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FOR

LAND APPLICATION OF SEWAGE SLUDGE

VOLUME I

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401 M Street SW
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Prepared by
Eastern Research Group
110 Hartwell Avenue
Lexington, MA 02173

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Eastern Research Group

Anne Jones	Project Manager
Leslie Beyer	Task Manager/Environmental Scientist
Michael Rookwood	Environmental Scientist
Janice Pacenka	Environmental Scientist
John Bergin	Copyeditor/Production Coordinator

Abt Associates

Kirkman O'Neal	Principal Investigator
Vicki Hutson	Project Manager
Daniel McMartin	Environmental Scientist
Elizabeth Fechner Levy	Environmental Scientist

Members of the Technical Subcommittee of the Peer Review Committee

Dr. Rufus Chaney	Dr. Robert Griffin	Dr. Al Page
Dr. Andrew Chang	Dr. Charles Henry	Dr. James Ryan
Dr. Willard Chappell	Dr. Terry Logan	Dr. John Walker
Dr. Lawrence Gratt	Dr. George O'Connor	Dr. Mel Webber

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LIST OF UNITS, ABBREVIATIONS, AND ACRONYMS

α	pollutant-specific empirical constant
α_i	intermediate variable (m^2/sec)
β	pollutant-specific empirical constant
θ_a	air-filled porosity of soil (unitless)
θ_e	effective porosity of soil (unitless)
θ_w	water-filled porosity of soil (unitless)
κ	intermediate variable (unitless)
ρ_{ss}	particle density of sewage sludge-soil mixture (kg/m^3)
ρ_w	density of water (kg/l)
σ_z	standard deviation of the vertical distribution of concentrations (m)
ϖ	wind speed (m/sec)
μg	microgram
a	empirical constant
A	area of SMA (m^2)
ABI	background concentration of pollutant in animal organ (μg-pollutant/g-organ DW)
ac	acre
ACGIH	American Conference of Governmental Industrial Hygienists
ADI	acceptable daily intake (mg/kg-BW)
APLR	annual pollutant loading rate (kg/ha•yr)
AR	sewage sludge application rate (mt/ha)
AR_c	cumulative sewage sludge application rate (mg/sewage sludge/ha)
A_{sma}	area affected by sewage sludge management (ha)
atm	atmosphere
A_{ws}	area of the watershed (ha)
AWSAR	annual whole sludge application rate (mt DW-sludge/ha•yr)
b	empirical constant
BACC	bioaccumulation factor for soil organisms (μg-pollutant/g-soil organism DW)(μg-pollutant/g-soil DW)$^{-1}$
BAF	bioaccumulation factor for pollutants in aquatic organisms (l/kg)
BAV	bioavailability factor for pollutants in the soil in soil organisms (unitless)
BC	background concentration of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)
BCF	pollutant-specific bioconcentration factor for pollutants in fish (l/kg)
BD	bulk density of soil in mixing zone (kg/m^3)
BI	background intake of pollutant from a given exposure route (mg-pollutant/day)
BS	background concentration of pollutant in soil (μg-pollutant/g-soil DW)
BW	body weight (kg)
C	concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
C_a	vapor concentration of pollutant in air-filled pore space of treated soil (kg-pollutant/m^3)

CAST	Council for Agricultural Science and Technology
CB	background concentration of pollutant in well-water (mg-pollutant/l-well-water)
CEC	Cation Exchange Capacity (cmol/kg)
CFR	Code of Federal Regulations
C_{lec}	unit concentration of the pollutant in leachate (1 mg-pollutant/l)
cm	centimeter
CPLR	cumulative pollutant loading rate (kg-pollutant/ha)
C_s	concentration of adsorbed pollutant in treated soil (kg-pollutant/kg-soil)
C_{sed}	dry weight concentration of pollutant in eroded soil (mg-pollutant/kg-soil DW)
C_{sms}	average pollutant concentration for soil eroding from the SMA (mg-pollutant/kg)
C_{sw}	concentration of pollutant in surface water (mg-pollutant/l-surface water)
C_t	total concentration of pollutant in treated soil (kg-pollutant/m^3)
CWA	Clean Water Act
C_{wel}	predicted concentration of the pollutant in well (mg-pollutant/l)
CWSS	Community Water Supply Study
DA	daily dietary consumption of animal tissue food group (g-animal tissue DW/day)
DC	daily dietary consumption of food group (g-diet DW/day)
D_a	the molecular diffusity of pollutant vapor in air (cm^2/sec)
d_e	depth of soil eroded from site each year (m/yr)
DE	exposure duration adjustment (unitless)
D_{ei}	intermediate variable (m^2/sec)
DF	dilution factor (unitless)
d_i	depth of incorporation for sewage sludge (m)
dL	deciliter
DW	dry weight
e	base of natural logarithms, 2.718 (unitless)
Eh	potential required to transfer electrons from the oxidant to the reductant
EPA	U.S. Environmental Protection Agency
EXP_{sw}	dose of pollutant received through surface water pathway (mg/kg•day)
FA	fraction of food group assumed to be derived from animals which ingest sewage sludge or forage grown on sewage sludge-amended soil (unitless)
FC	fraction of food group produced on sewage sludge-amended soil (unitless)
FD	fraction of diet considered to be soil organisms (g-soil organisms DW/g-diet DW)
FDA	U.S. Food and Drug Administration
f_{deg}	fraction of total loss caused by degradation (unitless)
f_{ero}	fraction of total loss caused by erosion (unitless)
FL	fraction of the animal diet assumed to be soil (g-soil DW/g-diet DW)
f_{lec}	fraction of total loss caused by leaching (unitless)
f_{ls}	fraction of total cumulative loading lost in human lifetime (unitless)

FM	pollutant-specific food chain multiplier (unitless)
FS	fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)
f_{vol}	fraction of total loss caused by volatilization (unitless)
f_{wel}	ratio of predicted concentration of pollutant in well to concentration in leachate (unitless)
FY	fiscal year
g	gram
GEMS	Graphical Exposure Modeling System
$\dot{H}$	nondimensional Henry's Law constant for the pollutant
H	Henry's law constant for the pollutant (atm-m^3/mol)
ha	hectare
HEI	Highly Exposed Individual
I_a	inhalation volume (m^3/day)
I_f	daily consumption of fish (kg/day)
IRIS	Integrated Risk Information System
I_s	soil ingestion rate (g-soil DW/day)
I_w	daily consumption of water (l-water/day)
k	loss rate constant (yr^{-1})
K	kilojoules
KD	equilibrium partition coefficient for the pollutant (m^3/kg)
K_{deg}	loss rate coefficient for degradation (units)
KD_{sw}	partitioning coefficient between solids and liquids within the stream (l/kg)
K_{ero}	loss rate coefficient for erosion (units)
kg	kilogram
K_{lec}	loss rate coefficient for leaching (yr^{-1})
km	kilometer
KOC	organic carbon partition coefficient (m^3/kg)
KOW	octanol-water partition coefficient for pollutant (units)
K_{tot}	total loss rate coefficient for the pollutant in treated soil (yr^{-1})
K_{vol}	loss rate coefficient for volatilization (yr^{-1})
l	liter
LC_{50}	lethal concentration of chemical (in liquid) at which 50 percent of study animals die
LD_{50}	lethal dose of chemical at which 50 percent of study animals die
ln	natural logarithm
LOAEL	Lowest Observed Adverse Effect Level
LOEL	Lowest Observed Effect Level
LS	human life expectancy (yr)
L_{sma}	distance between the SMA and the receiving water body (m)
m	meter
MCL	maximum contaminant level in drinking water, established by U.S. EPA (mg/l)
MDC	maximum concentration of pollutant in dust (μg-pollutant/g-soil DW)
MED	maximum equivalent dose
ME_{sma}	estimated rate of soil loss for the SMA (kg/ha•yr)
ME_{ws}	estimated rate of soil loss for the watershed (kg/ha•yr)
mg	milligram

MGD	million gallons/day
ml	milliliter
M_{lt}	mass of pollutant at end of individual lifetime (kg-pollutant/ha)
M_N	mass of pollutant after N applications (kg-pollutant/ha)
mo	month
mol	mole
MS	assumed mass of dry soil in upper 15 cm ($2 \cdot 10^9$ g-soil DW/ha)
mt	metric tons
M_t	mass of pollutant in soil at end of year t (kg/ha)
MTD	maximum tolerated dose
n	years of application (yr) until steady state conditions are reached
N	number of years in which sewage sludge is applied
Na	total emissions from the soil surface over time interval t_e (kg/m^2)
Na_s	emissions from the soil surface in first second (kg/m$^2 \cdot$sec)
NAS	National Academy of Sciences
Na_y	emissions from the soil surface in first year (kg/m$^2 \cdot$yr)
NCI	National Cancer Institute
NFCS	Nationwide Food Consumption Survey
NHANES II	Second National Health and Nutrition Examination Survey
NIOSH	National Institute for Occupational Safety and Health
NOAEL	No Observed Adverse Effect Level
NOEL	No Observed Effect Level
NR	annual recharge to ground water beneath the sludge management area (m/yr)
NSSS	National Sewage Sludge Survey
OPPTS	Office of Prevention, Pesticides and Toxic Substances (EPA) (formally OPTS)
OPTS	Office of Pesticides and Toxic Substances (EPA) (now OPPTS)
ORD	Office of Research and Development (EPA)
OST	Office of Science and Technology (EPA)
OSW	Office of Solid Waste (EPA) (suboffice of OSWER)
OW	Office of Water (EPA)
OWRS	Office of Water Regulations and Standards (EPA) (now OST)
PCBs	polychlorinated biphenyls
PCGEMS	Personal Computer version of the Graphical Exposure Modeling System
P_f	ratio of pollutant concentration in the edible portion of fish to concentration in whole fish (unitless)
P_l	percent liquid in the water column (unitless)
POTWs	publicly owned treatment works
ppm	parts per million
P_s	percent solids in the water column (unitless)
q_1^*	human cancer potency (mg/kg$\cdot$day)$^{-1}$
R	ideal gas constant ($8.21 \cdot 10^{-5}$ atm-m^3/k$\cdot$mol)
RC_{air}	reference air concentration for pollutant (μg-pollutant/m^3)
RC_{gw}	reference water concentration (mg/l)
RC_{lec}	reference concentration of pollutant in leachate beneath the land application site (mg-pollutant/l)
RCRA	Resource Conservation and Recovery Act

RC_{sed}	reference concentration of pollutant for soil eroding into stream (mg-pollutant/kg)
RC_{sma}	reference concentration for soil eroding from the sludge management area (mg/kg)
RC_{sma}	reference pollutant concentration for soil eroding from the SMA (mg-pollutant/kg)
RC_{sw}	reference water concentration for surface water (mg/l)
RDA	Recommended Dietary Allowance (mg/day)
RE	relative effectiveness of ingestion exposure (unitless)
RF	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RF_{air}	reference annual flux of pollutant emitted from the site (kg-pollutant/ha•yr)
RfD	oral reference dose (mg/kg•day)
RF_{gw}	reference annual flux of pollutant beneath the site (units)
RI	reference intake for carcinogen (mg/kg•day)
RIA	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RL	risk level (unitless)
RLC	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RP_a	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RP_c	reference cumulative application rate of pollutant (kg-pollutant/ha)
RSC	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RWS	Rural Water Survey
r´	distance from the center of the site to the receptor (m)
S	intermediate variable (unitless)
SCS	Soil Conservation Survey
sec	seconds
SMA	sludge management area
SMSA	Standard Metropolitan Statistical Area
SRAB	Sludge Risk Assessment Branch (EPA)
SRR	source-receptor ratio (sec/m)
S_{sma}	sediment delivery ratio for the SMA (unitless)
S_{ws}	sediment delivery ratio for the watershed (unitless)
T	temperature (kelvin)
$T_{0.5}$	half-life of pollutant in soil (yr)
TA	threshold concentration of pollutant in feed (μg-pollutant/g-feed DW)
TBI	total background intake of pollutant from all sources of exposure other than sewage sludge (mg-pollutant/day)
TBI_a	TBI for adults (mg/day)
TBI_t	TBI for toddlers (mg/day)
TDA	ACGIH total dust standard (10 mg/m^3)
t_e	duration of emissions (sec)
TO	threshold concentration of pollutant in animal organ (μg-pollutant/g-organ DW)

TP	length of "square wave" in which maximum total loss rate of pollutant (kg-pollutant/ha•yr) depletes total mass of pollutant applied annually to site (yr)
TPC	threshold phytotoxic concentration of pollutant in plaint issue (μg-pollutant/g-plant tissue DW)(kg-pollutant/ha)$^{-1}$
TPI	threshold pollutant intake level (μg-pollutant/g-diet DW)
TSCA	Toxic Substances Control Act
TSD	Technical Support Document
TSS	total suspended solids content of the stream (mg/l)
TWA	time-weighted average (μg/m^3)
UA	uptake response slope of pollutant in animal tissue food group (μg-pollutant/g-animal tissue DW)(μg-pollutant/g-diet DW)$^{-1}$
UC	uptake response slope of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)(kg-pollutant/ha)$^{-1}$
USDA	U.S. Department of Agriculture
USLE	Universal Soil Loss Equation
v	vertical term (unitless)
VADOFT	Vadose Zone Flow and Transport
wk	week
WW	wet weight
x	distance from center of SMA to the receptor (km)
x_y	lateral virtual distance (m)
yr	year

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GLOSSARY

Words and phrases specific to this document are defined below. Many of these definitions are included in Section 503.9, General Definitions, of Subpart A; Section 503.11, Special Definitions, of Subpart B; and Section 503.31, Special Definitions, of Subpart D (see Appendix A).

Adjusted reference intake of pollutants in humans—A health-based number that indicates how much of a pollutant can be ingested/inhaled by a person. If this exposure is exceeded, adverse health effects might occur in exposed individuals. This number is termed adjusted because it has been adjusted from a per weight basis to a particular body weight and exposure to other sources has been subtracted.

Agricultural land—Land on which a food crop, a feed crop, or a fiber crop is grown. This includes range land and land used as pasture.

Agronomic rate—The whole sludge application rate (dry-weight basis) designed (1) to provide the amount of nitrogen needed by the food crop, feed crop, fiber crop, cover crop, or vegetation grown on the land, and (2) to minimize the amount of nitrogen in the sewage sludge that passes below the root zone of the crop or vegetation grown on the land to the ground water.

Allowable daily intake (ADI)—The daily intake of a chemical that during an entire lifetime appears to be without appreciable risk on the basis of all the known facts at the time. It is expressed in milligrams of the chemical per kilogram of body weight (mg/kg).

Annual application rate—The pollutant limit for domestic septage applied to agricultural land, forests, or reclamation sites. The annual application rate depends on the nitrogen requirement of the crop or vegetation grown on the land where the domestic septage is applied and is expressed as an hydraulic loading rate in gallons per acre per year.

Annual pollutant loading rate—The maximum amount of a pollutant that can be applied to an area of land during a 365-day period.

Annual whole sludge application rate—The maximum amount of sewage sludge that can be applied to an area of land during a 365-day period.

Base flood—A flood that has a 1 percent chance of occurring in any given year (i.e., a flood with a magnitude equalled once in 100 years).

Bioaccumulation factor (BACC)—A factor that describes the concentration that is present in an organism because of a specific concentration of bioavailable pollutant in the soil.

Bioavailability factor (BAV)—A factor that describes the bioavailability of pollutants in sewage sludge/soil mixtures for uptake by organisms.

Bioconcentration factor—A measure of the partitioning of a chemical between water and aquatic organisms such as fish.

Bulk sewage sludge—Sewage sludge that is not sold or given away in a bag or other container for application to the land.

Cancer potency value (q_1^*)—The cancer potency value (q_1^*) represents the relationship between a specified carcinogenic dose and its associated degree of risk. The q_1^* is based on continual exposure of an individual to a specified concentration over a period of 70 years. Established EPA methodology for determining cancer potency values assumes that any degree of exposure to a carcinogen produces a measurable risk. The q_1^* value is expressed in terms of risk per dose and is measured in units of milligrams of pollutant per kilogram of body weight per day of exposure $(mg/kg \bullet day)^{-1}$.

Cation exchange capacity (CEC)—The upper limit on the ability of a solution to trade a positively charged ion for a negatively charged one.

Class I sewage sludge management facility—Any publicly owned treatment works (POTWs) as defined in 40 CFR 403.30 as being required to have an approved pretreatment program [including such POTWs located in a state that has elected to assume local program responsibilities pursuant to 40 CFR 403.10 (e)] and any treatment works treating domestic sewage, as defined in 40 CFR 122.2, classified as a Class I sludge management facility by the EPA Regional Administrator, or in the case of approved state programs, the Regional Administrator in conjunction with the State Director, because of the potential for its sewage sludge use or disposal practices to affect public health and the environment adversely.

Cover crop—A small grain crop, such as oats, wheat, or barley, not grown for harvest.

Cumulative pollutant loading rate—The maximum amount of an inorganic pollutant that can be applied to a unit area of land.

Distributor—A person who either delivers bulk sewage sludge to a person who applies the bulk sewage sludge to the land or who delivers bulk sewage sludge to a person who prepares the bulk sewage sludge for application to the land.

Domestic septage—Liquid or solid material removed from a septic tank, cesspool, portable toilet, Type III marine sanitation device, or similar treatment works that receives only domestic sewage. Domestic septage does not include liquid or solid material removed from a septic tank, cesspool, or similar treatment works that receives either commercial or industrial wastewater and does not include grease removed from a grease trap at a restaurant.

Domestic sewage—Waste and wastewater from humans or household operations that is discharged to or otherwise enters a treatment works.

Dry-weight (DW) basis—The method of measuring weight where, prior to be weighed, the material is dried at 105°C until reaching a constant mass (i.e., essentially 100 percent solids content).

Feed crops—Crops produced primarily for consumption for animals.

Fiber crops—Crops such as flax and cotton.

Food crops—Crops consumed by humans.

Forage—Crops consumed by animals.

Half-life of pollutant—The time required for one-half of the atoms of an isotope to decay.

Hectare—A metric measurement of land area equal to 2.471 acres.

Helminth ova—The egg of a parasitic intestinal worm.

Highly exposed individual (HEI)—The HEI is an individual who remains for an extended period of time at or adjacent to the site where the maximum exposure occurs.

Industrial wastewater—Wastewater generated in a commercial, industrial, or manufacturing process.

Integrated uptake biokinetic model (IUBK)—An uptake/biokinetic model developed by U.S. EPA's Environmental Criteria and Assessment Office. It predicts blood lead levels in populations exposed to lead in air, diet, drinking water, indoor dust, soil and paint.

Land application—The spraying or spreading of sewage sludge onto the land surface; the injection of sewage sludge below the land surface; or the incorporation of sewage sludge into the soil so that the sewage sludge can either condition the soil or fertilize crops or vegetation grown in the soil.

Land with a high potential for public exposure—Land that the public uses frequently. This includes, but is not limited to, a public contact site (e.g., park or golf course), and a reclamation site located in a populated area.

Monthly average—The arithmetic mean of all measurements taken during a given month.

Most probable number (MPN)—A unit that expresses the amount of bacteria per gram of total dry solids in sewage sludge.

National Sewage Sludge Survey (NSSS)—A survey conducted by the U.S. EPA in which questionnaires were administered to 479 POTWs practicing secondary or advanced treatment. In addition, sewage samples were collected from 200 of the POTWs and analyzed.

Oral reference dose (RfD)—See Reference dose.

Other container—Either an open or closed receptacle. This includes, but is not limited to, a bucket, a box, a carton, and a vehicle or trailer with a load capacity of 1 metric ton or less.

Pasture—Land on which animals feed directly on feed crops such as legumes, grasses, grain stubble, or stover.

Pathogenic organisms—Disease-causing organisms. This includes, but is not limited to, certain bacteria, protozoa, viruses, and viable helminth ova.

Permitting authority—Either EPA or a state with an EPA-approved sewage sludge management program.

