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Technical Background Document for the Sewage Sludge Exposure and Hazard Screening Assessment

Prepared for

Office of Water
U.S. Environmental Protection Agency

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List of Abbreviations

3MRA	Multimedia, Multipathway, Multireceptor Risk Assessment
ADD	average daily dose
AUR	air unit risk factor
BAF	bioaccumulation factor
BD	bulk density
CC	critical concentrations
CD	critical dose
CSF	cancer slope factor
CWA	Clean Water Act
DAF	dilution-attenuation factor
EFH	Exposure Factors Handbook
EPA	U.S. Environmental Protection Agency
ERL	effects range-low value
FOC	fraction organic carbon
GIS	geographic information system
GSCM	Generic Soil Column Model
HHB	human health benchmark
HQ	hazard quotient
IRED	Interim Reregistration Eligibility Decision
IRIS	U.S. EPA's Integrated Risk Information System
ISCST3	Industrial Source Complex Short-Term Model, Version 3
IWAIR	Industrial Waste Air Model
LADD	lifetime average daily dose
LAU	land application unit
MIBK	methyl isobutyl ketone
NAS	National Academy of Sciences
NODA	Notice of Data Availability
NSSS	1989 National Sewage Sludge Survey
OPP	U.S. EPA Office of Pesticide Programs
OSW	U.S. EPA Office of Solid Waste
OW	U.S. EPA Office of Water
PAD	population adjusted dose
RED	Reregistration Eligibility Decision
RfC	reference concentration
RfD	reference dose
SIS	Surface Impoundment Study
TRED	Tolerance Reregistration Eligibility Decision
UAC	unit air concentration
URF	unit risk factor
USLE	Universal Soil Loss Equation
WMU	waste management unit

Executive Summary

ES.1 Background

In February 1993, the U.S. Environmental Protection Agency (EPA) published the Standards for the Use or Disposal of Sewage Sludge (40 CFR Part 503). This rule is known as the Round One Sewage Sludge Regulation. 40 CFR Part 503 under section 405 of the Clean Water Act (CWA) contains management practices, pollutant limits for metals, and technology-based operational standards for pathogens that protect public health and the environment from reasonably anticipated adverse effects of pollutants in sewage sludge when the sewage sludge is land applied, placed in a surface disposal unit, or fired in a sewage sludge incinerator.

Section 405 of the CWA required EPA to propose and, after receipt and consideration of public comments, publish a decision to either (1) establish a Round Two regulation under Part 503 for additional pollutants in sewage sludge or (2) issue a finding of “no action” for these Round Two pollutants. In addition, Section 405(d)(2)(C) of the CWA requires that, bienially, EPA review the current literature to determine if additional chemical pollutants are warranted for addition to the Part 503 rule.

EPA also asked the National Research Council (NRC) of the National Academy of Sciences (NAS) to evaluate the technical basis of the Part 503 Round One rulemaking, report its conclusions, and make recommendations for future sewage sludge regulatory efforts. The NRC study took place between January 2001 and June 2002. In July 2002, the NRC published a report entitled *Biosolids Applied to Land: Advancing Standards and Practices* in response to EPA’s request. EPA has pursued the following NAS-recommended activities, which are described in this document:

- A literature review to identify potentially toxic chemicals that may be present in sewage sludge but that are not already addressed by EPA rulemaking activities (i.e., chemicals other than the Round One chemicals and the Round Two chlorinated dibenzo-p-dioxins, chlorinated dibenzofurans, and co-planer polychlorinated biphenyls [PCBs]).

- A screening assessment to identify which of these additional chemicals should be subjected to a multipathway exposure and hazard assessment.

These activities thus identify and select additional chemicals for the multipathway screening assessment. The purpose of this document is to present the methodology and results of the screening assessment that was conducted to identify additional pollutants for consideration in potential rulemaking under section 405(d)(2)(C) of the CWA.

ES.2 Overview of Screening Assessment Methodology

The 40 chemicals selected by EPA for exposure and hazard screening (see Table 1-1) were each evaluated in two sewage sludge management practices: (1) the application to agricultural land scenario, and (2) the sewage sludge lagoon scenario (i.e, surface disposal unit).

For the agricultural land application scenario, EPA assumed that sewage sludge is applied to both pastureland and cropland that are used to raise food for human consumption. The farmer was assumed to apply sewage sludge to pastureland and cropland at the appropriate agronomic rates (i.e, sewage sludge was applied biennially at a rate of 5 to 10 metric tons per hectare dry weight). The agricultural land application scenario considered exposure to humans and wildlife species following the application of sewage sludge containing each of the pollutants to a nationwide distribution of farms. Many parameters were set to higher-end or reasonable upper bound values to ensure that all potentially hazardous pollutants in sewage sludge were identified for an exposure and hazard assessment (see Table ES-1).

Application to both row crops and pasture includes runoff into two waterbody types:

- An index reservoir used as a source of drinking water by the farm family
- A farm pond populated and frequented by ecological receptors and used by the farm family for recreational fishing.

The “index reservoir” is modeled after the Shipman City Lake in Shipman, Indiana, for drinking water exposures. This reservoir covers 13 acres, is 9 ft deep, and has a watershed area of 427 acres. The ratio of drainage area to capacity (volume of water in the lake) is approximately 12 for the index reservoir in this assessment. These areas remain constant in this assessment, and the same index reservoir was assumed to occur in each of the 41 climate regions. Also, in the screening assessment, it was assumed that the 427-acre watershed area contains other farms that also apply sewage sludge occupying 10 to 80 percent of the watershed in aggregate (in addition to the modeled farm).

The second waterbody type is a farm pond and was used to evaluate ecological exposure, and human exposure from fish consumption. It was assumed that the pond’s total drainage basin includes the farm area and that the pond has a drainage-area-to-capacity ratio of five. The farm pond depth is assumed to be constant at 9 feet. The area of the modeled pond is proportional to the area of the farm. EPA also assumed that there is no buffer between the amended agricultural land and the farm pond; thus, EPA assumes that the erosion and runoff from the agricultural land go directly to the farm pond.

The lagoon scenario was the surface disposal unit chosen for the model because sewage sludge disposed of in such an impoundment is likely to have the greatest potential of the various surface disposal configurations to cause groundwater contamination. EPA assumed that sewage sludge is managed in a lagoon or non-aerated surface impoundment that contains 10 percent total suspended solids (TSS) with hydraulic residence times greater than 2 years, and that no food chain or ecological exposures occur from sewage sludge in this surface lagoon scenario. It was assumed that these impoundments are located in a rural industrial setting where residents live

Table ES-1. Reasonable Upper Bound Assumptions Used in the Agricultural Land Application Scenario

Parameter	Assumption
Chemical properties	If no data are found for hydrolysis or degradation, those values are assumed equal to zero.
Concentration	The concentration is assumed to be the 95^{th} percentile measured value from the 1989 National Sewage Sludge Survey (NSSS).
Receptors	Members of the subpopulation defined as subject to RME are assumed to be farmers living immediately adjacent to the farm where sewage sludge is applied. They are assumed to get a significant portion of all their diet items from homegrown products produced on sludge-amended soils and to drink and shower with either untreated surface water from the index reservoir or groundwater from a residential well immediately below the cropland. These individuals are more highly exposed to sewage sludge than the general population.
Site-specific parameters	A distribution of site-specific parameters was used for the 41 climate regions.
Air modeling data	Maximum values for air concentrations of vapors and particles and wet and dry deposition of vapors and particles are assumed to apply to the entire area of the cropland, pasture, buffer, and waterbody.
Groundwater screening	Groundwater ingestion assumes that the well water concentration is the concentration in the leachate at a depth of 1 m beneath the crop soil. The maximum annual concentration is used as the groundwater exposure concentration resulting from leachate.
Waterbody	A small, fixed-size index reservoir is used to evaluate ingestion of surface water receiving runoff. A small farm pond receiving runoff is used to evaluate fish ingestion and potential ecological impact.
Exposure factors	Distributions of values from the *Exposure Factors Handbook* (U.S. EPA, 1997a,b,c) are used to estimate exposure factors.
Ecological hazard	The most sensitive benchmark is used for each receptor/chemical combination. For chemicals and receptors without measured values, a default of one is used as the bioaccumulation factor (BAF). Maximum 1-day, 4-day, 21-day, or annual farm pond concentrations are used for ecological hazard to match with the duration of the study used as the basis of the benchmark. All ecological exposures are assumed to be from the sludge-amended areas. For the ingestion pathway, 100% of each receptor's diet is assumed to come from the sludge-amended field or the farm pond.

within a distribution of distances relatively close to the lagoon, where they might be exposed to ambient air contaminated by sludge pollutants or where they might ingest drinking water from residential groundwater wells. These modeled residents also use their residential wells as a source of drinking water and for other household uses, such as showering. Many parameters were set to higher-end or reasonable upper bound values to ensure that potentially hazardous pollutants in sewage sludge were identified for an exposure and hazard assessment (see Table ES-2).

Table ES-2. Reasonable Upper Bound Assumptions Used in the Sewage Sludge Lagoon Scenario

Parameter	Assumption
Chemical properties	If no data are found for hydrolysis or degradation, those values are assumed equal to zero.
Concentration	The concentration is the 95th percentile measured value from the 1989 NSSS.
Receptors	Modeled residents are members of a rural family who live downwind (based on prevailing winds) from the sewage sludge lagoon and have a residential well that is used for drinking water and showering.
Site-specific parameters	A distribution of site-specific parameters was used for the surface impoundment sites.
Air modeling data	Maximum values were used for air concentrations of at each receptor distance.
Groundwater screening	Residential well water concentration is one-half the concentration in the leachate immediately beneath the sludge lagoon. The maximum annual leachate concentration is used for noncancer endpoints. The maximum concentration in leachate for the exposure duration is used for cancer endpoints.
Exposure factors	Distributions of values from the *Exposure Factors Handbook* (U.S. EPA, 1997a,b,c) are used to estimate exposure factors.

For modeling exposure to humans, members of the subpopulation are defined as subject to reasonable maximum exposure (RME) and include a farm family (child and adult). For the agricultural land application scenario, the farm family is assumed to live on a farm and consume farm-raised foods where land-applied sewage sludge is used as fertilizer or a soil amendment and, therefore, are more highly exposed to sewage sludge than the general population. The farm family's diet is assumed to include a significant portion of home-produced foods, including exposed and protected fruits and vegetables, root vegetables, beef, and milk. Ecological species modeled include invertebrate and vertebrate animals and plants that may be exposed to contaminants through agricultural application of sewage sludge as a fertilizer or soil amendment.

The total ingestion dose from all ingestion pathways was compared with the critical dose to yield ingestion pathway screening results. For inhalation exposures, the annual average ambient air concentration and annual average shower air concentration were the exposure concentrations of concern and were compared with the critical concentrations to yield the inhalation screening results. Ecological receptors were assumed to forage on the agricultural land and in and around the farm pond. The ecological exposure concentrations or doses were compared with ecological benchmarks for the same time scale (1-day, 4-day, 21-day, or annual) to yield ecological screening results. Dermal exposure was not evaluated because dermal exposure is considered minimal for purposes of this screening assessment.

ES.3 Summary of Results

A screening assessment was performed for 40 selected pollutants using the two management scenarios. This section presents the list of pollutants that resulted in hazard quotients (HQs) greater than one for human health and greater than or equal to one for ecological species[1] at the 95th percentile of the HQ distribution. For this assessment, HQ is the ratio between the environmental concentration and the critical concentration, or the ratio between the receptor dose and the critical dose.

Table ES-3 presents the list of pollutants that had HQs greater than one in the human health screen. Table ES-4 presents the list of pollutants that had HQs greater than or equal to one in the ecological screen for the land application scenario. Table ES-5 presents the list of pollutants that had HQs greater than one for the human health screen in the sewage sludge lagoon scenario.

Table ES-3. Human Hazard Quotient Values Greater Than One at the 95th Percentile of the HQ Distribution by Pathway for the Agricultural Land Application Scenario

CASRN	Chemical	Pathway	Receptor	HQ
14797-65-0	Nitrite	Ingestion of Surface Water	Child	1.1
		Total Ingestion	Child	1.3
7440-22-4	Silver	Ingestion of Milk	Adult	3.8
			Child	12.0
		Total Ingestion	Adult	4.0
			Child	12.3

[1] Exposure at or below the human health benchmark values are considered protective of human health. Hence, the HQ values greater than one are considered to have failed the human health screen. Exposure at or above the ecological benchmarks or values are considered to exceed a level considered to be protective of wildlife species and the environment. Hence, the HQ values equal to or greater than one are considered to have failed the ecological screen.

Table ES-4. Hazard Quotient Values Greater Than or Equal to One at the 95th Percentile of the HQ Distribution for Aquatic and Terrestrial Wildlife Via Direct Contact Pathways[a]

CASRN	Chemical	Receptor[b]	HQ
67-64-1	Acetone	Sediment Biota	356.2
120-12-7	Anthracene	Sediment Biota	2.9
7440-39-3	Barium	Aquatic Community	235.7
7440-41-7	Beryllium	Aquatic Community	7.8
75-15-0	Carbon disulfide	Sediment Biota	1.9
106-47-8	4-Chloroaniline	Aquatic Invertebrates	1.3
333-41-5	Diazinon	Sediment Biota	1.1
206-44-0	Fluoranthene	Aquatic Community Sediment Biota	10.7 4.2
7439-96-5	Manganese	Aquatic Community	13.9
78-93-3	Methyl Ethyl Ketone	Sediment Biota	5.8
108-95-2	Phenol	Sediment Biota	102.4
129-00-0	Pyrene	Aquatic Community Sediment Biota Soil Biota	41.9 21.1 4.5
7440-22-4	Silver	Aquatic Community Aquatic Invertebrates Fish	246.6 28.2 4.8

[a] No pollutant resulted in an HQ equal to or greater than one for any wildlife species based on ingestion pathways.

[b] Sediment biota organisms include sediment invertebrates; aquatic community organisms include fish, aquatic invertebrates, aquatic plants, and amphibians; soil biota organisms include soil invertebrates.

Table ES-5. Human Hazard Quotient Values Greater Than One at the 95th Percentile of the HQ Distribution by Pathway for the Sewage Sludge Lagoon Scenario

CASRN	Chemical	Pathway	Receptor	HQ
7440-39-3	Barium	Drinking Water from Groundwater	Adult	1.5
			Child	3.5
106-47-8	4-Chloroaniline	Drinking Water from Groundwater	Adult	2.7
			Child	6.4
7439-96-5	Manganese	Drinking Water from Groundwater	Adult	32.3
			Child	76.3
14797-65-0	Nitrite	Drinking Water from Groundwater	Adult	13.6
			Child	33.8
14797-55-8	Nitrate	Drinking Water from Groundwater	Adult	9.2
			Child	23.0

ES.4 Document Organization

This background document is organized into the following sections:

- Section 1, *Planning, Scoping, and Problem Formulation*, describes the background and purpose of the screening assessment; the pollutants, sources, sites, receptors, exposure pathways, and endpoints considered in the assessment; and the conceptual model and analysis plan used to conduct the assessment.

- Section 2, *Analysis Phase*, describes the technical approach, assumptions, and data underlying the source modeling, fate and transport modeling, exposure modeling, and screening criteria development for the assessment.

- Section 3, *Screening Results*, presents the results of the screening assessment and discusses sources of variability and uncertainty in the assessment.

The following appendices, A through S, provide more detailed technical information on the data, models, and methods used in the screening assessment, as well as more detailed information on the results of the assessment:

- Appendix A, Characterization of Surface Impoundments

- Appendix B, Farm Size and Location

- Appendix C, Meteorological Data
- Appendix D, Soil Data
- Appendix E, Chemical Data
- Appendix F, Biota Data
- Appendix G, Surface Impoundment Model Documentation
- Appendix H, Source Model for Land Application Units
- Appendix I, Air Dispersion and Deposition Data and Modeling Input Files
- Appendix J, Surface Water Model
- Appendix K, Fate, Transport, and Hazard Calculations for Human Health and Ecological Effects
- Appendix L, Human Exposure Factors
- Appendix M, Bioaccumulation Factors and Bioconcentration Factors Used in the Ecological Screening Assessment
- Appendix N, Ecological Exposure Factors
- Appendix O, Human Health-Based Chemical Selection Process
- Appendix P, Ecological Benchmarks
- Appendix Q, Human Health Results
- Appendix R, Ecological Results
- Appendix S, Sensitivity Analysis Results.

1.0 Planning, Scoping, and Problem Formulation

The planning, scoping, and problem formulation phase of a screening assessment defines the objectives, basic framework, and plan for a subsequent risk assessment phase. This initial screening of pollutants in sewage sludge is designed to identify those pollutants that may pose risks to human health and the environment when sewage sludge is land applied or disposed in a sludge lagoon. The pollutants identified by the screening assessment will be further assessed through a more refined risk assessment and risk characterization and potentially included in the Standards for the Use or Disposal of Sewage Sludge (40 CFR Part 503).

This section begins with the regulatory background and purpose of this screening assessment (Section 1.1). The properties of sewage sludge are described in Section 1.2. Sewage sludge, along with the common sludge management practices (Section 1.3), defines the source term for this screening. The environmental settings and site layouts where these practices may occur are described in Section 1.4. Section 1.5 describes the conceptual model used in the screening. Section 1.6 describes the exposure pathways by which receptors can be exposed to sewage sludge pollutants, and Section 1.7 describes the human and ecological receptors of concern for the screening assessment. The human health and ecological endpoints selected for the assessment are described in Section 1.8. As the final output of the problem formulation phase, the analysis plan (Section 1.9) describes how this screening process was conducted to provide the U.S. Environmental Protection Agency (EPA) with the information needed to select the pollutants in need of further evaluation for possible inclusion in the sewage sludge management standards.

1.1 Background and Purpose

In February 1993, the EPA published the Standards for the Use or Disposal of Sewage Sludge (40 CFR Part 503). This rule is known as the Round One Sewage Sludge Regulation. Part 503 contains management practices, pollutant limits, and technology-based operational standards that protect public health and the environment from reasonably anticipated adverse effects of pollutants in sewage sludge when the sewage sludge is land applied, placed in a surface disposal unit, or fired in a sewage sludge incinerator.

Section 405 of the Clean Water Act (CWA) required EPA to propose and, after receipt and consideration of public comments, publish a decision to either (1) establish a Round Two regulation under Part 503 for additional pollutants in sewage sludge or (2) issue a finding of "no action" for these Round Two pollutants. In addition, Section 405(d)(2)(C) of the CWA requires that, bienially, EPA review the current literature to determine if additional chemical pollutants are warranted for addition to the Part 503 rule. In May 1993, EPA provided a preliminary list of 31 pollutants for the Round Two activity. EPA then conducted preliminary exposure analyses to determine which of these 31 pollutants to include on the final Round Two pollutant list. Based on the results of those analyses, three groups of pollutants were placed on the Round Two candidate list of pollutants:

- Polychlorinated dibenzo-p-dioxins (7 congeners)
- Polychlorinated dibenzofurans (10 congeners)
- Coplanar polychlorinated biphenyls (PCBs) (12 congeners).

EPA evaluated these pollutants (collectively known as dioxin and dioxin-like compounds [“dioxins”]) for the management practices of land application, disposal in surface impoundments, and incineration and issued subsequent rules for dioxins.

EPA also asked the National Research Council (NRC) of the National Academy of Sciences (NAS) to evaluate the technical basis of the Part 503 rulemaking, report its conclusions, and make recommendations for future sewage sludge regulatory efforts. The NRC study took place between January 2001 and June 2002. In July 2002, the NRC published a report entitled *Biosolids Applied to Land: Advancing Standards and Practices* in response to EPA’s request. On April 9, 2003 (68 Federal Register 17379-17395), EPA published its plan to respond to the NAS recommendations, along with its rationale and a solicitation for public comments. Since then, EPA has pursued the following NAS-recommended activities, which are described in this document:

- A literature review to identify potentially toxic chemicals that may be present in sewage sludge but that are not already addressed by EPA rulemaking activities.

- A screening assessment to identify which additional chemicals should be subjected to further evaluation or potentially considered in future rulemaking.

These activities thus identify and select additional chemicals for the multipathway exposure and hazard assessment. The purpose of this document is to present the screening methodology and results used to identify additional pollutants that require further evaluation and potential inclusion in future rulemaking activities under Part 503.

1.2 Characterization of Sewage Sludge

The characterization of sewage sludge includes the identification of the potential pollutants in the sludge, and the specification of other physical and chemical properties of sludge that are required to conduct a screening assessment.

1.2.1 Pollutants in Sewage Sludge

To identify pollutants for the screening assessment, EPA first compiled a list of more than 800 chemicals that occur in sewage sludge, then narrowed this list down to 40 pollutants by removing chemicals that had insufficient data for screening or that were otherwise unsuitable for the screening assessment.

EPA conducted an extensive literature search to obtain publicly available information on chemicals that may occur in sewage sludge, both at the national level and at the international level. The literature search covered 1990–2002 and identified a substantial number of chemicals found in sewage sludge from 25 countries. In addition, the 1989 National Sewage Sludge Survey (NSSS) (U.S. EPA, 1996) monitored about 400 chemicals. The list of chemicals from the NSSS was combined with the list of chemicals identified in the literature search, giving a total of 803 candidate chemicals for the screening assessment. These chemicals are listed in Table 1 of Appendix O.

EPA then applied a series of screening criteria to the list of 803 chemicals to eliminate chemicals that had insufficient data or were otherwise unsuitable for screening from further consideration. Each of these screening steps is described below.

- **Chemicals with no human health benchmarks or not occurring in sewage sludge—**EPA eliminated 571 chemicals based on the absence of health benchmark or occurrence information. EPA assessed the availability of human health benchmarks from a variety of sources (see Appendix O for a complete list). Chemicals with no human health benchmarks from any of those data sources were removed from consideration, because further hazard screening is not possible in the absence of toxicity values. In addition, if a chemical was not found in the literature search and was monitored but not detected in the NSSS, it was deleted from further consideration, because it appears not to be present in sewage sludge.

- **Chemicals already regulated in Round One—**EPA eliminated 9 metals that were regulated in Round One of the Part 503 sewage sludge standards.

- **Chemicals evaluated and determined not to be a hazard**—EPA eliminated 15 chemicals that are unlikely to pose a hazard from their presence in sewage sludge. Calcium and magnesium are essential nutrients. Phthalic anhydride degrades extremely rapidly in soil. Chromium is present in sewage sludge as the less toxic chromium III species and is unlikely to present a hazard. The remaining 11 chemicals in this category (aldrin, chlordane, DDD, DDE, DDT, dieldrin, heptachlor, heptachlor epoxide, hexachlorobenzene, lindane and toxaphene) are banned or severely restricted pesticides. These organochlorine pesticides were evaluated in 1992 and were not considered to present a health hazard from their presence in sewage sludge.

