Monte Carlo simulations were scattered in various sections and were integrated into the general discussions on selection of data, exposure scenarios, and pathways. As the computational algorithms for Monte Carlo simulation are relatively straightforward, the usefulness of the results is entirely dependent on a reasonable selection of parameters and data range and distribution. With the way the document is organized, it was difficult to get a comprehensive picture on exactly how the simulations were run. For example, how many parameters were involved and what ranges and distributions were used for a given simulation. It was also not clearly explained why a triangular distribution was used instead of another type of distribution.

Chapter 1 - Summary

General:

The PRC felt the summary was not very informative. The overall purpose of the document is not clear. At this point the reader cannot discern whether this is a risk assessment methodology document (descriptive), a risk assessment guidance document (prescriptive), a basis for regulations, or simply a risk assessment to determine if unacceptable risk results from the land application of CKD. It is clear that some risk assessment results have been generated, and as a summary it would seem that some measure of the risk associated with the use of CKD in terms of human health, phytotoxicity, and ecology should be presented in terms understandable to the lay person. In particular, the establishment of regulatory cutoff levels is mentioned yet these values are not present in the document (this mention of regulatory cutoff levels further confuses the reader as to the purpose of the document). The risk assessment really only covers the use of CKD as a liming material and this should also be clarified in this section. The addition of the word liming in the first sentence (. an agricultural soil liming amendment.) would help considerably.

Four receptor scenarios are presented, but it is never clear how these were selected for the detailed risk assessment that follows. What other scenarios were considered and why were the four presented here developed further?

Specific:

The references need some work. The reference for EPA 1988 should be either 1988a, 1988b, or 1988c. There is no EPA 1989 in the list of references.

Chapter 2 - Characterization of CKD

General:

The description of the samples used for the characterization data is lacking. The reference used (1996d) is incomplete so it would not be possible for someone to verify the data. Samples were collected from some 20 facilities, 10 that burned hazardous waste and 10 that did not, but there is no way to tell what proportion of the analyzed samples were from facilities that burned hazardous waste. Of the 11 samples analyzed for dioxin, for example, one could not be sure that only a single sample was analyzed from a hazardous waste burning facility. It is also not sufficient to say that metals were analyzed for 15 facilities (or dioxin for 11) because that does not indicate how many samples were analyzed in total for metals or dioxins. Were multiple samples run from one facility? There is a discrepancy between a description provided in Appendix C and the sample description in this section. On page 6 in Appendix C, reference is made to data for dioxins from 14 facilities and 63 facilities for metals. The data in Table 2, Appendix C, and Table 2-1 are nearly identical, suggesting the same data, but the descriptions do not match. The characterization of CKD is critical to this document, and the authors should carefully describe the samples that were used to ensure credibility.

There is no rational presented for the selection of the metals that are covered in the risk assessment. Several potentially important omissions include B, Co, Cu, Mo, and Zn. Were concentrations of these elements not determined in the samples that were analyzed? Were the concentrations below the detection limits of the elements listed above? Was there some other specific reason for the absence of these elements?

Specific:

Table 2-1 has a zero for the median Hg concentration. If this table is supposed to agree with Table 2 in Appendix C then this value should be 0.1. Define the meaning of "- -" for the background soil concentration for Cd The background soil concentration for Ag and Tl can not be zero. Select another reference if Dragun and Chiasson does not have values for these elements.

The reference to USEPA 1996b does not agree with the USEPA 1996d given on page 3.

The reviewers question the use of significant digits in Table 2-2. To state a concentration of 0.00188 ppb implies that you can distinguish between 0.00188 and 0.00189 ppb, which generally cannot be done.