Person who prepares sewage sludge—Either the person who generates sewage sludge during the treatment of domestic sewage in a treatment works or the person who derives a material from sewage sludge.

pH—The logarithm of the reciprocal of the hydrogen ion concentration. The pH measures acidity/alkalinity and ranges from 0 to 14. A pH of 7 indicates the material is neutral. Moving from a pH of 7 to 0, the pH indicates progressively more acid conditions. Moving from a pH of 7 to 14, the pH indicates progressively more alkaline conditions.

Pollutant ceiling concentrations—A pollutant concentration in sewage sludge, measured in milligrams of pollutant per kilogram of sewage sludge dry weight (mg-pollutant/kg-sewage sludge DW), above which sewage sludge cannot be applied to land.

Pollutant concentration limit—A pollutant concentration in sewage sludge, measured in milligrams of pollutant per kilogram of sewage sludge dry weight (mg-pollutant/kg-sewage sludge DW), above which treatment works are not subject to certain requirements of Subpart B.

Pollutant limit—A numerical value that describes the amount of a pollutant allowed per unit amount of sewage sludge (e.g., milligrams per kilogram of total solids); the amount of a pollutant that can be applied to an area of land (e.g., kilograms per hectare); or the volume of a material that can be applied to an area of land (e.g., gallons per acre).

Primary treatment sewage sludge—Sewage sludge resulting from primary wastewater treatment.

Public contact site—Land with a high potential for contact by the public. This includes, but is not limited to, public parks, ball fields, cemeteries, plant nurseries, turf farms, and golf courses.

Publicly owned treatment work (POTW)—Any device or system owned by a municipality or state entity used to treat (including recycling and reclamation) either domestic sewage or a combination of domestic sewage and industrial waste of a liquid nature.

Range land—Open land with indigenous vegetation.

Reclamation site—Drastically disturbed land that is reclaimed using sewage sludge. This includes, but is not limited to, strip mines and construction sites.

Recommended Dietary Allowances (RDAs)—RDAs are defined as the levels of intake of essential nutrients that, on the basis of scientific knowledge, are judged by the Food and Nutrition Board to be adequate to meet the known nutrient needs of practically all healthy persons (NAS, 1989).

Reference application rate of pollutant (RP)—The amount of pollutant that can be applied to a hectare of land without adverse effects. The units are kg-pollutant/ha.

Reference concentration of pollutant—The maximum concentration of pollutant in soil that is without adverse effects. The units are μg-pollutant/g-soil DW.

Reference dose (RfD)—A threshold dose below which adverse effects to human health are unlikely to occur. RfDs have units of mg-chemical/kg-body weight•day. EPA has developed RfDs for over 300 substances; they are listed in EPA's computerized Integrated Risk Information System (IRIS).

Regional Administrator—The administrator of EPA within the EPA Region.

Relative effectiveness of ingestion exposure—A unitless factor that accounts for the differences in the toxicological effectiveness of the source. These differences include bioavailability associated with the exposure medium (water vs. food) as well as differences in absorption caused by differences in the route of exposure (inhalation vs. ingestion).

Sewage sludge—Solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Sewage sludge includes, but is not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and material derived from sewage sludge. Sewage sludge does not include ash generated during the firing of sewage sludge in a sewage sludge incinerator or grit and screenings generated during preliminary treatment of domestic sewage in a treatment works.

Sewage sludge-amended soil—Soil to which sewage sludge has been added.

Sewage sludge sold or given away in a bag or other container—Formerly known as distribution and marketing. Sewage sludge that is either sold or given away in an open or closed receptacle with a load capacity of 1 metric ton or less. This includes, but is not limited to, a bucket, a box, a carton, and a vehicle or trailer with a load capacity of 1 metric ton or less.

Soil organisms—A broad range of organisms, including microorganisms and various invertebrates living in or on the soil.

Specific oxygen uptake rate (SOUR)—The mass of oxygen consumed per unit time per unit mass of total solids (dry-weight basis).

Standard metropolitan statistical area (SMSA)—Areas defined by the U.S. Census Bureau in which cities are combined with the surrounding suburban areas. These areas are used in many types of statistical analyses.

State Director—The director of the state agency that has an EPA-approved sewage sludge management program.

Subsurface injection of sewage sludge—Injection of sewage sludge beneath the surface of the land (one of the ten vector attraction reduction requirements in Part 503).

Surface disposal—The placement of sewage sludge on a surface disposal site. A surface disposal site is an area of land that contains one or more active sewage sludge units. An active unit is a unit of land that has not been closed on which only sewage sludge is placed for final disposal.

Threatened or endangered species—Species listed pursuant to Section 4 of the Endangered Species Act.

Threshold phytotoxic concentration of pollutant in plant tissue—The concentration of pollutant in plant tissue at which phytotoxicity (plant toxicity) is observed. The unit is μg-pollutant/g-plant tissue DW.

Threshold pollutant intake level—The maximum intake of a pollutant that would not cause a toxic effect to the most sensitive/most exposed species.

Time-weighted average (TWA) exposure—Average exposure to a contaminant that is calculated by weighting each exposure measurement by duration. For example, if one measurement was 50 ppm for 1 hour and the other measurement was 30 ppm for 2 hours, the TWA would be $[(50 \cdot 1) + (30 \cdot 2)] \div (1 + 2) = 37$ ppm. Most regulatory measures for worker safety are based on 8- or 10-hr TWAs.

Total background intake rate of pollutant from all other sources of exposure (TBI)—A summed total of all intakes from all exposures from sources other than sewage sludge. These exposures include background levels (natural and/or anthropic) in drinking water, food, and air.

Treatment of sewage sludge—The preparation of sewage sludge for final use or disposal. This includes, but is not limited to, thickening, stabilization, and dewatering of sewage sludge; it does not include storage of sewage sludge.

Treatment works—Any federally owned, publicly owned, or privately owned device or system used to treat (including recycle and reclaim) either domestic sewage or a combination of domestic sewage and industrial waste of a liquid nature.

Uptake response slope of pollutant—Calculated by regressing the concentration of pollutant in plant tissue (μg-pollutant/g-plant tissue DW) against a cumulative pollutant loading rate (kg-pollutant/ha) for the various treatment levels, including the control (non-treatment).

Vector attraction—The characteristic of sewage sludge that attracts rodents, flies, mosquitoes, or other organisms capable of transporting infectious agents.

Wet weight—Weight measured of material that has not been dried (see Dry-weight basis).

Wetlands—Areas that are inundated or saturated by surface water or ground water at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

SECTION ONE

INTRODUCTION

1.1 BACKGROUND TO THE PART 503 REGULATION

Under Section 405(d) of the Clean Water Act, the U.S. Environmental Protection Agency (EPA) is mandated to develop regulations to protect public health and the environment from reasonably anticipated adverse effects of pollutants that may be present in sewage sludge. This Act directs the Agency to develop and promulgate regulations for the use or disposal of sewage sludge.

In 1982, EPA established an Intra-Agency Sludge Task Force to recommend procedures for implementing a comprehensive regulatory program for sewage sludge management. The Task Force recommended the implementation of two regulations: one that would establish requirements for state sewage sludge management programs and one that would provide technical criteria for the use or disposal of sewage sludge.

As a result of the Task Force recommendation, EPA promulgated *State Sludge Management Program Regulations* (40 CFR Part 501). These regulations require states to develop management programs that comply with existing federal criteria for the use or disposal of sewage sludge. The regulations focus on the procedural requirements for submission, review, and approval of state sewage sludge management programs. These regulations also amend the National Pollutant Discharge Elimination System (NPDES) permit programs.

The recommendation of the Task Force also prompted renewed efforts to develop a sewage sludge regulation that provided technical criteria for the use or disposal of sewage sludge. Although the EPA Office of Solid Waste began preparing this regulation in 1980, the task was transferred to the Office of Water in 1984. A Wastewater Solids Criteria Branch was established under the Office of Water Regulations and Standards within the Office of Water to develop the risk assessment to support the rule. After the Office of Water was reorganized, the Office of

Water Regulations and Standards was renamed the Office of Science and Technology (OST), and the Wastewater Solids Criteria Branch was renamed the Sludge Risk Assessment Branch (SRAB). The SRAB developed *Standards for the Use or Disposal of Sewage Sludge* (40 CFR Part 503) and the risk assessment methodology used for the regulation.

1.2 DESCRIPTION OF THE PART 503 REGULATION

Part 503 sets requirements for sewage sludge applied to the land, placed on a surface disposal site, or fired in a sewage sludge incinerator. These requirements are included in five Subparts, Subparts A through E. Subpart A contains General Provisions. Subparts B and C specify requirements for sewage sludge applied to the land and placed on a surface disposal site, respectively. Subpart D, Pathogens and Vector Attraction Reduction, specifies requirements to reduce pathogens and vector attraction in sewage sludge that is applied to the land or placed on a surface disposal site. Subpart E contains the provisions for sewage sludge fired in a sewage sludge incinerator. The two subparts that most affect land application—Subparts A and B—are described in more detail in the following paragraphs.

Subpart A, General Provisions, defines the purpose and applicability of Part 503; specifies the compliance period for this regulation; specifies permits and direct enforceability; discusses the relationship of Part 503 to other regulations; allows for additional or more stringent requirements; specifies exclusions from the Part 503 regulation; specifies requirements for a person who prepares sewage sludge; presents methods for analyzing sewage sludge samples; and defines general terms used throughout Part 503. Subpart A requirements are presented in Appendix A.

Subpart B, Land Application of Sewage Sludge, specifies general requirements, pollutant limits, management practices, pathogen and vector attraction reduction requirements, frequency of monitoring requirements, recordkeeping requirements, and reporting requirements when sewage sludge is applied to the land.

1.3 SCOPE OF THE LAND APPLICATION TECHNICAL SUPPORT DOCUMENT

This technical support document, which consists of 16 sections, provides the risk assessment and the technical data and justifications that support Subpart B. The information contained here was used to establish general requirements, management practices, operational standards, frequency of monitoring, recordkeeping requirements, and reporting requirement practices, which are essential to protect human health and environment from pollutants in sewage sludge when the sewage sludge is applied to the land.

Section Two of this document, Land Application of Sewage Sludge, defines land application and discusses the types of land on which sewage sludge is used.

Sections Three through Five provide information on the risk assessment that supports Subpart B. Section Three describes the four steps used to develop a risk assessment: hazard identification, exposure assessment, dose/response analysis, and risk characterization. Section Four lists the organic and inorganic pollutants considered in the risk assessment and describes how EPA selected these pollutants. Section Five presents the risk assessment, which was conducted for 14 environmental pathways through which sewage sludge pollutants may reach target organisms such as plants, animals, and humans.

Section Six presents the pollutant limits in Part 503 and how they were derived from the risk assessment.

Section Seven describes the decisions that were made in developing Part 503, including the reasoning behind certain management practices, and the basis for EPA's decision to prohibit the development of site-specific pollutant limits.

Sections Eight through Fifteen present a summary of the requirements of Subpart B and provide justifications for these requirements. Section Eight discusses to whom and to what the land application requirements apply and exemptions from these requirements. Section Nine identifies words, phrases, and acronyms specific to Part 503. Most of these words, phrases, and acronyms are defined in the Glossary at the beginning of this document. Section Ten specifies general requirements for the preparers and appliers of sewage sludge or domestic septage. Section Eleven specifies management practices designed to control impacts of sewage sludge applied to land. Section Twelve presents the pathogen and vector attraction reduction requirements for sewage sludge and domestic septage applied to the land. Section Thirteen describes the frequency of monitoring of sewage sludge for pollutant concentrations, pathogens, and vector attraction reduction. It also presents the monitoring requirements for domestic septage for pathogens and vector attraction reduction. Section Fourteen describes the recordkeeping requirements for sewage sludge and domestic septage applied to the land. Section Fifteen presents the reporting requirements of sewage sludge treatment facilities. The references are contained in Section Sixteen.

In addition, 12 appendices are included. Part 503, Subparts A, B, and D are included in Appendix A. The justification for deletion of pollutants from Part 503 is included in Appendix B. The plant and animal uptake tables are included in Appendices C and D, respectively. The results of the plant phytotoxicity literature search and the phytotoxicity spreadsheets for copper, chromium, nickel, and zinc are included in Appendices E and F, respectively. Accumulation of Pollutant in Treated Soil, and Calculation of Square Wave for Ground Water Pathway is included in Appendix G. Partitioning of Pollutants Among Air, Water, and Solids in Soil is included in Appendix H. Derivation of First-Order Coefficient for Losses to Leaching is included in Appendix I. The input parameters used to derive reference application rates for Pathways 12 through 14 are included in Appendix J. Appendix K contains the justification for the annual application of domestic septage. Finally, Appendix L presents the calculations of amounts of sewage sludge, used or disposed, on which the frequency of monitoring requirements are based.

SECTION TWO

LAND APPLICATION OF SEWAGE SLUDGE

Sewage sludge is solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Sewage sludge includes domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and a material derived from sewage sludge (40 CFR Part 503).

Sewage sludge must be used or disposed properly. Most of the sewage sludge generated is used or disposed through land application, surface disposal, or incineration, or is codisposed with municipal solid waste. This section discusses the land application of sewage sludge. Surface disposal and incineration of sewage sludge are discussed in the *Technical Support Document for the Surface Disposal of Sewage Sludge* (U.S. EPA, 1992d) and the *Technical Support Document for Sewage Sludge Incineration* (U.S. EPA, 1992f), respectively. Requirements for sewage sludge disposed with municipal solid waste are presented in 40 CFR Part 258, *Criteria for Municipal Solid Waste Landfills.*

Land application is the spraying or spreading of sewage sludge onto the land surface; the injection of sewage sludge below the land surface; or the incorporation of sewage sludge into the soil so that the sewage sludge can either condition the soil, or fertilize crops or vegetation grown in the soil (40 CFR Part 503). Recently, land application of sewage sludge has gained attention as a viable option because of the growing amount of sewage sludge generated; the need to conserve natural resources; the need to reduce the use of chemical fertilizers yet still provide valuable plant nutrients; the legal restrictions on other disposal practices (e.g., ocean dumping); and the increasing costs of other disposal practices. However, certain concerns about land application need to be addressed. Land application of sewage sludge contaminated with toxic organics or inorganics can interfere with plant growth. These pollutants also can move up the food chain from plants to humans or plants to animals (including soil organisms and soil organism predators) and from plants to animals to humans. Furthermore, children might directly ingest sewage sludge, as might animals that are subsequently ingested, or whose products are ingested, by humans. In addition, when sewage sludge is improperly applied to land, pollutants can leach from the sewage sludge, contaminating surface and ground waters. Other pathways include airborne dust containing sewage sludge particles or air containing volatile pollutants that can be inhaled by humans. The pollutant limits set forth in Part 503 protect against these effects.

Part 503 distinguishes between the terms "apply" sewage sludge to land and "placing" sewage sludge on land and contains different requirements for each of these practices. The term "apply" means to apply sewage sludge to land to use the nutrient content or soil conditioning properties of the sewage sludge. When this is done, the land application requirements in Subpart B apply. When sewage sludge is not used for nutrients or soil conditioning, Part 503 defines the activity as "placing" sewage sludge on land; placing sewage sludge on land is termed surface disposal. When this is done, the surface disposal requirements in Subpart C apply.

Part 503 also distinguishes between "bulk sewage sludge" and "sewage sludge sold or given away in a bag or other container for application to the land" (formerly referred to as distribution and marketing). Bulk sewage sludge is sewage sludge in large quantities that is sold or given away to users such as manufacturers of sewage sludge fertilizer products for application to large areas of land (e.g., agricultural land). Sewage sludge is also sold or given away in bags or other containers for direct use by the purchaser or receiver of the sewage sludge as a fertilizer or soil conditioner on smaller units of land (e.g., lawns, home gardens, public contact sites). An "other container" is defined in Part 503 as an open or closed receptacle, such as a bucket, a box, a carton, or a vehicle with a load capacity of 1 metric ton or less (e.g., a pick-up truck or a trailer pulled by an automobile). A vehicle load capacity of 1 metric ton was chosen as the cut-off because the Agency assumed that the sewage sludge is applied to the land in small amounts and that it is not applied to the land in several applications.

Treatment of sewage sludge varies. It includes, but is not limited to, aerobic or anaerobic digestion, heat drying, mechanical dewatering, air drying, or composting. These treatment processes reduce the water content of sewage sludge, minimize odors and vector attraction, and decrease pathogens and organic chemical concentrations. In addition, wood chips or nutrient additives may be blended with sewage sludge to increase its fertilizing or soil-conditioning value. Lime or other chemicals also may be added to sewage sludge for various reasons (e.g., pH adjustment or pathogen reduction).

The risk assessment for the land application of sewage sludge (see Section Five) evaluates the possible contamination of surface and ground waters with pollutants from sewage sludge applied to the land, as well as the effects of human and wildlife ingestion of products grown on land on which sewage sludge has been applied. Adherence to the requirements in Part 503 also reduces pathogens in sewage sludge and the vector attraction of sewage sludge, and minimizes the potential for contamination of ground water with nitrogen.

Sewage sludge is applied to different types of land. It is applied to agricultural land to increase the production of crops such as food crops, feed crops and forage, and fiber crops (e.g., cotton). Sewage sludge also is applied to forest lands, reclamation sites (i.e., drastically disturbed lands), and public contact sites (e.g., golf courses).

2.1 AGRICULTURAL LAND

Both liquid and dewatered sewage sludge can be applied to agricultural lands. The method of application depends on the soil, the crops grown on the land, and the physical characteristics of the sewage sludge. Liquid sewage sludge can be applied using tractors, tank wagons, irrigation systems, or special application vehicles, or it can be injected under the surface layer of the soil. Surface application is normally limited to slopes of 6 percent or less to reduce surface runoff. As the sewage sludge dries, exposure to sun and air helps further degrade any organics, partially volatilize other organics, and reduce pathogens. After partial drying, the sewage sludge is usually incorporated into the topsoil by plowing or disking before row crops are planted.

Dewatered sewage sludge typically is applied to cropland using equipment similar to that used for applying limestone, animal manures, or commercial chemical fertilizers. Generally, the dewatered sewage sludge is applied to the surface and then incorporated into the soil by plowing or disking. When applied to pasture land, sewage sludge is usually applied to the surface without subsequent incorporation into the soil.

Liquid sewage sludge also can be injected below the surface. Injecting sewage sludge beneath the surface reduces the potential exposure of crops, grazing animals, and humans to sewage sludge pathogens and pollutants. In addition, subsurface application reduces odor and the attraction of vectors to the sewage sludge.

2.2 FORESTS, PUBLIC CONTACT SITES, AND RECLAMATION SITES

As previously discussed, sewage sludge also is applied to forest lands, public contact sites, and reclamation sites to fertilize vegetation grown on the land and to condition the soil. Sewage sludge application to forests increases forest productivity by enhancing the level of nutrients in the soil. The application rate for sewage sludge used in forests is approximately 10 to 100 metric tons dry weight per hectare (mt DW/ha) in a single application every 3 to 5 years. These rates typically are limited by the nitrogen needs of the trees.

Sewage sludge also is used as a soil conditioner or fertilizer on land having a high potential for public contact. These types of land include: public parks, ball fields, cemeteries, plant nurseries, highway median strips, and golf courses.

In land reclamation, sewage sludge is used to return barren land to productivity, or to provide the vegetative cover necessary for controlling soil erosion. A relatively large amount of sewage sludge must be applied to a land area (7 to 450 mt DW/ha) (Jewell, 1982) to provide sufficient organic matter and nutrients capable of supporting vegetation until a self-sustaining ecosystem can be established. Because of these typically large, one-time applications of sewage sludge, effective management criteria must concentrate on the extent to which surface water is contaminated by runoff and ground water contaminated by leaching.