- **Chemicals not occurring in U.S. sewage**—Only concentration values that have been measured in U.S. sewage sludge are considered appropriate for estimating exposure of the U.S. population to chemicals in sewage sludge. Therefore, EPA eliminated 129 chemicals not detected or not monitored in the NSSS and with no literature concentration values in U.S. sewage sludge.

- **Chemicals without chronic human health benchmarks from IRIS or OPP—**Of the health assessment databases EPA used to identify human health benchmarks, EPA considered the Integrated Risk Information System (IRIS) and Office of Pesticide Programs (OPP) databases best suited for the Agency's potential regulatory activities for this screening assessment. Therefore, EPA eliminated 17 chemicals that did not have IRIS or OPP human health benchmarks. In addition, EPA eliminated one chemical that does have an IRIS benchmark (strontium) because available data on the environmental properties of strontium are inadequate to conduct exposure screening. Note that the availability of ecological benchmarks was not a criterion for selecting or eliminating pollutants. Ecological benchmarks were identified or developed for the selected pollutants to the extent supported by available data when sufficient human health-related data existed.

- **Chemicals with an ongoing IRIS or OPP assessment—**IRIS and OPP are currently conducting a detailed review of recent scientific information for 20 chemicals. In addition, at the request of EPA, the NRC is conducting a review of the toxicological, epidemiological, clinical, and exposure data on oral ingested fluoride from drinking water and other sources. Because the results of these new health assessments are not yet available or may change, EPA has eliminated these 21 chemicals at this time.

This process resulted in the list of 40 chemicals that have been screened in the assessment described in this document. A more detailed discussion of the chemical selection process is presented in Appendix O. Table 1-1 lists the pollutants, their frequency of detection in sewage sludge, and their measured concentrations in sewage sludge. The screening concentration used in this assessment was the 95th percentile of the measured concentration in sludge in the 1989 NSSS.

Table 1-1. Pollutants Selected for Sewage Sludge Exposure and Hazard Screening Assessment

Chemical	CASRN[a]	95th Percentile of Concentration Range NSSS (mg/kg)[b]	Detect in NSSS (%)
Acetone	67-64-1	116	58
Acetophenone	98-86-2	32.9	2
Anthracene	120-12-7	32.9	2
Azinphos methyl	86-50-0	0.311	2
Barium	7440-39-3	1730	100
Benzoic acid	65-85-0	167	4
Beryllium	7440-41-7	8.00	22
Biphenyl, 1,1-	92-52-4	33.3	1
Butyl benzyl phthalate	85-68-7	32.9	9
Carbon disulfide	75-15-0	3.13	10
Chloroaniline, 4-	106-47-8	33.3	5
Chlorobenzene; phenyl chloride	108-90-7	3.13	2

(continued)

Table 1-1. (continued)

Chemical	CASRN[a]	95th Percentile of Concentration Range NSSS (mg/kg)[b]	Detect in NSSS (%)
Chlorobenzilate	510-15-6	0.0967	7
Chlorpyrifos	2921-88-2	0.157	3
Cresol, o- (2-methylphenol)	95-48-7	42.8	6
Diazinon	333-41-5	0.150	2
Dichloroethene, 1,2-trans-	156-60-5	2.94	1
Dichloromethane	75-09-2	31.3	42
Dioxane, 1,4-	123-91-1	3.13	2
Endrin	72-20-8	0.0415	6
Ethyl p-nitrophenyl phenylphosphorothioate; EPN; Santox	2104-64-5	0.124	2
Fluoranthene	206-44-0	32.9	5
Hexachlorocyclohexane, alpha-	319-84-6	0.0228	2
Hexachlorocyclohexane, beta-	319-85-7	0.0415	6
Isobutyl alcohol	78-83-1	3.13	3
Manganese	7439-96-5	1620	100
Methyl ethyl ketone	78-93-3	69.3	34
Methyl isobutyl ketone (MIBK); methyl-2-pentanone, 4-	108-10-1	15.6	2
Naled	300-76-5	0.840	2
Nitrate	14797-55-8	5020	95
Nitrite	14797-65-0	462	83
N-Nitrosodiphenylamine	86-30-6	65.8	1
Phenol	108-95-2	57.5	34
Pyrene	129-00-0	33.0	5
Silver	7440-22-4	128	84
Trichlorofluoromethane	75-69-4	3.47	5
Trichlorophenoxy) propionic acid, 2-(2,4,5-	93-72-1	0.040	15
Trichlorophenoxyacetic acid, 2,4,5-; 2,4,5-T	93-76-5	0.0505	29
Trifluralin	1582-09-8	0.155	3
Xylenes (mixture)	1330-20-7	6.63	4

[a] Chemical Abstract Service Registry Number
[b] Dry weight

1.2.2 Properties of Sewage Sludge

In addition to identifying the pollutants in sewage sludge, it was necessary to select representative values for physical properties of the sludge to conduct a modeled exposure and hazard screening assessment. For this screening assessment, EPA assumed that the physical properties of sewage sludge could be adequately characterized by a single set of fixed values. EPA developed values for some of the physical characteristics of sludge (e.g., bulk density [BD], percent solids, and fraction organic carbon [foc]) as part of the Round One risk assessment. For other required physical characteristics (porosity and silt content), if values were not available from EPA for a specific parameter, values for silt soil were used. Table 1-2 lists the sewage sludge characteristics used in this assessment and the sources of these values. The characteristics used in this screening assessment are the same as those used in the risk assessment conducted for the "Exposure Analysis for Dioxins, Dibenzofurans, and Coplanar Polychlorinated Biphenyls in Sewage Sludge," published in support of the NODA (June 12, 2002).

Table 1-2. Physical Characteristics of Sewage Sludge

Characteristic	Parameter Value	Units	Source
Dry bulk density (BD)	1.5	g/cm^3	Technical Support Document for Land Application of Sewage Sludge (U.S. EPA, 1992)
Fraction organic carbon (foc)	0.4	Unitless	Best professional judgment
Percent solid	40 (land appl.) 10 (lagoon)	Volume percent	2001 NSSS (U.S. EPA, 2001)
Porosity	0.4	Unitless	Based on Carsel and Parrish (1988)
Silt content	2.2 to 21 Uniform distribution	Mass percent	Table 13.2.2-1 AP-42 (U.S. EPA, 1995a)

1.3 Source Characterization

This screening assessment evaluated two sewage sludge management practices:

- Land application of sludge to pastureland and cropland
- Surface disposal in sewage sludge lagoons.

1.3.1 Agricultural Land Application Scenario

For this scenario, EPA assumed that sewage sludge is applied to both pastureland and cropland used to raise food commodities for human consumption. The farmer was assumed to apply sewage sludge to pastureland and cropland at the appropriate agronomic rates and conditions, as follows:

- Sewage sludge is applied at a rate of 5 to 10 metric tons per hectare per application (uniform distribution)

- Applications occur once every 2 years for a variable period from one to 40 years (20 applications)

- Cropland is tilled to a depth of 20 cm at application and at two additional times during the year

- Pastureland is not tilled, but the sludge is incorporated to a depth of 2 cm by bioturbidation.

These assumptions reflect agricultural practices common throughout the United States and are the same as those made for the exposure assessment for dioxins in sewage sludge applied to agricultural land (U.S. EPA, 2002b).

In this assessment, the application frequency of sewage sludge was considered constant. Sewage sludge was assumed to be applied to the soil once every other year over a variable period of 1 to 40 years. To model this application process, a triangular distribution of application periods with a minimum of 1, a maximum of 40, and a mode of 20 years was used. The period of sludge application and the rate of application were assumed to be independent. The exposure period for human receptors (i.e., the farm family) was constrained to begin within the period of application of sludge to the agricultural land, but could continue after applications ceased. Application rates for sewage sludge were not varied with location, crop type, or soil characteristics but were assumed to vary independently on a nationwide basis.

A single farmland configuration was assumed in this screening assessment; this configuration defines the area in the immediate vicinity of the farm applying sludge and defines the geographic relationship among the important features of the scenario, such as the cropland, pasture, residence, and waterbodies (see Section 1.4). This configuration was assumed to occur in all environmental settings and was evaluated at each of the 41 climatic regions in the assessment.

1.3.2 Surface Disposal/Sewage Sludge Lagoon Scenario

For this scenario, EPA assumed that sewage sludge was managed in a non-aerated surface disposal lagoon. The lagoon in this exposure and hazard assessment is represented by non-aerated surface impoundments with retention times greater than 2 years. The surface impoundment was assumed to operate for a period of 50 years, after which time it was closed. Only the active life (50 years) of the surface impoundment was modeled. Surface impoundments used in this assessment were selected from a national distribution of non-aerated, nonhazardous surface impoundments based on a representative sample of surface impoundments developed by the EPA Office of Solid Waste (OSW) as part of the Surface Impoundment Study (SIS) (U.S. EPA, 2001b). These surface impoundments were modeled using the data and locations reported in the survey. These data are presented in Appendix A.

1.4 Layout and Setting

Sewage sludge is managed across the United States; therefore, EPA chose a regional approach to capture the variability in site conditions across the United States. This approach combines regional data with data that represent a generic site layout. The approach differs somewhat for the land application and lagoon scenarios because of differences in the pathways evaluated (leading to different site layouts with different data requirements) and differences in the data available.

1.4.1 Agricultural Land Application Scenario

For the agriculture land application scenario, climate and soil data are needed to characterize the environmental setting. These data include the meteorologic data used for air modeling, and the soil and climate data used to estimate fate and transport of the pollutants in the soil, surface waterbody, and groundwater.

The approach for the land application scenario consists of the following elements:

- Regional meteorological, soil, and farm size data for 41 climate regions were selected to capture the variability across the United States

- The site layout data describe a generic setting with one-half of the farm devoted to cropland and one-half of the farm devoted to pasture. Two waterbodies were associated with each farm: (1) a standard index drinking water reservoir receiving runoff with a fixed-size watershed to characterize drinking water risk, and (2) a farm pond receiving runoff to characterize ecological risk and risk from ingestion of home-caught fish.

These elements are discussed in more detail below.

1.4.1.1 Regional Data. The regional data were intended to represent the variability in climate, soil, and farm size attributable to the variety of geographic locations for land application of sewage sludge throughout the United States. This assessment used 41 climate regions, shown in Figure 1-1. The boundaries of these regions were drawn to circumscribe areas that could be represented by a single set of climatic data. The boundaries take into account geographic boundaries, such as mountains, and other parameters that differentiate meteorological conditions (i.e., temperature and windspeed). For each climate region, a representative meteorological data set was selected; the location of this data set is also shown in Figure 1-1. This data set was assumed to be representative of the conditions throughout the entire region and was used for all iterations of the assessment for that climate region. Appendix C provides the details of the meteorologic and climatic data used in the screening assessment. Once the boundaries of the climatic regions were established, soil and field size data (which are also associated with geographic location) were linked to these same regions. Within each of the 41 climatic regions, soil data for areas designated as agricultural land use were used to characterize the soil for that region. This approach captures the variability in soils in a manner that is generally representative of agricultural lands across the United States. A geographic information system (GIS) was used to compile soil texture and other soil data within each climatic region. Appendix D provides a complete description of the soil data used.

Figure 1-1. Map of 41 climatic regions.

Agricultural field size is also associated with location but not directly linked to climate or soil conditions. Farms in the more densely populated eastern part of the United States are much smaller than farms and ranches in the less densely populated western part of the country. The median farm size for each county within the climate region was obtained from the Census of Agriculture.[1] From these data, the farm size modeled for each climate region was determined by taking the average of the median farm size for all counties in the climate region. Appendix B presents the farm sizes used in this assessment.

The regional environmental setting approach maintains the correlation between conditions that are likely to occur together and prevents implausible combinations from being chosen in the probabilistic assessment. Using this approach, a climatic region was randomly selected for each iteration in the assessment, and all data for that iteration (climatic, soil, and field size) were selected to be consistent with that geographic region.

1.4.1.2 Site Layout Data. A generic site configuration including cropland, pastureland, and a waterbody was used to model the land application scenario. Two site configurations were used to represent two different types of waterbodies. In the first site configuration, depicted in Figure 1-2, the waterbody is an "index reservoir." The index reservoir is represented by

[1] The Census of Agriculture (U.S. DOC, 1994) provides periodic and comprehensive statistics about agricultural operations, production, operators, and land use. It is conducted every 5 years for years ending in 2 and 7. Its coverage includes all operators of U.S. farms or ranches (Division A, SIC 01-02) that sold or normally would have sold at least $1,000 worth of agricultural products during the census year. In 1992, approximately 1.9 million operators produced $162 billion in crops and livestock.

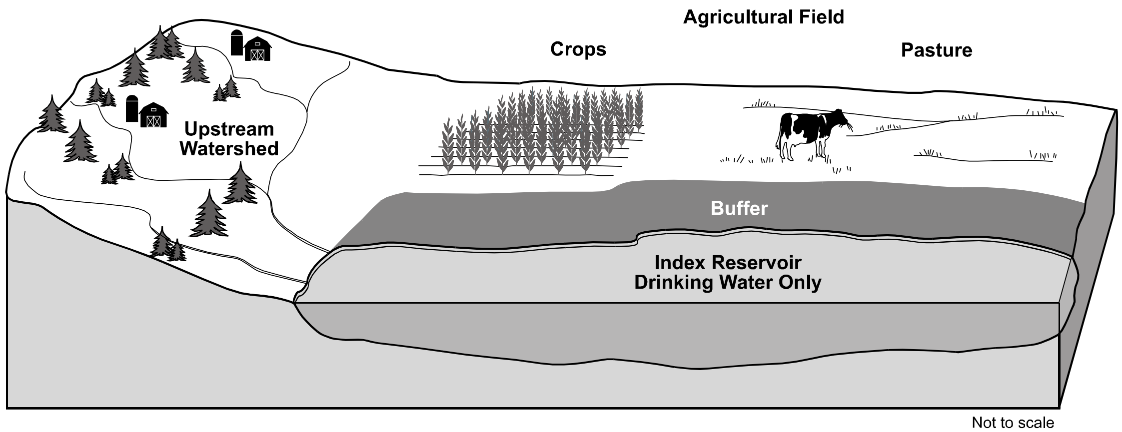

Figure 1-2. Agricultural field index reservoir scenario.

Shipman City Lake in Shipman, Indiana.[2] This reservoir has an area of 13 acres, a depth of 9 ft, and a watershed area of 427 acres. These values remain constant in the assessment, and the same index reservoir is assumed to occur in each of the 41 climate regions. The 427-acre watershed is assumed to contain other farms (in addition to the modeled farm) that also apply sewage sludge. These farms are assumed to occupy 10% to 80% of the 427-acre watershed. Drinking water exposures are assessed using this index reservoir, which receives runoff from agricultural land to which sewage sludge was applied as a fertilizer or soil amendment.

In the second site configuration, depicted in Figure 1-3, the waterbody is a farm pond. The farm pond is used to evaluate ecological exposures as well as human exposures via fish ingestion. The farm is assumed to be the total drainage basin for the farm pond. The area of the farm pond is not constant but is assumed to have a drainage-area-to-capacity ratio of 5. The farm pond depth is assumed to be constant at 9 ft; therefore, the area of the pond is proportional to the farm area. The farm pond is assumed to be located within or immediately adjacent to the farm, with the erosion and runoff from the agricultural land entering directly into the farm pond (no buffer).

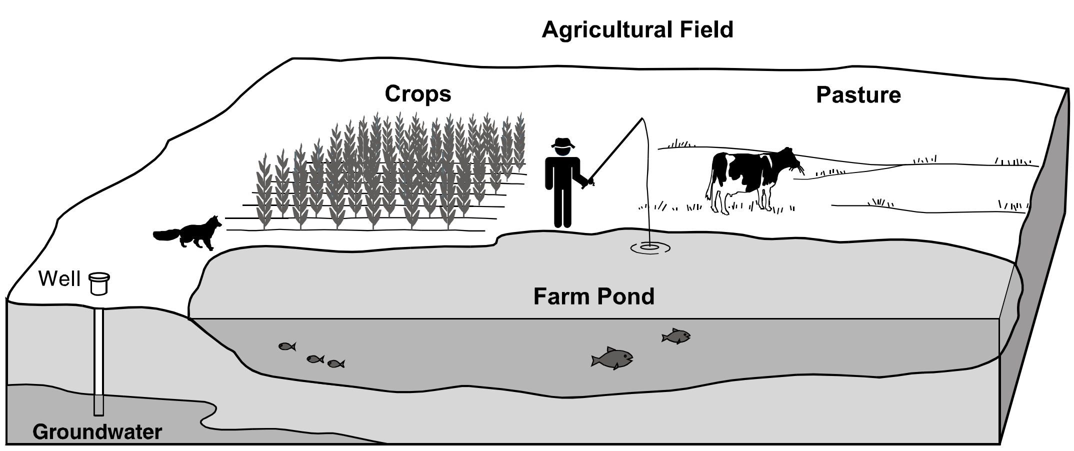

Figure 1-3. Agricultural field farm pond scenario.

[2] EPA also selected Shipman City Lake as the index reservoir to use in modeling exposures to pesticides from consumption of drinking water from surface water (U.S. EPA, 2001a).

Both site configurations—the index reservoir and the farm pond—are described in *FIRST: A Screening Model to Estimate Pesticide Concentrations in Drinking Water* (U.S. EPA, 2001a), which describes the characteristics of the drainage areas of both waterbodies.

1.4.2 Lagoon Scenario

For the lagoon scenario, only the meteorologic data used for air modeling are needed to characterize the environmental setting.

The approach for the lagoon scenario consists of the following elements:

- Meteorological data were used from the meteorological station nearest to (and most representative of) the actual location of each impoundment from the SIS
- A generic site layout was used to represent the risk to rural residents living at various distances from disposal impoundments.

The meteorologic and climate data used in the assessment are dependent on the impoundment location reported in the SIS. Data from the nearest, most representative meteorological station were used.

Sewage sludge lagoons were assumed to be similar to nonaerated, nonhazardous surface impoundments with long hydraulic residence times. These impoundments are assumed to be located in a rural industrial setting where rural residents may (1) live within a distribution of distances relatively close to the lagoon, (2) be exposed to ambient air contaminated by sludge pollutants, and (3) ingest drinking water from residential groundwater wells. These residents also use their residential wells as a source of tapwater for other household uses, such as showering. Figure 1-4 depicts the lagoon scenario.

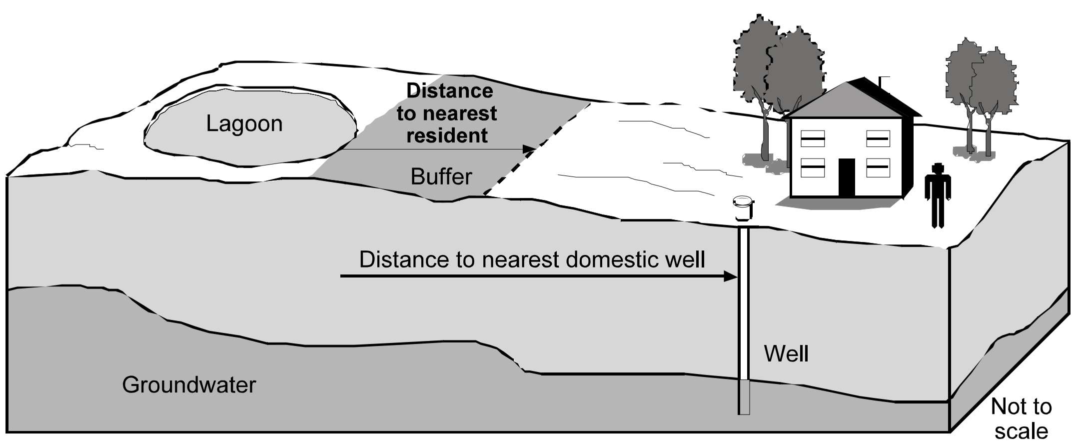

Figure 1-4. Sewage sludge lagoon scenario.

1.5 Conceptual Model

For both the agricultural land application and surface lagoon scenarios, conceptual models were developed to define the sources, releases, exposure pathways, and receptors to be addressed in the screening assessment. Figures 1-5 through 1-7 diagram these conceptual models for the agricultural land application with farm pond, agricultural land application with the index reservoir, and lagoon scenarios, respectively. These diagrams show how the data flow from the source models, which calculate releases to the environment, to the environmental fate and transport models, which calculate concentrations in the soil, sediment, surface water, leachate, and air. These media concentrations are then used to estimate pollutant movement through the food chain and finally exposures to human and ecological receptors.

Members of the human subpopulation defined as subject to reasonable maximum exposure (RME) are farm families assumed to live on a farm and consume farm-raised foods where land-applied sewage sludge is used as fertilizer or a soil amendment and, therefore, are more highly exposed to sewage sludge than the general population. All of the ingestion pathways (ingestion of food and water) were aggregated in the exposure models, where appropriate, to estimate total ingestion hazards to humans in this screening assessment. The ingestion and inhalation pathways were not aggregated. In this hazard screening assessment for sewage sludge, exposure to humans via inhalation for the pollutants that have reference concentration (RfC) values is negligible, as results indicate in the screen. The inhalation HQs for this screening assessment are several orders of magnitude lower than ingestion HQs and, thus, would not add meaningful results if aggregated. For the purposes of this screening assessment, a pathway providing exposure approximately three orders of magnitude lower than the predominant pathway (i.e., ingestion, in particular ingestion of drinking water) need not be aggregated.

The Agency did not assess exposure pathways for wildlife in the sewage sludge lagoon scenario (as a surface disposal unit) or the incineration scenario, but only in the land application scenario. EPA estimates that less than one percent of the sewage sludge produced annually in the United States is disposed of in surface disposal units, and approximately 17 percent is disposed of by combustion in sewage sludge incinerators. Thus, these disposal methods involve a relatively small proportion of total sewage sludge produced compared to land application of sewage sludge. In addition, surface disposal sites generally are areas with poor ecological habitat. Most of the sewage sludge produced in the United States goes to land application to fertilize crops or as a soil amendment. Therefore, the Agency did not assess aquatic and terrestrial wildlife exposure associated with surface disposal or incineration for this screening assessment. The land application scenario, which includes the treated agricultural cropland and pastureland and the farm pond, is more representative of wildlife habitat, and thus, where ecological exposures are most likely to happen. Therefore, EPA believes that assessment of wildlife exposure and hazard under the land application scenario is the most appropriate assessment and is protective of wildlife.

1.6 Exposure Pathways

As shown in Figures 1-5 through 1-7, the human and ecological receptors identified in the conceptual models for each of the sewage sludge management scenarios may be exposed through various pathways. This section describes the exposure pathways addressed for each receptor and scenario combination. More detailed information is provided in Appendices L and N.

1.6.1 Land Application Scenario

For the land application scenario, the farm family is the exposed human population. The ecological receptors for this scenario are terrestrial and aquatic wildlife species that frequent the crop and pasture or that live in or near the farm pond. The exposure pathways for each of these receptors are described in the following sections.

Human Receptors. The exposure pathways considered for the adult and child receptors are presented in Table 1-3. In summary, families living near sewage sludge incinerators and sewage-sludge lagoon, as well as farm families consuming food produced on sewage-sludge-amended soil, were considered the affected populations in this exposure screening assessment.