Chapter 3.0 - Agricultural Liming Practices

General:

There are some deficiencies in the methods used to select sites and soils that would be suitable candidates for CKD applications The authors are incorrect in assuming that liming materials would only be required on soils that were classified as generally acid by the 1968 data from the USDA (Figure 3-2) Cultural practices can produce acidic soils in areas noted as neutral or transitional or even generally alkaline according to the classification scheme used here. For example, the use of ammoniacal nitrogen fertilizers has produced large areas with acidic soils in the Central Plains that would not be considered in this risk assessment. For example, Kansas and Oklahoma are not included in Table 4. Appendix C, because they do not have soils classified as generally acid, yet there is a strong demand for liming materials in these two states These improper assumptions are made worse by the use of outdated soil classification information The data used to generate Figure 3-2 are over 30 years old and the terminology that is presented is not used anymore. The NRCS has soil classification data readily available at http://www.ftw.nrcs.usda.gov/ssur_data.html that includes the SSURGO database that would probably be the most appropriate for this application. Given the expanded region having soils that could receive CKD, some consideration needs to be given to climatic data used in the risk assessment. The rainfall and temperature distributions in the central plains are quite different than in the locations that were considered. There is no sensitivity analysis to indicate the effects of climatic data inputs on outcomes of estimation.

Specific

Page 7. The assumption regarding the use of CKD on low pH soils should be stated in the summary

Table 3-1. This table lists the high end deterministic values for tillage depth as lower than the central tendency value whereas Table 5, Appendix C, has the high end tillage depth as higher than the central tendency. Please clarify.

Page 8. What is meant by "tilling is assumed for 15 days per year?" Fifteen tillage operations? This might be appropriate for CKD used on a home garden, but would not be correct for typical crop production practices What about the use of CKD with reduced or no-till practices where the material may not be incorporated or may only be incorporated a few inches?

Page 9 Please include a figure caption and label the axes. The 100 year lifetime is different than used in the sensitivity analysis (Appendix C) Please explain.

Table 3-3 Soil texture information should be supplied. The worst case scenario for land application of CKD would be a coarse-textured soil with the saturated zone near the surface Why was Indianapolis, IN eliminated from consideration?

Page 10. To limit the use of CKD to within 20 miles of the place of production seems arbitrary. What is the basis for this limitation? A larger radius should be considered.

Chapter 4.0 - Fate and Transport in the Environment

General:

This section covers the basics of fate and transport for organic and inorganic contaminants in CKD It is not clear how K_d values were obtained for Pb and Sb since it is specifically mentioned that MINTEQ was used for Ag, Ba, Be, Cd, Hg, and Ni and empirical relationships were used for As, Cr, Se and Tl. No references are cited for the empirical relationships for K_d values for As, Cr, Se, and Tl and they should be provided. In particular, the relationships indicate As adsorption increases as pH increases and this runs contrary to what chemistry would suggest for anionic compounds that do not form insoluble precipitates at a high pH. The most likely oxidation state for As in surface soils would be V as arsenate and not III as arsenite The reviewers disagree with the statement that the geochemistry for As, Cr, and Se is poorly understood as considerably research has been done with each of these elements Some assumptions used in the MINTEQ modeling are questionable, but the net effect would seem to be to overestimate risk. Given the assumptions that were used and the conclusion that site-specific soil parameters were determined not to be risk drivers, it seems unlikely that correcting the assumptions will change the overall outcome of the risk assessment.

The approach used for dioxin and metal partitioning in soil using the Jury equations appears reasonable with the exception of the errors noted on pages 8 and 9

A standard approach was used to determine risk from PM_{10} The authors might want to consider recent emphasis on $PM_{2.5}$ in addition to PM_{10} It is not clear whether the inhalation pathway risk was due to contaminants in the PM_{10} or from the PM_{10} itself. If the risk was for contaminants associated with PM_{10} then the assumptions regarding enrichment factors (PM_{10} versus whole soil contaminant concentrations) need to be stated.

The use of Br factors from the *Technical Support Document for Land Application of Sewage Sludge* is inappropriate, although the reviewers are not aware of data dealing specifically with CKD. The matrix for biosolids would be completely different than CKD due to the presence of the organic materials and other constituents that may act as metal absorbents. The Br values used in California Department of Food and Agriculture (1998), a risk assessment for As, Cd and Pb in inorganic fertilizers, are generally higher than those presented here. Many of the Br values presented in the California report are derived from studies using inorganic salts, illustrating the influence of the source of the element. It is not likely that plant uptake studies using inorganic metal salts would be more appropriate for CKD than those from biosolids Alternatively, metal uptake studies using coal fly ash, wood ash, or flue-gas desulfurization by-products would also seem more appropriate than studies utilizing biosolids. There is also a problem with the terms and abbreviations used for the plant-soil bioconcentration factor In other places it is called the plant biotransfer factor and either Br or BCF are used as the abbreviation. These should be uniform throughout the document.