The application of sewage sludge to forests and reclaimed land has received far less attention as an option for using sewage sludge than applying it to agricultural land; however, a considerable amount of research in the United States and elsewhere has focused on the effects of these practices. On an experimental basis, sewage sludge has been applied to forests in at least 10 states and most extensively in the Pacific Northwest (Preamble to 40 CFR Parts 257 and 503, 1989). Metropolitan Seattle and a number of smaller towns in the state of Washington apply sewage sludge to forests on a relatively large scale. These forests represent a wide array of site conditions and tree species. Pilot and full-scale demonstration projects have been undertaken in at least 20 states to study the application of sewage sludge to land that has been reclaimed. The results of research on application of sewage sludge to forests and reclaimed lands suggest that sewage sludge can be used effectively to increase forest productivity, help reclaim disturbed sites, and improve low-productivity soils without causing significant environmental problems when the application of the sewage sludge is managed properly. The following factors should be considered in these situations:

- Degree to which the sewage sludge is stabilized (e.g., pathogen and vector attraction reduction).
- Sewage sludge application rates.
- Degree of land slope.
- Siting issues (e.g., quality of aquifer, depth to ground water, type and age of tree stand, buffer zones).

Research on application of sewage sludge to forest land also has shown that trees and herbaceous plants take up inorganics from the soil and accumulate them at significant, but different, rates. Pollutant uptake levels observed in trees under field conditions have generally been small and do not cause phytotoxic conditions, although not all tree species responded well under all test conditions. Nonetheless, excellent growth responses for some species, even exceeding growth achieved using chemical fertilizers, have been noted.

SECTION THREE

RISK ASSESSMENT METHODOLOGY

This chapter discusses current EPA methods and established Agency policies for performing a risk assessment. This process was outlined originally by the National Academy of Sciences (NAS, 1983a) and was established as final Risk Assessment Guidelines in the Federal Register (1986d). Five types of guidelines were issued:

- Guidelines for Carcinogen Assessment
- Guidelines for Estimating Exposure
- Guidelines for Mutagenicity Risk Assessment
- Guidelines for Health Effects of Suspect Developmental Toxicants
- Guidelines for Health Risk Assessment of Chemical Mixtures.

The Risk Assessment Methodology consists of four distinct steps: hazard identification, dose-response evaluation, exposure evaluation, and characterization of risks.

3.1 HAZARD IDENTIFICATION

The primary purposes of hazard identification are to determine whether the chemical poses a hazard and whether there is sufficient information to perform a quantitative risk assessment. Hazard identification consists of gathering and evaluating all relevant data that help determine whether a pollutant poses a specific hazard, then qualitatively evaluating those data on the basis of the type of health effect produced, the conditions of exposure, and the metabolic processes that govern chemical behavior within the body. Thus, the goals of hazard identification are to determine whether it is appropriate scientifically to infer that effects observed under one set of conditions (e.g., in experimental animals) are likely to occur in other settings (e.g., in human beings), and whether data are adequate to support a quantitative risk assessment.

The first step in hazard identification is gathering information on the toxic properties of chemical substances. The principal methods are animal studies and controlled epidemiological investigations of exposed human populations.

The use of animal toxicity studies is based on the longstanding assumption that effects in human beings can be inferred from effects in animals. There are three categories of animal bioassays: acute exposure tests, subchronic tests, and chronic tests. The usual starting point for such investigations is the study of acute toxicity in experimental animals. Acute exposure tests expose animals to high doses for short periods of time, usually 24 hours or less. The most common measure of acute toxicity is the lethal dose (LD_{50}), the average dose level that is lethal to 50 percent of the test animals. LD_{50} refers to oral doses. LC_{50} designates the inhalation dose at which 50 percent of the animals exposed died. LC_{50} is also used for aquatic toxicity tests and refers to the concentration of the test substance in the water that results in 50 percent mortality in the test species. Substances exhibiting a low LD_{50} (e.g., for sodium cyanide, 6.4 mg/kg) are more acutely toxic than those with higher values (e.g., for sodium chloride, 3,000 mg/kg) (NIOSH, 1979).

Subchronic tests for chemicals involve repeated exposures of test animals for 5 to 90 days, depending on the animal, by exposure routes corresponding to human exposures. These tests are used to determine the No Observed Adverse Effect Level (NOAEL), the Lowest Observed Adverse Effect Level (LOAEL), and the Maximum Tolerated Dose (MTD). The MTD is the largest dose a test animal can receive for most of its lifetime without demonstrating adverse effects other than cancer. In studies of chronic effects of chemicals, test animals receive daily doses of the test agent for approximately 2 to 3 years. The doses are lower than those used in acute and subchronic studies, and the number of animals is larger because these tests are trying to detect effects that will be observed in only a small percentage of animals.

The second method of evaluating health effects uses epidemiology—the study of patterns of disease in human populations and the factors that influence these patterns. In general, scientists view well-conducted epidemiological studies as the most valuable information from which to draw inferences about human health risks. Unlike the other approaches used to evaluate health effects, epidemiological methods evaluate the direct effects of hazardous substances on human beings. These studies also help identify human health hazards without requiring prior knowledge of disease causation, and they complement the information gained from animal studies.

Epidemiological studies compare the health status of a group of persons who have been exposed to a suspected causal agent with that of a comparable nonexposed group. Most epidemiological studies are either case-control studies or cohort studies. In case-control studies, a group of individuals with a specific disease is identified (cases) and compared with individuals not having the disease (controls) in an attempt to ascertain commonalities in exposures they may have experienced in the past. Cohort studies start with a group of people (a cohort) considered free of the disease under investigation. The health status of the cohort known to have a common exposure is examined over time to determine whether any specific condition or cause of death occurs more frequently than might be expected from other causes.

Epidemiological studies are well-suited to situations in which exposure to the risk agent is relatively high; the adverse health effects are unusual (e.g., rare forms of cancer); the symptoms of exposure are known; the exposed population is clearly defined; the link between the causal risk agent and adverse effects in the affected population is direct and clear; the risk agent is present in the bodies of the affected population; and high levels of the risk agent are present in the environment.

The next step in hazard identification is to combine the pertinent data to ascertain the degree of hazard associated with each chemical. In general, EPA uses different approaches for qualitatively assessing the risk or hazard associated with carcinogenic versus noncarcinogenic effects. For noncarcinogenic health effects (e.g., systemic toxicity), the Agency's hazard identification/weight-of-evidence determination has not been formalized and is based on a qualitative assessment.

EPA's guidelines for carcinogenic risk assessment (Federal Register, 1986b) group all human and animal data reviewed into the following categories based on degree of evidence of carcinogenicity:

- Sufficient evidence
- Limited evidence (e.g., in animals, an increased incidence of benign tumors only)
- Inadequate evidence
- No data available
- No evidence of carcinogenicity.

Human and animal evidence of carcinogenicity in these categories is combined into the following weight-of-evidence classification scheme:

- Group A—Human carcinogen
- Group B—Probable human carcinogen
  - B1—Higher degree of evidence
  - B2—Lower degree of evidence
- Group C—Possible human carcinogen
- Group D—Not classifiable as to human carcinogenicity
- Group E—Evidence of noncarcinogenicity

Group B, probable human carcinogens, is usually divided into two subgroups: B1, chemicals for which there is some limited evidence of carcinogenicity from epidemiology studies; and B2, chemicals for which there is sufficient evidence from animal studies but inadequate evidence from epidemiology studies. EPA treats chemicals classified in categories A and B as suitable for quantitative risk assessment. Chemicals classified as Category C receive varying treatment with respect to dose-response assessment, and they are determined on a case-by-case basis. Chemicals in Groups D and E do not have sufficient evidence to support a quantitative dose-response assessment.

The following factors are evaluated by judging the relevance of the data for a particular chemical:

- Quality of data.
- Resolving power of the studies (significance of the studies as a function of the number of animals or subjects).
- Relevance of route and timing of exposure.
- Appropriateness of dose selection.
- Replication of effects.
- Number of species examined.
- Availability of human epidemiologic study data.
- Relevance of tumors observed (e.g., forestomach, mouse liver, male rat kidney)

Although the information gathered during the course of identifying each chemical hazard is not used to estimate risk quantitatively, hazard identification enables researchers to characterize the body of scientific data in such a way that two questions can be answered: (1) Is a chemical a hazard? and (2) Is a quantitative assessment appropriate? The following two sections discuss how such quantitative assessments are conducted.

3.2 DOSE-RESPONSE EVALUATION

Estimating the dose-response relationships for the chemical under review is the second step in the risk assessment methodology. Evaluating dose-response data involves quantitatively characterizing the connection between exposure to a chemical (measured in terms of quantity and duration) and the extent of toxic injury or disease. Most dose-response relationships are estimated based on animal studies, because even good epidemiological studies rarely have reliable information on exposure. Therefore, this discussion focuses primarily on dose-response evaluations based on animal data.

There are two general approaches to dose-response evaluation, depending on whether the health effects are based on threshold or nonthreshold characteristics of the chemical. In this context, thresholds refer to exposure levels below which no adverse health effects are assumed to occur. For effects that involve altering genetic material (including carcinogenicity and mutagenicity), the Agency's position is that effects occur at very low doses, and therefore, they are modeled with no thresholds. For most other biological effects, it is usually (but not always) assumed that "threshold" levels exist.

For nonthreshold effects, the key assumption is that the dose-response curve for such chemicals exhibiting these effects in the human population achieves zero risk only at zero dose. A mathematical model is used to extrapolate response data from doses in the observed (experimental) range to response estimates in the low-dose ranges. Scientists have developed several mathematical models to estimate low-dose risks from high-dose experimental risks. Each model is based on general theories of carcinogenesis rather than on data for specific chemicals. The choice of extrapolation model can have a significant impact on the dose-response estimate. For this reason, the Agency's cancer assessment guidelines recommend the use of the multistage model, which yields estimates of risk that are conservative, representing a plausible upper limit of risk. With this approach, the estimate of risk is not likely to be lower than the true risk (Federal Register, 1986b).

The potency value, referred to by the Carcinogenic Assessment Group as q_1^*, is the quantitative expression derived from the linearized multistage model that gives a plausible upper-bound estimate to the slope of the dose-response curve in the low-dose range. The q_1^* is expressed in terms of risk-per-dose, and has units of $(mg/kg \bullet day)^{-1}$. These values should be used only in dose ranges for which the statistical dose-response extrapolation is appropriate. EPA's q_1^* values can be found in the Integrated Risk Information System (IRIS) (U.S. EPA, 1992h), accessible through the National Library of Medicine.

Dose-response relationships are assumed to exhibit threshold effects for systemic toxicants or other compounds exhibiting noncarcinogenic, nonmutagenic health effects. Dose-response evaluations for substances exhibiting threshold responses involve calculating what is known as the Reference Dose (oral exposure) or Reference Concentration (inhalation exposure), abbreviated to RfD and RfC, respectively. This measure is used as a threshold level for critical noncancer effects below which a significant risk of adverse effects is not expected. The RfDs and RfCs developed by EPA can be found in IRIS.

The RfD/RfC methodology uses four experimental levels: No Observed Effect Level (NOEL), No Observed Adverse Effect Level (NOAEL), Lowest Observed Effect Level (LOEL), or Lowest Observed Adverse Effect Level (LOAEL). Each level is stated in mg/kg•day, and all the levels are derived from laboratory animal and/or human epidemiology data. When the appropriate level is determined, it is then divided by an appropriate uncertainty (safety) factor. The magnitude of safety factors varies according to the nature and quality of the data from which the NOAEL or LOAEL is derived. The safety factors, ranging from 10 to 10,000, are used to extrapolate from acute to chronic effects, interspecies sensitivity, and variation in sensitivity in human populations. They are also used to extrapolate from a LOAEL to a NOAEL. Ideally, for all threshold effects, a set of route-specific and effect-specific thresholds should be developed. If information is available for only one route of exposure, this value is used in a route-to-route extrapolation to estimate the appropriate threshold. Once these values are derived, the next step is to estimate actual human (or animal) exposure.

3.3 EXPOSURE EVALUATION

Exposure evaluation uses data concerning the nature and size of the population exposed to a substance, the route of exposure (i.e., oral, inhalation, dermal), the extent of exposure (concentration times time), and the circumstances of exposure.

There are two ways of estimating environmental concentrations:

- Directly measuring levels of chemicals (monitoring)
- Using mathematical models to predict concentrations (modeling)

In addition, an analysis of population exposure is necessary.

3.3.1 Monitoring

Monitoring involves collecting and analyzing environmental samples. These data provide the most accurate information about exposure. The two kinds of exposure monitoring are personal monitoring and ambient (or site and location) monitoring.

Most exposure assessments are complicated by the fact that human beings move from place to place and are therefore exposed to different risk agents throughout the day. Some exposure assessments attempt to compensate for this variability by personal monitoring. Personal monitoring uses one or more techniques to measure the actual concentrations of hazardous substances to which individuals are exposed. One technique is sampling air and water. The amount of time spent in various microenvironments (i.e., home, car, or office), may be combined with data on environmental concentrations of risk agents in those microenvironments to estimate exposure.

Personal monitoring may also include the sampling of human body fluids (e.g., blood, urine, or semen). This type of monitoring is often referred to as biological monitoring or biomonitoring. Biological markers (also called biomarkers) can be classified as markers of exposure, of effect, and of susceptibility. Biological markers of exposure measure exposure either to the exogenous material, its metabolite(s), or to the interaction of the xenobiotic agent with the target cell within an organism. An example of a biomarker of exposure is lead concentration in blood. In contrast, biologic markers of effect measure some biochemical, physiologic, or other alteration within the organism that points to impaired health. (Sometimes the term biomonitoring is also used to refer to the regular sampling of animals, plants, or microorganisms in an ecosystem to determine the presence and accumulation of pollutants, as well as their effects on ecosystem components.)

Ambient monitoring (or site or location monitoring) involves collecting samples from the air, water, soil, or sediments at fixed locations, then analyzing the samples to determine environmental concentrations of hazardous substances at the locations. Exposures can be further evaluated by modeling the fate and transport of the pollutants.

3.3.2 Modeling

Measurements are a direct and preferred source of information for exposure analysis. However, such measurements are expensive and are often limited geographically. The best use of such data is to calibrate mathematical models that can be more widely applied. Estimating concentrations using mathematical models must account not only for physical and chemical properties related to fate and transport, but must also document mathematical properties (e.g., analytical integration versus statistical approach), spatial properties (e.g., one, two, or three dimensions), and time properties (steady-state versus nonsteady-state).

Hundreds of models for fate, transport, and dispersion from the source are available for all media. Models can be divided into five general types by media: atmospheric models, surface-water models, ground water and unsaturated-zone models, multimedia models, and food-chain models. These five types of models are primarily applicable to chemicals or to radioactive materials associated with dusts and other particles.

Selecting a model for a given situation depends on the following criteria: capability of the model to account for important transport, transformation, and transfer mechanisms; fit of the model to site-specific and substance-specific parameters; data requirements of the model, compared to availability and reliability of off-site information; and the form and content of the model output that allow it to address important questions regarding human exposures.

To the extent possible, selection of the appropriate fate and transport model should follow guidelines specified for particular media where available; for example, the Guidelines on Air Quality Models (U.S. EPA, 1986f).

3.3.3 Population Analysis

Population analysis involves describing the size and characteristics (e.g., age/sex distribution), location (e.g., workplace), and habits (e.g., food consumption) of potentially exposed human and nonhuman populations. Census and other survey data often are useful in identifying and describing populations exposed to a chemical.

Integrated exposure analysis involves calculating exposure levels, along with describing the exposed populations. An integrated exposure analysis quantifies the contact of an exposed population to each chemical under investigation via all routes of exposure and all pathways from the sources to the exposed individuals. Finally, uncertainty should be described and quantified to the extent possible.

3.4 RISK CHARACTERIZATION

This final step in the risk assessment methodology involves integrating the information developed in hazard identification, dose-response assessment, and exposure assessment to derive quantitative estimates of risk. Qualitative information should also accompany the numerical risk estimates, including a discussion of uncertainties, limitations, and assumptions. It is useful to distinguish methods used for chemicals exhibiting threshold effects (i.e., most noncarcinogens) from those believed to lack a response threshold (i.e., carcinogens).

For carcinogens, individual risks are generally represented as the probability that an individual will contract cancer in a lifetime as a result of exposure to a particular chemical or group of chemicals. Population risks are usually estimated based on expected or average exposure scenarios (unless information on distributions of exposure is available). The number of persons above a certain risk level, such as 10^{-6}, or above a series of risk levels (10^{-5}, 10^{-4}, etc.), is another useful descriptor of population risks. Thus, individual risks also may be presented using cumulative frequency distributions, where the total number of people exceeding a given risk level is plotted against the individual risk level.

For noncarcinogens, dose-response data above the threshold are usually lacking. Therefore, risks are characterized by comparing the dose or concentration to the threshold level, using a ratio in which the dose is placed in the numerator and the threshold in the denominator. Aggregate population risks for noncarcinogens can be characterized by the number of people exposed above the RfD or RfC. Recall that the hazard identification step for threshold chemicals is addressed qualitatively, because no formal Agency weight-of-evidence evaluation is currently available for noncarcinogenic chemicals. The same approach can be used to assess both acute and chronic hazards. For assessing acute effects, the toxicity data and exposure assessment methods must account for the appropriate duration of exposure.

SECTION FOUR

POLLUTANTS OF CONCERN FOR PART 503 RISK ASSESSMENT

Section 503.13 of Subpart B limits either the concentration of 10 pollutants in sewage sludge or the amount of these 10 pollutants that can be applied to a unit of land (see Section Six). This section describes how the Agency selected these 10 regulated pollutants.

4.1 INITIAL LIST OF POLLUTANTS

The Agency's initial focus was to identify pollutants that may pose health or environmental hazards when sewage sludge is used or disposed. The EPA Office of Science and Technology (OST) began by developing a list of pollutants of concern. To develop this list, which was compiled using readily available data, the following variables were considered: frequency of occurrence, aquatic toxicity, phytotoxicity, human health effects, domestic and wildlife effects, and plant uptake.

Originally, four use or disposal practices were identified: land application, landfilling (now called surface disposal), incineration, and ocean dumping. Four meetings of experts were convened during April and May of 1984. Each meeting evaluated the potential pollutants of concern for each use or disposal practice by answering the following questions:

- For which pollutants are there sufficient data indicating that such pollutants present a potential hazard if used or disposed by the practice in question?
- For which pollutants are there sufficient data indicating that such pollutants do not present a potential hazard or problem to human health or the environment?
- For which pollutants are there insufficient data to make a conclusive recommendation concerning potential hazard?

The experts were given broad latitude in determining which pollutants to evaluate; they were allowed to add or delete items from the list. Based on the experts' recommendations, 50 pollutants and 7 pathogens were identified for further analysis. In addition, the experts designated which environmental exposure pathways were of concern for each pollutant or pathogen. For land application, 10 environmental pathways and 31 pollutants of concern were identified (see Tables 4-1 and 4-2).

4.2 ENVIRONMENTAL PROFILES

An environmental profile was developed for each pollutant and each pathogen. Each profile consisted of two sections: a compilation of data on toxicity, occurrence, and fate and effects for the pollutant; and an evaluation of the hazard specific to the environmental pathways for the use or disposal practice of concern.

Hazards were evaluated using hazard indices. Hazard indices are calculated using equations in which the projected concentration of pollutant in soil is compared to the lowest concentration of that pollutant in soil shown to be toxic to the highly exposed individual. The concentration of pollutant in soil is projected for both "typical and worst" pollutant concentrations in sewage sludge for three different sewage sludge loading rates (i.e., 5 mt/ha, 50 mt/ha, and 500 mt/ha). Values less than 1 indicate that the pollutant is not toxic to the HEI for the particular combination of pollutant concentration in sewage sludge and sewage sludge loading rate used in calculating the index. All index values of less than 1 generated under worst-case conditions (i.e., using worst pollutant concentration in sewage sludge at the highest sewage sludge loading rate), were dropped for further analysis for the particular pathway.