For the agricultural land application scenario, human members of the subpopulation defined as subject to RME are members of a farm family assumed to live on a farm and consume farm-raised foods where land-applied sewage sludge is used as fertilizer or a soil amendment. These individuals are more highly exposed to sewage sludge than the general population. In addition, EPA assumed that a higher percentage of the farm family's diet consists of food grown on sewage-sludge-amended soil. EPA also assumed that the adults on the farm consume fish caught from a nearby waterbody (a pond) and that the farm family also raises a significant portion of its fruit and vegetable diet on sewage-sludge-amended soils. In addition, the farm family is exposed through drinking water or showering in either untreated surface water from an index reservoir or groundwater from a residential well.

Table 1-3. Human Exposure Pathways for the Agricultural Land Application Scenario

Receptor	Inhalation of Ambient Air	Inhalation of Shower Indoor Air (Groundwater or Surface Water)	Ingestion of Soil	Ingestion of Untreated Drinking Water (Groundwater or Surface Water -Index Reservoir)	Ingestion of Produce	Ingestion of Beef and Dairy Products	Ingestion of Fish (Farm Pond)
Adult farmer	✔	✔	✔	✔	✔	✔	✔
Child farm resident	✔	✔	✔	✔	✔	✔	✔

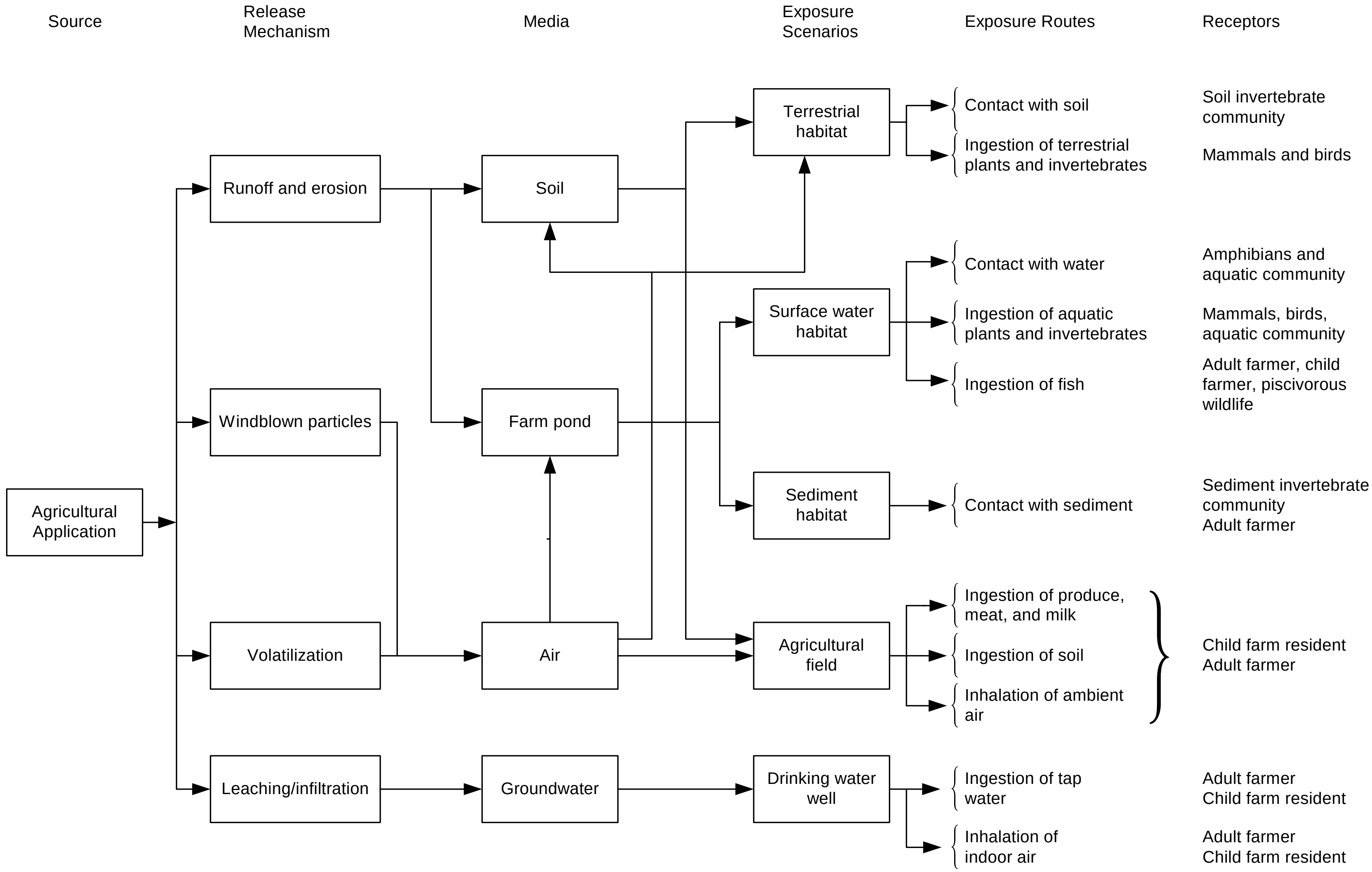

Figure 1-5. Conceptual model for the agricultural land application scenario (with farm pond).

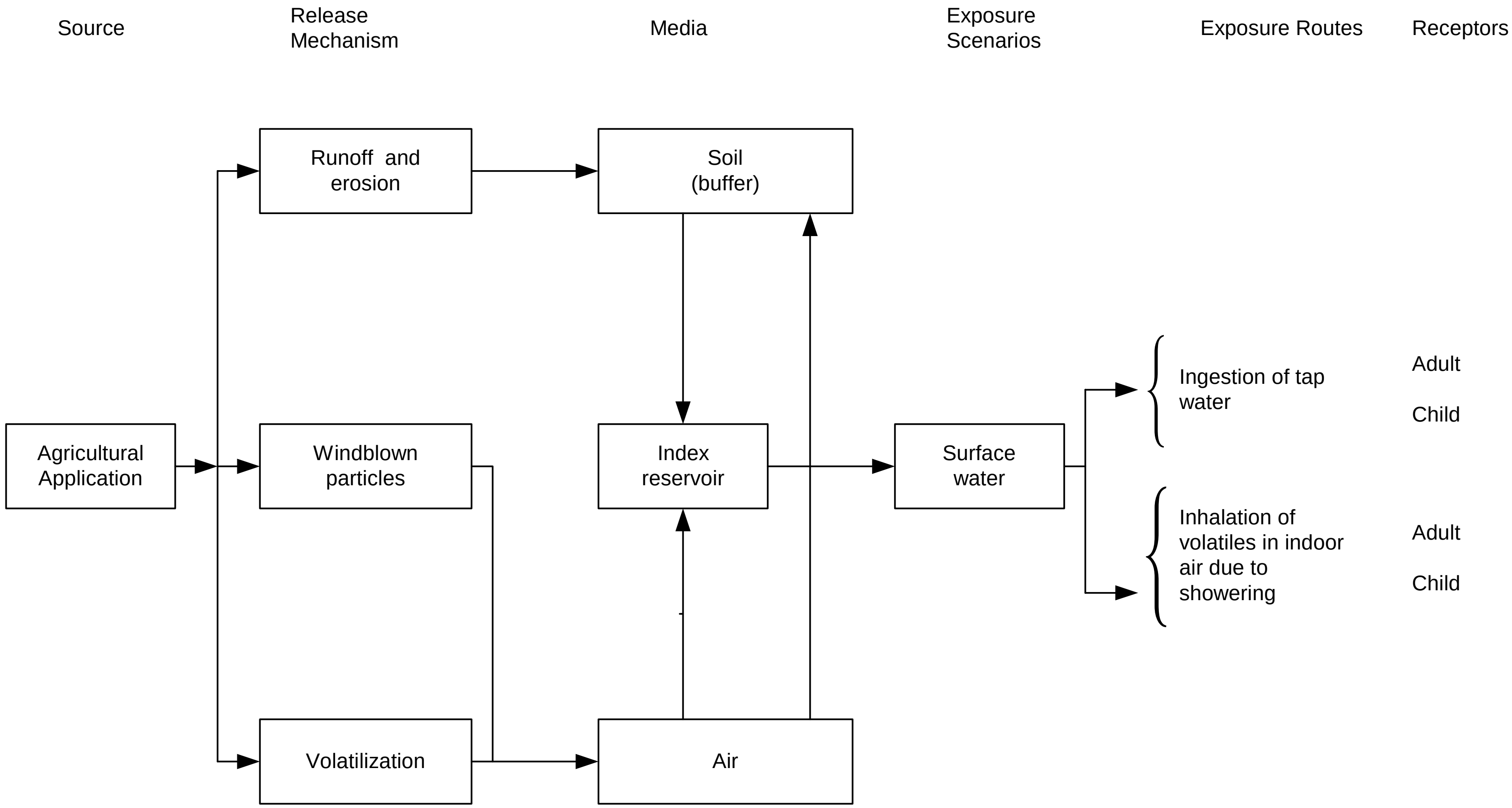

Figure 1-6. Conceptual model for exposure to household tapwater in the agricultural land application scenario (with index reservoir).

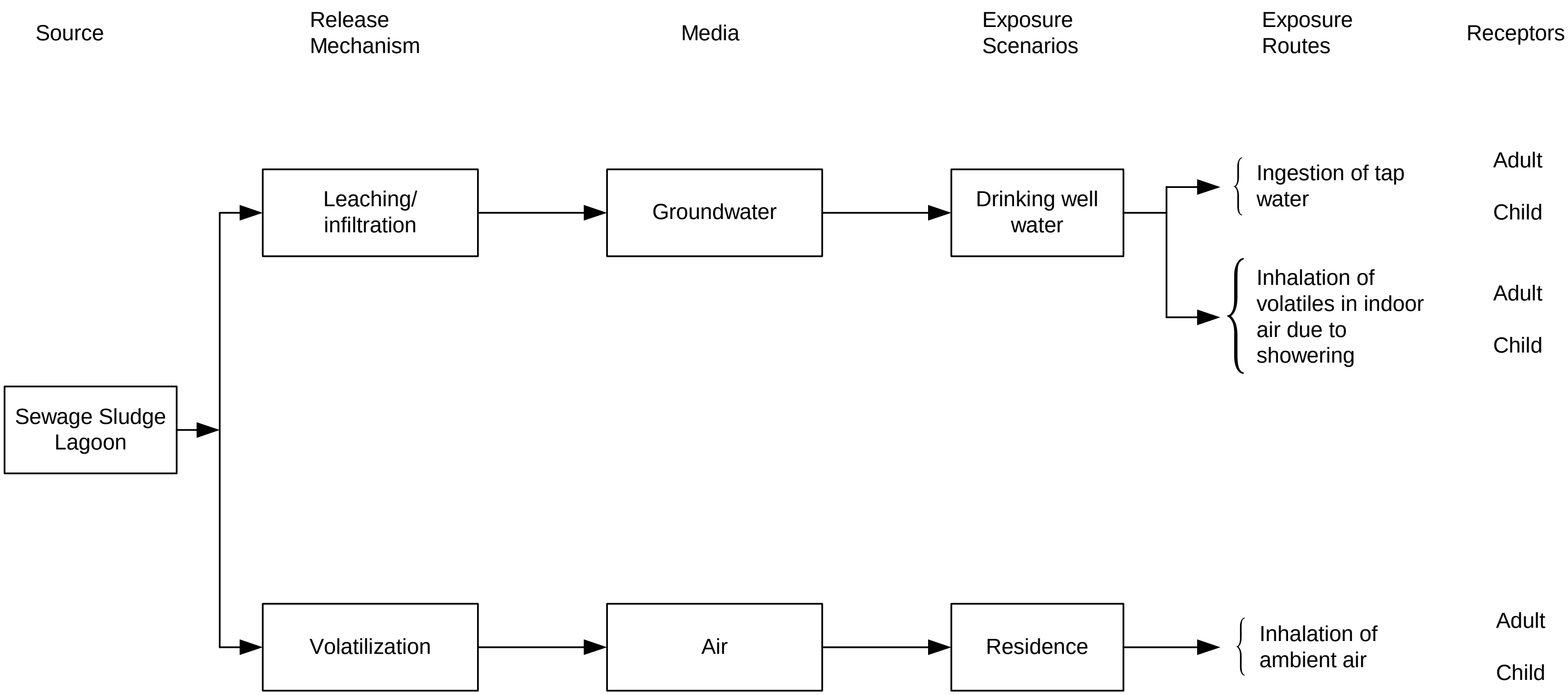

Figure 1-7. Conceptual model for sewage sludge lagoon.

Ecological Receptors. The ecological receptors considered in the land application scenario are assumed to be exposed on the farmland and in the farm pond. The exposure pathways assessed include direct exposure through contact with contaminated media and indirect exposure through ingestion of contaminated food and surface water. The environmental media assessed are soil, sediment, and surface water. Table 1-4 shows the pathways assessed for the different ecological receptors.

Table 1-4. Exposure Pathways for Wildlife Species[a]

Receptor	Direct Contact	Direct Contact Medium	Ingestion
Fish	✔	Surface water (farm pond)	
Aquatic invertebrates	✔	Surface water (farm pond)	
Aquatic plants	✔	Surface water (farm pond)	
Amphibians	✔	Surface water (farm pond)	
Aquatic community	✔	Surface water (farm pond)	
Sediment biota	✔	Sediment (farm pond)	
Soil invertebrates	✔	Soil (agricultural field)	
Mammals			✔
Birds			✔

[a] Sediment biota organisms include sediment invertebrates; aquatic community organisms include fish, aquatic invertebrates, aquatic plants, and amphibians; soil biota organisms include soil invertebrates. Individual mammal and bird species assessed are listed in Table 1-6 and are exposed through ingestion of contaminated terrestrial and aquatic prey and food items.

1.6.2 Lagoon Scenario

The exposed human population for the sewage sludge lagoon scenario is a family living near a facility with a sludge lagoon. This family has a residential drinking water well. The exposure pathways for adults and children in the sewage sludge lagoon scenario are presented in Table 1-5.

Ecological receptors are not considered in this scenario.

Table 1-5. Human Exposure Pathways for the Sewage Sludge Lagoon Scenario

Receptor	Inhalation of Ambient Air	Inhalation of Indoor Shower Air (Groundwater)	Ingestion of Drinking Water (Groundwater)
Adult resident	✔	✔	✔
Child resident	✔	✔	✔

1.7 Receptors

This screening assessment considers both human and ecological receptors in the agricultural application scenario. Only human receptors are considered in the sludge lagoon scenario.

1.7.1 Agricultural Land Application Scenario

In this screening assessment, as stated above in Section 1.6, the receptors considered in the agricultural application scenario include members of the farm family who apply sewage sludge on their farms and ecological receptors who live on or near the farm.

Human Receptors (Adult Farmer and Child Farm Resident). For the agricultural land application scenario, human members of the subpopulation defined as subject to RME are members of a farm family assumed to live on a farm and consume farm-raised foods where land-applied sewage sludge is used as fertilizer or a soil amendment. These individuals are more highly exposed to sewage sludge than the general population. In addition, EPA assumed that a higher percentage of the farm family's diet consists of food grown on sewage-sludge-amended soil. EPA also assumed that the adults on the farm consume fish caught from a nearby waterbody (a pond) and that the farm family also raises a significant portion of its fruit and vegetable diet on sewage-sludge-amended soils. In addition, the farm family is exposed through drinking water or showering (inhalation exposure) in either untreated surface water from an index reservoir or groundwater from a residential well.

Both adult and child members of a farm family are assumed to be exposed to contaminants through the application of sewage sludge to their own farm. The farm family is assumed to be living on the farm during the time that sludge is applied. The adults are assumed to be 20 years old or older when exposure begins, and the children in the farm family are assumed to begin exposure at 1 year of age.

Ecological Receptors. Ecological receptors include invertebrate and vertebrate animals and plants that may be exposed to contaminants through the agricultural application of sewage sludge. Ecological receptors are assumed to be exposed in the cropland and pasture and in the farm pond; therefore, both aquatic and terrestrial receptors were assessed. Two general types of receptors were included: single species, such as the raccoon or the red tail hawk, and assemblages of species, or communities, such as soil invertebrates. Tables 1-6 and 1-7 show the 36 ecological receptors considered in this assessment.

Table 1-6. Ecological Receptors—Mammal and Bird Wildlife Species

Species	Scientific Name	Feeding Guild[a]	Trophic Level[b]
American kestrel	*Falco sparverius*	C	T2
American robin	*Turdus migratorius*	O	T2
American woodcock	*Scolopax minor*	O	T2
Belted kingfisher	*Ceryle alcyon*	O	T2
Black bear	*Ursus americanus*	O	T3
Canada goose	*Branta canadensis*	H	T1
Cooper’s hawk	*Accipiter cooperi*	C	T3
Coyote	*Canis latrans*	O	T3
Deer mouse	*Peromyscus maniculatus*	O	T2
Eastern cottontail rabbit	*Sylvilagus floridanus*	H	T1
Great blue heron	*Ardea herodias*	O	T2
Green heron	*Butorides virescens*	O	T2
Least weasel	*Mustela nivalis*	C	T2
Little brown bat	*Myotis lucifugus*	I	T2
Long-tailed weasel	*Mustela frenata*	C	T2
Mallard	*Anas platyrhynchos*	O	T2
Meadow vole	*Microtus pennsylvanicus*	H	T1
Mink	*Mustela vison*	C	T2
Muskrat	*Ondatra zibethicus*	H	T1
Northern bobwhite	*Colinus virginianus*	O	T2
Prairie vole	*Microtus ochrogaster*	H	T1
Raccoon	*Procyon lotor*	O	T2
Red fox	*Vulpes vulpes*	O	T3
Red-tailed hawk	*Buteo jamaicensis*	C	T3
Short-tailed shrew	*Blarina brevicauda*	O	T2
Short-tailed weasel	*Mustela erminea*	C	T2
Tree swallow	*Tachycineta bicolor*	O	T2
Western meadowlark	*Sturnella neglecta*	O	T2
White-tailed deer	*Odocoileus virginianus*	H	T1

[a] Feeding guild: C = carnivore, H = herbivore, I = insectivore, O = omnivore.
[b] Trophic level: T1 = prey, not a predator; T2 = both a predator and prey; T3 = a top predator, not prey.

Table 1-7. Ecological Receptors—Communities

Receptor	Environmental Medium/Location
Fish	Surface water/farm pond
Aquatic invertebrates	Surface water/farm pond
Aquatic plants	Surface water/farm pond
Amphibians	Surface water/farm pond
Aquatic community	Surface water/farm pond
Sediment invertebrates	Sediment/farm pond
Soil invertebrates	Soil/agricultural fields

Screening assessments often address a few selected receptors known to be highly exposed to the pollutants of interest. For example, the phase 1 screening for dioxins in land-applied sewage sludge assessed risks to four receptors whose diets consist primarily of fish or sediment and soil invertebrates. Dioxin congeners are known to bioaccumulate in these food items, and these receptors were assumed to reflect high exposure levels. However, for this assessment, 40 different pollutants were assessed, including metals, pesticides, and other organics, and exposure pathways of concern included ingestion, as well as direct contact in three different environmental media (soil, sediment, and surface water).

Selecting a small group of receptors known to reflect the highest exposure levels for all pollutants and pathways was not possible because of the wide range in chemical properties. Therefore, the approach adopted was to assess receptors covering all trophic levels (T1 through T3) and feeding guilds (herbivory, omnivory, and carnivory) likely to occur in an agricultural setting and to include both mammals and birds for as many trophic level-feeding guild combinations as possible. Receptor species were selected based on feeding and foraging habitat. Wildlife species are assumed to spend 100 percent of their time on the farm following application of sewage sludge. Thus, 100 percent of their diet comprises contaminated food items. Animals that are expected to derive a significant portion of their diet from a farm scenario were included, as well as those that feed in and around farm ponds. In addition, species with broad distribution across the United States were selected to the extent possible. Feeding guilds were used to indicate diet preference, and trophic levels indicate placement on the food chain.

1.7.2 Lagoon Scenario (Human Only)

For the surface disposal unit scenario, EPA defined RME as exposure to a rural family living near a sewage sludge lagoon. This family is exposed through the ambient air and through the ingestion of drinking water and showering with tapwater from a residential drinking water well. There are no ecological receptors in this scenario.

1.8 Endpoint Selection

The endpoints selected for the screening assessment were chosen based on the most restrictive benchmarks available for each pollutant to be screened for both human receptors and ecological receptors. The selected endpoints are described in the following sections.

1.8.1 Human Health Benchmarks

The human health benchmarks selected for evaluation in the sewage sludge screening assessment include both cancer and noncancer benchmarks. HHBs were considered available for the screening assessment only if the HHB is posted on the IRIS Web site or a reregistration eligibility decision (RED) or interim reregistration eligibility decision (IRED) document is signed and posted on OPP’s Web site. These databases are readily available to the public, provide a detailed explanation of the scientific basis of the health assessment, and are likely to be relatively stable (i.e., not subject to change before the next 2-year sewage sludge review cycle).

In the screening assessment, an OPP health assessment of a pesticide registered for food uses took precedence over an IRIS assessment of the same pesticide. For all other pollutants, the IRIS benchmark was used.

HHBs developed by IRIS and OPP used in this screening assessment include chronic reference doses (RfDs), chronic population adjusted doses (PADs), inhalation reference concentrations (RfCs), oral cancer slope factors (CSFs), and inhalation air unit risk factors (AURs). Table 1-8 presents the various HHBs available for the 40 chemicals selected for exposure and hazard screening.