The atmospheric concentrations of CKD constituents were used to estimate the exposure risk to airborne metals and dioxins at the application site. The estimations were entirely based on hypothetical situations and model calculations and therefore it would be difficult to reviewers of this document to comment on the accuracy of the results without repeating all of the model simulations. We chose to comment on the appropriateness of the simulation models, exposure scenarios, and input data The general considerations were

1) Exposure to airborne CKD constituents: direct inhalation by farmers, vapor uptake by plants, and dry deposition of particulates to plants. Exposure due to dispersion to offsite locations is not significant.

2) Pathways: volatilization, emissions due to wind erosion, and emissions due to agricultural tilling

3) Emission estimation methods: volatilization was based on the Jury partition model while particulate emissions were based on two empirical equations for estimating PM_{10} and PM_{30} from wind erosion and tilled fields.

4) Air dispersion and deposition. Gaussian plume model ISCST3 was used to estimate vapor concentration and dry deposition rates (default option was used).

The assumptions were:

1) Fields are not covered by continuous vegetation or snow and surface soil has an unlimited reservoir of erodible surface particles

2) Silt contents ranging from 3 to 87% has no significant influence on the risk estimation.

3) Fields tilled for 730 hours

4) No dry deposition on rainy days and wet deposition is negligible.

5) Three field sizes: 800 m x 800 m, 950 m x 950 m, 1150 m x 1150 m

6) Climatic data from Alpena, MI; Indianapolis, IN; and Miami, FL.

In this estimation, outputs from Jury's model (dioxin vapor fluxes) and results from calculations by two empirical equations (for airborne particulate fluxes due to wind erosion and agricultural tillage) were linked with ISCST3 to obtain the actual air concentration estimates. The models used in the simulation were all standard models (except Jury's transport model) used by federal agencies. While the outcome cannot be verified by actual measurements, in this case, model simulation is appropriate because there is no other reliable way of estimating. As the assumptions used in developing the exposure scenarios and selecting input data to calculate fluxes and concentrations were in general cautious (such as 730 hours of tillage time), the end results of parameter estimation would therefore be conservative. If there is a fault with this estimation (if geographical location of the application site is not an issue), it would have to be on the potential of over estimating concentrations of airborne substances due to volatilization, wind erosion, and tillage operations. As a result, subsequent calculation on vapor adsorption and foliar deposition of dioxin and metals (or concentration in plants) could be over estimated. Generally, an overestimation may be compensated by conducting a Monte Carlo simulation which takes into consideration the distribution of parameter values. In this case, the authors of the document reported that many parameters such as soil texture and the size of the application field had no significant effect on the outcome. The concentration estimations of airborne pollutants would remain essentially a function of the CKD application rates.

Specific:

Page 20. Target pH values for corn would be between 6.5 and 7.0, not 6.0 as stated here. An upper-end pH as high as 8.3 would be more reasonable given the reaction that occurs when CKD is added to soil. The pH will increase considerably at first, to values in excess of 9.0, and then conversion of $Ca(OH)_2$ to $CaCO_3$ will reduce the pH to approximately 8.3 while equilibrium with

$CaCO_3$ is maintained. Some farmers do apply liming materials in excess of their needs, which suggests that soil pH levels may be maintained at values greater than 7.0 for significant periods of time

Page 20-21. The emphasis on iron-oxide content seems to be driven by the fact that MINTEQ can handle this adsorbent rather than by reality. The lack of consideration of clays as absorbents is a significant omission, but this is one of the assumptions that will over estimate risk (predict lower K_d values) Some speciation models (GEOCHEM, SOILCHEM) will handle clays and efforts could be made to utilize these models instead of MINTEQ. The cation exchange capacity of most of the soils being considered for CKD applications will be predominantly from the permanent charge in 2:1 clays and not the variable charge associated with Al and Fe oxides Further compounding this problem is the use of a single value for the iron-oxide content (Table 3-3) for all soils. The NRCS soil characterization laboratory in Lincoln NE should have better data than what is used here.