For each pathway, remaining pollutants (i.e., pollutants having index values equal to or greater than 1 underwent an incremental ranking). The purpose of this ranking was to evaluate what portion of the total hazard associated with a pollutant for a particular pathway was attributable to sewage sludge. To make such an evaluation, the index value generated using the null or background value was subtracted from the total hazard index value for the worst-case

TABLE 4-1

ENVIRONMENTAL PATHWAYS OF CONCERN IDENTIFIED FOR THE LAND APPLICATION OF SEWAGE SLUDGE

Pathway	Description of HEI
1. Sludge → Soil → Plant → Human	Consumer ingesting plants grown in sewage sludge-amended soil.
2. Sludge → Soil → Plant → Human	Residential home gardener.
3. Sludge → Human	Children ingesting sludge.
4. Sludge → Soil → Plant → Animal → Human	Farm households producing a major portion of the animal products they consume. It is assumed that the animals eat plants grown in sewage sludge-amended soil.
5. Sludge → Soil → Animal → Human	Farm households consuming livestock that ingest soil while grazing.
6. Sludge → Soil → Plant → Animal	Livestock ingesting crops grown on sewage sludge-amended soil.
7. Sludge → Soil → Animal	Grazing livestock ingesting sewage sludge-amended soil.
8. Sludge → Soil → Plant	Plants grown in sewage sludge-amended soil.
9. Sludge → Soil → Soil Biota	Soil biota living in sewage sludge-amended soil.
10. Sludge → Soil → Soil Biota → Soil Biota Predator	Animals eating soil biota living in sewage sludge-amended soil.

TABLE 4-2

POLLUTANTS SELECTED FOR ENVIRONMENTAL PROFILE DEVELOPMENT FOR LAND APPLICATION

Inorganics	Organics
Arsenic	Aldrin/Dieldrin
Cadmium	Benzo(a)anthracene
Chromium	Benzo(a)pyrene
Cobalt	Bis (2-ethylhexyl) phthalate
Copper	Chlordane
Fluoride	DDD/DDE/DDT
Iron	Heptachlor
Lead	Hexachlorobenzene
Mercury	Hexachlorobutadiene
Molybdenum	Lindane
Nickel	Methylene bis (2-chloro-aniline) (MOCA)
Selenium	Methylene chloride
Zinc	n-Nitrosodimethylamine
	Pentachlorophenol
	Polychlorinated biphenyls (PCBs)
	Toxaphene
	Trichloroethylene
	Tricresyl phosphate

scenario. The resulting incremental values were placed in one of four groups: less than 1; 1 to 100; 100 to 1,000; and greater than 1,000. The higher rankings signify greater potential risk. Pollutant/pathway combinations having incremental values of more than 1 were subsequently evaluated in a detailed risk assessment for the final rule. A summary of the results of the land application environmental profiles and hazard indices for pollutants can be found in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sewage Sludge: Methods and Results* (U.S. EPA, 1985c).

The sewage sludge pollutants evaluated for pathways 1 through 10 for land application under Part 503 appear in Table 4-3. Not all of the pollutants were assessed for each pathway, however, because some pollutants were screened out by incremental ranking. Although fluoride and iron were not screened out, they were not evaluated in the risk assessment for the final rule. The concern for fluoride was based on one study (Davis, 1980) in which a high concentration was used and effects were only observed in plants, not animals. Similarly for iron, one study in which sewage sludge containing 11 to 12 percent iron was applied to pasture on which cows grazed directly; the cows had iron-induced copper deficiency (Decker et al., 1980a). Both iron and fluoride were dropped early in the risk assessment, because the effects of each were based on single anomalous studies in which the concentration of the pollutant was very high relative to "normal sludge" and because insufficient data were available on which to base a risk assessment.

4.3 ADDITIONAL PATHWAYS

Four of the pathways analyzed for the final Part 503 rulemaking (Pathways 11 through 14) were not evaluated in the initial screening process described in Section 4.2, because they were not considered very likely routes for exposure, assuming good management practices were in place for land application of sewage sludge. After this assumption was challenged, the Office of Research and Development (ORD) developed a methodology to evaluate these pathways, shown below, in the risk assessment.

TABLE 4-3

POLLUTANTS FOR WHICH RISK WAS ASSESSED FOR PATHWAYS 1 THROUGH 10

Inorganics	Organics
Arsenic	Aldrin/Dieldrin
Cadmium	Benzo(a)pyrene
Chromium	Chlordane
Copper	DDT/DDE/DDD (total)
Lead	Heptachlor
Mercury	Hexachlorobenzene
Molybdenum	Hexachlorobutadiene
Nickel	Lindane
Selenium	n-Nitrosodimethylamine
Zinc	Polychlorinated biphenyls (PCBs)
	Toxaphene
	Trichloroethylene

Pathway Number	Description	Highly Exposed Individual
Pathway 11	Sewage Sludge→Soil→Airborne Dust→Human	Tractor operator
Pathway 12	Sewage Sludge→Soil→Surface Water→Human	Humans eating fish and drinking water
Pathway 13	Sewage Sludge→Soil→Air→Human	Humans breathing volatile pollutants
Pathway 14	Sewage Sludge→Soil→Ground Water→Human	Humans drinking water from wells

Pathway 11, the particulate resuspension pathway, was analyzed only for agricultural land application use, with the Highly Exposed Individual (HEI) defined as a tractor driver plowing large areas. For this pathway, the Agency evaluated the risk of exposure to pollutants listed in Table 4-4. Exposure to particulates in nonagricultural settings (i.e., in forests, reclamation sites, and public contact sites) where tractors are not ordinarily used is presumably insignificant; therefore, it was not modeled.

In the hazard indices generated by EPA in 1985, no hazard indices were generated for Pathway 12, the surface-water pathway, and Pathway 14, the ground water pathway. However, because the surface disposal of sewage sludge can be considered a worst-case scenario of land application, the pollutants listed for the surface disposal practice in the hazard indices were evaluated for both Pathways 12 and 14 (see Table 4-5). For Pathway 13, which evaluates the volatilization of pollutants and subsequent inhalation of the vapor, the pollutants assessed are shown in Table 4-6.

TABLE 4-4

POLLUTANTS FOR WHICH RISK ASSESSMENTS WERE PERFORMED FOR PATHWAY 11 (TRACTOR OPERATOR) FOR LAND APPLICATION OF SEWAGE SLUDGE

Inorganics	Organics
Arsenic	Aldrin/Dieldrin
Cadmium	DDD/DDE/DDT
Chromium	Polychlorinated biphenyls (PCBs)
Copper	
Lead	
Mercury	
Nickel	

TABLE 4-5

POLLUTANTS FOR WHICH RISK ASSESSMENTS WERE PERFORMED FOR PATHWAY 12 (SURFACE WATER) AND PATHWAY 14 (GROUND WATER) FOR LAND APPLICATION OF SEWAGE SLUDGE

Inorganics	Organics
Arsenic	Benzene
Cadmium	Benzo(a)pyrene
Chromium	Bis (2-ethyl hexyl) phthalate
Copper	Chlordane
Lead	DDT/DDD/DDE
Mercury	Lindane
Nickel	n-Nitrosodimethylamine
	Polychlorinated biphenyls (PCBs)
	Toxaphene
	Trichloroethylene

TABLE 4-6

POLLUTANTS FOR WHICH RISK ASSESSMENTS WERE PERFORMED FOR PATHWAY 13 (VAPOR) FOR LAND APPLICATION OF SEWAGE SLUDGE

Organics
Benzene
Benzo(a)pyrene
Bis (2-ethyl hexyl) phthalate
Chlordane
DDT/DDD/DDE
Lindane
n-Nitrosodimethylamine
Polychlorinated biphenyls (PCBs)
Toxaphene
Trichloroethylene

SECTION FIVE

RISK ASSESSMENT FOR THE LAND APPLICATION OF SEWAGE SLUDGE

5.1 INTRODUCTION

Risk assessments were conducted for application of sewage sludge onto agricultural land and nonagricultural land (i.e., forest land, reclamation land, and public contact sites). These risk assessments, which are described in this document, form the basis for the sewage sludge pollutant loading limits specified in Section 503.13 of 40 CFR Part 503 Standards for the Use or Disposal of Sewage Sludge.

Risk assessments were conducted for 14 exposure pathways identified for agricultural land and 12 exposure pathways identified for nonagricultural land. Pathway 2, human toxicity from ingesting plants grown in the home garden, and Pathway 11, human exposure through inhalation of particulates resuspended by tilling sewage sludge, were not analyzed for nonagricultural application because these are not appropriate exposure scenarios for nonagricultural land. The pathways assessed are summarized in Table 5.2.1-1.

5.1.1 Acknowledgments

For agricultural land, risk assessments for Pathways 1 through 10 were conducted by the Peer Review Committee. This committee was formed in response to the proposed rule in which EPA requested that the U.S. Department of Agriculture (USDA) Cooperative States Research Service (CSRS) Regional Research Technical Committee (W-170) review the scientific and technical bases of the proposed rule. (The W-170 committee is a CSRS committee formulated for conducting regional research by researchers from land grant universities, agricultural experiment stations, and USDA laboratories throughout the United States.) In response, the W-170 formed a Peer Review Committee (PRC) composed of 35 recognized academic, government, and private industry experts in the field of sludge application to land. The PRC members

TABLE 5.2.1-1

ENVIRONMENTAL PATHWAYS OF CONCERN
IDENTIFIED FOR APPLICATION OF SEWAGE SLUDGE TO AGRICULTURAL LAND

Pathway	Description of HEI
1. Sewage Sludge→Soil→Plant→Human	Human ingesting plants grown in sewage sludge-amended soil.
2. Sewage Sludge→Soil→Plant→Human	Residential home gardener.
3. Sewage Sludge→Human	Children ingesting sewage sludge.
4. Sewage Sludge→Soil→Plant→ Animal→Human	Farm households producing a major portion of the animal products they consume. It is assumed that the animals eat plants grown in soil amended with sewage sludge.
5. Sewage Sludge→Soil→Animal→ Human	Farm households consuming livestock that ingest sewage sludge while grazing.
6. Sewage Sludge→Soil→Plant→ Animal	Livestock ingesting crops grown on sewage sludge-amended soil.
7. Sewage Sludge→Soil→Animal	Grazing livestock ingesting sewage sludge.
8. Sewage Sludge→Soil→Plant	Plants grown in sewage sludge-amended soil.
9. Sewage Sludge→Soil→Soil Organism	Soil organisms living in sewage sludge-amended soil.
10. Sewage Sludge→Soil→Soil Organsim→ Soil Organism Predator	Animals eating soil organisms living in sewage sludge-amended soil.
11. Sewage Sludge→Soil→Airborne Dust→Human	Tractor operator exposed to dust while plowing large areas of sewage sludge-amended soil.
12. Sewage Sludge→Soil→Surface Water→Human	Water Quality Criteria for the receiving water for a person who consumes 0.04 kg/day of fish and 2 liters/day of water.
13. Sewage Sludge→Soil→Air→Human	Human breathing volatile pollutants from sewage sludge.
14. Sewage Sludge→Soil→Ground Water→Human	Human drinking water from wells contaminated with pollutants leaching from sewage sludge-amended soil to ground water.

critically evaluated the methodology and data utilized to assess risk as part of developing criteria for land application of potentially toxic chemicals in municipal sewage sludge. EPA's Office of Water (OW) conducted the risk assessment for Pathway 11. The risk assessments for Pathways 12, 13, and 14 were conducted for EPA by Abt Associates Inc. and reviewed by the Peer Review Committee.

For nonagricultural land, Charles Henry of the University of Washington conducted the risk assessments for Pathways 1 through 10 (excluding Pathway 2, as discussed above). Pathways 12, 13, and 14 are identical for agricultural and nonagricultural land, so Abt Associates' assessment of agricultural Pathways 12, 13, and 14 was also used for the nonagricultural pathways.

5.1.2 EPA Decisions Concerning Assumptions, Data Used for Environmental Exposure Evaluations

This section explains the concept of the highly exposed individual (HEI) that EPA used as a target organism to be protected. Depending on the pathway of exposure, the HEI could be a human, plant, animal, or environmental endpoint, such as surface or ground water. This section also explains EPA decisions affecting the risk assessment performed for the land application of sewage sludge. These decisions represent the way in which EPA applied its risk assessment methodology to developing pollutant limits for Subpart B of the sewage sludge regulation.

5.1.2.1 Highly Exposed Individual

The risk-based models developed for the Part 503 regulation were designed to limit potential exposure of a highly exposed individual (HEI) to the pollutants of concern. The HEI is an individual who remains for an extended period of time at or adjacent to the site where the maximum exposure occurs.

The 1989 proposed Part 503 rule considered the exposed individual to be a "most exposed individual" (MEI). EPA changed the exposed individual from the MEI to the HEI so that the final rule would be consistent with a statement in the rule's legislative history that calls for protecting individuals and populations that are "highly exposed to reasonably anticipated adverse conditions." In developing Subpart B of the rule, EPA used different HEIs in evaluating each pathway of potential exposure from the toxic effects of pollutants in land-applied sewage sludge.

For agricultural settings for Pathway 1, which is designed to protect consumers who eat produce grown in sewage sludge-amended soil, the HEI is assumed to live in a region where a relatively high percentage of the available cropland receives sludge applications. Although all vegetables in the diet could be presumed to be affected, this assumption was considered to be too severe a worst case. Instead it was assumed that the HEI ingests a mix of crops from land on which sludge was applied as well as from land on which sludge was not applied.

For nonagricultural settings for Pathway 1, the HEI is a person who regularly harvests edible wild plants (i.e., berries and mushrooms) from forests or range lands that have been amended with sewage sludge. This food is preserved by drying, freezing, or canning and is, hence, available for consumption throughout the year. It is also assumed that an individual could continue with this practice for a lifetime, estimated as 70 years.

Pathway 2 evaluates the effects to home gardeners from consuming crops grown in residential home gardens that have been amended with sewage sludge. The major difference between Pathways 1 and 2 is the fraction of food assumed to be grown on sewage sludge-amended soil. The HEI for Pathway 2 is the home gardener who produces and consumes potatoes, leafy vegetables, fresh legumes, root vegetables, garden fruits (e.g., tomatoes, eggplants), sweet corn, and grains. (These are also consumed but not produced by the HEI in Pathway 1.) Unlike Pathway 1, peanuts and dried legumes are not included, because the HEI in Pathway 2 is unlikely to grow them in residential settings.

The HEI for Pathway 3, which assesses the hazard to a child from ingesting undiluted sewage sludge, is a child ingesting sewage sludge from storage piles or from the soil surface. For the residential setting, this HEI is assumed to be a child between the ages of 1 and 6. In the nonagricultural setting, it is unlikely that a child younger than 4 years old would be unattended for a long enough time to ingest the sludge. The HEI for the nonagricultural setting is therefore assumed to be exposed for 2 years between the ages of 4 and 6.

The HEI for Pathway 4 is an individual consuming foraging animals that consumed feed crops or vegetation grown on sewage sludge-amended soils. The HEI is assumed to consume daily quantities of the various animal tissue foods and to be exposed to background levels of pollutants from sources other than sludge. For the agricultural setting, the affected animal foods evaluated were beef, beef liver, lamb, pork, poultry, dairy, and eggs.

In the nonagricultural setting, the HEI for this pathway is assumed to be a hunter who preserves meat (including liver) for consumption through the year. The animals hunted in the forest and eaten are assumed to be deer and elk. Although other animals could be hunted and consumed, the Agency evaluated only these large mammals because their greater size makes them capable of having a more significant impact on the total human diet.

Pathway 5 involves the application of sewage sludge to the land, the direct ingestion of this sewage sludge by animals, and, finally, the consumption of contaminated animal tissue by humans. The HEI is assumed to consume various animal tissue foods and is also assumed to be exposed to a background intake of pollutants.

Pathway 6 evaluates animals that ingest plants grown on sewage sludge-amended soil. The HEI for both agricultural and nonagricultural uses is a highly sensitive herbivore that consumes plants grown on sewage sludge-amended soil. Background intake is taken into account by considering background concentration of pollutants in forage crops. In a forest application site there are two HEIs: domestic animals that graze, and small herbivorous mammals such as deer mice that live their entire lives in a sewage sludge-amended area feeding on seeds and small plants close to the layer of soil amended with sewage sludge. In the agricultural setting, the HEI is a larger grazing mammal, such as a sheep.

The HEI for Pathway 7 is an herbivorous animal that incidentally consumes sewage sludge adhering to forage crops and/or sewage sludge on the soil surface. Background intake is considered to be from ingesting soil having background levels of pollutant. Since forest animals more typically browse rather than graze, the HEI for agricultural settings is used as a reasonable worst-case surrogate for the nonagricultural HEI.

Pathway 8, the plant phytotoxicity pathway, assumes for its HEI a plant sensitive to the pollutants in sewage sludge. The literature search carried out for this pathway included information on nonagronomic species, which were shown to be no more sensitive than agronomic species. Therefore, the limits set for agricultural species also protect wild species found in nonagricultural settings.

The HEI for Pathway 9 is a soil organism sensitive to the pollutants in sewage sludge—an earthworm. Since all soil organisms are wild species, the same HEI is used for the agricultural as well as the nonagricultural settings.

The HEI for Pathway 10, the soil organism-predator pathway, is wildlife—the shrew mole--that consumes soil organisms that have been feeding on sewage sludge-amended soil. As with Pathway 9, the same HEI is used for both the nonagricultural and agricultural pathways.

Pathway 11, which protects humans from the effects of airborne dusts containing sewage sludge, has as its HEI a tractor driver tilling a field. This pathway evaluates the impact of particles that have been resuspended by the driver's tilling dewatered sewage sludge into the soil. This pathway applies only to the agricultural setting, since tractors are not usually found in nonagricultural settings such as forests.

Pathway 12, the soil erosion pathway, has as an HEI a human who consumes 2 liters/day of drinking water from surface water contaminated by soil eroded from a site where sewage sludge has been land-applied and who ingests 0.04 kg/day of fish from surface waters contaminated by sewage sludge pollutants. The HEI is the same for agricultural and nonagricultural practices.

The HEI for Pathway 13 is a human who inhales the vapors of any volatile pollutants that may be in the sewage sludge when it is applied to the land. The wind direction is assumed never to change, so that the HEI is assumed to live at the downwind edge of the site. The same plume model was used for both the agricultural and nonagricultural settings.

The HEI for Pathway 14 for agricultural and nonagricultural settings is an individual who obtains his or her drinking water from ground water located directly below a field to which sewage sludge has been applied.

5.1.2.2 Decisions Related to Calculating the Human Dose

5.1.2.2.1 Oral Reference Dose (RfD)

An oral reference dose (RfD) of a pollutant is a threshold below which effects adverse to human health are unlikely to occur. Where the Agency has not published human health criteria for a noncarcinogenic pollutant, the RfD listed in EPA's computerized Integrated Risk Information System (IRIS) was used (U.S. EPA, 1992h). The RfDs listed in IRIS are based on a process within the Agency that includes review of the latest scientific information.

5.1.2.2.2 Recommended Dietary Allowances (RDAs)

RDAs are defined as the levels of intake of essential nutrients that, on the basis of scientific knowledge, are judged by the Food and Nutrition Board to be adequate to meet the known nutrient needs of practically all healthy persons (NAS, 1989). Although RfDs were used to determine the concentrations of inorganic pollutants that are protective of human health, the RDA was used in two cases: zinc and copper. Since there is at present no Agency-approved RfD for copper, the RDA was used as a reasonably protective dose. In the case of zinc, the Agency has established an RfD, but that value is insufficient to meet the daily nutritional requirements of the exposed population. The Agency therefore chose to use the higher RDA value.