Table 1-8. Human Health Benchmarks for Pollutants Selected for the Sewage Sludge Exposure and Hazard Screening Assessment

Chemical	CASRN	RfD (mg/kg/d)	PAD (mg/kg/d)	CSFo $(mg/kg/d)^{-1}$	RfC (mg/m^3)	AUR $(\mu g/m^3)^{-1}$	Source
Acetone	67-64-1	0.9					IRIS
Acetophenone	98-86-2	0.1					IRIS
Anthracene	120-12-7	0.3					IRIS
Azinphos methyl	86-50-0	0.0015	0.0015		0.0022		OPP
Barium	7440-39-3	0.07					IRIS
Benzoic acid	65-85-0	4.0					IRIS
Beryllium	7440-41-7	0.002			0.00002	0.0024	IRIS
Biphenyl, 1,1-	92-52-4	0.05					IRIS
Butyl benzyl phthalate	85-68-7	0.2					IRIS
Carbon disulfide	75-15-0	0.1			0.7		IRIS
Chloroaniline, 4-	106-47-8	0.004					IRIS
Chlorobenzene; phenyl chloride	108-90-7	0.02					IRIS
Chlorobenzilate	510-15-6	0.02					IRIS

(continued)

Table 1-8. (continued)

Chemical	CASRN	RfD (mg/kg/d)	PAD (mg/kg/d)	CSFo $(mg/kg/d)^{-1}$	RfC (mg/m^3)	AUR $(\mu g/m^3)^{-1}$	Source
Chlorpyrifos	2921-88-2	0.0003	0.00003		0.00005		OPP
Cresol, o- (2-methylphenol)	95-48-7	0.05					IRIS
Diazinon	333-41-5	0.0002	0.0002		0.00006		OPP
Dichloroethene, 1,2-trans-	156-60-5	0.02					IRIS
Dichloromethane	75-09-2	0.06		0.0075		0.00000047	IRIS
Dioxane, 1,4-	123-91-1			0.011			IRIS
Endrin	72-20-8	0.0003					IRIS
Ethyl p-nitrophenyl phenylphosphorothioate; EPN; Santox	2104-64-5	0.00001					IRIS
Fluoranthene	206-44-0	0.04					IRIS
Hexachlorocyclohexane, alpha-	319-84-6			6.3		0.0018	IRIS
Hexachlorocyclohexane, beta-	319-85-7			1.8		0.00053	IRIS
Isobutyl alcohol	78-83-1	0.3					IRIS
Manganese	7439-96-5	0.14 (food);0.047 (water, soil)			0.00005		IRIS
Methyl ethyl ketone	78-93-3	0.6			5		IRIS
Methyl isobutyl ketone (MIBK); Methyl-2-pentanone, 4-	108-10-1				3.0		IRIS
Naled	300-76-5	0.002	0.002		0.0004		OPP
Nitrate	14797-55-8	1.6					IRIS
Nitrite	14797-65-0	0.1					IRIS
N-Nitrosodiphenylamine	86-30-6			0.0049			IRIS
Phenol	108-95-2	0.3					IRIS
Pyrene	129-00-0	0.03					IRIS
Silver	7440-22-4	0.005					IRIS
Trichlorofluoromethane	75-69-4	0.3					IRIS
Trichlorophenoxy) propionic acid, 2-(2,4,5-	93-72-1	0.008					IRIS
Trichlorophenoxyacetic acid, 2,4,5-; 2,4,5-T	93-76-5	0.01					IRIS
Trifluralin	1582-09-8	0.024		0.0077			OPP
Xylenes (mixture)	1330-20-7	0.2			0.1		IRIS

RfD = reference dose; PAD = population-adjusted dose; CSFo = oral cancer slope factor;
RfC = reference concentration; AUR = air unit risk factor

1.8.2 Ecological Endpoints

For an ecological screening assessment, endpoints are defined as “explicit expressions of the actual environmental value that is to be protected” (U.S. EPA, 1998). The values to be protected for this assessment are viable wildlife populations and ecological communities. However, in many cases, available ecotoxicological data do not directly address population- or community-level effects (e.g., resource availability, age structure, or predator-prey relationships). Particularly for the ingestion pathways, available data provide information on effects on individual organisms, such as reproductive or developmental effects or mortality. Therefore, benchmarks were selected that reflect effects that can be related to population viability.

Effects on reproductive success and growth and development are generally recognized as relevant to population and community viability, and these were the preferred endpoints when selecting ecological benchmarks. On the other hand, effects such as liver damage are not necessarily indicative of population-level effects and were not used to develop ecological benchmarks. Thus, many of the available mammalian toxicological data used for HHBs are not considered useful for ecological benchmarks. This approach assumes that if individuals are protected from adverse reproductive and developmental effects, protection at the population and community levels is inferred.

For many of the chemicals assessed, particularly the pesticides, the only ecotoxicological data identified were for mortality endpoints (e.g., lethal dose 50 [LD_{50}] and lethal concentration 50 [LC_{50}] values reflecting levels at which 50% of the test subjects died). In general, such data are not considered sufficiently protective for a screening-level assessment, but in the absence of other benchmarks, lethality endpoints do provide a basis for assessment. Therefore, benchmarks based on mortality endpoints were included in the ecological screening when more appropriate data could not be identified. Appendix P provides the critical endpoint that served as the basis for each benchmark used in the assessment. Further discussion of methods for selecting benchmark data is presented in Section 2.5.2, Ecological Screening Criteria.

1.9 Analysis Plan

The analysis plan describes how the relationships among the sources, release mechanisms, exposure scenarios, receptors, and benchmarks were considered in the analysis phase of the risk-based screening assessment. The plan includes the rationale behind the relationships that are addressed and the methods, models, data gaps, and uncertainties associated with the data and models. Because this is the first step in a tiered assessment, many of these data gaps and model uncertainties may be addressed in subsequent stages of the analysis.

1.9.1 Probabilistic Approach

EPA adopted a probabilistic approach for this assessment (see Section 2.1) to capture the nationwide variability in human and ecological exposures associated with sewage sludge management. This approach was consistent with EPA's probabilistic risk assessment guidance. The probabilistic approach involves running the modeling system for 3,000 iterations for each scenario and chemical of concern in sewage sludge. By varying model inputs across these iterations, the assessment captures the regional and national variability in site conditions, sludge management operations, exposure factors, receptor locations, and other factors that affect how people and organisms are exposed to pollutants in sewage sludge.

Within this probabilistic framework, each iteration is a predetermined deterministic calculation of the model. The approach is implemented by setting up input files prior to the assessment that include data that are randomly selected based on the regional setting and scenario selected for each iteration. Chemical-specific data are generally constant across all iterations[3] and are not correlated with other input parameters.

The primary constraint for other parameters in the assessment is the source location. For the agricultural land scenario, the location is determined by randomly selecting a climate station for each iteration. The selection of a climate station limits regionally collected data, which include soil data, long-term climate data, daily meteorological data, and farm size data.

For the lagoon scenario, a surface impoundment is randomly selected from the SIS survey database[4], and the SIS survey database is used to provide site-specific data (e.g., meterological data and surface impoundment dimensions) for that impoundment.

The probabilistic assessment cycles through the types of receptors addressed in the assessment, including adult and child receptors and ecological receptors. Receptor type determines the exposure factors used in the assessment. Receptor type and exposure factors are not specific to location and, for the human health assessment, are varied nationally. Exposure factors are randomly chosen for each iteration and are not correlated with each other or with geographic locations. Ecological receptors' exposure factors are set at median values and are not varied.

All parameters are selected prior to the assessment and, except for the chemical-specific inputs, the same 3,000-record input data set is used for each chemical addressed in the assessment. This will allow additive risk across chemicals to be considered in subsequent analyses.

1.9.2 Source Modeling

The source modeling simulates the release of pollutants as a result of the management of sewage sludge in lagoons or by application to agricultural land. The source models consider releases of pollutants to the environment through volatilization, and leaching to groundwater from lagoons. In the case of application of sludge to agricultural land, erosion from the agricultural land to nearby land and waterbodies is also modeled. The source modeling considers the environmental setting for each sludge management location modeled. Both source models used in this assessment were developed for EPA OSW to estimate releases from waste management units (WMUs) for the identification of hazardous wastes. These models have been peer reviewed and verified for accuracy. More details on each of the models can be found in Section 2.2 and in Appendices G and H.

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[3] Metal partition coefficients are varied using empirical distributions and are the only variable chemical-specific inputs.

[4] Surface impoundments were selected from the subset of nonaerated SIS surface impoundments with waste residence times of 2 years or more.

1.9.3 Fate and Transport Modeling

The fate and transport modeling addresses the movement of pollutants through the environment once they are released from the agriculture field or lagoon. The air model used in this assessment is the Industrial Source Complex Short-Term Model, Version 3 (ISCST3). ISCST3 is a steady-state Gaussian plume model used for modeling concentration, dry deposition, and wet deposition from point, area, volume, and open-pit sources; it was designed primarily to support EPA's regulatory modeling programs.

The agricultural land application source model also estimates erosion of soil runoff of pollutants from the agricultural land directly to the farm pond or through the buffer to the nearby index reservoir. The index reservoir drains a larger watershed area that also contains other agricultural land amended with sewage sludge. The additional contribution of pollutant to the index reservoir from these other areas of agricultural land application is estimated by extending the pollutant concentrations estimated from modeling of the primary farm to the entire watershed. The agricultural land application source model also estimates leachate concentrations at a depth of 1 m under the agricultural land. This leachate concentration is used as the concentration in the residential well that may be used as a drinking water source and as a source for tapwater used for showering. The ISCST3 air modeling was performed for these specific farm areas and locations as a part of the exposure assessment conducted for dioxins in sewage sludge applied to agricultural land, and the dispersion and deposition factors developed for that assessment were used.

The surface impoundment source model used to simulate sewage sludge lagoons estimates emissions of pollutants in vapor form to air and leaching of pollutants to groundwater. The modeling of vapors emitted from surface impoundments in specific locations was performed in support of Industrial Waste Air (IWAIR) model development. As with the sludge-amended land, the concentration of pollutants in the leachate under the surface impoundment is adjusted to represent dilution by ambient groundwater by using a protective dilution-attenuation factor (DAF). The residential well is assumed to be used as a source of drinking water and as a source for other household uses, such as showering.

1.9.4 Human Exposure Modeling

The outputs from the fate and transport model are used to estimate the amount of each pollutant to which the farm family or residents are exposed. In the agricultural scenario, farm family members are assumed to consume homegrown produce and animal products as a substantial portion (up to 49 percent) of their diet. After the fate and transport models have predicted concentrations of pollutants in the air, soil, water, and sediment, pollutant concentrations are calculated in food chain items.

Pollutants in air may be deposited on plants growing in the agricultural field. Simultaneously, these plants may take up pollutants from the soil. Plants thus accumulate pollutants from both routes (from air and soil) into the fruits and vegetables consumed by the farm family. In addition, beef and dairy cattle may consume forage and silage that are grown on a sludge-amended farm. Subsequently, the farm family may consume home-produced beef and dairy products from these animals. In addition, pollutants applied to the farm may erode and run off into the farm pond and accumulate in fish. The fish in the farm pond may be caught and consumed by members of the farm family. Family members are also assumed to incidentally ingest soil from the crop area close to their house and to drink and shower with water from either the index reservoir or an onsite residential well. In addition, the farm family breathes the ambient air on the farm.

The residents who live near the sewage sludge lagoon are assumed to drink and shower with water from an onsite residential well and to breathe the ambient air at their residential location. Section 2.4.1 describes the human exposure modeling conducted for this assessment.

1.9.5 Ecological Exposure Modeling

Ecological receptors occur only in the agricultural application scenario. For the screening assessment, it is assumed that 100 percent of receptors' diets comes from the farm pond and farm fields where sludge is applied. The aquatic receptors (aquatic community, aquatic plants, aquatic and benthic invertebrates, amphibians, and fish) are exposed in the farm pond. The terrestrial receptors (mammals, birds, and soil invertebrates) feed and forage on the crop field and pasture. In addition, some of the mammals and birds eat fish, benthic organisms (e.g., mussels and insect larvae), and aquatic plants from the farm pond. The concentrations in the soil, water, and vegetation to which the ecological receptors are exposed are the same as those calculated for the human health modeling. In addition, the surface water model generates sediment concentrations for the ecological exposure modeling. There are no ecological receptors associated with the index reservoir or the sewage sludge lagoon. The farm pond is considered to be a representative and protective scenario for evaluating exposures to ecological receptors (see discussion in Section 1.5). Section 2.4.2 describes the ecological exposure modeling conducted for this assessment.

1.9.6 Screening Criteria Development

The screening criteria for this assessment are based on both cancer and noncancer effects for human receptors and on effects relevant to population sustainability and community structure and function for ecological receptors. Criteria were developed for several key exposure pathways, including ingestion, inhalation (human health only), and direct contact (ecological risk only). These screening criteria are intended for use in the risk estimation by comparing each receptor-specific criterion (in units of dose or concentration) to the dose or concentration, as appropriate, predicted by the model.

The screening criteria used in this assessment are critical doses (CDs) or critical concentrations (CCs). The CCs are used as an air pathway criterion. For air exposures to pollutants with noncancer endpoints, the CC is the RfC as reported in IRIS. For air exposures to pollutants with cancer endpoints, the CC is associated with a risk of 1E-5, based on the AUR. If a pollutant has both a cancer and a noncancer inhalation benchmark, the lower CC calculated by these methods is the CC used as the screening criterion.

The screening criterion used for the ingestion pathways is the CD. For ingestion exposures to pollutants with noncancer endpoints, the CD is the RfD reported in IRIS or the RfD or the PAD reported in the RED and IRED documents issued by OPP. For ingestion exposures to pollutants with cancer endpoints, the CD is calculated as the dose that yields a cancer risk level of 1E-5 (1 in 100,000) over a lifetime (this dose is calculated as 1E-5/$CSF_{\_oral}$).

For ecological receptors, CDs were used for ingestion pathways (i.e., for mammals and birds), whereas CCs were used for direct contact exposures (e.g., fish and aquatic invertebrates). Additional detail on the development of screening criteria for this screening assessment can be found in Section 2.5.

2.0 Analysis Phase

The problem formulation phase presented in Section 1 provides the blueprint for the analysis phase of the screening assessment. As discussed in Section 1, EPA adopted a probabilistic approach for this assessment to capture the national variability in human and ecological exposures associated with sewage sludge managed through application to agricultural lands and disposal in sewage sludge lagoons. Section 2.1 describes the framework for the probabilistic assessment of chemicals of concern in sewage sludge, a simulation consisting of 3,000 iterations that varies data on region, waste management characteristics, exposure factors, receptor locations, and other variable input parameters to the model. Sections 2.2 through 2.5 describe the technical approach, assumptions, and data for the major modeling components (i.e., source; fate and transport; and exposure) and the development of screening criteria.

2.1 Probabilistic Modeling Framework

For each scenario and chemical evaluated, the screening analysis used 3,000 iterations of the probabilistic analysis. The analysis was implemented using a looping structure developed and applied for the agricultural land and lagoon scenarios as shown in Figures 2-1 and 2-2, respectively.

In this analysis, all chemical-specific parameters were assumed constant, with the exception of partition coefficients (K_d values) for metals, which were randomly sampled from empirical distributions during construction of the input files. Chemical inputs were not assumed to be correlated with other parameters.

For the agricultural land scenario, the location was determined by randomly selecting a climate station for each of the 3,000 iterations. For the lagoon scenario, a surface impoundment was randomly selected from the SIS survey database[1], and the location of that surface impoundment was used to determine the climate station for that iteration.

[1] Surface impoundments were selected from the subset of nonaerated SIS surface impoundments with waste residence times of 2 years or greater.

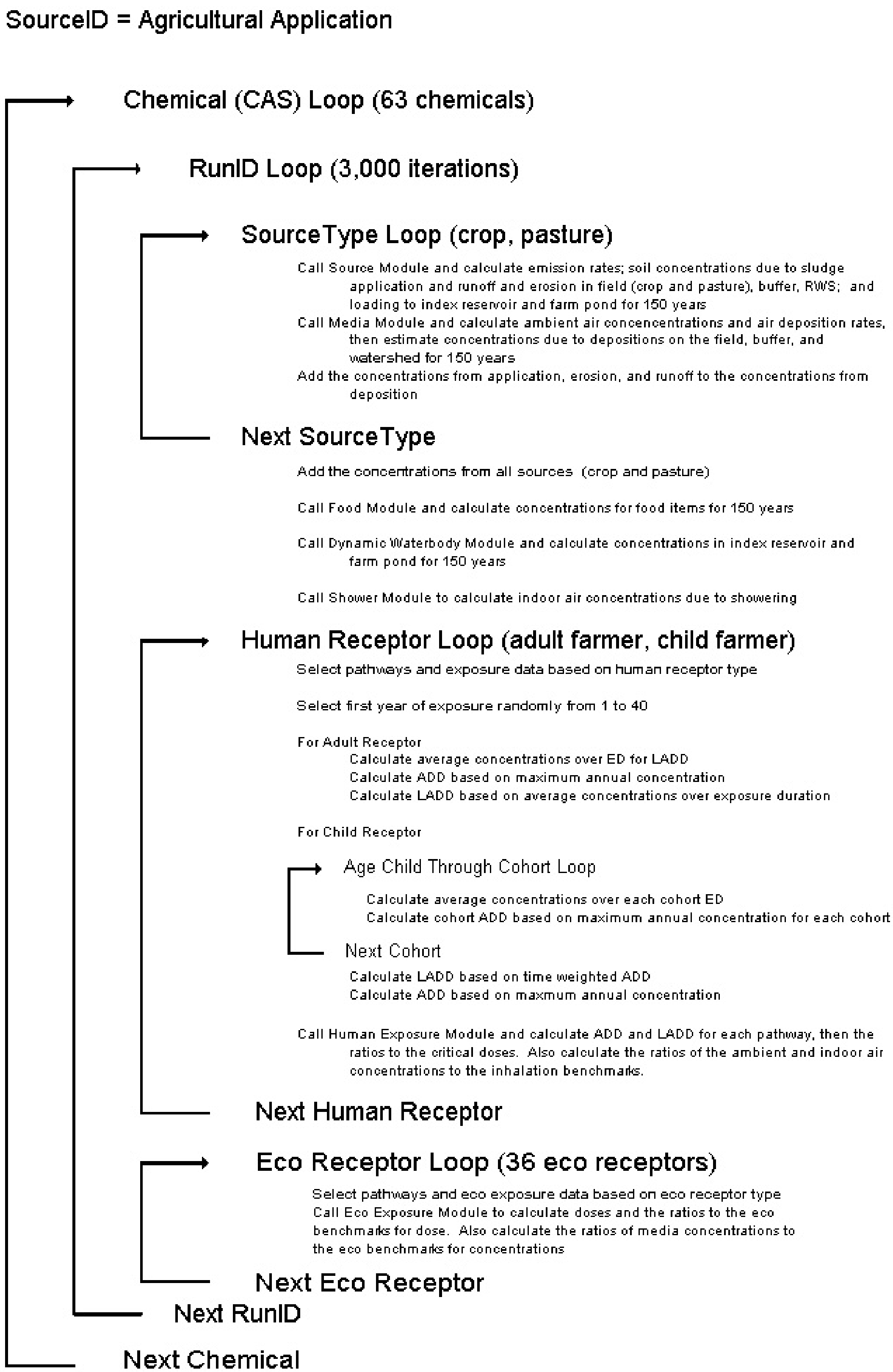

Figure 2-1. Looping structure for agricultural land application modeling.

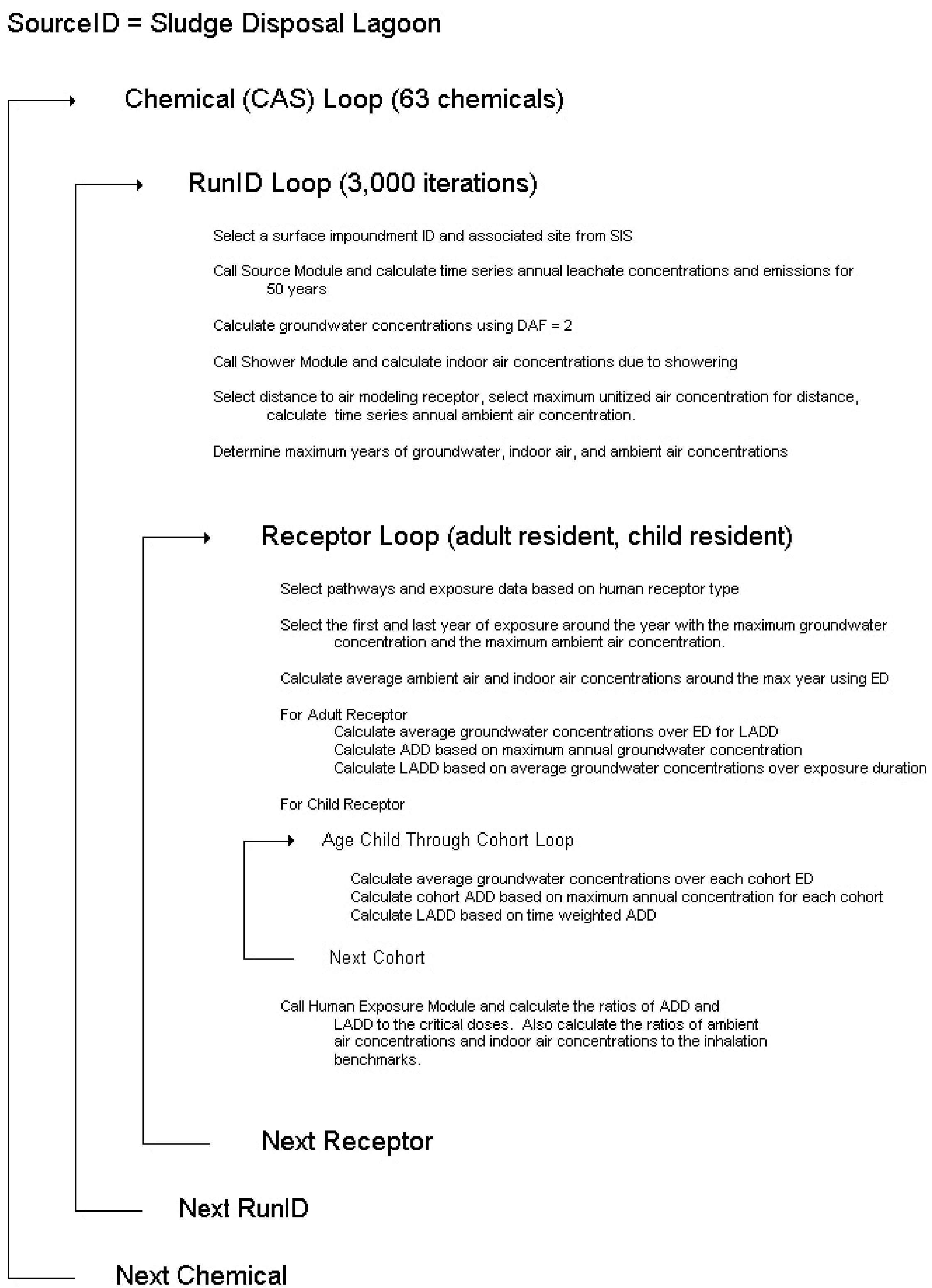

Figure 2-2. Looping structure for sewage sludge lagoons.

The selection of a climate station limits regionally collected data (e.g., soil data, meteorological data, farm size) to conditions prevalent in the selected climate region. For soils, the probability of selecting a particular soil type was dependent on the prevalence of that soil type within the climate region. The remainder of the regional data were held constant for all iterations for a climate region. These data are the long-term climate data, the daily meteorological data, source area (farm area and surface impoundment area), and air modeling data (dispersion and deposition results that depend on the meteorological data and the source area).