Page 21 It is not reasonable to assume that soil pore water has a composition similar to that of rain. Similarly, the carbon dioxide concentration in the soil air is several hundred times that in the atmosphere. The considerable difference in carbon dioxide enrichment between rainwater and the soil solution results in a marked difference in the solubility of a number of elements and influences their speciation For instance, the Ca concentration in the soil solution can be in the range of 0.005 to 0.01 M, which is many times higher than the value given in Table 4-2. If the actual soil solution composition is not known, average values from other locations should be used instead of rainwater.

Page 22 Be consistent with the use of units. You have used English (tons/acre) and metric (cm) units simultaneously.

Page 23. In some locations, a soil Pb concentration of 842 mg/kg would indicate soil remediation is necessary. This and other values in Table 4-3 seem too high. If one calculates the application of Pb in kg/ha from 14 applications at 2 tons/acre and a Pb concentration of 1346 mg/kg (95 th percentile) you get 85 kg/ha. In a 20 cm soil layer this translates into an increase in soil Pb concentration of approximately 57 mg/kg. What is the reason for using 14 applications at 2 tons/acre? The application rate is less than the central tendency shown in Table 3-1 and 14 applications doesn't agree with the application frequency and 100 year lifetime values that are used. Please explain.

Page 24 It is stated that the background soils for the three sites are characterized by large quantities of clays, yet Table 4-5 shows very high silt contents. Please clarify.

Page 24. The reviewers agree that it is reasonable to not consider competition between trace metals, but feel that competition between Ca and metals should be considered Calcium would be high in these systems and the presence of high Ca levels would tend to decrease K_d values for the metals of concern.

Page 24. The use of an intermediate value for pH throughout the lifetime of the agricultural field does not simulate reasonable worst case scenarios. If one wants to conservatively estimate risk from cationic metals, the soil pH should be acidic, for example, which might occur when CKD is used for a period of time with no additional applications, followed by soil acidification. A soil pH of 5.0-5.5 would be better for assessing the risk from cationic metals

Page 26. It would seem that equation 4-6 should multiply the concentration of contaminant in the CKD times the application rate rather than the soil concentration by the application rate. This has implications for equation 4-11 as well

Page 27 Equation 4-8 should have exp(-kt). The minus sign on k was left out

Page 27. This is a rather arbitrary way of calculating degradation. It assumes that we have no information on degradation rates, but have an experimental data base of environmental persistence values, which embody all of the effects that lead to dissipation of contaminant from soil. Degradation is estimated as the amount determined from this loss coefficient minus the calculated material losses from all other mechanisms Why not calculate degradation directly from a degradation half-life? Although laboratory derived values of this parameter are crude, they will probably be at least as accurate as they are calculated in this document, and quite possibly more so. With the present approach, the validity of the expected loss of contaminant mass depends on whether or not the chosen k_{soil} is correct. The data source for the k_{soil} values should also be stated.

Page 28. The section at the top of the page is very confusing. All that is required is to state that the height of the soil does not increase with the added material. The reference to a subsurface layer that is not used is superfluous to the modeling discussion and very confusing.

Page 28. Provide the units for tillage depth in Equation 4-11.

Page 28. Equation 4-13 is only valid when $V_E = 0$ and cannot be added to a convective term to produce convective-dispersive volatilization.

Page 29 Equation 4-15 is wrong. To derive the equation you need, you must let $H_e \to \infty$ in equation 25 of Jury et al (1983) which produces (in Jury's units):

$$J_s(0,t) = \frac{1}{2} C_o V_E \{erfc[\frac{V_E t}{\sqrt{4 D_E t}}] - erfc[\frac{L - V_E t}{\sqrt{4 D_E t}}]\} + C_o \sqrt{\frac{D_E}{\pi t}} [\exp(-\frac{V_E^2 t}{4 D_E}) - \exp(-\frac{(L + V_E t)^2}{4 D_E t})]$$

This reduces to Equation 4-13 when $V_E = 0$ and is correct when $V_E \neq 0$. It is also not clear what the relationship is between the volatilization equations derived in this section and the volatilization transfer coefficient given in Appendix A on page A1 13. The latter is an empirical engineering correlation There is also some question about assuming that $H_e \to \infty$ since some of the dioxins have low enough Henry's Law constants that they would accumulate in the boundary layer.