5.1.2.2.3 Lead Pollutant Limit

In Pathway 3, EPA used the integrated uptake biokinetic model (IUBK) to evaluate the effects from lead when children ingest sewage sludge. The IUBK model used a lead blood level not to exceed 10 micrograms per deciliter, a 30 percent absorption value, and a 95th-percentile population distribution to protect the HEI. Using these values in the model results in an allowable lead concentration in sewage sludge of 500 parts per million (ppm). In addition, the lead pollutant limit calculated by the Land Application Technical Review Committee was based on the observation that body burdens (absorption) of animals fed up to 10 percent of their diet as sewage sludge did not change until the lead concentration in the sewage sludge exceeded 300 ppm. To minimize the lead concentration in sewage sludge, the Agency selected the more conservative numerical limit for this pathway for the final Part 503 rule—300 ppm (or μg-lead/g-sewage sludge DW).

Several reasons support this decision. First, such action would provide an additional margin of safety with respect to lead contamination of soil and thereby any threat to the bodies of growing children. Because childhood ingestion of dirt is so widespread, and the potential consequences so severe, a highly conservative limit is warranted, especially in the context of regulatory decisions that authorize a threshold pollutant such as lead to be added to the environment. In addition, a 300-ppm concentration of lead in soil corresponds to a lead concentration in sludge that was consistent with the quality of current sewage sludge at all but a small number of publicly owned treatment works (POTWs). The social cost of the additional safety factor is therefore small relative to the potential benefit.

Coincidentally, this approach yielded the same pollutant limit calculated by the Peer Review Committee based on the observation that animals fed up to 10 percent of their diet as sewage sludge had body burdens (absorption) exceeding 300 ppm. These data further support the appropriateness of the value chosen by the Agency.

5.1.2.2.4 Cancer Potency

The cancer potency value (q_1^*) represents the relationship between a specified carcinogenic dose and its associated degree of risk. The q_1^* is based on an individual's continual exposure to a specified concentration of carcinogen over a period of 70 years. Established EPA methodology for determining cancer potency values assumes that any degree of exposure to a carcinogen produces a measurable risk. The q_1^* value is expressed in terms of risk per dose and is measured in units of the inverse of milligrams of pollutant per kilogram of body weight per day of exposure $(mg/kg \bullet day)^{-1}$.

The organic pollutants in sewage sludge for which limits were proposed for land application are listed in Table 4-7. However, in the final Part 503 standards for land application, EPA deleted all of the organic pollutants. Section 6.1 of this document discusses the reasons for these deletions.

5.1.2.2.5 Level of Protection

The carcinogenic risk level for the HEI is central to EPA's risk assessment methodology. EPA has selected risk levels of between $1 \bullet 10^{-4}$ and $1 \bullet 10^{-6}$ in several regulatory applications, depending on the statute, the surrounding issues, the uncertainties, and the available data bases. In the case of sewage sludge applied to land, EPA chose as a public health goal the risk level of $1 \bullet 10^{-4}$, or the probability of 1 cancer case in 10,000 individuals. This target was selected because the aggregate risk assessment did not indicate significant carcinogenic risk from this practice (i.e., less than one case per year), even in the absence of regulation.

In determining the appropriate doses to use in the exposure assessment models for carcinogenic pollutants, EPA used the quotient of an incremental risk and the potency value, q_1^*. The incremental risk is defined as the probability that an individual will contract cancer following a lifetime of exposure to the maximum modeled long-term ambient concentration. The incremental risk cannot be construed as an absolute measure of the risk to the exposed population, because there are inherent uncertainties in determining the cancer potency for each chemical. Furthermore, that a case occurs does not indicate the severity of its outcome. Nor does an additional cancer case necessarily mean a mortality. Therefore, such estimates are best construed as relative estimates of the likelihood of cancer.

To reduce this aggregate carcinogenic risk, the Agency chose to regulate land application of sewage sludge such that each carcinogen present in the sludge does not exceed an incremental unit risk of $1 \cdot 10^{-4}$ to the HEI. The incremental risk for this practice considers only application of sewage sludge to land; it does not consider exposure from other background sources, natural or anthropogenic.

5.1.2.2.6 Relative Effectiveness of Exposure (RE)

The relative effectiveness (RE) of exposure value as used in the land application risk assessment is a unitless factor that shows the relative toxicological effectiveness of an exposure by a given route when compared with another route. In addition to route differences, RE can also reflect differences in the exposure conditions (e.g., when nickel is ingested in water, absorption has been estimated to be five times greater than when it is ingested in food). It is preferable to develop reasonable estimates of the RE values for the various exposure assessment pathways. However, it is widely recognized that the RE factor should be applied only when well-documented and well-referenced information is available on the pharmacokinetics of pollutants. Time constraints and insufficient documentation of these factors led the Agency to the conservative assumption that all of the RE factors used in the land application risk assessment for the final rule are equal to one.

5.1.2.2.7 Duration of Exposure

For all pathways, except Pathway 3, the exposure was assumed to occur for 70 years, based on the Agency-approved estimate of 70 years as the lifespan for adults. For Pathway 3, which assesses children eating sludge, a policy decision was made to use 5 years as the duration of exposure for the agricultural pathway. The reason is that children exhibit most hand-to-mouth activity for the 5 years between the ages of 1 and 6. For nonagricultural settings, such as forest lands, it is unlikely that a child younger than 4 years of age would be unattended long enough to ingest sewage sludge. The assumed duration of exposure for this practice is 2 years between the ages of 4 and 6.

5.1.2.2.8 Body Weight

As defined by EPA's Cancer Assessment Group, lifetime exposures for adults are estimated for a 70-kg (154-pound) man, which is considered the standard body weight of an adult male (U.S. EPA, 1990f). In the agricultural setting, it is assumed that a child could potentially be exposed from ages 1 to 6. In the nonagricultural setting, it is assumed that the child would be exposed from ages 4 to 6. A toddler in the agricultural setting is estimated to weigh 16 kg (35 pounds), whereas the older child in the nonagricultural setting is estimated to weigh 19 kg (42 pounds).

5.1.2.2.9 Total Background Intake (For Humans)

Total background concentrations of pollutants from sources other than sludge are derived from typical values for drinking water, air, and food for both adults and children. The Agency concluded that risk would be underestimated if data for minimally exposed individuals were used, whereas risk would be overestimated if background values for the most exposed individuals were used. Since conservative assumptions are used in determining the values for most of the variables in this risk assessment, more realistic standards for regulating the expected conditions will be produced by using average values for this parameter.

5.1.2.3 Pathway-Specific Policy Decisions

5.1.2.3.1 Fraction of the Diet Assumed to Be From Sludge-Amended Soil (Pathway 1)

EPA estimated that 2.5 percent of the HEI's vegetable, fruit, and grain diet was grown on sludge-amended fields. See Section 5.2.1.4.1.2.8 for a complete discussion of the derivation of this percent.

5.1.2.3.2 Fraction of Food Produced by Home Gardeners (Pathway 2)

In 1989, in the risk assessment for the proposed rule, the Agency used data from a USDA market-basket survey for 1965-66 to determine the fraction of vegetable and meat groups produced by home gardeners. However, as a result of scientific peer review, public comments, and the availability of more recent data, the Agency has increased the fraction of food that households produce from their gardens. Furthermore, the Agency multiplied the fraction of food from the nonmetropolitan category of the more recent 1978 USDA survey by a factor of 2.17. This factor was derived from the fraction of U.S. households (46 percent) that produce some of their own food from home gardens. (See Section 5.2.2.4.1 for a complete discussion.)

5.1.2.3.3 Soil Ingestion Rate for Children (Pathway 3)

The soil ingestion rate for children (0.2 g/day) used in the Pathway 3 risk assessment is that recommended and used by the Agency's Office of Solid Waste and Emergency Response (OSWER) (U.S. EPA, 1989d). OSWER suggests Agency-wide use of this value to protect the children at highest risk, unless there are compelling reasons to do otherwise.

5.1.2.3.4 Ingestion Rate of Soil by Animals/Fraction of Farm Treated with Sewage Sludge (Pathways 5 and 7)

The Agency determined that the fraction of farmland treated and the rate of sludge ingested are significantly less than the assumptions used (100 percent and 8 percent, respectively) in the risk assessment for the proposed rule. The fraction of sewage sludge grazing cattle ingest (adhering to plants and/or directly from the soil surface averaged over a season) is 2.5 percent (Chaney et al., 1987; Bertrand et al., 1981). These data are derived from fecal studies of cattle that were not allowed to graze on pasture during application of sewage sludge or for a 21-day period after application. However, the maximum fraction of a farm treated with sewage sludge in a given year is approximately 33 percent (based on discussions with regulatory officials in several states). Assuming that cattle are rotated among several pastures, the actual fraction of the diet that is sewage sludge (chronic lifetime model approach) will be lower than the 2.5 percent assumed.

Cattle grazing on land treated with sewage sludge compost that was applied the previous growing season ingest approximately 1.0 percent sewage sludge (Decker et al., 1980). When a weighted average is calculated from these two values of ingested sewage sludge (i.e., 0.67 x 2.5 + 0.33 x 1.0), the long-term average sewage sludge in the diet of cattle is 1.5 percent (Chaney et al., 1991a). Therefore the exposure assessment for the final rule used 33 percent as the maximum fraction of a farm's area treated with sewage sludge, and 1.5 percent as the rate at which cattle ingest sewage sludge (averaged over a season) while grazing in pastures amended 30 days before the animals enter the field.

5.1.2.3.5 Decision to Retain The Phytotoxicity Pathway (Pathway 8)

The Agency decided to continue to evaluate the phytotoxicity pathway for the final rule and to use, whenever possible, field data derived from sewage sludge. Continuing to evaluate Pathway 8 is appropriate, because including this pathway in the risk assessment protects public health and the environment to a greater extent.

5.1.2.3.6 Inhalation Rate for Adults (Pathways 11 and 13)

The model for both Pathway 11 (inhalation of sewage sludge pollutants by a tractor operator) and Pathway 13 (inhalation of volatile pollutants from sewage sludge) used the Agency-approved value of 20 cubic meters of air per hour to represent the inhalation rate for the highly exposed adult.

5.1.2.3.7 Chronic Fresh Water Criteria (Pathway 12)

The reference water concentration of sewage sludge for the surface water pathway is based on either human health criteria, adjusted for total background intake, or a chronic fresh water criteria, whichever is more limiting. The Agency based the chronic freshwater criteria on the latest Ambient Water Quality Criteria where available. Where chronic values were not available, acute values were substituted. If no criteria were available, the Lowest Observed Adverse Effect Level (LOAEL) was used.

5.1.2.3.8 Distance to Well—Surface Water Pathway (Pathway 12)

In performing the risk assessment on the effects on surface waters of applying sewage sludge to land, the Agency conservatively assumed, as a "reasonably worst-case" exposure scenario, that the HEI lives at the down-gradient edge of the land application site. Consequently, the distance from the down-gradient edge of the sewage sludge management area to a potential well is assumed to be 0 meters.

5.1.2.3.9 Reference Water Concentration for Surface Water (Pathway 12)

The reference water concentration for the surface water pathway is based either on human health criteria, adjusted for total background intake, or on chronic fresh water criteria, whichever is the more limiting. It is also assumed that the highly exposed individual ingests 2 liters of water per day, eats 0.04 kg of fish per day, and weighs 70 kg, based on Agency-approved exposure factors (U.S. EPA, 1986g; Callahan et al., 1989).

5.1.2.3.10 Width of Buffer Zone (Pathway 12)

The width of the buffer zone between the sludge management area and the nearest body of surface water is assumed to be 10 meters in the model for estimating the effects of land-applied sludge pollutants on surface waters. A buffer zone of identical width is also assumed to protect all remaining surface water within the watershed. Since this assumption is critical in calculating adequately protective criteria for this pathway, the Agency imposed this set-back distance as a required management practice in the final rule.

5.1.2.3.11 Soil Type (Pathways 12 and 14)

The type of soil in the mixing zone, in the unsaturated zones, and in the saturated zones affects the ability of the contaminant to move vertically and laterally to aquifers and wells. In general, the pollutant transfer potential of a soil is greatly affected by the type of clay present, the shrink/swell potential of that clay, and the grain size of the soil. Thus, the less the clay shrinks and swells and the smaller the grain size of the soil, the lower is the pollutant transfer potential associated with that soil. Soil types in the unsaturated zone, in order of increasing pollutant transfer potential, are: nonshrinking clay, clay loam, silty loam, loam, sandy loam, shrinking clay, sand, gravel, and thin or absent soil (U.S. EPA, 1985a). The Agency used sandy soil as a "reasonable worst-case" value, since no reasonable person would grow crops on gravel or thin/absent soil amended with sewage sludge.

5.1.2.3.12 Background Concentrations of Pollutants in Ground Water (Pathway 14)

To ensure that ground water does not exceed the maximum contaminant level (MCL), any pre-existing ground water concentrations had to be considered in addition to pollutant contributions from land-applied sewage sludge. The Agency used values for background concentrations of inorganic pollutants taken from the National Inorganic and Radionuclides Survey. Where concentrations of a given metal in a particular sample fell beneath the limit of detection, the Agency conservatively decided to use a value of one-half the detection limit to derive these averages. Since most organic contaminants have short half-lives and are less likely to be found in uncontaminated ground waters, EPA assumed their background concentrations were equal to zero.

5.1.2.3.13 Maximum Contaminant Levels (MCLs) (Pathway 14)

For all contaminants, except n-nitrosodimethylamine and DDT, the reference water concentrations for ground water were calculated by adjusting the Agency-approved MCLs for background concentrations of the contaminant expected for ground water. For n-nitrosodimethylamine and DDT, the reference water concentrations were derived from the human cancer potency at a risk level of 10^{-4} because MCLs were not available.

5.1.2.3.14 Number of Applications of Sludge (Pathway 14)

Deriving the criteria for the ground water pathway for metals requires that the number of applications of sludge be specified in order to determine the length of time required for pollutants to be depleted from the site. The Agency made a policy decision to assume that the modeled land application site receives annual applications of sludge for 20 consecutive years. The Agency thinks this is a "reasonably worst-case" value and is also consistent with the "useful life of application sites" described by the U.S. EPA in the 1983 Process Design Manual for Land Application of Municipal Sludge (U.S. EPA, 1983d).

5.1.2.3.15 One-Meter Depth to Ground Water (Pathway 14)

The model for Pathway 14, the ground water pathway, assumes that the water table under a site to which sewage sludge is land applied will not be greater than 1 meter from the treated surface. The Agency chose this value as a "reasonably worst-case" assumption, because it was unlikely that crops would be grown if the depth to ground water was less than 1 meter. Otherwise, root zones of plants would become saturated, thereby reducing crop productivity.

5.1.2.3.16 Porosity of Sludge/Soil (Pathway 14)

Porosity is the ratio of the void volume of a given mass of soil or rock to the total volume of that mass. Porosity, an important factor in calculating leaching of contaminants to ground water, is usually reported as a decimal fraction or percentage, and ranges from zero (no pore space) to one (no solids). For soil types with small particle sizes, such as clay, porosity increases to a maximum of around 0.5. Porosities of coarser media, like gravel, decrease to a minimum of around 0.3. As explained in Section 5.1.2.3.11, EPA based the assessment of the ground water and surface water pathways on sandy soil. In order to consistently use sandy soil as the soil type, the Agency used the total porosity of sand (0.4) (Todd, 1980) to represent porosity within the mixing, unsaturated, and saturated soil zones.

5.1.2.5 Policy Decisions Affecting Several Pathways

5.1.2.5.1 Food Consumption for Humans

In the proposed rule, the EPA used the highest consumption data for all age and sex groups to represent the human diet from infancy to 70 years of age. As a result of public comment and further reflection, the Agency concluded that the additive effects of these conservative assumptions yielded an unreasonably worst-case exposure model for the final rule. Hence, EPA has revised its human dietary exposure for application of sewage sludge to agricultural land and for sewage sludge sold or given away in a bag or other container. The approach used in the risk assessment for the final rule employs integrated consumption rates for both sexes over a lifetime of 70 years and derives a time-weighted value.

5.1.2.5.2 Soil Concentrations of Background Pollutants

For the exposure assessment, the Agency used the median background concentrations of agricultural soils to represent the background soil levels of inorganic sewage sludge pollutants (i.e., metals). (Half of these values came from the data base of Holmgren et al. (1993), one of the most reliable analyses of background concentrations of chemicals in soils available.) EPA recognized that choosing average values would over-estimate exposure in some cases while under-estimating in others, but concluded that this represented an appropriate choice. However, if worst-case background levels for highly contaminated soils had been used in the risk assessment, it is likely that some areas would have already approached or even exceeded the allowable cumulative limits. Basing the numeric limits on these few heavily polluted sites would have eliminated land application for many sewage sludges and violated the beneficial reuse philosophy of the Agency. This approach was considered too "worst-case" and rejected. Average values are therefore used to offset the more conservative estimates used for other variables in the model. The Agency concluded that this approach produced a more realistic rule that still protects human health and the environment.

In the case of organic pollutants in sewage sludge, most of which degrade over time and do not persist indefinitely (as is assumed for the metals), the Agency considered it sufficiently protective to assume zero concentration prior to applying sewage sludge to the land. Hence, for organic pollutants, the risk assessment for the final rule evaluates only the incremental risk from organic pollutants over background exposure. In any case, numeric criteria for all of the organic pollutants were deleted from the final Part 503 rules for reasons described in Section 6.1.

5.1.2.5.3 Depth of Incorporation/Mass of Soil

In order to model the effects of applying sewage sludge to land, the Agency had to assume a particular depth to which sewage sludge is incorporated into the soil. Incorporation is usually accomplished by disking or chisel-plowing surface-applied sewage sludge, or by directly injecting it into the soil. For most pathways of exposure, the Agency assumed that sewage sludge is mixed into the soil to a depth of 15 cm and that the dry mass of this upper layer is $2 \cdot 10^9$ g DW/ha (Naylor and Loehr, 1982; Donahue et al., 1983). Exceptions to this assumption, however, were made for Pathways 3, 5, and 7. For Pathway 3 (the child eating sludge), EPA recognized that homeowners who fertilize their lawns with sewage sludge are unlikely to incorporate these products into an already established cover, thereby destroying their lawns. Instead they would probably spread it on top of the grass, and children would ingest it in an undiluted form. Likewise, for Pathways 5 and 7, EPA recognized that animals grazing on land to which sewage sludge has been applied would also ingest undiluted sludge adhering to roots or foliage.

5.1.2.5.4 Minimum pH Requirement

The Agency recognized that soil pH is one of the strongest influences on the capability of plants to absorb pollutants from the sewage sludge/soil mixture. Absorption of these pollutants can cause direct phytotoxic effects to the plant itself or, alternatively, the inorganic pollutants can accumulate in the plant tissues and cause adverse effects to humans or animals ingesting them. The risk assessment took into account the effects of low pH on plant uptake of metals by including a range of study conditions in evaluating both crop uptake and phytotoxicity. Therefore, the Part 503 numerical limits protect health and the environment under most of U.S. soil conditions without requiring pH control for all agricultural land practices. The result of not regulating minimum soil pH simply means that under some "unreasonably worst-case" conditions, the numeric limitations are not as protective as in the "reasonably worst-case" conditions modeled in the risk assessments for the final rule.

5.2 APPLICATION OF SEWAGE SLUDGE TO AGRICULTURAL LAND

5.2.1 Agricultural Pathway 1 (Human Toxicity from Plant Ingestion)

5.2.1.1 Description of Pathway

Sewage Sludge → Soil → Plant → Human

This pathway evaluates crops grown for human consumption on land to which sewage sludge had previously been applied. Uptake of sewage sludge pollutants is assumed to occur through the plant roots. It is assumed that direct adherence of sewage sludge or soil to crop surfaces is minimal, and that crops are washed before consumption. The relevant practices for this pathway include agricultural use in both large agribusiness farms and small truck farms.

5.2.1.2 Pollutants Evaluated

As discussed in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results* (EPA, 1985c), copper, molybdenum, and chromium were screened out. In addition, lead was not evaluated because no RfD was available (see Section 5.2.1.4.1.2.2). Further, four organics that were screened out were evaluated because data were readily available: hexachlorobutadiene, lindane, n-nitrosodimethylamine, and trichloroethylene. The evaluated pollutants are listed in Table 5.2.1-2.