The next loop in the probabilistic analysis cycled through the types of receptors addressed in the analysis. The model considered both adult and child receptors. The receptor type determined the exposure factors used in the analysis. Receptor type and exposure factors were not specific to location[2]; as a result, any receptor could be present at any location with any applicable exposure parameter values. This assumption applies to ecological receptors and to humans. Although some of the ecological receptors are not distributed throughout the United States (e.g., eastern cottontail rabbit), the species included were selected to provide as broad a distribution as possible. They are considered representative of receptors that would be exposed throughout the United States. Receptor-specific exposure factors include exposure duration, the year that exposure starts (for the agricultural scenario), dietary consumption rates, ingestion and inhalation rates, individual body weight, and showering parameters (e.g., shower duration). A set of adult and child exposure parameters was chosen for each iteration. Exposure parameters were not correlated with each other or with geographic locations. Ecological exposure factors were set at median values and were not varied.

All parameters were selected prior to the analysis and all 3,000 sets of selected parameters were placed in a database according to run number. For each chemical, the model stepped through the run numbers, using the selected parameters to calculate results for each of 3,000 iterations. In this way, the same non-chemical-specific parameters were used for each iteration of the analysis for every chemical. Thus, if it is appropriate to add the effects of different chemicals together (e.g., for carcinogens or chemicals with noncancer effects on the same target organ), the results can be summed on an iteration-by-iteration basis.

2.2 Source Modeling

Modeling the release of pollutants from the agricultural land and the sewage sludge lagoon requires models that are specific to these management practices. This section describes how the source models were applied in the screening analysis.

2.2.1 Modeling Agricultural Fields

Chemical releases from agricultural fields to surrounding media were simulated using a modified version of the land application unit (LAU) model initially developed as part of the Multimedia, Multipathway, Multireceptor Risk Assessment (3MRA) modeling system (U.S.

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[2] Human exposure factors are selected from national distributions developed from data in EPA's *Exposure Factors Handbook* (U.S. EPA, 1997a,b,c). Ecological exposure factors are taken from EPA's *Wildlife Exposure Factors Handbook* (U.S. EPA, 1996), as well as several other sources, as described in Appendix N.

EPA, 2002b). An overview of the LAU model is presented in the following sections. Appendix H describes the important assumptions inherent in the LAU modeling approach, the fundamental fate and transport algorithms (the Generic Soil Column Model [GSCM]), its hydrology and soil erosion methodologies, the methods for estimating particulate emissions to the atmosphere, and modifications required to execute the LAU model for purposes of this analysis.

The inputs to the LAU model include

- Physical and chemical properties of the pollutant
- Size of the agricultural field
- Characteristics of the sludge (e.g., percent solids, bulk density, foc)
- Soil and climate conditions at the farm site
- Daily meteorologic data at the farm site
- Agricultural practices (e.g., application rate, tilling frequency)
- Site geometry (e.g., location of waterbody with respect to agricultural land).

The LAU model uses these inputs to estimate the vertical movement of the pollutants within the agricultural land (releases through leaching to groundwater), volatile and particle releases to the air, and horizontal movement of pollutants (runoff and erosion from the agricultural land across any buffer area to a nearby waterbody). These estimates are made using the GSCM as the computational engine. The particle emissions from the agricultural land as a result of tilling operations and wind erosion are estimated using equations based on empirical relationships developed by EPA in 1986 (updated, U.S. EPA, 1995a) and by Cowherd et al. (1985), and summarized in U.S. EPA (1995b). The model considers losses from the agricultural land due to hydrolysis and biodegradation, as well as leaching and volatilization.

The outputs of the agricultural application source model are:

- Annual vertical profile of the concentration of the pollutant in the soil of the agricultural land and buffer due to application of sewage sludge before the air deposition of pollutants

- Annual emission of volatile pollutants from the surface of the agricultural land

- Annual emission of pollutants sorbed to particles from the surface of the agricultural land due to tilling and wind erosion

- Daily concentrations and mass of soil eroded from the agricultural land (used in calculating the load to the farm pond or to the buffer)

- Daily concentrations and mass of soil eroded from the buffer area (used in calculating the load to the farm pond)

- Daily concentrations and volume of runoff from the agricultural land (used in calculating the load to the farm pond or to the buffer)

- Daily concentrations and volume of runoff from the buffer area (used in calculating the load to the farm pond)

- Annual infiltration rate of water from the agricultural land

- Annual leachate flux of pollutant from the agricultural land.

2.2.2 Modeling Sewage Sludge Lagoons

A lagoon of the type used to manage sewage sludge can be represented as a surface impoundment for modeling purposes. This screening assessment used a surface impoundment model initially developed for the 3MRA modeling system (U.S. EPA, 2002b) to estimate releases to the environment through the emission of volatile pollutants to the air and through the leaching of soluble pollutants to the groundwater. Appendix G provides a detailed description of the background and application of the surface impoundment model.

The surface impoundment model predicts emissions under normal operating conditions; the model does not estimate emissions due to overflows or structural failures of the impoundment. Emissions are assumed to occur only while the surface impoundment is operational; thus, pollutant releases are calculated for 50 years, which is the assumed operational life of sewage sludge lagoons. The surface impoundment model uses the following types of inputs to estimate environmental releases:

- Physical and chemical properties of the pollutant
- Characteristics of the sludge (e.g., percent solids, bulk density, foc)
- Size and characteristics of the lagoon
- Soil and climate conditions at the site of the lagoon.

The specific inputs and the data used in the surface impoundment source model are found in Appendix G. The surface impoundment model uses these data and considers losses in the impoundment due to hydrolysis, biodegradation, and the partitioning to and settling of suspended solids. The model takes into consideration the effects of environmental and waste temperatures on the fate of chemicals in the impoundment.

The outputs from the surface impoundment model include the following:

- Emission rates for volatile constituents from the surface of the lagoon
- Infiltration rate of liquid from the lagoon
- Leachate flux of pollutant from the lagoon.

The leachate flux and the infiltration rate are used to calculate the concentration of the pollutant in the leachate released from the bottom of the lagoon.

2.3 Fate and Transport Modeling

This section describes the methodology and the models used to predict the fate and transport of pollutants in the environment after release from the agricultural land or lagoon.

Once pollutants are released, they move through the environment by the natural processes depicted in Figure 2-3. The purpose of the fate and transport modeling is to estimate the concentrations of pollutants in environmental media (i.e., air, soil, and food items) at the point of exposure. To predict a pollutant's movement through these different media, several media-specific fate and transport models are employed. Fate and transport models are a series of either computer-based algorithms or sets of equations that predict chemical movement due to natural forces. These fate and transport models integrate information on a site's geology, hydrology, and meteorology with chemical, physical, and biological processes that take place in the environment. The result is a simulation of chemical movement in the environment and a prediction of the concentration of a chemical at specific locations called the "exposure points."

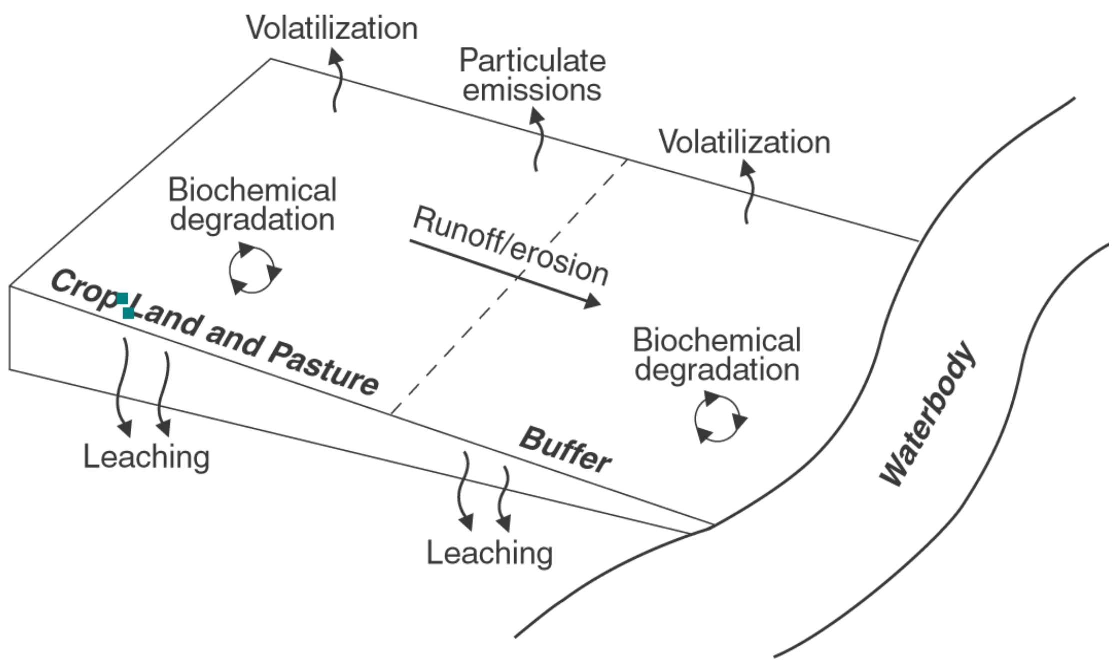

Figure 2-3. Emissions mechanisms in the local watershed.

The following fate and transport models were used for this analysis:

- Air dispersion and deposition model (ISCST3)
- Watershed and waterbody models
- Dilution-attenuation factor for groundwater transport
- Food chain model.

These models and the general framework for performing the fate and transport modeling are described in the following sections. Section 2.3.1 discusses the air dispersion and deposition modeling. Section 2.3.2 describes the watershed and waterbody model used to determine watershed soil, farm pond, and index reservoir pollutant concentrations, along with the approach used to estimate groundwater concentrations. Detailed descriptions of the models and a comprehensive list of the input values used in them can be found in Appendices I, J, and K. The calculations of the food chain model are based on these media concentrations and are presented in Section 2.3.3. Section 2.3.4 describes the aquatic food web calculation used in the ecological assessment.

2.3.1 Air Dispersion and Deposition Modeling (ISCST3)

Dispersion modeling uses a computer-based set of calculations to estimate ambient ground-level constituent concentrations associated with constituent releases from sewage sludge management practices. The dispersion model uses information on meteorology (e.g., windspeed, wind direction, temperature) to estimate the movement of pollutants through the atmosphere. Movement downwind is largely determined by windspeed and wind direction. Dispersion around the centerline of the plume is estimated using empirically derived dispersion coefficients that account for movement of pollutants in the horizontal and vertical directions. In addition, pollutant movement from the atmosphere to the ground is also modeled to account for deposition processes driven by gravitational settling and removal by precipitation.

The inputs to the air dispersion and deposition model include

- Surface area of the agriculture field or lagoon
- Meteorologic data for the site of the farm or lagoon
- Locations of potential receptors.

The input data and the resulting unitized air concentrations used in this analysis for the air dispersion modeling (for the sewage sludge lagoons) are provided in Appendix I.

The air dispersion and deposition modeling conducted for this analysis produced output data that were used to calculate environmental media concentrations and food chain concentrations. The dispersion model outputs included air concentration of vapors and particles, wet deposition of vapors and particles, and dry deposition of particles. Dry deposition of vapors was also calculated, but outside the dispersion model. For the sewage sludge lagoon scenario, only air dispersion modeling of vapors was performed because the only air emissions from lagoons are vapors, and therefore, the only exposure point concentration required is the air concentrations of vapors at the exposure point.

For the agricultural application scenario, the ISCST3 modeling included all potential outputs over a grid of receptor points. These outputs were processed in a GIS to produce the following outputs:

- Air concentration of vapors and particles
- Wet deposition of vapors and particles
- Dry deposition of particles.

These outputs were produced for each of the following locations:

- Agricultural land (crop and pasture)
- Buffer area (residential exposure)
- Watershed area
- Waterbodies (index reservoir and farm pond).

For the screening analysis, the maximum grid point value for each output was used to represent the air modeling results for each location with the exception of the watershed, where the average of the grid point values was used.

2.3.2 Estimation of Soil, Water, and Sediment Concentrations

This section describes how total soil concentration was estimated for each of the locations in the conceptual site (cropland, pasture, buffer, and watershed). These concentrations are common to both the human health and ecological screening analysis. It also describes the components that make up the two waterbodies modeled in this analysis. The first waterbody is EPA's index reservoir for evaluating drinking water exposures to pesticides (Shipman Lake), a 13-acre lake that has a 427-acre watershed and is separated from the sludge-amended agricultural land by a 10-ft buffer. This waterbody was used as a drinking water source in this analysis. The second waterbody is a farm pond that is located immediately adjacent to the sludge-amended land and receives runoff and erosion directly from the sludge-amended land (no buffer). The farm pond is the site of all ecological receptor exposures and is used for recreational fishing by the farm family. Finally, this section describes the dilution-attenuation factor used to estimate the groundwater concentrations used for drinking water and showering.

2.3.2.1 Soil Concentrations. Soil concentrations were calculated considering pollutant loads from the direct agricultural application of sewage sludge to agricultural fields (which are assumed to be half cropland and half pasture) and aerial deposition of pollutants onto cropland, pasture, the buffer area, and the regional watershed. For the agricultural land where sewage sludge is applied, pollutant concentrations in soil change with each year of sludge application. During the application period, the pollutant concentrations in soils resulting from aerial deposition also change.

In each case, the concentration of a contaminant in the soil is determined by the flux of chemical (from application or deposition) and loss mechanisms of that chemical from the soil. Soil losses accounted for in this analysis include erosion, biodegradation, volatilization, leaching, and dissolved loss in surface runoff. For a particular site and model iteration, these loss processes were assumed to be the same in all locations across the site and surrounding watershed.

Temporal changes in soil concentration were accounted for through annual average soil concentrations produced by the land application model and annual estimates of deposition from the air model. For a particular iteration, the model used an average value over the exposure duration. In addition, the concentrations due to air deposition were added to the concentrations in the soil due to application of sludge (cropland to pasture and pasture to cropland[3]) and upslope erosion (agricultural field to buffer).

The areas modeled for soil concentrations differ for the two land application scenarios.

[3] Sludge applications to the adjacent cropland and pastureland are modeled simultaneously for a given iteration. The cropland receives depositional loads from the pasture, and the pasture receives depositional loads from the cropland.

- For the farm pond scenario, the source model calculated soil concentrations for the cropland and pasture only, which comprise the entire watershed for the pond.

- For the drinking water (index) reservoir scenario, soil concentrations were calculated for cropland, pasture, a buffer area between the farm and the waterbody (the local watershed), and a regional watershed that feeds the drinking water reservoir.

The regional watershed area was assumed to be agricultural land, some of which (10 percent to 80 percent) is also amended with sewage sludge. To account for this additional load of pollutants in the watershed area, the soil concentrations in the agricultural field were scaled to the area of amended agricultural land in the regional watershed. In addition, the regional watershed soil receives a chemical load via averaged air deposition rates from the modeled agricultural field. These soil chemical loads (application and deposition) were totaled to estimate soil concentrations in the regional watershed, which, in turn, were used to estimate chemical loads to the index reservoir from soil erosion and overland transport (see Appendix J for methods).

2.3.2.2 Predicting Surface Water Concentrations. The waterbodies in this analysis include the index reservoir, which is a source of drinking water, and a farm pond, where ecological receptors live and feed and from which the farm family catches fish. Pollutants enter the waterbody by any of four pathways:

1. Constituents in the air above the waterbody can be deposited directly onto the waterbody's surface. This occurs for airborne particles via dry and wet deposition due to gravitational settling and scavenging by precipitation, respectively.

2. Vapors can also deposit directly onto the waterbody's surface via scavenging by precipitation (i.e., wet deposition).

3. Constituents on the soils can enter the waterbody through runoff and erosion. This occurs directly from the sludge-amended agricultural field to the farm pond and from the sludge-amended agricultural field to the buffer to the index reservoir.

4. Pollutants deposited onto soils in the upstream watershed also enter the index reservoir through runoff and erosion.

Thus, the total pollutant load to each of the waterbodies is the sum of all of the loads to that waterbody from these pathways. The methods used to develop this load are presented in Appendix J.

The index reservoir also requires a base flow. Base flow represents the component of streamflow that is not direct surface runoff. The watershed model provides a base flow to the index reservoir. The waterbody models take the inputs from these sources (daily loads due to erosion, runoff, and deposition) and use these loads in addition to other inputs for the waterbody (area, depth, and baseflow) to estimate concentrations in the various components of the waterbody over varying time periods. The concentration was estimated for pollutants in the dissolved phase in the water column, in the suspended solids, and in the benthic sediment. These estimates consider losses due to hydrolysis and/or biodegradation. The mechanism used to calculate the concentrations in each component of the each of the two waterbodies is presented in Appendix J.

2.3.2.3 Predicting Groundwater Concentrations. The concentration of the pollutant in leachate may be diluted in the groundwater system before reaching a nearby residential well. This dilution is estimated in this screening analysis by the application of a dilution-attenuation factor (DAF). No chemical-specific groundwater modeling was performed for the screening analysis. The DAF used in this screening analysis was the 10^{th} percentile DAF estimated by performing chemical-specific modeling for a variety of chemicals in a distribution of surface impoundments. This modeling was conducted for the Industrial Waste Management Evaluation Model (IWEM). IWEM considered chemicals with a range of chemical and physical properties in a representative nationwide sample of surface impoundments. EPA placed residential wells at a fixed distance of 150 m from the edge of the impoundments from the SI to calculate DAFs for IWEM. This screening analysis, used a DAF of 2 (10^{th} percentile DAF from the Tier 1 IWEM analysis) to estimate the concentration of each pollutant in the nearby residential well from the SI leachate concentration. For the constituents that exceed the critical dose for groundwater ingestion in the lagoon scenario and remain in the analysis, pollutant- and site-specific groundwater modeling will be conducted during the full-scale modeling.

Groundwater concentrations in the agricultural application scenario are assumed to be the leachate concentration at a depth of 1 m below the surface. No DAF is applied to this concentration.

2.3.3 Calculation of Food Chain Concentrations

Food chain exposures were evaluated for the agricultural application scenario. After the fate and transport models have predicted concentrations of pollutants in the air, soil, water, and sediment, pollutant concentrations are calculated in food items. Pollutants pass from contaminated soil, water, sediment, and air through the food chain to the farm family and ecological receptors. For example, pollutants in air may be deposited on plants growing in the agricultural field. Simultaneously, these plants may take up pollutants from the soil and accumulate pollutants from both routes in the fruits and vegetables consumed by the farm family and ecological receptors. In addition, beef and dairy cattle, as well as wildlife receptors, may consume forage and silage that are grown in sludge-amended pasture soil. Subsequently, the farm family may consume home-produced beef and dairy products from these animals. Similarly, pollutants applied to the agricultural land may erode and run off into a farm pond and accumulate in fish and other aquatic biota. The fish in the farm pond may be caught and consumed by members of the farm family, and aquatic biota may be consumed by wildlife receptors.

This section presents the methodology used to calculate pollutant concentrations for each of the diet items in the food chain pathways considered.

2.3.3.1 Terrestrial Food Chain. The terrestrial food chain is designed to predict the accumulation of a pollutant in the edible parts of food crops eaten by the farm family and in plants and prey items consumed by wildlife receptors. Edible crops include exposed and protected fruits, exposed and protected vegetables, and root vegetables. The term “exposed” refers to the fact that the edible portion of the produce is exposed to the atmosphere. The term “protected” refers to the fact that the edible portion of the produce is shielded from the atmosphere. Examples of the categories include tomatoes (exposed vegetable), corn (protected vegetable), apples (exposed fruit), oranges (protected fruit), and potatoes (root vegetables). In addition, the farm family is assumed to raise beef and dairy cattle that forage on the pasture, consume silage raised on the cropland, and consume associated soil. Figure 2-4 shows the data flow into and out of the farm food chain model. The equations used to calculate the food chain concentrations of pollutants are presented in Appendix K. Bio-uptake factors are provided in Appendix F.

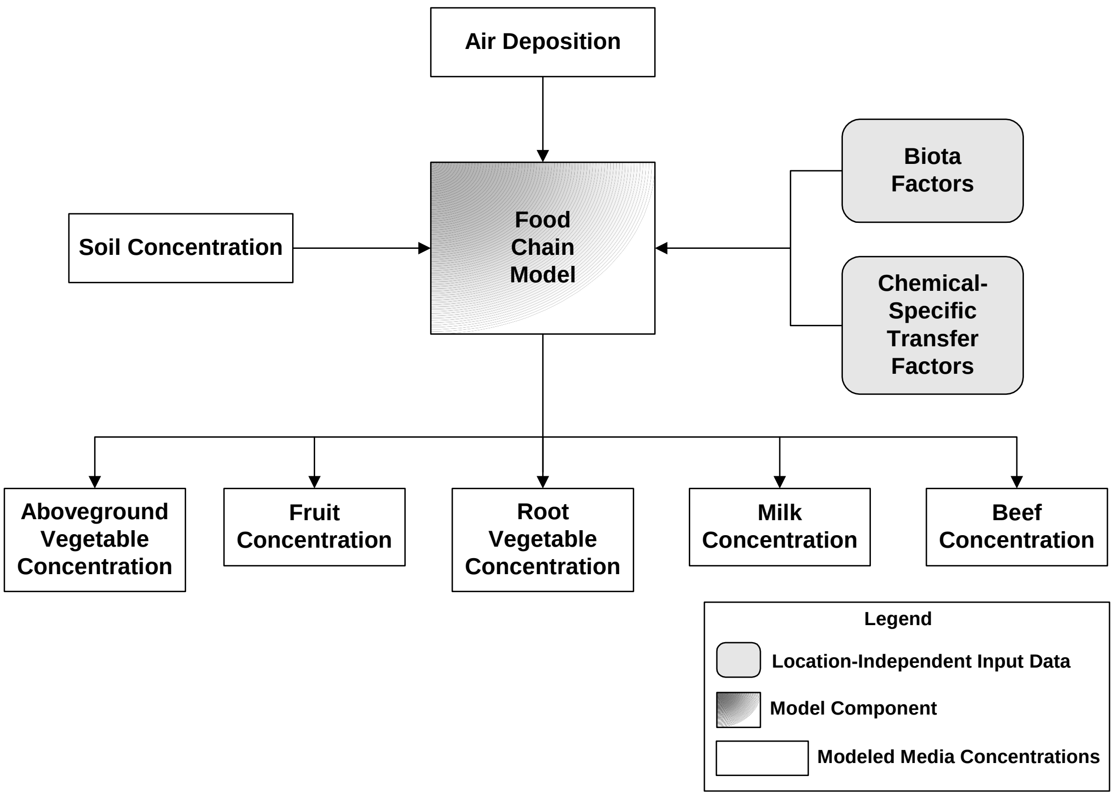

Figure 2-4. Farm food chain model.

Ecological receptors also are exposed to contaminants through ingestion of terrestrial food items. The terrestrial food chain for ecological receptors also includes vegetation and prey items in the diet. Figure 2-5 illustrates the terrestrial food chain modeled for ecological exposure. The screening analysis conservatively assumes that receptors take all of the vegetation in their diets from the farm field where sewage sludge is applied. Herbivorous receptors, such as the white-tailed deer, and omnivorous receptors, such as the raccoon and the red fox, eat similar types of vegetation as do the human receptors (e.g., exposed vegetables) and the beef and dairy cattle (e.g., forage grass) raised by the farm family. The concentrations in vegetation in the ecological receptors’ diets were predicted using the same modeling approach as that used to predict concentrations in the human diet.