Page 31. Provide information on how these values were obtained from the Jury equations. What was the CKD application rate and frequency and what values were used for contaminant concentrations? What about metals?

Page 34. There is no soil classification for silty till shown in Table 4-5. Provide the source of data for that used in Table 4-6

Page 35. We question the assumption that exposures from transporting, loading, and unloading CKD will be minimal compared to continuous releases from the agricultural field due to wind erosion and tilling The CKD materials can be fine powders that can produce considerable dust during handling.

Page 35. There is some confusion regarding the site selection. Earlier the three sites were in MI, NY, and SC and now we have MI, IN, and FL. What soil data was used for this study?

Page 37 What does M-O represent in Table 4-7.

Page 40 Define Rp for Equation 4-21

Page 41 and 42. References to Table 4-9 are not correct.

Page 42. Define Rp for Equation 4-23. Change the first minus sign to an equal sign.

Page 47. What is the source of the 0.01 empirical correction factor used to adjust the RcF values for barley roots? Is there a model available for bulky roots rather than trying to adapt a model for barley?

Page 50 The assumption that all soils in the watershed are the same is a poor one

Page 51. The units do not work out for Equation 4-27. In the second term on the right side, area and concentration variables are missing and from the fourth term the conversion factor of 0.001 is missing.

Page 52. The enrichment ratios for metals are often >1.

Page 52. $S_{c,erode}$ is not defined for Equation 4-28 It must have units of mg/kg for the units in the equation to work out.

Page 53. The units do not work out in Equation 4-30. The problem is with ($X_{c,sa}$ x SD_{sb}) in the numerator of the first term

Page 56 Provide units for the Henry's law constant, molecular weight, solubility and RfD in Table 4-16. Define all abbreviations used in this table.

Page 57. Soil microorganisms are capable of methylating Hg, which is contrary to the statement made in the second paragraph. The reference to Table 4-14 in the third paragraph is not correct.

Page 58. Put (HQ) in the table heading.

Page 59. Provide references for the data in Tables 4-18 and 4-19.

Page 59. The reference to Table 4-18 in the last paragraph should be to Table 4-20.

Page 61. There is no reason to have Pb vegetable concentrations in this table if they are all zero. There are too many significant digits for soil Pb concentration. How were the soil Pb concentrations obtained? Were there assumptions about CKD application rate and CKD Pb concentrations that were used to generate the range of soil Pb concentrations used in the IEUBK modeling? What assumptions were used in the IEUBK for soil Pb bioavailability and other parameters? The simulation clearly shows potential problems between the 95th and 100th percentiles.

Chapter 5 - Scenarios and Exposure Routes

General:

The scenarios and exposure routes considered for the receptor scenarios seem reasonable and justifiable

Specific:

Page 63. The use of a 60 kg average body weight will overestimate risk for most adults.

Page 64. Why was a triangular distribution selected, especially since the authors recognized this distribution may overestimate the frequency of high-end ingestion which would be the most critical scenario

Page 65. Throughout this chapter it would be helpful if the figures had captions, the axes on the figures were labeled, and the source of data in the table/figure combinations was cited, if appropriate

Page 65. It appears that a single value was used to represent the fraction of vegetable consumption that was home-grown on contaminated soil. Judging from the values in Table 5-3, this would be a worst possible scenario. Again, it was a conservative bias in selection of input data. In deterministic calculations it is acceptable to use the worst case scenario. The home-grown fraction of vegetables would be such a variable and a distribution of values should be assigned if one does Monte Carlo simulation. At least a sensitivity analysis should be conducted to show that the fraction of vegetable consumption that was home grown is not a risk driver

Page 66 It seems odd that the fraction of dietary item listed as home-produced is higher for households on farms compared to households with gardens. Are we assuming that farm households also have gardens?