5.2.1.3 Highly Exposed Individual

Pathway 1 is designed to protect consumers who eat produce grown in soil amended with sewage sludge. This HEI is assumed to reside in a region where a relatively high percentage of the available cropland receives sewage sludge applications, so that all crops in the diet could be affected. However, it is assumed that the HEI ingests a mix of crops from land on which sewage sludge is applied and from land on which sewage sludge is not applied. The percentage of crops

TABLE 5.2.1-2

POLLUTANTS EVALUATED FOR AGRICULTURAL PATHWAY 1

Inorganics	Organics
Arsenic	Aldrin/Dieldrin
Cadmium	Benzo(a)pyrene
Mercury	Chlordane
Nickel	DDD/DDE/DDT
Selenium	Heptachlor
Zinc	Hexachlorobenzene
	Hexachlorobutadiene
	Lindane
	n-Nitrosodimethylamine
	Polychlorinated biphenyls (PCBs)
	Toxaphene
	Trichloroethylene

grown on sewage sludge-amended land and ingested by the HEI is set at 2.5 percent. This assumption is discussed in detail in Section 5.2.1.4.1.2.8. The assumed duration of exposure is 70 years.

5.2.1.4 Algorithm Development

For pathways in which humans are the target organism, the endpoint of the analysis is a reference application rate of pollutant, RP (kg-pollutant/ha), which is the amount of the pollutant that can be applied to a hectare of agricultural land without adverse effects. The RP is either a cumulative application rate, RP_c, or an annual application rate, RP_a. RP_c is the total amount of pollutant that can be applied to a hectare; it is used for pollutants that are assumed not to degrade in the environment (i.e., inorganics, aldrin/dieldrin, and chlordane). RP_a is appropriate for organic compounds that do degrade in the environment (e.g., lindane, trichloroethylene), because it allows for degradation effects to be incorporated into the analysis. To evaluate the potential for adverse effects, an adjusted reference intake of pollutants for humans (RIA μg-pollutant/day) was calculated; it is a health-based number that indicates how much of the pollutant can be ingested by a person with minimal risk of adverse effects. If the RIA were to be exceeded, adverse health effects might occur in the exposed individuals. The RIA is termed "adjusted," because it is a health-based reference intake value that has been adjusted from a per weight basis to a particular human body weight, and from which exposure to other sources has been subtracted. The resultant number is the allowable intake over and above background per person.

The procedure for determining RIA varies according to whether the pollutant acts by a threshold or nonthreshold mechanism of toxicity. For reasons explained in Section 5.2.1.4.1.2.2, inorganic compounds were treated as having a threshold mechanism of toxicity, while organic compounds were evaluated as carcinogens having no threshold of toxicity. The equations and descriptions of the variables in the equations used to derive the RIA are presented separately for inorganics and organics.

5.2.1.4.1 Inorganics

5.2.1.4.1.1 Equations

RIA is calculated from:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI \right) \cdot 10^3 \quad (1)$$

where:

RIA	=	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

Then, RP_c is calculated from:

$$RP_c = \frac{RIA}{\Sigma(UC_i \cdot DC_i \cdot FC_i)} \quad (2)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(kg-pollutant DW/ha)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

5.2.1.4.1.2 Input Parameters

5.2.1.4.1.2.1 Adjusted Reference Intake

The values used to calculate RIAs are designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk. The definition and derivation of each of the parameters used to estimate RIA for threshold-acting toxicants are further discussed in the following sections.

5.2.1.4.1.2.2 Oral Reference Dose, RfD

When toxicant exposure is by ingestion, the threshold assumption has traditionally been used to establish an "acceptable daily intake," or ADI. The Food and Agricultural Organization and the World Health Organization have defined ADI as "the daily intake of a chemical which, during an entire lifetime, appears to be without appreciable risk on the basis of all the known facts at the time. It is expressed in milligrams of the chemical per kilogram of body weight (mg/kg)" (Lu, 1983). Procedures for estimating the ADI from various types of toxicological data were outlined by the U.S. EPA in 1980 (*Federal Register*, 1980a). The Agency has since adopted the term, "oral reference dose," or RfD, to avoid the connotation of acceptability.

Values of RfD for noncarcinogenic or systemic toxicity have been derived by several groups within the Agency. These values were developed by EPA and are found in EPA's Integrated Risk Information System (IRIS), which is accessible through the National Library of Medicine. IRIS contains RfDs for over 300 chemicals (U.S. EPA, 1992h). For Pathway 1, the applicable RfDs from IRIS and the health effects they protect against are shown in Table 5.2.1-3. For zinc, the Recommended Dietary Allowance (RDA) was used instead of the RfD, because the RfD does not provide the recommended dietary allowance of zinc, which is required to maintain health in the exposed population.

TABLE 5.2.1-3

RfDS AND RDAS

Pollutant	RfD (mg/kg•day)	Route of Exposure (animal)	Most Sensitive Endpoint
Arsenic	0.0008	oral (human)	Hyperpigmentation, keratosis, and possible vascular complications
Cadmium	0.001	oral (human)	Proteinuria
Mercury (inorganic)	0.0003	oral (rat)	Autoimmune effects
Nickel	0.02	oral (rat)	Decreased body and organ weights
Selenium	0.005	oral (rat)	Selenosis (hair, nail loss, etc.)
Zinc	0.21[a]	oral (human)	Decrease in erythrocyte superoxide dismutase (ESOD)

[a]The RfD did not meet the minimum recommended dietary allowance (RDA). Therefore, in lieu of the RfD, the RDA was used: the RDA of 15 mg/day for adults (NAS, 1989, p.209) was divided by 70 kg (body weight) to yield 0.21 mg/kg•day.

The RfD for inorganic arsenic for this pathway was 0.0008 mg/kg•day, based on hyperpigmentation, keratosis, and possible vascular complications following oral exposure to humans. The Agency's approved RfD is currently 0.0003 mg/kg•day. However, there was not a clear consensus among Agency scientists on the oral RfD. Strong scientific arguments can be made for various values, within a factor of 2 or 3 of the currently recommended RfD value (i.e., 0.0001 to 0.0008 mg/kg•day). Utilizing the flexibility offered by this range, EPA elected to use the least conservative value, 0.0008 mg/kg•day, as the most appropriate value to use in the risk assessment, because most of the model inputs, as well as the low probability of continuous exposure from this source as compared to other sources such as drinking water, are conservative.

When an RfD was not available in IRIS, the pending value was used, if available, or, if one had been previously used but had been withdrawn, the former approved value was used.

Where pollutants had both carcinogenic and noncarcinogenic effects, the carcinogenic effect was used as the most sensitive endpoint, unless the cancer was associated with a route of exposure other than ingestion of food, because Pathway 1 evaluates effects related to ingestion of food. Some inorganic compounds have carcinogenic effects noted in IRIS, but all were based on routes of exposure other than ingesting food. For example, lung cancer is associated with inhaling arsenic, and skin cancer is associated with drinking water contaminated with arsenic, but no cancer is related to ingestion of arsenic in food. Therefore, arsenic is treated as a noncarcinogen for this risk assessment. Because all the cancer effects associated with inorganic compounds were due to routes of exposure other than food ingestion, inorganic compounds were assessed as noncarcinogens. All organic compounds were assessed as carcinogens as discussed further in Section 5.2.1.4.2.2.5.

5.2.1.4.1.2.3 Human Body Weight, BW

The choice of human body weight, BW (kg), for use in risk assessment depends on the definition of the individual at risk, which, in turn, depends on exposure and susceptibility to adverse effects. Since the RfD is defined as the dose of pollutant per unit of body weight that can be tolerated over a lifetime, an adult body weight of 70 kg was used.

5.2.1.4.1.2.4 Relative Effectiveness of Ingestion Exposure, RE

Relative effectiveness of ingestion exposure (RE) is a unitless factor that accounts for the differences in the toxicological effectiveness of the source. These differences include bioavailability associated with the exposure medium (water versus food), as well as differences in absorption caused by differences in the route of exposure (inhalation versus ingestion). Differences in absorption between the routes of inhalation and ingestion can significantly influence: the quantity of a chemical that reaches a particular target tissue; the length of time it takes to get there; and the degree and duration of the effect. For example, carbon tetrachloride and chloroform were estimated to be 40 percent and 65 percent as effective, respectively, by inhalation as by ingestion, based on absorption differences (U.S. EPA, 1984i,j).

In addition to route differences, RE can also reflect differences in bioavailability associated with the exposure matrix. For example, absorption of nickel ingested in water has been estimated to be five times that of nickel ingested in diet (U.S. EPA, 1985e). RE also reflects changes in chemical specification in the food and changes in absorption caused by the simultaneous presence of other chemicals.

An RE factor should be applied only where well-documented/referenced information is available on the pollutant's observed relative effectiveness, or its pharmacokinetics. Since limited information exists for the pollutants and exposure pathways evaluated in this risk assessment, RE was conservatively set to 1 for all pollutants for all pathways in this risk assessment.

5.2.1.4.1.2.5 Total Background Intake Rate of Pollutant from All Other Sources of Exposure, TBI

Humans are exposed to pollutants found in sewage sludge (e.g., cadmium, volatile organic compounds), even if no sewage sludge is applied to agricultural land. These sources include background levels (natural and/or anthropogenic) in drinking water, food, and air.

The total background intake (TBI) rate of pollutant from all other sources of exposure should be a summed total of all toxicologically effective intakes from all exposures not related to sewage sludge. To determine the effective TBI, the background intake of pollutant from a given exposure route, BI, must be divided by the relative effectiveness of ingestion exposure (RE) for that route. Thus, the TBI can be derived after all the background exposures have been determined using the following equation:

$$TBI\ (mg/day) = \frac{BI\ (food)}{RE\ (food)} + \frac{BI\ (water)}{RE\ (water)} + \frac{BI\ (air)}{RE\ (air)} + \frac{BI\ (n)}{RE\ (n)} \quad (3)$$

where:

TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
BI	=	background intake of pollutant from a given exposure route, indicated (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure by the route indicated (unitless)

When TBI is subtracted from the weight-adjusted RfD, the remainder defines the increment that can result from sewage sludge use or disposal without exceeding the threshold. The TBIs used for adults are summarized in Table 5.2.1-4.

5.2.1.4.1.2.6 Uptake of Pollutants by Plants, UC

To determine the uptake of pollutants by plants, five steps were taken: (1) the primary literature was reviewed and all relevant studies were carefully evaluated; (2) the relevant data were compiled in a data base; (3) the uptake slope for each study was determined by linear regression of concentration of pollutant in plant tissue against application rate of pollutant; (4) the plants were placed in groups (e.g., leafy vegetables, garden fruits); and (5) the uptake slope of each plant group was calculated for each pollutant using the geometric mean of the uptake slopes for relevant studies. For plant studies in which the slope was negative or zero, a conservative default slope of 0.001(μg-pollutant/g-plant tissue DW)(μg-pollutant/g- soil/DW)$^{-1}$ was used.

TABLE 5.2.1-4

TOTAL BACKGROUND INTAKE—ADULTS (mg/day)

Chemical	Air[a]	Diet[b]	Water[a]	Total
Arsenic	0.005	0.006[b,c]	0.001	0.012
Cadmium	0.00014	0.012[b]	0.004	0.01614
Mercury	0.0002	0.002[b]	0.001	0.0032
Nickel	0.001	0.162[a]	0.010	0.173
Selenium	0.001	0.104[b]	0.010	0.115
Zinc	negligible	13.0[b]	0.42	13.42

[a]Source: Contractor Reports to EPA on Occurrence and Exposure in Relation to Drinking Water Regulations.

[b]Data from Dr. M. Bolger of FDA (Personal communication to Jim Ryan, 1992). Represents exposure for food and all liquids except drinking water for the 1988 to present market basket analysis.

[c]Dietary intake was reported as 0.29 mg/day for total arsenic. Since approximately 80 percent of dietary arsenic is in the less toxic organic form, only 20 percent of the total is used to evaluate the effects of inorganic arsenic from dietary sources.

Plant Uptake of Metals

Many different kinds of studies have been conducted to determine the relationship between concentration of metal in the growth medium and plant uptake of that metal. Studies have been conducted in the field or in pots, and with different forms of metal—metal salts, metal salt-amended sludges, and nonamended sludges (Logan and Chaney, 1983; Page et al., 1987). Depending on the study design, widely divergent plant uptake has been observed. These findings relate to the differences between salts and sludge, and between growing plants in pots and growing them in the field (see also deVries, 1980).

Some studies compared the metal uptake of plants grown in pots inside and outside the greenhouse to plants grown with equal metal applications in the form of sludge in the field (deVries and Tiller, 1978; Davis, 1981a,b). When sludge was applied in the field, much lower plant uptake slopes [(plant metal concentration):(soil metal concentration)] were obtained than when the same plants were grown with the same soil outdoors in pots; plants grown indoors in pots had even higher uptake slopes. Pot studies overestimate metal phytoavailability for four reasons. First, the indoor and outside environments differ in patterns of soil temperature and water use. In the humid greenhouse, transpiration is increased, which increases metal flow to the roots by convection, and increases transfer to leaves in the transpiration stream. Second, all of the nutrients required to support the growth of the test plants in pots must be applied to a limited soil volume; this soil volume has a very high concentration of soluble salts, which increases the concentration of metals and the diffusion of metals from the soil particles to the roots. Third, when fertilizers contain NH_4-N, rhizosphere acidification in the small volume of soil in a pot can increase metal uptake. Fourth, the soil-sludge mixture in pots comprises the whole rooting medium, while in the field the sludge is mixed only into the tillage depth (usually less than 20-cm deep), and much of the plant root system is below this depth.

Perhaps the biggest source of difference in plant uptake is attributable to the form in which the metal is applied: metal salts and metals in nonsalt forms as found in sewage sludge. Although metal salts are not typically found in sewage sludge, they have been used extensively in experimental studies to measure plant uptake of metals. Studies using metal salts, however, added either to soil or a sewage sludge-soil mixture, tend to overpredict field response. In many studies in which metal salts and metal-contaminated sludge were added to the same soil, the salts caused severe phytotoxicity in crops, while yield increased in crops to which sludge alone had been applied.

Although many of these studies suffered from errors due to difference in pH between the salts and the sludge (added metal salts displace protons from the soil and lower pH), some had equal pH. For example, in the greenhouse pot study of Korcak (1986), equivalent metal salts or 224 mt/ha of sludge were added to a number of soils with widely different properties; salts caused phytotoxicity to corn on all soils, but sludge containing an equal amount of metallic pollutant caused no phytotoxicity. Plant uptake of metal salts and metal in sludge was also compared in field studies. For instance, Ham and Dowdy (1978) compared metal uptake by soybean when equivalent concentrations of metal as metal salts and metal in sludge were applied in the field, and they found much higher metal uptake from the salts. Soil properties strongly affected metal uptake on the metal salt-amended soils, but had little effect on the sludge-amended soils.

A limit to plant uptake has not been found in studies conducted with metal salts, even though plants increasingly take up metal salts as their concentration in sewage sludge is increased. Researchers have attempted to characterize the chemical aspects of sludge that make metals in sludge so much less available to plants (phytoavailable) than metal salts. Phytoavailability is directly related to the specific metal adsorption capacity—the ability to selectively adsorb heavy metals in the presence of 3-10 mM Ca^{2+}, which is present in the soil solution of most fertile soils. In sludge, this capacity increases the ability of the soil-sludge mixture to adsorb metals, thereby reducing the phytoavailability of sludge-borne metals.

The inorganic part of the sludge contributes much of the specific capacity of sludge to adsorb metals. As summarized by Corey et al. (1987), iron, aluminum, and manganese oxides in soil and sludge exhibit specific metal adsorption properties. Even though sludge organic matter is oxidized over time, if soil pH does not fall, the rate at which crops accumulate metals in soil decreases over time. This finding indicates that the adsorption sites of the inorganic components of sludge are sufficient to adsorb enough metals so that metals in sludges are, over time, less available to plants. Because the sludge chemistry controls the phytoavailability of sludge-applied metals, plant uptake approaches a plateau with increasing rates of applying sludge, rather than showing the usual linear increase with increasing rates of applying metal salts.

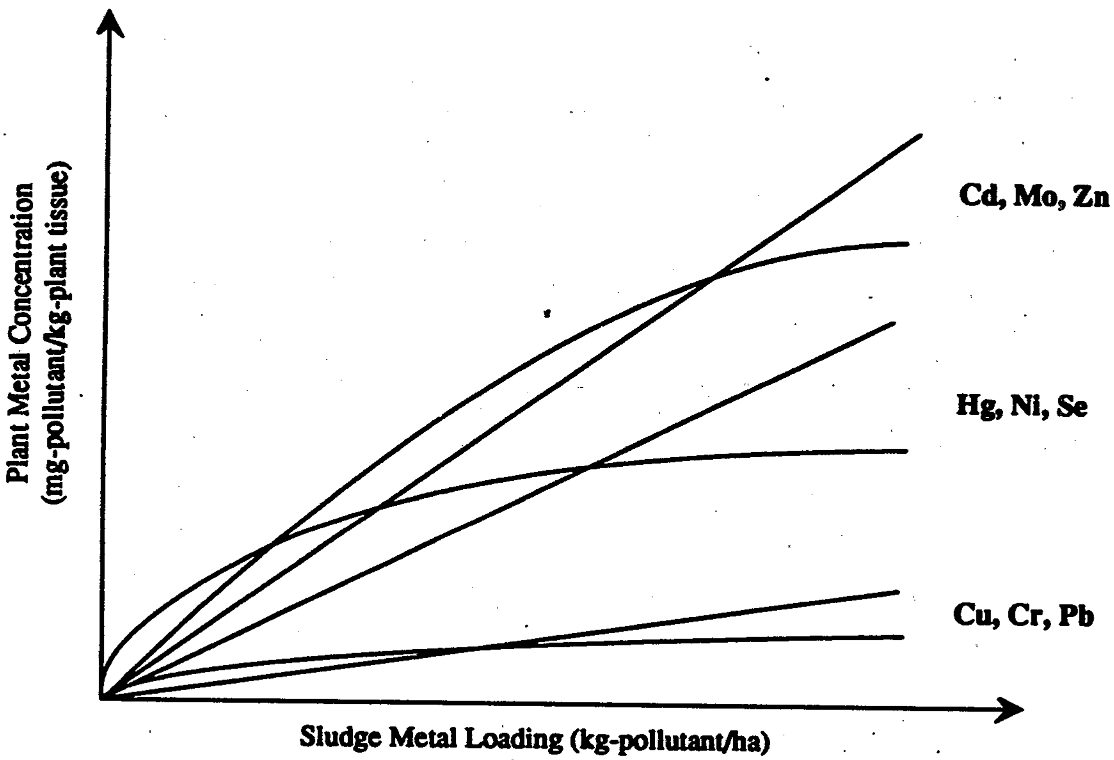
All these data from research on sludge versus metal salts, and the effect of sludge metal concentration on phytoavailability of sludge-applied metals (including the plateau response finding of Chaney et al., 1982) led Corey et al. (1987) to conclude that specific adsorption of metals by sludge surfaces would normally be the controlling factor in metal phytoavailability in soil-sludge mixtures. They also concluded that a plateau response would be the expected pattern of response, and that some sludges could be so low in metals, and so high in metal-specific adsorption capacity, that addition of sludge could actually reduce metal uptake by plants. This response has been observed for cadmium with several studies in pots and field. This model integrates data from many studies that initially appeared to offer conflicting results. Uptake by plants of sludge-applied cadmium is additive, but along a plateau response curve rather than a linear response curve.