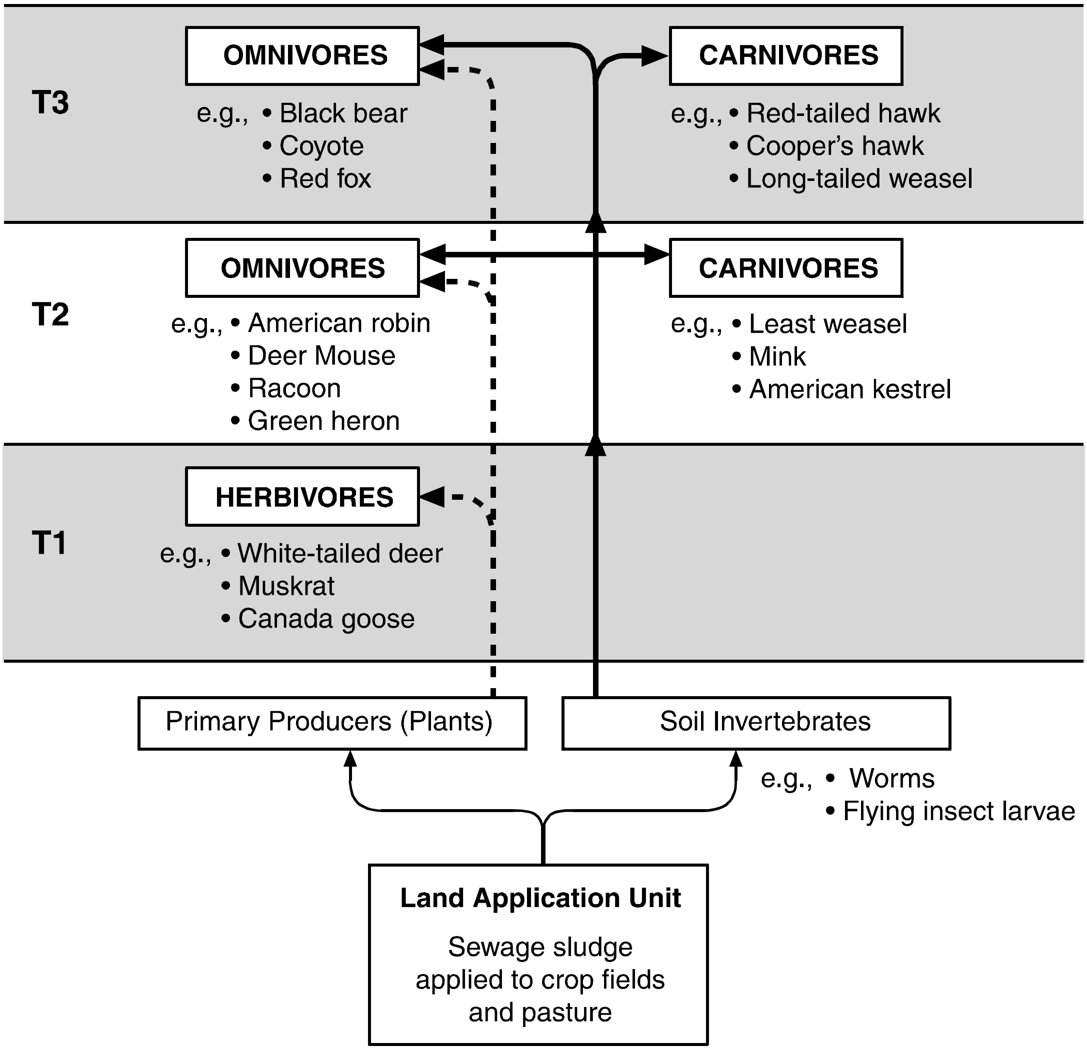

Figure 2-5. Terrestrial food web, including example receptors.

Omnivorous and carnivorous receptors eat a variety of terrestrial vertebrates, such as small mammals and birds, and soil invertebrates. Again, it was conservatively assumed that all terrestrial prey come from the agricultural field where sewage sludge is applied. Concentrations in terrestrial prey items were calculated by applying chemical-specific bioaccumulation factors (BAFs) to the soil concentrations. However, BAFs for organic chemicals in this analysis were generally lacking for terrestrial prey types, and a default value of 1 was used for all organics for terrestrial prey. For metal contaminants, BAFs derived from empirical data were identified in the literature for worms and for small mammals. In the absence of BAFs for other prey types (e.g., small birds, lizards and reptiles, and larger mammals), the small mammal BAFs were used for all terrestrial vertebrate prey, and the worm BAFs were used for all terrestrial invertebrate prey. The BAFs used to calculate food item concentrations are shown in Appendix M.

2.3.4 Calculation of Aquatic Food Web Concentrations

Some of the ecological receptors are exposed to contaminants through the ingestion of aquatic food items, including fish, sediment invertebrates (e.g., mussels), and aquatic plants in the farm pond. For example, wading birds, such as the great blue heron, eat fish and sediment invertebrates; the muskrat eats aquatic vegetation; and the raccoon eats a variety of fish, amphibians, and sediment invertebrates, in addition to a wide variety of terrestrial items. Figure 2-6 illustrates the aquatic food web modeled in the screening analysis. The screening analysis assumed that all aquatic items in the receptors' diets come from the farm pond. The concentrations in the fish and aquatic plants are calculated by applying chemical-specific bioconcentration factors (BCFs) to the water concentration, and the concentrations in the sediment invertebrates are calculated by applying BCFs to the sediment concentrations. BCF values for the aquatic food chain were the same as those used in the human exposure modeling to calculate concentrations in fish tissue. These values are shown in Appendix E.

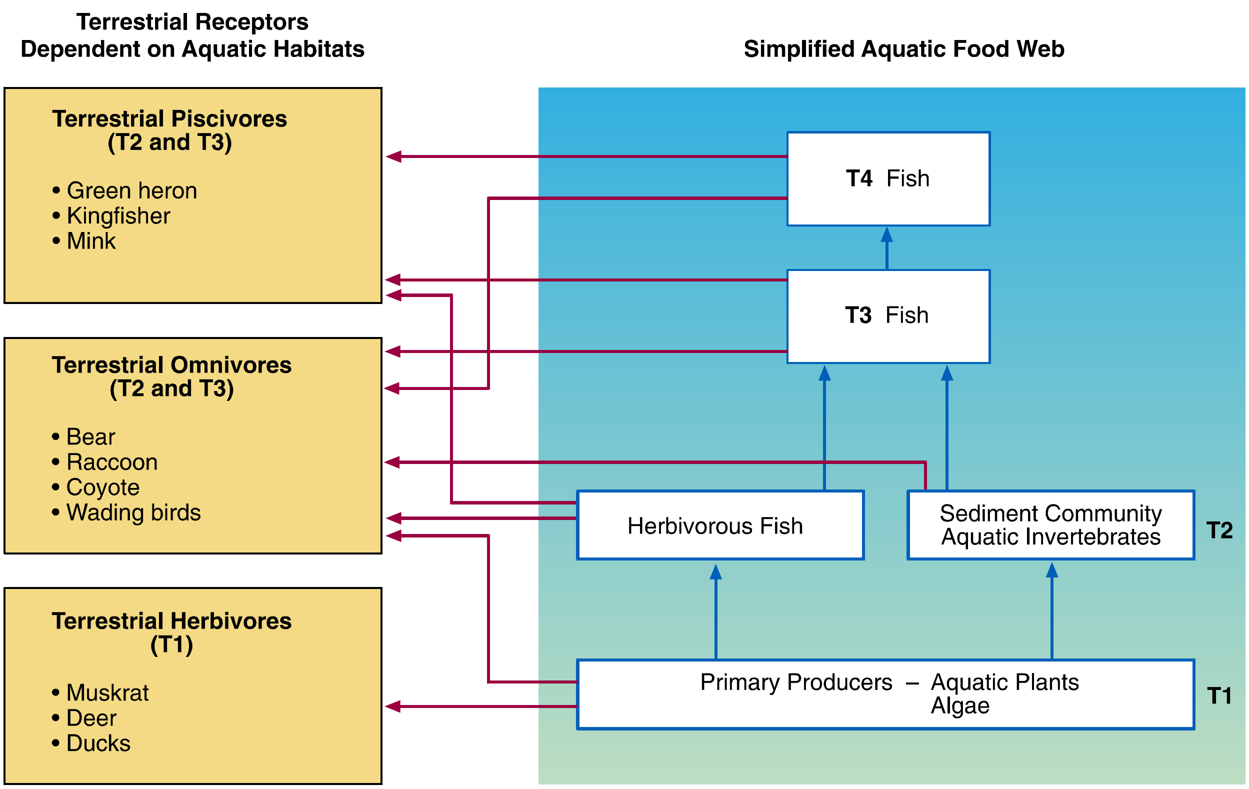

Figure 2-6. Aquatic food web, including example receptors.

2.4 Exposure Modeling

The pollutant concentrations in the food chain items identified in the previous section are used to estimate human and ecological exposures. This section describes the human and ecological exposure modeling.

2.4.1 Human Exposure Modeling

Human exposures occur as a result of disposal of sewage sludge in a lagoon or application of sewage sludge to agricultural land. The human exposures assumed for the sewage sludge lagoon scenario are presented in Table 2-1. A resident family was assumed to live near a facility with a sewage sludge lagoon and breathe the air at that location. In addition, the family was assumed to have a residential well that supplies tapwater to the household for use as drinking water and for showering for the family. The air exposures (ambient and indoor) were calculated by estimating the average daily air concentration of vapors to which an individual may be exposed. The exposure through the drinking water route was estimated by multiplying the maximum annual concentration of the pollutant in the groundwater by the consumption rate of the individual. This is the average daily dose (ADD) for an individual. To estimate a lifetime average daily dose (LADD) needed to screen for constituents with cancer endpoints, the ADD for each year of the exposure duration was summed and divided by the lifetime (70 years) for the adult and child resident who drink water from the residential well (exposure frequency is assumed to be 350 days per year, and the period of exposure was assumed to coincide with the highest annual exposure concentrations).

Table 2-1. Human Exposure Pathways for the Sewage Sludge Lagoon Scenario

Receptor	Ingestion of Drinking Water (Groundwater)	Inhalation of Indoor Air[a]	Inhalation of Ambient Air
Adult resident	✓	✓	✓
Child resident	✓	✓	✓

[a] Indoor air contaminated from showering.

For the purposes of this hazard analysis, ADD was defined as

$$ADD = C \times IR \tag{2-1}$$

where

ADD = average daily dose (mass constituent/body weight mass/day)
C = concentration (mass/volume or mass/mass)
IR = intake rate (mass/body weight mass/time or volume/body weight mass/day).

The LADD, used for assessing risks for carcinogenic effects, was defined as

$$LADD = \frac{C \times IR \times ED \times EF}{AT \times 365} \tag{2-2}$$

where

LADD = lifetime average daily dose (mass constituent/body weight mass/day)
C = average concentration (mass/mass or mass/volume)
IR = intake rate (mass/body weight mass/time or volume/body weight mass/day)
ED = exposure duration (yr)

EF = exposure frequency (d/yr)
AT = averaging time (yr, 70-year lifetime)
365 = unit conversion factor (d/yr).

The exposure pathways considered for the farm family are presented in Table 2-2. The same general approach used to estimate exposures for the lagoon scenario was used to estimate exposures for the agricultural application scenario. In the agricultural application scenario, however, more exposure routes are considered in the analysis. The air exposures were estimated using the same method as was used for the lagoon scenario. The air exposures (ambient and shower) were calculated by estimating the average daily air concentration of vapors and particles (ambient only) to which an individual may be exposed.

All ingestion pathways for the agricultural application scenario (drinking water, soil, produce, beef, milk, and fish) were estimated using the same method. An annual ADD or LADD was estimated for each exposure pathway individually, and the doses for all pathways were then summed to yield a total ADD or LADD for the farmer and child across all pathways. The exposure factors used in this analysis are described in detail in Appendix L.

Table 2-2. Human Exposure Pathways for the Agricultural Land Application Scenario

Receptor	Inhalation of Ambient Air	Ingestion of Drinking Water (Ground Water or Index Reservoir)	Ingestion of Soil	Ingestion of Above- and Belowground Produce	Ingestion of Beef and Dairy Products	Ingestion of Fish (Farm Pond)
Adult farmer	✔	✔	✔	✔	✔	✔
Child farm resident	✔	✔	✔	✔	✔	✔

2.4.2 Ecological Exposure Modeling

The ecological screening analysis is based on (1) predicted chemical concentrations in environmental media (e.g., soil, sediment), and (2) predicted exposure doses for birds and mammals. The predicted chemical concentrations were compared to either an environmental quality criterion (e.g., Ambient Water Quality Criterion) or a concentration-based benchmark for certain receptors (e.g., early life-stage lethality to amphibians in direct contact with contaminated water). The predicted doses were compared to dose-based benchmarks (in mg/kg-day) to screen for potential ecological hazard to these receptor species.

For exposures assessed on the basis of medium concentration (or direct contact) shown in Table 2-3, maximum annual average chemical concentrations were used for soil and sediment, and multiple averaging times were used for chemical concentrations in surface water. For example, if the benchmark for fish was derived from a 96-hour study, the 4-day maximum concentration was selected as the exposure concentration. Appendix P provides the exposure duration assumed for each receptor and constituent.

Table 2-3. Receptors Assessed Using Media Concentrations

Receptor	Exposure Concentration
Fish	Surface water concentration (farm pond)
Aquatic invertebrates	Surface water concentration (farm pond)
Aquatic plants	Surface water concentration (farm pond)
Amphibians	Surface water concentration (farm pond)
Aquatic community	Surface water concentration (farm pond)
Sediment invertebrates	Sediment concentration (farm pond)
Soil invertebrates	Soil concentration (agricultural field)

For the ingestion pathway, exposure dose was calculated as a function of the concentrations in each receptor's diet, and receptor-specific ingestion rates and body weight. Dietary composition was based on species-specific data on foraging and feeding behavior and reflected a year-round adult diet. Diet items were grouped in 17 categories, including different types of vegetation (e.g., fruits, forage, grain, roots) and several categories of prey (e.g., small birds, small mammals, invertebrates, fish). For example, the American robin's dietary composition is as follows (Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996):

Diet Item	Dietary Percentage Range
Soil invertebrates (other than earthworms)	8 to 93
Fruits	7 to 92
Earthworms	15 to 27
Forage	0 to 24

Each receptor's diet was constructed using the average of the minimum and maximum percentages for each diet item, beginning with the item with highest value and proceeding through the diet items until a full diet (100 percent) was accumulated. Thus, the robin's diet would consist of 50.5 percent soil invertebrates and 49.5 percent fruits, based on the following average dietary percentages:

Diet Item	Average
Soil invertebrates	50.5
Fruits	49.5
Worms	21
Forage	12

The dietary composition used for each receptor species is presented in Appendix N.

Each receptor's exposure dose was calculated as a function of its respective ingestion rate, body weight, and the concentrations in the various diet items. In addition to prey and plant items, soil, sediment, and drinking water ingestion were also accounted for. Soil and sediment ingestion are expressed as a fraction of total diet. Ingestion dose was calculated as

$$Dose_A = \frac{\Sigma(IR_{diet} \times C_{diet\ Aj} \times DietFrac_j) + (C_{soil/sed\ A} \times IR_{diet} \times S_{frac}) + (C_{sw\ A} \times IR_{water})}{BW} \qquad (2\text{-}3)$$

where

$Dose_A$	=	Exposure dose for chemical *A* (mg/kg-d)
IR_{diet}	=	Species-specific dietary ingestion rate (kg WW/d)
$C_{diet\ Aj}$	=	Concentration of chemical *A* in diet item *j* (mg/kg WW)
$DietFrac_j$	=	Fraction of diet consisting of item *j* (unitless)
$C_{soil/sed\ A}$	=	Concentration of chemical *A* in soil or sediment (mg/kg)
S_{frac}	=	Fraction of soil or sediment in the diet (unitless)
$C_{sw\ A}$	=	Concentration of chemical *A* in surface water (mg/L)
IR_{water}	=	Species-specific water ingestion rate (L/d)
BW	=	Species-specific average adult body weight (kg).

The species-specific exposure factors (ingestion rates and body weights) were taken from EPA's *Wildlife Exposure Factors Handbook* (U.S. EPA, 1993) and are presented in Appendix N.

2.5 Screening Criteria Development

2.5.1 Human Health Screening Criteria

The human health benchmarks used in this assessment are critical doses (CDs) or critical concentrations (CCs). The CCs were used as air pathway criteria. For air exposures to pollutants with noncancer endpoints, the CC is the RfC as reported in IRIS. For air exposures to pollutants with cancer endpoints, the CC is associated with a cancer risk of 1E-5, based on the AUR. If a pollutant had both a cancer and noncancer inhalation benchmark, the lower CC calculated by these methods was the CC used as the screening criterion.

The human health benchmarks used for the ingestion pathways is the CD, which was compared to the ADD (for noncarcinogens) or LADD (for carcinogens). For ingestion exposures to pollutants with noncancer endpoints, the CD was the RfD reported in IRIS or the RfD or the PAD reported in the RED or IRED documents issued by EPA OPP. For ingestion exposures to pollutants with cancer endpoints, the CD was calculated as the dose that yields a cancer risk level of 1E-5 (1 in 100,000) over a lifetime (that dose was calculated as 1E-5/ $CSF_{\_oral}$).

The screening criteria used in this analysis are presented in Table 2-4.

Table 2-4. Human Health Screening Criteria for Pollutants

Chemical	CASRN	Oral Critical Dose (mg/kg/d)	Inhalation Critical Concentration (mg/m^3)
Acetone	67-64-1	0.9	
Acetophenone	98-86-2	0.1	
Anthracene	120-12-7	0.3	
Azinphos methyl	86-50-0	0.0015	0.0022
Barium	7440-39-3	0.07	
Benzoic acid	65-85-0	4.0	
Beryllium	7440-41-7	0.002	0.000004
Biphenyl, 1,1-	92-52-4	0.05	
Butyl benzyl phthalate	85-68-7	0.2	
Carbon disulfide	75-15-0	0.1	0.7
Chloroaniline, 4-	106-47-8	0.004	
Chlorobenzene; Phenyl chloride	108-90-7	0.02	
Chlorobenzilate	510-15-6	0.02	
Chlorpyrifos	2921-88-2	0.00003	0.00005
Cresol, o- (2-methylphenol)	95-48-7	0.05	
Diazinon	333-41-5	0.0002	0.00006
Dichloroethene, 1,2-trans-	156-60-5	0.02	
Dichloromethane	75-09-2	0.0013	0.02
Dioxane, 1,4-	123-91-1	0.000909	
Endrin	72-20-8	0.0003	
Ethyl p-nitrophenyl phenylphosphorothioate; EPN; Santox	2104-64-5	0.00001	
Fluoranthene	206-44-0	0.04	
Hexachlorocyclohexane, alpha-	319-84-6	0.0000016	0.000006
Hexachlorocyclohexane, beta-	319-85-7	0.0000056	0.00002
Isobutyl alcohol	78-83-1	0.3	
Manganese	7439-96-5	0.14[a]	0.00005
Methyl ethyl ketone	78-93-3	0.6	5.0
Methyl isobutyl ketone (MIBK); Methyl-2-pentanone, 4-	108-10-1		3.0
Naled	300-76-5	0.002	0.0004
Nitrate	14797-55-8	1.6	
Nitrite	14797-65-0	0.1	
N-Nitrosodiphenylamine	86-30-6	0.002	

(continued)

Table 2-4. (continued)

Chemical	CASRN	Oral Critical Dose (mg/kg/d)	Inhalation Critical Concentration (mg/m^3)
Phenol	108-95-2	0.3	
Pyrene	129-00-0	0.03	
Silver	7440-22-4	0.005	
Trichlorofluoromethane	75-69-4	0.3	
Trichlorophenoxy) propionic acid, 2-(2,4,5-	93-72-1	0.008	
Trichlorophenoxyacetic acid, 2,4,5-; 2,4,5-T	93-76-5	0.01	
Trifluralin	1582-09-8	0.0013	
Xylenes (mixture)	1330-20-7	0.2	0.1

For human receptors, the air concentration at the receptor location is compared to the screening criterion (CC). For all the ingestion pathways, the total ADD or LADD calculated for a receptor is compared to the CD. If any of these ratios is greater than one, the pollutant fails the screening criterion and is retained in the analysis for additional study.

[a] The oral critical dose for manganese from drinking water and soil is 0.047 mg/kg/day.

2.5.2 Ecological Screening Criteria

The screening criteria for ecological receptors are benchmarks expressed in terms of media concentration (e.g., mg/L for surface water or mg/kg for soil) or in terms of dose (mg/kg^{-d}). Because there is no single repository for approved ecological benchmarks analogous to IRIS, benchmarks were derived from various EPA and other government reports and from toxicological studies in the open literature.

Several factors were considered in selecting toxicological data for use in developing benchmarks. These factors include, for example, the effect level, exposure duration, measurement endpoint, and completeness of reported information. The objectives of the selection process were to:

- Use data from reliable, preferably peer-reviewed sources
- Use data that are relevant to the assessment endpoints (population/community viability)
- Select the lowest (most protective) value that is relevant and appropriate.

The decision framework process used for selecting benchmark data is illustrated in Table 2-5. The preferred characteristics, shown in the second column, are the target objectives for data selection. If data meeting the preferred condition were not available for a pollutant-receptor combination, then other data were considered. For example,

- Reproductive and growth effects and mortality data would be selected for consideration, while data on liver damage would not be considered because it is not necessarily relevant to population viability

- For mammal or bird data, studies in which the dose is administered in feed would be considered, while dermal injection studies would not be considered because they do not necessarily reflect ingestion exposure

- For aquatic studies, data from flow through tests would be selected over equivalent data from static tests

- Because the screening assessment addresses long term chronic exposure, studies based on longer durations (generally longer than 96 hours) were preferred

- Endpoints measuring lethality (e.g., LC_{50}) were considered only in cases where non-lethal endpoints (e.g., chronic NOECs and LOECs) are not available. Risk results based on benchmarks derived from lethality data must be interpreted differently than results based on non-lethal effects (e.g., reduced growth or hatching success). See Section 3.3.1 for further discussion of interpreting lethality-based results

- Measured values were preferred over predicted (e.g., values generated based on structure activity relationships [SARs])

- All else being equal, the lowest acceptable value was selected.

Different references were consulted for different receptors and environmental media. Table 2-6 shows the references consulted for benchmarks. Numbers preceding each reference indicate the data quality hierarchy. The ecological benchmarks used in the screening analysis and their respective sources are provided in Appendix P.

Ecological hazard was expressed in terms of hazard quotients (HQs). For the direct exposure pathway, HQs were calculated as the ratio of the exposure concentration to the relevant benchmark. For example, the HQ for fish was calculated as the ratio of the surface water concentration to the fish benchmark. For the ingestion pathway, the HQs were the ratio of the exposure dose to the relevant benchmark. An HQ greater than or equal to one is an indication that further analysis may be warranted.