Page 69-86. This section contains probabilistic distributions of consumption rates for home grown fruit and vegetables and the probabilistic distribution of home grown beef and dairy intake. For each data set, there was a table listing consumption rates and their corresponding probability figure that presumably depicted the probabilistic distribution in graphical form. The scales of the figures were not easy to understand. The horizontal scale (consumption rate) was confusing because the marked intervals on each graph did not always have the same range. The vertical scale (presumably probability) was not labeled. Tables 5-8 and 5-9 had identical tabulated distribution patterns but the distribution patterns were not the same graphically. This was in contrast to Table 5-12 vs. Table 5-13 and Table 5-14 vs Table 5-15 where tabulated and graphical distributions agreed. Tables 5-28 and 5-29 had very similar tabulated distribution values but the graphical distribution patterns were quite different. Perhaps the uneven horizontal scale had something to do with it.

Page 71. For many of these probability tables the continuous range does not steadily increase, as is the case for Table 5-11. The first range is 0.0000 to 0.0000 and the second range is 0.0000 to 0.0004. There are also different font sizes used within tables. Is there a reason for this?

Chapter 6. - Ecological Screening Analysis

The reviewers concluded that this section is inadequate. The use of ecological benchmarks for soil and phytotoxicity from the *Technical Support Document for the Land Application of Sewage Sludge* is again inappropriate. This direct comparison can lead to arguments that rules for biosolids should be applied to CKD, as commented earlier, and that the CKD soil numbers are acceptable even though no studies have been done to directly compare their results. The reviewers suggest a literature review of ecological benchmarks for metals from various sources with a presentation of a range of values so it can be determined where the range of soil concentrations shown in Table 6-1 are in comparison to other benchmarks. There have been a number of ecological risk assessments performed for metal contaminated sites that can be used as a guide for ecological benchmarks for soil and phytotoxicity. The authors are also referred to Will and Suter (1995)

Chapter 7. - Risk Assessment Results

General.

The reviewers generally felt this section was inadequate. This section represents the culmination of all of the efforts to this point and yet it is summarized in less than one page. The reader is forced to scan all of the tables themselves to determine when Tl and As present unacceptable risk for the child of farmer scenario or which dioxin congeners present unacceptable risk for the farmer and child of farmer scenarios. Summary tables are drastically needed here as well as considerably more interpretation and summarization. The issue of Pb is not addressed in this section at all, and wasn't summarized in Chapter 4 either

After studying the entire document, the purpose of the effort is still not clear, although the accomplishments are more obvious. If the risk assessment results are to agree with what is presented in the summary (Chapter 1), the reader was expecting to find regulatory cutoff levels here, but there are none. It is clear that the report is not a risk assessment methodology or guidance document.

It is encouraging to see the results of the deterministic and probabilistic analyses agree fairly well.

Specific:

Page 90 These tables could be a little more user friendly if it was clear which columns were hazard quotients and which were risk factors. If one does not know this information (it can be ascertained from Appendix B) there should be a reference to it in this section. Similarly, it would be useful to state the critical values used to determine when there is increased risk (HQ ≥ 1, Risk $\geq 10^{-5}$). Not all such values are written in bold type.

Page 104 and 107. The table headings should indicate dioxins and not metals.

Appendix A

In many of the tables there are separate columns for central tendency and high end values yet only a single value is provided These columns should be combined when there is no need for the separate columns.

Table A-1.1 ER is not defined.

Table A-1.2 A_B is not defined

Table A-1.6 What is the background document that is referred to in this table and others?

Table A-1.8. There should be a different value of b for each location if this variable is soil-specific

Table A-1 10 Give units on 0 1 conversion factor (g m^2/kg cm^2).

Table A-2.3. Is $X_{c,WT}$ the same as $X_{e,F}$?

Table A-2.4. Unclosed parenthesis on the units for C_{wtot}.

Table A-2.5 The units for Kd_{sw} should be cm^3/g and not g/cm^3.

Table A-2 7. Why is TSS set to be a constant 80 mg/L?

Table A-2.11. Why is the bed sediments concentration set to 1?

Table A-2.20. The values of OC_{bs} seem extremely low. Are they correct?

Table A-3.1. A conversion from g/kg to mg/kg is needed. The same holds for Tables A-3.4 and A-4 3.

Table A-3.2. A conversion from cm^3 to m^3 is needed. The same holds for Tables A-3.5 and A-4.4.

Table A-5.1 to 5.6. The calculated values listed in these tables suggest that Sc can be found in Appendix A, but where? Where in Appendix B and D can you find the other values?