This phenomenon has been argued to be due to competition between solids in soil and in sludge for trace metal binding, which progressively favors sludge as the sludge application rate increases. This suggests that there should be a maximum plant uptake for a trace metal in a given sludge (Corey et al., 1987; Logan, 1989). (Such behavior has not been observed with metal salts.) In some studies, particularly with copper, lead, and chromium, there was no plant uptake response to added sludge beyond that of the first sludge increment.

Based on evaluating hundreds of plant uptake studies, metals can be placed in three groups in decreasing order of uptake as follows: (1) cadmium, molybdenum, and zinc; (2) mercury, nickel, and selenium; (3) copper, chromium, and lead (Logan, 1992). In all cases, a close examination of the data shows that the rate response curves have a tendency to be curvilinear (i.e., the rate of uptake decreases with increased sludge metal loading). For copper, chromium, and lead, there appears to be an upper bound to trace metal content in the plant regardless of sludge metal loading. For the other metals, plant concentration increases over the entire range of sludge metal loading, but to levels that are lower than those predicted using a linear response model. The results are shown in Figure 5.2.1-1, which shows that when a linear

FIGURE 5.2.1-1

GENERALIZED PLANT UPTAKE RESPONSE CURVES FOR TRACE ELEMENTS IN THE 503 RULE, AND THE EFFECT OF APPLYING A LINEAR RESPONSE MODEL.



Source: Logan, 1992.

response is assumed, the plant uptake of metal from sewage sludge is underestimated at low metal loadings and overestimated at high loadings.

Elapsed Time after Sewage Sludge Application. Another factor shown to affect plant uptake of sewage sludge metals is time elapsed after sewage sludge application. In their analysis of long-term field sewage sludge studies, Chang et al. (1987b) concluded that plant availability of sludge-borne metals was highest during the first year after sewage sludge is applied.

Jing and Logan (1992b) reported on the phytoavailability of sludge-applied cadmium from many different sludges, where equal amounts of cadmium were applied in each pot. Crop uptake of cadmium increased with increasing concentration of cadmium in sludge. This is explained in terms of the filling of specific cadmium binding sites in the sludge. The population of cadmium binding sites varies widely in strength of specific cadmium adsorption; as sludge cadmium concentration increases, the least strongly bound cadmium is more phytoavailable. Over time, some of the cadmium is taken up by plants or removed through leaching or erosion. As the cadmium concentration in soil decreases, the remaining cadmium is bound to the most strongly adsorbing sites in the sludge, decreasing its availability to plants and its subsequent uptake by plants. The specific metal adsorptive capacity of sludge persists as long as the heavy metals of concern persist in the soil (Chaney and Ryan, 1992a). The persistence of metal adsorption by sewage sludge has been demonstrated in studies on field plots, some of which have been monitored for up to 20 years after the last sludge application, and studies in greenhouses evaluating soil from farms to which sewage sludge has been applied on a long-term basis.

Because plant uptake of pollutants in sewage sludge decreases as the time since the last application of sewage sludge increases, using the first-year response curve generated by a single, large addition of sewage sludge will overestimate the metal accumulation in plants grown in well-stabilized sewage sludge/soil systems. Since the risk assessment of sewage sludge disposal addresses long-term risk, data from field sewage sludge studies with long-term data (i.e., data for more than 1 year of sewage sludge application) were preferentially used when available. However, most of the field studies of sewage sludge were conducted for less than 5 years. Although these studies would be expected to show more uptake than studies of shorter duration, the data in these studies were used, since they constituted the best available information. The data used in this risk assessment, therefore, are conservative.

pH. Of all the soil variables reported to affect plant uptake of sludge-applied metals (e.g., organic matter content, cation exchange capacity, soil texture, pH), only pH consistently has a significant effect (Page et al., 1987). Sanders and coworkers found that for each sludge/metal combination, as pH was decreased, a threshold pH was reached below which metal solubility sharply increased (Sanders et al., 1986a). However, sewage sludge tends to buffer soil pH in the range of 6 to 7, except on acid soils of low-buffering capacity where sewage sludge is low in base-forming metals (e.g., calcium, magnesium); and on soils with significant free calcium carbonate, which are buffered by carbonate equilibria at pH ranges of 7 to 8. In phytotoxicity studies in sludge-containing metals, phytotoxicity has been observed when extremely low pH was reached. When high cumulative applications of sludges containing low concentrations of metals were applied, and when soil pH was allowed to drop to 4.5, phytotoxicity to soybeans (Lutrick et al., 1982) and rye (King and Morris, 1972) was observed. Correcting the soil pH to almost 6 completely halted the yield reduction.

In natural soil systems, as the pH decreases below 5.5, a rapid exponential increase in soluble aluminum and manganese occurs. This increase adversely affects plant growth in all but the most tolerant species (Pearson and Adams, 1967). Normally, good agricultural practice requires the soil pH to be greater than 5.5 to avoid natural aluminum and manganese phytotoxicity in crops. Therefore, agricultural lands to which sludge is applied will rarely, if ever, have pH below 5.5. Nevertheless, the data set on which plant uptake was based includes data from studies with pH measures as low as 4.5. Overall, 40 percent of the total data set comes from studies in which the pH was less than 6. Thus, the acid soil system is well represented within the data set. The remaining data came from studies in which the pH ranged from 6 to 8.

Cation Exchange Capacity (CEC). Although cation exchange capacity (CEC) has been used for the past 10 to 15 years as one of the primary soil properties to govern metal loadings, research on the relationship between CEC and plant uptake of metals has been minimal and the results conflicting (Sommers et al., 1987). For example, Hinesly et al. (1982) evaluated the effect of CEC on cadmium uptake by corn grown in pots. The study showed that CEC inversely affected the uptake of cadmium by corn when the cadmium was supplied as a soluble salt, but not when it was supplied as a constituent of municipal sewage sludge (Sommers et al., 1987). Korcak and Fanning (1985) confirmed these findings in greenhouse studies. Based on these and other studies, Sommers et al. (1987) recommended abandoning the practice of using CEC as a basis for establishing metal-loading limits. Consequently, the effect of CEC on metal uptake by plants has not been considered in this risk assessment.

Comparison of Data Used to Results of the National Sewage Sludge Survey

Since sewage sludge metal concentrations and/or sewage sludge loadings were not given in all of the references cited, it was not possible to determine soil metal concentrations for all studies. However, total metal loadings were given for all studies. These metal loadings were compared with the metal loadings calculated using the National Sewage Sludge Survey (NSSS) data for the median, 90th, and 95th percentiles and a sewage sludge application rate of 1,000 metric tons dry weight per hectare (mt DW/ha). The results are presented in Table 5.2.1-5; they document that the data base for plant uptake of metals covers the high-end range of the concentration distributions for cadmium, nickel, and lead documented in the NSSS.

Since only two studies in the data base (the high-rate studies at the University of California-Riverside and the University of Illinois) had application rates greater than 1,000 mt DW/ha, the high metal concentrations of the studies in the data base do not result from larger or more frequent applications of sewage sludge, but from higher metal concentrations in the sewage sludge under study. Most of the studies in the data base were conducted in the 1970s and 1980s when sewage sludge contained higher concentrations of pollutants than it does now. For example, the Chicago sewage sludge of the 1970s had a cadmium concentration of approximately 200 mg/kg, whereas in the NSSS, the 95th percentile for cadmium was 90 mg/kg. Since uptake slopes decrease with lower metal sludges versus higher metal sludges, using the data base, which contains data on high-metal sludges, will overpredict plant uptake. Thus this risk assessment conservatively estimates plant uptake of metals in sludge by including studies on sludges with high metal loadings.

TABLE 5.2.1-5

SEWAGE SLUDGE STUDY DATA POINTS

Metal	Field Sewage Sludge Study Data Points	Percentage of Data Points from Plant Uptake Studies with Metal Loadings Greater Than Values from NSSS at These Percentiles When Applied at 1,000 dmt/ha		
		Mean	90th Percentile	95th Percentile
Arsenic	4	0	0	0
Cadmium	167	35.9	35.9	18.5
Copper	127	0	0	0
Lead	52	26.9	5.8	5.8
Mercury	20	0	0	0
Nickel	125	49.9	25.6	8.8
Selenium	21	9.5	0	0
Zinc	154	7.1	0	0

Source: Logan, 1992.

Methodology for Calculating Plant Uptake Slopes

To select the input factors, the data collected for the previous EPA risk assessment for the land application of sewage sludge (U.S. EPA, 1989f) were reviewed and edited using a five-step approach. First, all references for the data base were obtained either from EPA's own archive or from other sources. All secondary references were replaced with primary references where possible. The original papers were checked against the reference citation, and the citation was changed if necessary. Next, the data in the papers were checked against the tabulated data, and changes were made as needed. Then missing or misleading information was noted with each tabular citation as needed. Fourth, corrected data were used to calculate new uptake slopes. Fifth, the corrected data base was supplemented with additional data from the literature.

The plant uptake slope was determined for each pollutant for each study used. Uptake response slopes were calculated by regressing the concentration of pollutant in plant tissue (μg-pollutant/g-plant tissue DW) against a cumulative pollutant loading rate (kg-pollutant/ha) for the various treatment levels, including the control.[*] It should be noted that, where the control application rate was zero, the tissue concentration was greater than zero because of background levels of these elements in the soil.

For this risk assessment, the sources from which the data were extracted presented the sewage sludge metal loadings in a variety of ways, making it difficult to calculate uptake slopes in a systematic manner. For example, some studies gave the sewage sludge loading rate and a metal analysis of the sewage sludge, making it necessary to calculate the metal-loading rate (kg/ha). Other studies provided soil metal concentrations, in which case the depth to which sewage sludge was incorporated had to be assumed to calculate an effective metal-loading rate. Some studies did not provide the metal concentration in the control plot (i.e., the plot on which sewage sludge was not applied). In this case, an average background level for that metal was assumed (Table 5.2.1-6). To address these differences in the data sources, the following procedures for extracting data, converting it, and calculating uptake slopes were followed:

1. Once a reference was obtained, a full reference citation was recorded and the pertinent data were extracted.

TABLE 5.2.1-6

NATIONAL BACKGROUND CONCENTRATIONS OF POLLUTANTS IN U.S. SOIL

Chemical	Number of Samples	Soil Concentration (μg/g)	References
Arsenic	16	3.0	Baxter et al., 1983[a]
Cadmium	3,325	0.2[b]	Holmgren et al., 1992
Mercury	NR[c]	0.1	US Geological Survey, 1970 (p. 1)
Nickel	3,325	18.0[b]	Holmgren et al., 1992
Selenium	NR[c]	0.21	Cappon, 1984 (p. 100)
Zinc	3,325	54.0[b]	Holmgren et al., 1992

[a]As quoted in U.S. EPA, 1989f.
[b]Median.
[c]NR = Not reported.

2. Ancillary data, such as plant type, soil pH, type of sewage sludge, and application rates, were recorded.

3. If sewage sludge loading and sewage sludge metal concentration data were given, the inorganic loading rate (kg/ha) was calculated by the formula:

   Metal load (kg/ha) =

   Sewage sludge load (mt DW/ha) • sewage sludge metal concentration (mg/kg) • 10^{-3}

4. If the metal concentration in soil was given, the metal loading rate (kg/ha) was calculated from the formula:

   Metal load (kg/ha) = soil metal concentration (mg/kg) • 2 (conversion factor)

   (The conversion factor was based on the assumption that the soil in which the sewage sludge is incorporated weighs 2,000 mt DW/ha based on an assumed average bulk density of 1.33 g/cm^3 and a soil incorporation depth of 15 cm.)

5. The plant uptake slope was calculated for each study. For studies in which one metal application rate and one plant tissue concentration were given the uptake slope is:

$$UC = \frac{\text{Tissue Concentration } (\mu\text{g-pollutant/g-plant tissue DW})}{\text{Metal Application Rate } (\mu\text{g-pollutant/g-soil DW})}$$

   For studies in which multiple application rates and tissue concentrations were given, the slope was determined by least squares linear regression.

6. Where calculated uptake slopes were negative or less than 0.001, the value of the slope was set equal to 0.001 as a conservative default.

All of the studies in the data base were placed in one of three categories:

- **Type A Studies**—Studies conducted in the field with sewage sludge.

- **Type B Studies**—All other studies conducted with sewage sludge. These include field studies with sewage sludge spiked with additional metals; and greenhouse studies in which the plants were grown in pots, not in the field (referred to in this document as pot studies).

- **Type C Studies**—All other studies. These studies are primarily those with metal salts or metal-contaminated soils, or mine tailings.

Data derived from sewage sludge applications in the field are most appropriate for use in risk assessments because they most resemble the conditions being regulated. Field data were used when available. Greenhouse studies where plants are grown in pots are often known to overpredict uptake under field conditions (Logan and Chaney, 1983). However, in the absence of field data, data from pot studies may be useful, especially those in which large pots are used to minimize restriction of root growth. Therefore, some data from pot studies were used to provide an upper bound of exposure when no other data were available. Studies where plants are grown in solution culture were not used, since no reliable method for relating concentration in solution to total soil concentration in the field or to application rate has been developed (U.S. EPA, 1989a). Similarly, studies where sewage sludge was applied over growing plants demonstrate physical adherence rather than physiological uptake through the root system, so they were not used either. Because plants take up metal salts to a greater degree than other forms of metal, and because metal salts are not found in sewage sludge, using metal salt data would greatly overpredict plant uptake of metals in sewage sludge. Therefore, metal salt data were used in this risk assessment only to evaluate plant uptake of metals in cases where no other data were available.

A summary of the types of studies used, in terms of plant group and pollutant, is presented in Table 5.2.1-7. In all but three cases, the exposure assessment was based entirely on Type A studies. Data from Type B sewage sludge pot studies were used for mercury and selenium. Type C data were used for arsenic for all food groups except leafy vegetables, for which Type A data were availabie. Although preference was given to sewage sludge studies conducted in the field with multiple rates and multiple years of application, the limited data base for most contaminants required that all Type A studies be considered, regardless of duration.

Appendix C contains all the data points, including the type of plant and the plant part (e.g., leaf, grain) studied, as well as plant uptake slopes for each study reviewed. The crops that humans consume were divided into seven categories: grains and cereals (e.g., barley, wheat); potatoes; leafy vegetables (e.g., swiss chard, rape, collard greens, lettuce, cabbage, broccoli); legumes (e.g., beans, peas); root vegetables (e.g., carrots, turnips, onions, beets, radishes); garden fruits (e.g., tomatoes, eggplant, peppers); and peanuts. (These categories correspond to those used to estimate human dietary intake in Table 5.2.1-9, discussed in the next section.) For each

TABLE 5.2.1-7

STUDY TYPES USED TO CALCULATE PLANT GROUP UPTAKE OF POLLUTANTS

Food Group	Arsenic	Cadmium	Mercury	Nickel	Selenium	Zinc
Garden fruits	C	A	A	A	A	A
Grains and cereals	C	A	B	A	A	A
Leafy vegetables	A	A	A	A	A	A
Legumes	C	A	A	A	A	A
Potatoes	C	A	B	A	B	A
Root vegetables	C	A	A	A	A	A

Note: If no data were available, a default uptake slope of 0.001 was used.

pollutant, the plant uptake slopes for the studies applicable to each plant group were averaged, using the geometric mean of the uptake slopes. The results are summarized in Table 5.2.1-8. In the case of peanuts, UC value was set equal to that of the other legumes for which data were available.

5.4.1.4.1.2.7 Daily Dietary Consumption of Food Group, DC

To quantify potential dietary exposures resulting from the land application of sewage sludge, the amounts of various types of foods consumed over a lifetime were estimated. The most detailed sources of dietary information include the U.S. Department of Agriculture (USDA) Nationwide Food Consumption Survey 1977-78 (NFCS), and the Second National Health and Nutrition Examination Survey, 1976-1980 (NHANES II). Pennington (1983) used both of these sources to calculate food consumption rates for eight age/sex groups, ranging in age from infancy to 65 years. Because Pennington's work is the most recent and the best documented evaluation of dietary intake, it was considered to be the best available information. The list provides average, fresh-weight consumption data for over 234 foods (201 adult foods and 33 infant/junior foods). Although the Pennington (1983) food list provides a very detailed picture of the human diet, it cannot be used in its published form for risk assessments of the present type, because of the food items listed are complex prepared foods (such as soup, pizza), rather than the raw commodities (such as vegetables, meats) for which contaminant uptake data are available. Therefore, to predict the impact of sewage sludge application using uptake data, the diet must be reorganized to determine the respective consumed amounts of these raw commodities that are consumed.

Two previous efforts have been made to reorganize the Pennington (1983) diet. In 1981, the U.S. EPA Office of Solid Waste (OSW) proposed an approach that grouped the 201 adult foods into the 12 dietary categories (used in the previous FDA Total Diet Study food list) to estimate the amount of cadmium in the typical U.S. diet (Flynn, 1981). However, the individual foods in the 12 categories are not broken down according to their contents (e.g., beef and vegetable stew was listed in the "meat, fish, and poultry" group). In addition, some of the listed items consist largely of added water, such as canned, reconstituted bouillon (also listed under

TABLE 5.2.1-8

UPTAKE SLOPES FOR INORGANIC POLLUTANTS BY PLANT GROUP

Plant Group	Pollutant					
	Arsenic	**Cadmium**	**Mercury**	**Nickel**	**Selenium**	**Zinc**
Grains and cereals	0.002	0.031	0.043	0.003	0.001	0.027
Potatoes	0.002	0.004	0.001	0.005	0.021	0.012
Leafy vegetables	0.018	0.182	0.005	0.016	0.008	0.125
Legumes	0.001	0.002	0.001	0.031	0.012	0.018
Root Vegetables	0.004	0.032	0.007	0.004	0.011	0.022
Garden fruits	0.001	0.045	0.005	0.003	0.010	0.023
Peanuts	0.001	0.002	0.001	0.031	0.012	0.018

TABLE 5.2.1-9

FOOD CONSUMPTION RATES FOR RAW AGRICULTURAL COMMODITIES BY AGE AND SEX

Consumption by Age and Sex								
Category	**6-11 MO.**	**2 YR.**	**14-16 F**	**14-16 M**	**25-30 F**	**25-30 M**	**60-65 F**	**60-65 M**
------g dry weight/day------								
Food Derived Directly From Plants								
Wheat	27.6020	42.2344	61.5025	97.2110	52.8166	78.5058	45.8331	64.4170
Corn	3.9986	15.3541	18.5795	27.8431	13.8710	21.7827	12.3873	17.2590
Rice	2.2249	4.5845	5.1368	6.6381	4.7765	6.7825	4.0244	4.3960
Oats	3.7298	2.6502	1.0994	2.6740	1.0900	1.5519	1.8611	2.1391
Other grain	0.0106	0.0771	0.1022	1.3660	2.8673	24.0360	0.8504	7.9668
Total grain	37.5658	64.9004	86.4205	135.7323	75.4214	132.6589	64.9562	96.1779
Potatoes	5.6673	10.0335	15.9724	22.8305	13.2108	21.3447	12.0376	17.5425
Leafy vegetables	0.8380	0.4854	1.1341	1.2970	2.1703	2.1527	2.7815	2.5232
Legumes	3.8094	4.5571	6.3902	10.5176	7.8752	11.7527	8.1826	10.8195
Roots	3.0400	0.6678	1.3125	2.1398	1.5157	2.0296	1.5110	1.7705
Garden fruits[a]	0.6650	1.6690	3.0740	3.8632	4.1004	5.4053	4.5935	5.1207
Peanuts	0.3363	2.2082	1.7821	4.0428	1.5396	3.3153	1.3398	2.4798
Mushrooms	0.0001	0.0127	0.0551	0.0320	0.1374	0.1355	0.0508	0.0705
Vegetable oil	27.6209	17.6867	30.2176	44.5719	29.7018	44.7022	23.7050	31.9650
Food Derived From Animals								
Beef	3.9890	9.6621	16.6613	26.5872	17.3708	29.1939	14.1238	22.5623
Beef liver	0.1666	0.2401	0.2766	0.4363	1.2309	0.9214	0.9639	1.4427

TABLE 5.2.1-9 (cont.)