Table 2-5. Criteria for Selecting Toxicological Data

Component	Preferred	Not preferred	Not allowed
Assessment Endpoint (Effect)	Effects related to population or community viability: reproduction, growth	Mortality	Effects **not** related to population or community viability
Mammal and Bird Studies: Type	Ingestion (dietary and other)studies		Injection studies
Mammal and Bird Studies: Reported data	Test species, test duration, and body weight reported	Test species, test duration, or body weight **not** reported	
Aquatic Studies: study design	Flow through	Static	
Study Duration	Chronic, longest	Shorter, acute	
Measurement endpoint	NOEL - LOEL, MATL, other threshold effects levels	LC_{50}, LD_{50}, EC_{50}	
Measured vs. Predicted Values	Measured	Predicted	
Value	Lowest (most toxic) value	Higher values	

Table 2-6. Sources for Ecological Benchmarks

	Organic Contaminants	Metal Contaminants
Water	1. U.S. EPA, 2002a (NAWQC) 2. Suter and Tsao, 1996 3. Canadian Council of Ministers of the Environment, 2002 4. U.S. EPA, 2003a (EFED Database) 5. California EPA, 2003 6. U.S. EPA, 2003b (ECOTOX database)	1. U.S. EPA, 2002a (NAWQC) 2. Suter and Tsao, 1996 3. Canadian Council of Ministers of the Environment, 2002 4. U.S. EPA, 2003a (EFED Database) 5. California EPA, 2003 6. U.S. EPA, 2003b (ECOTOX database)
Soil	1. Effroymson et al., 1997 2. Canadian Council of Ministers of the Environment, 2002 3. U.S. EPA, 2003b (ECOTOX database)	1. Effroymson et al., 1997 2. Canadian Council of Ministers of the Environment, 2002 3. U.S. EPA, 2003b (ECOTOX database)
Sediment	1. Jones et al., 1997 2. Canadian Council of Ministers of the Environment, 2002 3. U.S. EPA, 2003b (ECOTOX database)	1. Jones et al., 1997 2. Canadian Council of Ministers of the Environment, 2002 3. U.S. EPA, 2003b (ECOTOX database)
Mammals and Birds	1. Sample et al., 1996 2. U.S. EPA, 2003a (EFED Database) 3. U.S. EPA, 2003b (ECOTOX database)	1. Sample et al., 1996 2. U.S. EPA, 2003a (EFED Database) 3. U.S. EPA, 2003b (ECOTOX database)

3.0 Screening Results

For chemicals with human health benchmark (HHB) values for ingestion, the results of the screening analysis are a ratio of the estimated average daily dose (ADD) or lifetime average daily dose (LADD) to a critical dose (CD) for each pollutant. For chemicals with an HHB for inhalation, the average daily air concentration is compared with the critical concentration (CC) for these pollutants. If either of these ratios exceeds one at the 95^{th} percentile of the hazard quotient (HQ) distribution, the pollutant fails the screen. A similar comparison is performed for ecological benchmark values. If the HQ based on a wildlife toxicity endpoint equals or exceeds one for any pollutant, that pollutant is considered to fail the screening assessment for that representative ecological receptor.

3.1 Human Health Screening Results

The human health screening assessment was performed using CDs and CCs based on both cancer and noncancer endpoints. The CDs based on noncancer endpoints were compared with the ADD for both the adult and child receptors. The CDs based on cancer endpoints were compared with the LADD. Similar comparisons were made for the inhalation endpoints. The CCs based on noncancer and noncancer endpoints were compared with the average daily concentration to which humans were assumed to be exposed.

In both the agricultural land application scenario and the sewage sludge lagoon scenario, no pollutants with cancer endpoints had HQs greater than one. No pollutant with either a cancer or noncancer endpoint had HQs greater than one on the basis of an inhalation exposure.

Nitrite had HQs greater than one in both scenarios, based on the ingestion of drinking water from groundwater in the sewage sludge lagoon scenario, and based on the ingestion of drinking water from surface water and total ingestion in the agricultural land application scenario. Silver had HQs greater than one for the agricultural land application scenario only. Barium, manganese, nitrate, and 4-chloroaniline had HQs greater than one for the lagoon scenario only. Table 3-1 presents the results for the pollutants that had HQs greater than one for the agricultural land application scenario, and Table 3-2 presents the results for the pollutants that had HQs greater than one for the sewage sludge lagoon scenario.

Table 3-1. Human Hazard Quotient Values Greater Than One at the 95th Percentile of the HQ Distribution by Pathway for the Agricultural Land Application Scenario

CASRN	Chemical	Pathway	Receptor	HQ
14797-65-0	Nitrite	Ingestion of Surface Water	Child	1.1
		Total Ingestion	Child	1.3
7440-22-4	Silver	Ingestion of Milk	Adult	3.8
			Child	12.0
		Total Ingestion	Adult	4.0
			Child	12.3

Table 3-2. Human Hazard Quotient Values Greater Than One at the 95th Percentile of the HQ Distribution by Pathway for the Sewage Sludge Lagoon Scenario

CASRN	Chemical	Pathway	Receptor	HQ
7440-39-3	Barium	Drinking Water from Groundwater	Adult	1.5
			Child	3.5
106-47-8	4-Chloroaniline	Drinking Water from Groundwater	Adult	2.7
			Child	6.4
7439-96-5	Manganese	Drinking Water from Groundwater	Adult	32.3
			Child	76.3
14797-65-0	Nitrite	Drinking Water from Groundwater	Adult	13.6
			Child	33.8
14797-55-8	Nitrate	Drinking Water from Groundwater	Adult	9.2
			Child	23

3.2 Ecological Screening Results

The ecological screening assessment addressed risks from direct contact with contaminated media and from ingestion of contaminated food and feed. The ecological screening was performed by comparing environmental concentrations to comparable benchmark values for the agricultural land application scenario. Hazards are expressed as HQs calculated as the ratio of the exposure dose, or concentration, to the relevant benchmark.

Table 3-3 shows the pollutants that had ecological HQs greater than one at the 95th percentile of the HQ distribution for the direct contact pathway. There was no ingestion hazard for any aquatic or terrestrial wildlife species from any of the chemicals. Complete results are presented in Appendix R.

Table 3-3. Hazard Quotient Values Equal to or Greater Than One at the 95th Percentile of the HQ Distribution for Aquatic and Terrestrial Wildlife Via Direct Contact Pathways

CASRN	Chemical	Receptor[a]	HQ
67-64-1	Acetone	Sediment Biota	356.2
120-12-7	Anthracene	Sediment Biota	2.9
7440-39-3	Barium	Aquatic Community	235.7
7440-41-7	Beryllium	Aquatic Community	7.8
75-15-0	Carbon disulfide	Sediment Biota	1.9
106-47-8	4-Chloroaniline	Aquatic Invertebrates	1.3
333-41-5	Diazinon	Sediment Biota	1.1
206-44-0	Fluoranthene	Aquatic Community Sediment Biota	10.7 4.2
7439-96-5	Manganese	Aquatic Community	13.9
78-93-3	Methyl Ethyl Ketone	Sediment Biota	5.8
108-95-2	Phenol	Sediment Biota	102.4
129-00-0	Pyrene	Aquatic Community Sediment Biota Soil Biota	41.9 21.1 4.5
7440-22-4	Silver	Aquatic Community Aquatic Invertebrates Fish	246.6 28.2 4.8

[a] Sediment biota organisms include sediment invertebrates; aquatic community organisms include fish, aquatic invertebrates, aquatic plants, and amphibians; soil biota organisms include soil invertebrates.

3.2.1 Direct Contact Pathway

The direct contact pathway analysis assesses risks to ecological receptors exposed through direct contact with contaminated media—surface water, sediment, and soil.

Thirteen pollutants had HQs that were greater than one. The ecological benchmark values for different receptors and pollutants are based on different measurement endpoints and therefore reflect varying levels of protection. In most cases, the benchmarks are based on chronic effects data for reproductive and developmental endpoints, such as lowest observed adverse effects levels (LOAELs) or effects range-low values (ERLs). As such, an HQ below one indicates that adverse effects at the population or community level are not expected from that particular pollutant for that particular receptor. However, for some of the chemicals assessed, the only aquatic ecotoxicological data identified were for mortality endpoints (e.g., LC_{50} values reflecting levels at which 50 percent of the test subjects died). The implications of risk results that are based on lethality benchmarks are not equivalent to those that are based on chronic effects endpoints. An HQ below one that is based on a lethality endpoint may still imply impacts to the receptor. For example, an HQ of 0.1 that is based on an LC_{50} value may result in lethality to a significant percentage of the population (e.g., 10 percent). This result may be of much greater ecological significance than an HQ of 1.0 that is based, for example, on a LOAEL for reproductive fitness, which may only affect a small percentage of the population.

3.2.2 Ingestion Pathway

The ingestion pathway analysis assesses risks to ecological receptors exposed through ingestion of plants, prey, and drinking water, and through incidental ingestion of soil and sediment. Diet items include terrestrial plants and prey taken from the agricultural fields and aquatic plants and prey taken from the farm pond. No pollutant had HQ values greater than one for aquatic or terrestrial receptor species. Results are presented in Appendix R.

3.3 Analysis of Variability and Uncertainty

This is a screening assessment and therefore, where uncertainty and variability were identified, the choice was made to err on the side of being more protective.

Variability arises from true heterogeneity in characteristics, such as body weight differences within a population or differences in contaminant levels in the environment.

Uncertainty represents lack of knowledge about factors, such as the nature of adverse effects from exposure to constituents, that may be reduced with additional research.

Variability and uncertainty are fundamentally different. Variability represents true heterogeneity in characteristics, such as body weight differences within a population or differences in pollutant levels in the environment. It accounts for the distribution of risk within the exposed population. Uncertainty, on the other hand, represents lack of knowledge about factors, such as adverse effects from pollutant exposure, that may be reduced with additional research to improve data or models.

This discussion describes the treatment of variability and uncertainty in reference to some parameters used to describe human and ecological exposures and risk. Treatment of variability using a Monte Carlo simulation forms the basis for the exposure distributions. Previous sections of this document describe how distributions were generated and values were estimated for input parameters. They also describe how these values were used in the models and in calculations to produce a national-level distribution of exposure concentrations and doses. Uncertainty necessitated the use of assumptions and default values in this screening assessment. This discussion focuses on how this treatment of variability and uncertainty affects the results.

3.3.1 Parameter Variability

Variability is often used interchangeably with the term uncertainty, but the two are not synonymous. Variability is tied to variations in physical, chemical, and biological processes and cannot be reduced with additional research or information. Although variability may be known with great certainty (e.g., age distribution of a population may be known and represented by the mean age and its standard deviation), it cannot be eliminated and needs to be treated explicitly in the assessment. Spatial and temporal variability in parameter values used to model exposure account for the distribution in the exposed population.

For example, the meteorological parameters used in dispersion modeling, such as windspeed and wind direction, are measured hourly by the National Weather Service at many locations throughout the United States, and statistics about these parameters are well documented. Although the distributions of these parameters may be well known, their actual values vary spatially and temporally and cannot be predicted exactly. Thus, the concentration calculated by a dispersion model for a particular receptor for a particular time period will provide information on average conditions that may over- or underpredict actual concentrations. Much of the temporal variation is accounted for by using models such as ISCST3 that calculate concentrations hourly and sum these hourly values to provide annual concentration estimates. Additionally, using meteorological data from multiple monitoring stations located throughout the United States can account for some, but not all, spatial variability.

In planning this assessment, it was important to specifically address as much of the variability as possible, either directly in the Monte Carlo analysis or through disaggregation of the data into discrete elements of the analysis. For example, use of a refined receptor grid accounts for spatial variability in concentrations on and around the agricultural field where sewage sludge is applied. Variability in agricultural practices is accounted for by using distributions that represent the range of possible agricultural practices.

Because sewage sludge is generated nationwide, its application to agricultural fields may occur anywhere in the United States. Thus, this assessment characterized environmental conditions that influence the fate and transport of constituents in the environment using regional data based on climatic conditions. Spatial variability in environmental setting was accounted for by using 41 different climatic regions throughout the contiguous 48 states.

The risk assessment components discussed include the following:

- Source characterization and emissions modeling
- Fate and transport modeling
- Exposure modeling.

3.3.1.1 Source Characterization and Emissions Model Variables. The specific agricultural fields where sludge was applied were not known; however, EPA assumed that sewage sludge could be applied to any agricultural land. For this assessment, agricultural field areas were varied according to climatic regions. The median farm size for each climatic region was used to represent the regional variability of farm size. However, uncertainty about farm size within a climatic region remained. Distributions were used to capture nationwide variability in agricultural practices. The variation in median farm size based on regions and the nationwide distribution of agricultural practice parameters was used in the probabilistic assessment to characterize the national variation in farm areas and operating characteristics.

Source partition modeling was performed for 41 different climatic regions, which allowed variation in location-dependent parameters (e.g., soil, temperature, precipitation) to be considered explicitly in the modeling. Variation in these parameters influenced variation in predicted air emissions rates and leachate concentrations. Meteorological data sets were combined with the surface area of the agricultural field to provide unit air concentrations (UACs), which were used with emissions data to estimate air concentrations for cropland and pastures. Soil data sets were combined with the meteorologic locations to provide distribution of soil types and characteristics.

In the Monte Carlo analysis, the agricultural field characteristics, environmental conditions from 41 climatic regions, and parameter values for sludge characteristics were combined to produce the 3,000 iterations of the source partition model calculations. The source model calculations generated the distribution of environmental releases used in the fate and transport modeling.

3.3.1.2 Fate and Transport Model Variables. The parameter values required to model contaminant fate and transport were obtained from regional databases. The treatment of regional variation in location-dependent parameters used in fate and transport modeling is discussed in the following sections.

Dispersion Model Variables. To capture geographic variation, dispersion modeling was conducted using meteorological data sets from 41 different meteorological stations throughout the contiguous 48 states. This provided regional representation of the variability in meteorological data. The 41 meteorological stations do not represent every site-specific condition that could exist in the continental United States. However, in selecting the climatic regions, consideration was given to represent different Bailey's ecological regions and to not exclude from the assessment those areas with unique dispersion characteristics (e.g., coastal areas). Thus, it is believed that these 41 climatic regions are a reasonable representation of the variability in meteorological conditions for the United States.

Soil and Water Model Variables. Soil characteristics were based on the location of the 41 climatic regions used in the modeling. Soil characteristics for all nonurban soil within the climatic region were used to determine the soil characteristics for watershed modeling. This approach captured the national distribution of soil types and accounted for regional variation in soil characteristics.

Waterbody characteristics for the index reservoir and its associated watershed size were not varied in the fate and transport modeling. However, in addition to variation in soil type and precipitation, watershed modeling also took into account regional variation in agricultural field size, which can affect constituent loading to the waterbody via runoff and erosion. The farm pond varied in size on a regional basis in relation with regional variation in farm size.

Terrestrial and Aquatic Food Chain Variables. No regional variations were explicitly considered for the aquatic food chain modeling. However, agricultural field size and variation in regional watershed characteristics affect runoff and erosion loadings to the waterbodies modeled in this assessment, which indirectly affects the food chain modeling.

Exposure Modeling Variables. Individual physical characteristics, activities, and behavior are quite different. As such, the exposure factors that influence the exposure of an individual, including inhalation rate, ingestion rate, body weight, and exposure duration, are quite variable. To include this variability explicitly in the assessment, statistical distributions for these variables were used for each receptor in the assessment: adult, child, and infant in the farm family and a recreational fisher. For adults, a single exposure factor distribution was used for males and females. For child exposures, one age (age 1) was used to represent the age at the start of exposure, because this age group is considered to be most sensitive for most health effects. Exposure parameter data from the *Exposure Factors Handbook* (EFH; U.S. EPA, 1997a,b,c) were used to establish statistical distributions of values for each exposure parameter for each receptor.

Summary of Variability Considerations. In summary, a distribution of exposures was developed that includes specific consideration of the variability in

- Agricultural field size
- Agricultural practices
- Regional-specific environmental conditions
- Exposure factors for each receptor.

Taken together, these form the basis for national exposure concentration distributions for use in the screening assessment.

3.4 Uncertainty

Uncertainty is a description of the imperfection in knowledge of the true value of a particular parameter. In contrast to variability, uncertainty is reducible by additional information-gathering or analysis activities (e.g., better data, better models). EPA typically classifies the major areas of uncertainty in risk assessments as scenario uncertainty, model uncertainty, and parameter uncertainty. Scenario uncertainty refers to missing or incomplete information needed to fully define exposure and dose. Model uncertainty is a measure of how well the model simulates reality. Parameter uncertainty is the lack of knowledge regarding the true value of a parameter used in the assessment.

Although some aspects of uncertainty were directly addressed in this assessment, much of the uncertainty associated with this assessment could only be addressed qualitatively. Significant sources of uncertainty are presented in this section. If the assessment directly addressed uncertainty, the approach used is described. If the assessment did not directly address uncertainty, a qualitative discussion of its importance is provided.

3.4.1 Scenario Uncertainty

Sources of scenario uncertainty include the assumptions and modeling decisions that are made to represent an exposure scenario. The hypothetical farm scenario is a major source of uncertainty in this assessment. The assessment is based on a single conceptual site model that assumes that sewage sludge is applied to a farm that is half cropland and half pasture and that the farm family lives adjacent to those areas. There are no data about the specific farms where this is done. However, it is known that sewage sludge is applied to both cropland and pastures nationwide. Therefore, a hypothetical farm was developed to allow the estimation of exposure from the application of sewage sludge to farms producing all types of agricultural products anywhere in the nation. These are reasonable assumptions; however, much uncertainty is associated with the scenario. The lack of information to define and model actual exposure conditions introduced uncertainty into this assessment, but the assessment is reasonable and protective in the light of the associated scenario uncertainty.

The hypothetical sewage sludge lagoon scenario is also a major source of uncertainty in this assessment. There are no data specifically about lagoons where sewage sludge is managed. Therefore, human exposures to pollutants released from sewage sludge lagoons are calculated using a national distribution of nonaerated surface impoundments. Families are assumed to live near the impoundment, breathe the ambient air, and use groundwater. This is a reasonable and protective scenario, but there is much uncertainty associated with it.

3.4.1.1 Receptor Populations Evaluated. The human receptors evaluated for the agricultural application scenario are the farm family, which includes an adult farmer and a child. Exposure estimates presented in this document address hypothetical chronic exposures for these receptors and are designed to provide a realistic range of potential scenarios. Although it is possible for any type of individual to be present on a farm where sewage sludge is applied, to ensure that all potential receptors and exposure pathways are evaluated, it is assumed that at least an adult farmer and child live on each farm modeled. This simplifying assumption allows the evaluation of all receptors and pathways in all locations. Although these assumptions include scenario uncertainty, they are reasonable and protective.

3.4.1.2 Characteristics and Location of Waterbodies. One aspect of the site configuration of particular relevance to the drinking of surface water and the aquatic food chain modeling is the location and characteristics of the waterbodies. The size of the waterbodies affects pollutant concentration predicted for that waterbody. The location of the waterbody was assumed to be at the edge of the agricultural field. Because there are no site-specific locations for the farms and nearby waterbodies, there is uncertainty associated with the placement and dimensions of the nearest surface water source for drinking water and the associated watershed. Therefore, a single index reservoir and associated watershed were used. Although this assumption has much uncertainty associated with it, this is a protective assumption.

The assumptions made for this risk assessment also allow the evaluation of the fish ingestion pathway based on reasonable and protective assumptions. The uncertainty associated with this portion of the scenario must also be considered in the qualitative evaluation of uncertainty. The assumptions about the location and size of the stream may bias the risk results for the fish ingestion pathway, resulting in higher risk estimates.

3.4.2 Model Uncertainty

Model uncertainty is associated with all models used in all phases of a risk assessment because models and their mathematical expressions are simplifications of reality that are used to approximate real-world conditions and processes and their relationships. Computer models are simplifications of reality, requiring exclusion of some variables that influence predictions but that cannot be included in models either because of their complexity or because data are lacking on a particular parameter. Models do not include all parameters or equations necessary to express reality because of the inherent complexity of the natural environment and the lack of sufficient data to describe the natural environment. Because this is a probabilistic assessment that predicts what may occur with the management of sludge under assumed scenarios, it is not possible to compare the results of these models to any specific situation that may exist (sometimes referred to as model validation).

The risk assessor needs to consider the importance of excluded variables on a case-by-case basis because a given variable may be important in some instances and not important in others. A similar problem can occur when a model that is applicable under one set of conditions is used for a different set of conditions. In addition, in some instances, choosing the correct model form is difficult when conflicting theories seem to explain a phenomenon equally well. In other instances, EPA does not have established model forms from which to choose to address certain phenomena, such as facilitated groundwater transport.

Models used in this screening assessment were selected based on science, policy, and professional judgment. These models were selected because they provide the information needed for this assessment and because they are generally considered to be state of the science. Even though the models used in the risk analyses are used widely and have been accepted for numerous applications, they each retain significant sources of uncertainty. Evaluated as a whole, the sources of model uncertainty in this assessment could result in either an overestimation or an underestimation of risk.

3.4.2.1 Air Dispersion Modeling. The ISCST3 model was used to calculate the dispersion of particle and vapor emissions from a waste management unit. This model has many capabilities needed for this assessment, such as the ability to model area sources. For dispersion modeling of this type, ISCST3 is considered a fairly accurate model with error within about a factor of 2. It does not include photochemical reactions or degradation of a chemical in the air, which results in additional model uncertainty. Deposition and associated plume depletion are important for particulates and vapors and were explicitly incorporated into this assessment. Currently, algorithms specifically designed to model the dry deposition of gases have not been verified for the specific compounds in question (primarily volatile organics). In place of algorithms, a transfer coefficient was used to model the dry deposition of gases. A concern with this approach is that the deposition is calculated outside of the model. As a result, the mass is deposited on the ground from the plume and is not subtracted from the air concentrations estimated by ISCST3. This results in a slight nonconservation of mass in the system.

Other uncertainties introduced into the assessment in dispersion modeling are related to agricultural field shape. The shape (square and rectangular) of the agricultural field modeled in this assessment introduces some uncertainty because its actual orientation to the wind direction is not known.

3.4.3 Parameter Uncertainty

Parameter uncertainty occurs when (1) there is a lack of data about the values used in the equations, (2) the data that are available are not representative of the particular instance being modeled, or (3) parameter values cannot be measured precisely or accurately because of limitations in measurement technology. Random, or sample, errors are a common source of parameter uncertainty that is especially critical for small sample sizes. More difficult to recognize are nonrandom or systematic errors that result from bias in sampling, experimental design, or choice of assumptions.

3.4.3.1 Pollutant Concentrations. Another source of uncertainty in this assessment is the concentration of the pollutants in sewage sludge. The concentration data used in the screening assessment are the 95^{th} percentile concentrations measured in the 1988–1989 NSSS.