Table A-5.2. Is I_{ev} the same as I_{ag}? The units work out to be mg/d while the units listed for Iag are given as mg/kg FW. The unit problem is also found in Tables A-5 3 and A-5.4.

Table A-5.3. The value of Pd is calculated, but how?

Table A-5 4. Is I_{ex} the same as I_{ev} and is Pr_{bg} the same as Pr_{bv}?

Table A-5 5. The values for some of the parameters vary, but the location of the calculations are unknown.

Table A-5.6. Where in Appendix A and D can these values be determined?

Table A-5.7. There are no units given for I_{ex} and I_{ev}.

Table A-5 8 and 5 9. Where in Appendix B and D can these values be determined?

Table A-5.11. Table A-5.7 calculates daily intake, not cancer risk as suggested in the equation given

Table A-6.1. Where in Appendix A and B can these calculations be found?

Table A-6.2 C_s and ED are not defined.

Table A-6.4. References to Tables A-61 and A-62 should probably be A-6.1 and A-6.2

Appendix B

There is no numbered list of references corresponding to the last column in each table.

Change Ba_{beef}/Ba_{pork} to Ba_{beef}, Ba_{pork} as the current usage implies a ratio Change the definition to read "Biotransfer factor for beef or pork".

Appendix C

This is clearly a document produced by another group of individuals other than the ones preparing the main body of this draft document. It was completed almost one year in advance of the draft document, yet it appears that it was not integrated into the report and was tacked on at the end. Because this starts out as a PRELIMINARY DRAFT, should additional work have been conducted?

Page 2. How were the risk drivers determined? References are not properly formatted, i.e., is it USEPA a, b, or c?

Page 3. How were the potential risk drivers determined? The risk ratio is used in this table and the description of the risk ratio is not presented until page 16. The risk ratio should be defined the first time it is used The values for the risk ratios in the table are actually the range of risk ratios and this should be clarified. The range of risk ratios do not agree with those shown in Tables 10 to 13

Page 4. This is a poorly referenced table. References are not listed in the reference section. There should be a value listed for the background soil concentration for Cd. The reference column only refers to the background soil concentration and should be indicated as such.

Page 5 What are the units for the background soil concentrations?

Page 6. What 14 facilities supplied the samples for dioxin analysis and what 63 facilities supplied samples for metals? On page 3 in the Characterization of CKD section of the main document there were only 20 facilities sampled. Why the difference? References are incorrectly written. There is an incomplete sentence on the second from the last line.

Page 7. Note that almost all of the sites are east of the Mississippi River. The sixth line from the bottom should read 2, 3, and 5 years according to Table 5. Where is the reference for RTI (1996)? Reword the sentence starting with "The bulk density ..."

Page 8. In the main body of the document the lifetime of an agricultural field or home garden was assumed to be 100 years. Why were the lifetimes for the field and garden assumed to be 40 years in this analysis? References are needed for Table 5. Why would a steady state be reached if applications are to be continued?

Page 9. There are contradictory statements made on this page. First it is stated that particles greater than PM_{10}'s are not important, yet in the equation PM_{30}'s are used. Why? What is the extra "I" in the definition of K_d? Separate N_{op}, which is on the same line as S. What does the "total waste stream" in the second paragraph from the bottom refer to with respect to this analysis?

Page 10. Why was silt used as a parameter in the sensitivity analysis? References are needed on this page. Is it USEPA 1993 a, b, or c? Change the word theat to that. Change form to from on the 11th line from the bottom.

Page 11. Old information is used for the soil taxonomic information. Change n to in. Soil Foc are extremely low. Because the CKD was only supposed to be used on acid soils, why is the 95th percentile value equal to 7.2?

Page 12. Rewrite first sentence. References are needed for the Metal Speciation and Partitioning section. Other references are reported incorrectly.

Page 13. References are needed for footnotes of Table 8. USEPA 1992 and 1996 - a, b, or c?

Page 14. Why are the units different from the equation given? References are needed for section 7.0.

Page 15. Why are there no data for ingestion by children other than soil?

Page 16. Watch the extra periods. Rewrite the last few sentences in the second from the last paragraph.