3.4.3.2 Agricultural Field Parameters. Source characterization required making assumptions about agricultural practices on farms where sludge may be applied. There is much uncertainty associated with the actual practices used on farms where sludge is applied. It is not known what area is amended with sludge, what crops or animals are raised on the amended land, or what specific practices are used. The parameters used in this assessment represent the data available on potential agricultural practices. For this reason, substantial uncertainty remains concerning the variable values for agricultural practices.

3.4.3.3 Watershed Universal Soil Loss Equation (USLE) Parameters. A combination of region-specific and national default parameters was used along with the USLE to model soil erosion losses from watersheds to waterbodies. The USLE calculations are particularly sensitive to site-specific values; thus, uncertainty is associated with using regional and national parameter values. Many of the USLE parameters were based on the regional meteorological and regional soil data used in other parts of the assessment. These include soil erodibility factor (K), rainfall erosivity, and slope. Other parameters were based on national default values (e.g., cover and management factors) or default relationships with other factors (e.g., length was determined as a function of slope).

3.4.3.4 Sludge Characteristics. Few data were available on the physical and chemical characteristics of sewage sludge. To address this lack, assumptions on specific sludge characteristics were based on general knowledge of sludge. In this assessment, except for constituent concentration (which was measured), general sludge characteristics were used, including default assumptions for bulk density, moisture, and porosity.

3.4.3.5 Exposure Uncertainty. Exposure modeling relies heavily on default assumptions concerning population activity patterns, mobility, dietary habits, body weights, and other factors. As described earlier in the variability section, the probabilistic assessment for the adult and child exposure scenario addressed the possible variability in the exposure modeling by using distributions of values for exposure factors. There are some uncertainties, however, in the data that were used. Although it is possible to study various populations to determine various exposure parameters (e.g., age-specific soil ingestion rates or intake rates for food) or to assess past exposures (epidemiological studies) or current exposures, risk assessment is about prediction. Therefore, long-term exposure monitoring in this context is infeasible.

The EFH (U.S. EPA, 1997a,b,c) provides the current state of the science concerning exposure assumptions, and it was used throughout this assessment. To the extent that actual exposure scenarios vary from the assumptions in this risk assessment, risks could be under- or overestimated. For example, there could be farmers and children who have higher exposures than those predicted; however, it is more likely that actual exposures for most of these individuals would fall within the predicted range and, moreover, would be similar to what was modeled.

3.4.3.6 Ecological Exposure Uncertainty. For the ingestion pathway, it is assumed that 100 percent of the receptors' food and water comes from the farm field where sewage sludge is applied and from the associated farm pond. The actual proportion of wildlife receptors' diets that would be contaminated depends on a number of factors such as the species' foraging range, quality of food source, season, intra- and interspecies competition, to name just a few. Considerable uncertainty is associated with estimating what proportion of the diet would be contaminated. For purposes of the screening assessment, it is conservatively assumed that all food and drinking water come from the farm where sludge is applied.

Exposure dose is calculated using BCFs and BAFs to estimate the transfer of pollutants from environmental media into food items. Uncertainty is associated with models used to estimate BCFs for aquatic biota. Furthermore, because bioaccumulation factors specifically for sediment biota were not available, the aquatic BCFs were used to estimate transfer of constituents from sediment to sediment biota. The aquatic BCFs were developed based on surface water concentrations and concentrations in aquatic biota, thus uncertainty is introduced by applying these values to sediment biotransfer. In addition, as noted in Section 2.3.3.1, soil-based BAFs for organic chemicals are unavailable, and a default value of 1 was used to estimate concentrations in terrestrial prey for all organics. While this approach introduces uncertainty, the chemicals addressed in the assessment are not known to be significant bioaccumulators, and the default value of 1 is considered reasonably conservative.

Finally, the BAFs identified in the literature for worms are applied for all soil invertebrates, and the BAFs for small mammals are applied for all terrestrial vertebrate prey (small mammals, birds, and herpetofauna). The worm BAFs and small mammal BAFs were developed based on measured concentrations in worms and small mammals, respectively. Applying these values to derive concentrations in prey of widely varying faunal classes introduces uncertainty in the exposure dose calculations.

3.4.3.7 Human Health Values. The Agency routinely accounts for uncertainty in its development of RfDs and other HHBs. For example, if certain toxicological data are missing from the overall toxicological database (e.g., reproductive data), the Agency will account for this by applying an uncertainty factor.

3.4.3.8 Exposure Factors. For most exposure factors addressed, data analyses involved fitting distributions of data summaries from the EFH (U.S. EPA, 1997a,b,c), in most cases by fitting distributions to selected percentiles. It is assumed that little information is lost by fitting to percentiles versus fitting to raw data. However, some believe that such analyses should always be based on raw data, synthesizing all credible sources.

Three standard two-parameter probability statistical distributions (gamma, lognormal, and Weibull) were used for this assessment. These distributions are special cases of a three-parameter distribution (generalized gamma) that allows for a likelihood ratio test of the fit of the two-parameter models. Other statistical distributions are possible (e.g., U.S. EPA, 2000), but the technique used in this assessment offered considerable improvement over using a lognormal model in all cases, and it was appropriate for this assessment. In support of this conclusion, a comparison of results showed that the three-parameter generalized gamma distribution did not significantly improve on goodness of fit over the two-parameter distributional forms in 58 of 59 cases at the 5 percent level of significance.

Although they offer significant improvement in objectivity over visual estimation, goodness-of-fit tests used to determine which statistical distribution to use for a particular parameter are themselves subject to some uncertainty that should be considered in their application to exposure factors. One area of concern is uncertainty about how the survey statistics in the EFH (U.S. EPA, 1997a,b,c) were calculated. All of the statistics that have been used to assess goodness of fit assume a random sample, which may or may not be a valid assumption for EFH data. Specifically, many of the EFH data sources are surveys that, in many cases, do not involve purely random samples. Rather, they use clustering and stratification, primarily for economic reasons.

3.4.4 Sensitivity Analysis

EPA conducted a statistically based sensitivity analysis to rank the variable parameters in the risk screening assessment according to their contribution to the variability of the resulting HQ calculated for each receptor and constituent combination. This methodology is referred to as a “response surface regression approach” because it uses models similar to those used in a response surface experiment. A response surface methodology uses a statistical approach to designing experiments and an associated model estimation methodology. The terminology “response surface” derives from the fact that a regression model involving a number of continuous independent variables can be viewed as providing an estimated surface of the results in space. Often, a goal of response surface experimentation is to ascertain the combination(s) of input variable values that will yield a minimum or a maximum response. The complexity of the model (e.g., whether it contains only first- and second-order terms or terms of higher degree) determines the general shape of the contours and the degree to which the “true” surface can be approximated.

In this analysis, a regression analysis was applied to a linear equation to estimate the relative change in the output of a probabilistic simulation relative to the changes in the input variable values. This methodology is one of the recommended methods for conducting a sensitivity analysis based on the results of a Monte Carlo analysis described in Appendix B of *RAGS 3A - Process For Conducting Probabilistic Risk Assessment - Draft* (U.S. EPA, 1999b).

Sensitivity analyses historically were conducted by evaluating how much change in risk occurred as a result of varying an individual input variable from a median or mean value to a 90^{th} percentile (high end) value or a 10^{th} percentile (low end) value, depending upon which extreme value produced the higher risk value. However, when the risk depends on the aggregate impact of a number of input variables, such an approach may not necessarily identify the most important inputs. This may occur for several reasons:

- The ranges chosen for the various input variables may not be defined consistently
- Various input variables may interact with one another (i.e., the effect of input X_1 on an outcome Y depends on the level of other inputs X_2, X_3, etc., so that the observed effect of X_1 depends on what values were chosen for the other variables as well)
- Nonlinear effects may obscure the effect of the input variable (e.g., if only low and high values of an input variable are examined, but the relationship between the risk and the input variable is of a quadratic nature, then the importance of the input variable may be overlooked).

To address such issues, statistical regression methods were used to perform the sensitivity analysis. Although regression methods have distinct advantages over previous approaches, certain limitations remain. Regression methods are not capable of determining the sensitivity of model results to input variables that are not varied in the analysis (e.g., assumptions) or are not otherwise included within the scope of the analysis (e.g., model-derived variables). If for some reason the most important variables are not varied or their variability is improperly characterized, the sensitivity analysis may not identify them as being important.

This sensitivity analysis was conducted on a data set generated during modeling of each pathway. This data set included a set of input variables (X_1, X_2, ..., X_p) that were used in the modeling simulation. In this case, the *X*s are parameters associated with management practices, site, environmental conditions, and exposure parameters. The result of interest is the HQ calculated for each pollutant/receptor/management practice combination.

The regression approach uses the various combinations of *X* values that were used during the simulation and the resulting HQ values as input data to a regression model. Functions of the results variables (denoted as *Y*s) were treated as dependent variables; for example, *Y* denoted the logarithm of the HQ. Functions of the *X*s were treated as independent variables. The goals of the approach were to

- Determine a fairly simple polynomial approximation to the simulation results that expressed the *Y*s as functions of the *X*s
- Optimize this "response surface" and assess the importance of the various *X*s by performing statistical tests on the model parameters

- Rank the *X*s based on their relative contribution (in terms of HQ) to the final response surface regression model.

These goals were realized using a second-order regression model. Such a model takes the following form:
where the βs are the least squares regression estimates of the model parameters.

The statistical significance of the parameters associated with the first-order, squared, and cross-product terms were tested and all nonsignificant terms were removed from the model. The parameters in this reduced model were then re-estimated and the testing was repeated. This was

$$\hat{Y} = \hat{\beta}_0 + \sum_{k=1}^{p} \hat{\beta}_k x_k + \sum_{k=1}^{p} \hat{\beta}_{kk} x_k^2 + \sum_{k=1}^{p-1} \sum_{j=k+1}^{p} \hat{\beta}_{kj} x_k x_j \qquad (3\text{-}1)$$

done to capture the most important independent variables (*X*s) that influence the dependent variables (*Y*s).

Once the final regression model was developed, the input parameters (*X*s) were ranked based on the percent of the HQ accounted for by that parameter. The percent HQ was calculated using the following equation:

$$Percent\ HQ = \frac{[FMSS - RMSS]}{[FMSS + ERSS]} \qquad (3\text{-}2)$$

where

FMSS = model sum of squares for the final model

RMSS = model sum of squares for a model in which all terms involving x_u are removed (i.e., a reduced model)

ERSS = model error sum of squares.

The major steps in the sensitivity analysis are identified below, along with details on the reasons for these steps.

1. **Perform any necessary manipulations on the data set.** To perform the sensitivity analysis, the data set must contain only one record for each Monte Carlo iteration, and all variables in the data set must be numeric.

2. **Remove any variables that are constants.** Any variable that was constant across all Monte Carlo iterations does not have any effect on the resulting HQ and was removed from the data set prior to the start of the regression analysis.

3. **Perform transformations (e.g., log, square root) to the continuous input variables, if necessary, so that all input variables will have approximately symmetric distributions.** Transforming the input variables so that each one has an approximately symmetric distribution is necessary to make the standardization of the variables meaningful (i.e., so the mean is near the midpoint of the extremes, and the mean and standard deviation are not highly related).

4. **Check the correlations of the transformed input variables and remove any input variables that are highly correlated with other input variables in the data set.** Regression analysis measures the linear relationship between the terms in the model and the response variable. If two or more input variables are highly correlated with one another, then there is a strong linear relationship between those input variables. Keeping all highly correlated variables in the model will reduce the significance of each of the correlated input variables because each one is essentially explaining the same linear relationship with the response variable (i.e., the effect of one such variable may mask the effect of another).

5. **Standardize the transformed variables.** Standardizing the input variables (i.e., subtracting the mean and dividing by the standard deviation) allows the regression results to be independent of the magnitude of the value of the input variables. The larger value input variables could cause the regression results to seriously underestimate the effects of the smaller value input variables on the changes in environmental concentration and HQ. The combination of transforming and standardizing the input variables creates more optimal conditions for regression analysis.

6. **Use response surface regression methods to test for the main effects, squared terms, and cross products that have the greatest effect on the log(HQ) and develop a model for log(HQ) based on the results of the regression analysis.** After the response surface regression results are obtained, the significance of each term on environmental concentration is evaluated. First, any second-order terms that are determined not to have a significant effect on the environmental concentration are dropped from the model. Any first-order term that is part of a significant second-order term remains in the model, regardless of the level of significance of that first-order term. For example, if the second-order term $X_1 \times X_2$ has a significant effect on the environmental concentration and remains in the model, then both of the first-order terms X_1 and X_2 also remain in the model. Any first-order terms that are determined not to be significant and not to have any significant second-order terms are dropped from the model. The regression analysis is then conducted again on the reduced model. This process is repeated until all of the second-order terms in the model have significant effects on the environmental concentration and no more terms can be removed. The iterative process of dropping insignificant terms and re-evaluating the model allows only the input variables with the greatest effect on the environmental concentration to remain in the model.

7. **Test for the effect of each variable on log(HQ) and use the *p*-values to rank the variables by the amount of effect each variable has on log(HQ).** Because the final model will most likely contain first- and second-order terms involving the same input variables, *F*-tests must be performed to evaluate the effect of each input variable in the final model on the log(HQ). The *F*-tests of each variable will be of the form

$$F = \frac{[FMSS - RMSS] \ / \ [FMDF - RMDF]}{FRSS \ / \ FRDF} \qquad (3\text{-}3)$$

where

FMSS	=	model sum of squares for full model
RMSS	=	model sum of squares for reduced model
RMDF	=	model degrees of freedom for reduced model
FMDF	=	model degrees of freedom for full model
FRSS	=	residual sum of squares for full model
FRDF	=	residual degrees of freedom for full model.

The full model refers to the model containing all significant terms in the final log(HQ) model. The reduced model refers to the full model minus all terms containing the input variable *X* whose significance is being tested. The *F*-tests evaluate the effect of variable *X* on the HQ by evaluating the differences when variable *X* is in the regression model (full model) and when all model terms containing variable *X* are removed (reduced model). If a substantial increase in the residuals results from ignoring terms involving the variable *X*, then *F* will be "large," implying that these factors can be considered important, in the sense that they require different regression coefficients for the *X*s. The ordering of the *p*-values from such tests can then be used to rank the importance of the various factors on the HQ. The parameters responsible for most of the HQ variability as identified by the sensitivity analysis are presented in the accompanying tables. Detailed results of the sensitivity analysis are presented in Attachment A to this memorandum.

3.4.4.1 Results for Sewage Sludge Lagoons. The screening assessment for sewage sludge managed in lagoons identified six constituents that had human health HQs greater than one for one or more receptors: barium, 4-chloroaniline, manganese, nitrate, and nitrite. A sensitivity analysis was performed for each receptor that had an HQ greater than one for these constituents.

Tables 3-4 to 3-7 show the results for metals. The sensitivity analysis results for the metals indicate that the most important variable is the metal Kd. The one metal for which we had sludge-specific Kd values was silver, and that metal did not result in an HQ greater than one for the sewage sludge lagoon scenario. The exposure factors are important variables for metals in this analysis. Exposure factors most likely will not be refined in a detailed risk assessment.

The results for metals are presented below; only receptors with an HQ greater than one are shown. Note that in all result tables, SS stands for sum of squares and DF for degrees of freedom.

Table 3-4. Sensitivity Analysis Results for Barium in Sewage Sludge Managed in Sewage Sludge Lagoons (Adult)

Variable Name	Reduced Model SS	Reduced Model DF	Full Model SS	Full Model DF	Variable SS	Percent Variation
Kd	1505.62	32	22411.66	38	20906.04	93
Adult drinking water consumption rate	21605.46	37	22411.66	38	806.20	4

98 percent of variation is accounted for by this method.

Table 3-5. Sensitivity Analysis Results for Barium in Sewage Sludge Managed in Sewage Sludge Lagoons (Child)

Variable Name	Reduced Model SS	Reduced Model DF	Full Model SS	Full Model DF	Variable SS	Percent Variation
Kd	1863.173	35	22760.94	39	20897.77	92
Child drinking water consumption rate	21583.06	38	22760.94	39	1177.883	5

98 percent of variation is accounted for by this method.

Table 3-6. Sensitivity Analysis Results for Manganese in Sewage Sludge Managed in Sewage Sludge Lagoons (Adult)

Variable Name	Reduced Model SS	Reduced Model DF	Full Model SS	Full Model DF	Variable SS	Percent Variation
Kd	828.43	28	2844.38	31	2015.95	70.9
Adult drinking water consumption rate	2135.12	30	2844.38	31	709.26	24.9
Adult body weight	2750.71	30	2844.38	31	93.67	3.3

100 percent of variation is accounted for by this method.

Table 3-7. Sensitivity Analysis Results for Manganese in Sewage Sludge Managed in Sewage Sludge Lagoons (Child)

Variable Name	Reduced Model SS	Reduced Model DF	Full Model SS	Full Model DF	Variable SS	Percent Variation
Kd	1320.07	28	3334.88	31	2014.82	60
Child drinking water consumption rate	2163.38	30	3334.88	31	1171.51	35
Child body weight	3282.85	30	3334.88	31	52.03	2

99 percent of variation is accounted for by this method.

Table 3-8 shows the results for an organic chemical (4-chloroanaline). The results of the sensitivity analysis performed for organic constituents are not as straightforward as the results for metals. The only organic constituent that had an HQ value greater than one was 4-chloroaniline. The constituent 4-chloroaniline failed on the basis of the ingestion of drinking water in the sewage sludge lagoon scenario. For this constituent, three parameters accounted for most of the variability in the HQ values: site latitude, site longitude, and drinking water consumption rate. Other parameters that appeared on the list were body weight, surface impoundment descriptors, and soil parameters.

Table 3-8. Sensitivity Analysis Results for 4-Chloroaniline in Sewage Sludge Managed in Sewage Sludge Lagoons (Adult and Child)

Parameter	Reduced Model SS	Reduced Model DF	Full Model SS	Full Model DF	Variable SS	Percent Variation
Site latitude	2066.16	46	2890.25	55	824.09	29
Consumption of drinking water	2084.55	54	2890.25	55	805.70	28
Site longitude	2356.09	45	2890.25	55	534.16	18

88 percent of variation is accounted for by this method.

Tables 3-9 and 3-10 show the results for inorganics. The inorganic, nonmetal constituents, nitrate and nitrite, are assumed to have a Kd of one and to move unimpeded through the subsurface. For these constituents, only exposure parameters (drinking water consumption rates and body weights) were identified as responsible for the variability in the HQ values.

Table 3-9. Sensitivity Analysis Results for Nitrate in Sewage Sludge Managed in Sewage Sludge Lagoons (Adult and Child)

Variable Name	Reduced Model SS	Reduced Model DF	Full Model SS	Full Model DF	Variable SS	Percent Variation
Drinking water consumption rate	126.58	24	945.25	25	818.68	87
Body weight	847.00	24	945.25	25	98.26	10

97 percent of variation is accounted for by this method.

Table 3-10. Sensitivity Analysis Results for Nitrite in Sewage Sludge Managed in Sewage Sludge Lagoons (Adult and Child)

Variable Name	Reduced Model SS	Reduced Model DF	Full Model SS	Full Model DF	Variable SS	Percent Variation
Drinking water consumption rate	126.58	24	945.26	25	818.68	87
Body weight	847.00	24	945.26	25	98.26	10

97 percent of variation is accounted for by this method.

3.4.4.2 Results for Agricultural Land Application of Sewage Sludge. The screening assessment for sewage sludge managed by agricultural land application identified two constituents that had human health HQs greater than one. The screening assessment does not include groundwater modeling, but uses the leachate concentration of the constituent estimated at a depth of 1 meter immediately under the agricultural land as the drinking water concentration for exposure to groundwater that is used for drinking and showering. This is an extremely protective assumption; in a detailed assessment, groundwater modeling can be included to evaluate this pathway more realistically. The highest ranking variables for all constituents in the sensitivity analysis for human health pathways are as follows:

- Drinking water consumption rates and body weights,
- Total amount of sludge applied to the land (rate of sludge application and the number of years sludge is applied),
- Time period during and after sludge application when adults and children live on the farm,
- Air modeling data (air concentrations of particles and vapors and wet and dry deposition of particles) in various areas within the conceptual site,
- Factors that affect runoff from the farm (length-slope factor, erosivity factor, erodibility factor, silt content of soils, and curve number applied to the farm), and
- Kd's for metals.

The distribution of values used in this assessment is from the *Exposure Factors Handbook* (EFH) and represents true variability in this parameter that most likely will remain in the detailed assessment. The air modeling variables were set to maximum values for each geographic area for the screening assessment. These distributions can be refined in the detailed assessment. The factor that is specific to metals is the Kd (soil-water partitioning coefficient). The only metal with sludge-specific values for this parameter is silver. The values for the other metals can be refined to be more appropriate for the sewage sludge matrix in the detailed assessment.

The constituents that had HQ values greater than one for one or more human receptors are as follows:

- Nitrite
- Silver.

The sensitivity analysis results for these chemicals are shown in Tables 3-11 to 3-13.

Table 3-11. Sensitivity Analysis Results for Nitrite in Sewage Sludge Managed by Agricultural Land Application (Child)

Variable Name	Reduced Model SS	Reduced Model DF	Full Model SS	Full Model DF	Variable SS	Percent Variation
Child (1-5 years) drinking water consumption rate	2859.77	83	3730.73	84	870.96	23
Last year sludge is applied	3498.32	80	3730.73	84	232.41	6
Year child moves to the farm	3582.54	79	3730.73	84	148.19	4
Residence period child lives on the farm	3593.41	83	3730.73	84	137.32	4

64 percent of variation is accounted for by this method.

Table 3-12. Sensitivity Analysis Results for Silver in Sewage Sludge Managed by Agricultural Land Application (Adult)

Variable Name	Reduced Model SS	Reduced Model DF	Full Model SS	Full Model DF	Variable SS	Percent Variation
Adult drinking water consumption rate	3345.80	71	4107.59	72	761.79	19
Last year of sludge application	3532.30	69	4107.59	72	575.30	14
Residence period adult farmer lives on the farm	3563.25	71	4107.59	72	544.35	13
Year adult moves to the farm	3827.35	67	4107.59	72	280.24	7
Rainfall factor	3982.22	69	4107.59	72	125.37	3

70 percent of variation is accounted for by this method.

Table 3-13. Sensitivity Analysis Results for Silver in Sewage Sludge Managed by Agricultural Land Application (Child)

Variable Name	Reduced Model SS	Reduced Model DF	Full Model SS	Full Model DF	Variable SS	Percent Variation
Child (1-5 years) drinking water consumption rate	2305.33	97	3144.67	98	839.33	27
Last year of sludge application	2735.15	94	3144.67	98	409.52	13
Year child moves to the farm	2965.26	92	3144.67	98	179.40	6
Residence period child lives on the farm	3025.46	97	3144.67	98	119.21	4
Rate of application of sludge	3040.12	96	3144.67	98	104.55	3

73 percent of variation is accounted for by this method.

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