Category	6-11 MO.	2 YR.	14-16 F	14-16 M	25-30 F	25-30 M	60-65 F	60-65 M
	Consumption by Age and Sex							
	------g dry weight/day------							
Lamb	0.1393	0.0768	0.0618	0.0439	0.3317	0.2600	0.2110	0.2134
Pork	1.3382	4.2907	7.4094	10.3101	7.0893	13.4471	7.5549	12.3284
Poultry	2.2693	3.7573	6.3271	7.7314	6.1537	9.1333	6.2793	7.4611
Fish	0.3387	1.2005	2.5395	2.6764	3.5013	4.6697	3.6293	4.1075
Egg	3.2709	6.9135	6.0974	8.9355	6.6567	10.0347	7.1952	11.4666
Dairy	40.6970	32.9356	34.0111	53.0223	22.5046	32.5447	19.3580	25.4705
Beef fat	2.4448	6.4794	12.5395	19.8966	13.8234	26.9786	10.7518	17.3979
Beef liver fat	0.0455	0.0656	0.0756	0.1193	0.3364	0.2518	0.2634	0.3943
Lamb fat	0.1443	0.0795	0.0640	0.0455	0.3435	0.2693	0.2185	0.2210
Dairy fat	38.9867	16.4844	18.7030	30.1483	15.1627	22.7856	12.2980	16.7264
Pork fat	2.0059	8.1900	10.2186	15.2742	9.7095	19.2524	9.9596	16.1116
Poultry fat	1.0957	0.8319	1.2237	1.5970	1.2416	1.8352	1.2157	1.3982
Other	78.8062	67.7638	85.1162	127.2669	80.8883	105.5348	78.6520	94.0083

[a]Garden fruits refers to the vegetables we eat that are fruits (botanically speaking), such as tomatoes, peppers, and cucumbers. It does not refer to apples, blueberries, etc.

Source: U.S. EPA, 1989a.

"meat, fish, and poultry"). Therefore, the resulting consumption values for each food still did not reflect the raw commodities.

A second approach was presented in the draft Air Quality Criteria Document for Lead (U.S. EPA, 1984a). Here, many of the individual foods from the Pennington (1983) diet were fractionally apportioned into different food groups. For example, the food item "pancakes" was apportioned as follows: 60 percent food crops, 10 percent dairy, and 30 percent meat, representing the contribution from grains and milk and eggs, respectively. However, the number of food groups employed was too few for use with the present methodology; that is, all crops were lumped into a single category. In addition, the apportionments were made not on the basis of weight of each ingredient as desired for this analysis, but on the basis of the amount of lead in each ingredient.

Therefore, a new analysis of the Pennington (1983) diet was required for this methodology. EPA converted the list into amounts of unprocessed commodities consumed (U.S. EPA, 1989a). The percentages of dry matter and fat for each component were also listed. These components were then aggregated into the specific commodity groups required for this methodology. A summary of consumption for each category by each age/sex group is presented in Table 5.2.1-9. Two categories listed in Table 5.2.1-9 were later dropped—vegetable oil and mushrooms. Vegetable oil was excluded, because it is the Agency's understanding that neither the organic or inorganic pollutants from sewage sludge would remain after commercial processing. Mushrooms were not evaluated because they constitute a negligible portion of the human diet.

Table 5.2.1-9 presents food consumption for the eight age/sex groups that constitute a subset of the total population. To develop an estimate of food consumption for the population as a whole, the dietary consumption rates in Table 5.2.1-9 of males and females for each age group (i.e., 14 to 16 years, 25 to 30 years, and 60 to 65 years) were averaged. Since the data in Table 5.2.1-9 did not cover all possible ages from infancy to 70 years, the age categories were enlarged. To do this, the intake data for infants 6 to 11 months old in Table 5.2.1-9 were used to represent all infants less than 1 year old in Table 5.2.1-10; the data for 2-year-olds in Table 5.2.1-9 were used to represent the intake of 1- to 5-year-olds in Table 5.2.1-10; the intake data

TABLE 5.2.1-10

DIETARY INTAKE OF FOODS FOR DIFFERENT AGE GROUPS AND ESTIMATED LIFETIME AVERAGE DAILY FOOD INTAKE FOR 70 YEARS.

	AGE (yrs.)						
Category	**<1**	**1-5**	**6-13**	**14-19**	**20-44**	**45-70**	**Estimated Lifetime**
	-----g-diet DW/day-----						
	Food Derived Directly From Plants						
Wheat	27.6020	42.2344	60.7956	79.3568	65.6612	55.1251	**60.3**
Corn	3.9986	15.3541	19.2827	23.2113	17.8269	14.8232	**17.0**
Rice	2.2249	4.5845	5.2360	5.8875	5.7795	4.2102	**5.03**
Oats	3.7298	2.6502	2.2685	1.8867	1.3210	2.0001	**1.85**
Other grain	0.0106	0.0771	0.4056	0.7341	13.4516	4.4086	**6.49**
Total grain	37.5658	64.9004	87.9884	111.0764	104.0402	80.5671	**90.7**
Potato	5.6673	10.0335	14.7175	19.4015	17.2777	14.7901	**15.6**
Leafy vegetables	0.8380	0.4854	0.8505	1.2155	2.1615	2.6523	**1.97**
Legumes	3.8094	4.5571	6.5055	8.4539	9.8139	9.5011	**8.75**
Roots	3.0400	0.6678	1.1970	1.7262	1.7726	1.6408	**1.60**
Garden fruits	0.6650	1.6690	2.5688	3.4686	4.7529	4.8571	**4.15**
Peanuts	0.3363	2.2082	2.5603	2.9125	2.4274	1.9098	**2.25**
Mushrooms	0.0001	0.0127	0.0282	0.0436	0.1365	0.0606	**0.078**
Vegetable oil	27.6209	17.6867	27.5407	37.3947	37.2020	27.8350	**31.2**

TABLE 5.2.1-10 (cont.)

Category	AGE (yrs.) <1	1-5	6-13	14-19	20-44	45-70	Estimated Lifetime
	-----g-diet DW/day-----						
	Food Derived From Animals						
Beef	3.9890	9.6621	15.6432	21.6243	23.2823	18.3431	19.3
Beef liver	0.1666	0.2401	0.2983	0.3565	1.0762	1.2033	0.90
Lamb	0.1393	0.0768	0.0648	0.0529	0.2958	0.2122	0.20
Pork	1.3382	4.2907	6.5752	8.8598	10.2682	9.9417	9.05
Poultry	2.2693	3.7573	5.3933	7.0292	7.6435	6.8702	6.70
Fish	0.3387	1.2005	1.9042	2.6080	4.0855	3.8684	3.37
Egg	3.2709	6.9135	7.2149	7.5164	8.3457	9.3309	8.32
Dairy	40.6970	32.9356	38.2261	43.5167	27.5246	22.4142	28.9
Beef fat	2.4448	6.4794	11.3488	16.2181	20.4010	14.0748	15.5
Beef liver fat	0.0455	0.0656	0.0815	0.0974	0.2941	0.3289	0.246
Lamb fat	0.1443	0.0795	0.0671	0.0548	0.3064	0.2198	0.208
Dairy fat	38.9867	16.4844	20.4550	24.4256	18.9742	14.5122	18.1
Pork fat	2.0059	8.1900	10.4682	12.7464	14.4810	13.0356	12.7
Poultry fat	1.0957	0.8319	1.1211	1.4103	1.5384	1.3069	1.34

TABLE 5.2.1-10 (cont.)

	AGE (yrs.)						
Category	**<1**	**1-5**	**6-13**	**14-19**	**20-44**	**45-70**	**Estimated Lifetime**
	-----g-diet DW/day-----						
Other	78.8062	67.7638	86.9777	106.1915	93.2116	86.3302	**89.1**

$$\text{Estimated Lifetime Average Daily Food Intake} = \frac{<1 + 5 \bullet (1-5) + 8 \bullet (6-13) + 6 \bullet (14-19) + 25 \bullet (20-44) + 25 \bullet (45-70)}{70}$$

for ages 14 to 16 were used to represent the intake of 14- to 19-year-olds in Table 5.2.1-10; for ages 6 to 13 years, intake was arbitrarily set equal to the average of that for the 1- to 5-year-olds and the 14- to 19-year-olds in Table 5.2.1-9; the intake data for 25- to 30-year-olds in Table 5.2.1-9 were used to represent the intake of 20- to 44-year-olds in Table 5.2.1-10; and the intake data for 60- to 65-year-olds in Table 5.2.1-9 were used to represent the intake for 45- to 70-year-olds in Table 5.2.1-10. The resulting numbers were used to calculate a weighted average intake for each food group over a lifetime according to the equation shown at the bottom of Table 5.2.1-10. This weighted average is called the Estimated Lifetime Average Daily Food Intake.

5.2.1.4.1.2.8 Fraction of Food Produced on Sewage Sludge-Amended Soil, FC

The fraction of an individual's diet affected by sewage sludge is proportional to the percentage of diet produced on sewage sludge-amended land. If the sewage sludge was distributed proportionally by crop on the available land, the fraction of a food group originating from sewage sludge-amended soil could not exceed the fraction of cropland in the United States that would be needed to receive all the sewage sludge produced. This approach assumes that using typical rates of fertilization and irrigation results in yields equivalent to those resulting from sewage sludge application.

The Council for Agricultural Science and Technology (CAST, 1976) estimated that if all the sewage sludge generated in the United States was distributed evenly on cropland and crops, 0.49 to 1.98 percent of the total available cropland was required based on 1 percent and 4 percent available (inorganic) nitrogen, respectively, plus an additional 15 to 20 percent of this amount in the organic form. (Acreages were calculated on the basis of applying sewage sludge at rates that supply 100 lb of available nitrogen per acre (112 kg/ha).) If the same percentage of each food group was grown on sewage sludge-amended soil, the fraction of a food group assumed to originate from sewage sludge-amended soil would be 0.49 to 1.98 percent. If mixing were incomplete, the fraction of a particular food group grown on sewage sludge-amended soil could be much lower or much higher. Of the 48 states for which data were available, the range of cropland needed was 146 percent for Rhode Island and 0.08 percent for North Dakota (see

Table 5.2.1-11). Therefore, assuming complete mixing nationwide may not be sufficiently conservative. Since using the CAST estimate of the United States as a whole may not be sufficiently worst-case, the arithmetic mean of the estimates for the United States and New Jersey, 29 percent [(2 + 55)/2], was used to represent the percentage of food grown on agricultural land that has been treated with sewage sludge for the case in which all sewage sludge is applied to land used exclusively to grow crops for human consumption.

Not all of the sewage sludge produced, however, is applied to land. Large treatment plants (greater than 10 million gallons/day [MGD]), characteristic of large population centers, apply 16 percent of their sewage sludge to land; while small plants (less than 1 MGD), characteristic of rural areas, apply 31 percent of their sewage sludge to land (Pierce and Bailey, 1982). Although both of these percentages apply to all land (agricultural as well as other types of land), for the purposes of this risk assessment, the conservative assumption was made that these percentages applied solely to agricultural land. Pierce and Bailey (1982) used a weighted average of the small and large plants and estimated that 17 percent of all sewage sludge produced is applied to agricultural land.

The product of the percentage of human diet from crops grown on sewage sludge-amended soil if all sewage sludge is land-applied to agricultural land (29 percent), times the estimated percentage of sewage sludge that is actually land-applied (17 percent), yields a value of 0.050 (0.29 x 0.17), or 5.0 percent, as a reasonable worst-case estimate. The use of this value for all food groups may overestimate exposure, because not all sewage sludge-grown crops are used for human consumption. For example, livestock feed, export, and seed uses of grain produced in the United States exceed the amounts used directly for human food production (CAST, 1976). Therefore one-half of 5.0 percent, or 2.5 percent, was used as a reasonable estimate of the percentage of food grown for human consumption on agricultural land on which sewage sludge has been applied.

5.2.1.4.1.3 Input and Output Values

Input and output values for inorganic pollutants are presented in Table 5.2.1-12.

TABLE 5.2.1-11

ESTIMATED ANNUAL CROPLAND REQUIREMENTS FOR UTILIZATION OF THE SLUDGE IN AGRICULTURE IN THE UNITED STATES IN 1985

		Cropland Required to Accept the Sludge Having the Indicated Content of Nitrogen[b]	
		1% Available Nitrogen	4% Available Nitrogen
State	Population[a] (Millions)	Percent of Total Cropland	Percent of Total Cropland
Alabama	3.91	0.75	3.02
Arkansas	2.45	1.39	5.54
Alaska	2.18	0.19	0.75
California	23.66	2.52	10.09
Colorado	2.73	0.33	1.31
Connecticut	3.53	16.11	64.42
Delaware	0.66	0.90	3.61
Florida	9.90	4.91	19.64
Georgia	5.51	0.77	3.10
Idaho	0.72	0.11	0.46
Illinois	12.56	0.38	1.51
Indiana	6.07	0.34	1.36
Iowa	2.95	0.08	0.33
Kansas	2.25	0.07	0.28
Kentucky	3.79	0.55	2.21
Louisiana	3.84	0.72	2.87
Maine	0.98	1.60	6.39
Maryland	4.86	2.17	8.70
Massachusetts	6.56	29.93	119.72
Michigan	10.18	1.11	4.44
Minnesota	4.33	0.15	0.59

TABLE 5.2.1-11 (cont.)

		Cropland Required to Accept the Sludge Having the Indicated Content of Nitrogen[b]	
		1% Available Nitrogen	4% Available Nitrogen
State	Population[a] (Millions)	Percent of Total Cropland	Percent of Total Cropland
Mississippi	2.39	0.29	1.18
Missouri	5.25	0.27	1.09
Montana	0.67	0.05	0.20
Nebraska	1.53	0.06	0.24
Nevada	0.68	0.93	3.72
New Hampshire	0.88	5.48	21.90
New Jersey	8.49	13.83	55.34
New Mexico	1.09	0.60	2.41
New York	20.13	3.38	13.51
North Carolina	6.09	0.88	3.51
North Dakota	0.57	0.02	0.08
Ohio	12.12	0.77	3.09
Oklahoma	2.88	0.19	0.76
Oregon	2.43	0.63	2.52
Pennsylvania	13.03	1.99	7.96
Rhode Island	1.07	36.61	146.46
South Carolina	2.97	0.74	2.97
South Dakota	0.65	0.03	0.12
Tennessee	4.86	0.72	2.89
Texas	12.85	0.38	1.52
Utah	1.23	0.73	2.90
Vermont	0.50	0.59	2.36
Virginia	5.70	1.37	5.48

TABLE 5.2.1-11 (cont.)

		Cropland Required to Accept the Sludge Having the Indicated Content of Nitrogen[b]	
		1% Available Nitrogen	4% Available Nitrogen
State	Population[a] (Millions)	Percent of Total Cropland	Percent of Total Cropland
Washington	3.68	0.52	2.09
West Virginia	1.84	1.66	6.63
Wisconsin	4.87	0.36	1.46
Wyoming	0.33	0.12	0.50
USA	234.50	0.49	1.98

[a]1985 population estimates for population and cropland projects (Water Resources Council, 1972).

[b]Sewage sludge containing 1 percent or 4 percent available nitrogen (i.e., inorganic nitrogen) plus an additional 15 to 20 percent of this amount in organic form. Percentage of cropland is calculated on the basis of applying sludge at rates that supply 112 kg of available nitrogen per hectare.

Source: CAST, 1976

TABLE 5.2.1-12

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 1

Arsenic

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.002	15.5954	0.025	0.00073
Leafy vegetables	0.018	1.9672	0.025	0.00091
Legumes	0.001	8.7462	0.025	0.00024
Root vegetables	0.004	1.5950	0.025	0.00015
Garden fruits	0.001	4.1517	0.025	0.00015
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.002	90.6802	0.025	0.00430
		sum UC*DC*FC		0.00654

RfD	0.0008
BW	70
RE	1
TBI	0.012
RIA	44

RPc	6700

Cadmium

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.004	15.5954	0.025	0.00155
Leafy vegetables	0.182	1.9672	0.025	0.00895
Legumes	0.002	8.7462	0.025	0.00041
Root vegetables	0.032	1.5950	0.025	0.00129
Garden fruits	0.045	4.1517	0.025	0.00468
Peanuts	0.002	2.2538	0.025	0.00011
Grains and cereals	0.031	90.6802	0.025	0.07118
		sum UC*DC*FC		0.08817

RfD	0.001
BW	70
RE	1
TBI	0.01614
RIA	53.86

RPc	610

Mercury

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.004	1.9672	0.025	0.00022
Legumes	0.001	8.7462	0.025	0.00023
Root vegetables	0.007	1.5950	0.025	0.00028
Garden fruits	0.005	4.1517	0.025	0.00047
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.043	90.6802	0.025	0.09688
		sum UC*DC*FC		0.09854

RfD	0.0003
BW	70
RE	1
TBI	0.0032
RIA	17.8

RPc	180

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.1-12 (cont.)

Nickel

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.005	15.5954	0.025	0.00195
Leafy vegetables	0.016	1.9672	0.025	0.00078
Legumes	0.031	8.7462	0.025	0.00672
Root vegetables	0.004	1.5950	0.025	0.00015
Garden fruits	0.003	4.1517	0.025	0.00034
Peanuts	0.031	2.2538	0.025	0.00173
Grains and cereals	0.003	90.6802	0.025	0.00755
		sum UC*DC*FC		0.01922

RfD	0.02
BW	70
RE	1
TBI	0.173
RIA	1227

RPc	63000

Selenium

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.021	15.5954	0.025	0.00810
Leafy vegetables	0.008	1.9672	0.025	0.00038
Legumes	0.012	8.7462	0.025	0.00273
Root vegetables	0.011	1.5950	0.025	0.00043
Garden fruits	0.010	4.1517	0.025	0.00106
Peanuts	0.012	2.2538	0.025	0.00070
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.01567

RfD	0.005
BW	70
RE	1
TBI	0.115
RIA	235

RPc	14000

Zinc

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.012	15.5954	0.025	0.00454
Leafy vegetables	0.125	1.9672	0.025	0.00613
Legumes	0.018	8.7462	0.025	0.00387
Root vegetables	0.022	1.5950	0.025	0.00087
Garden fruits	0.023	4.1517	0.025	0.00240
Peanuts	0.018	2.2538	0.025	0.00100
Grains and cereals	0.027	90.6802	0.025	0.06064
		sum UC*DC*FC		0.07944

RfD	0.21
BW	70
RE	1
TBI	13.42
RIA	1280

RPc	16000

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.1-12 (cont.)

Notes:

Totals may not add due to rounding.

UC = uptake response slope of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)

DC = daily dietary consumption of food group (g-diet DW/day)

FC = fraction of food group produced on sewage sludge-amended soil (unitless)

RfD = oral reference dose (mg/kg-day)

BW = human body weight (kg)

RE = relative effectiveness of ingestion exposure (unitless)

TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)

RIA = adjusted reference intake of pollutant in humans (μg-pollutant/day)

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

5.2.1.4.1.4 Sample Calculations

The following calculations, using arsenic as an example, show the derivation of the risk assessment output for Agricultural Pathway 1:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3$$

$$= \left(\frac{0.0008 \cdot 70}{1} - 0.012\right) \cdot 10^3 \quad (4)$$

$$= 44 \ \mu g\text{-arsenic/g} \cdot day$$

where:

RIA	=	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

Substituting the above value for RIA and the value for the $\Sigma(UC \cdot DC \cdot FC)$ as given in Table 5.2.1-12 into Equation 2, RP_c is calculated to be:

$$RP_c = \frac{RIA}{\Sigma(UC_i \cdot DC_i \cdot FC_i)}$$

$$= \frac{44}{0.00654} \quad (5)$$

$$= 6{,}700 \ kg\text{-arsenic/ha}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)

UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(kg-pollutant DW/ha)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage-sludge-amended soil (unitless)

5.2.1.4.2 Organics

5.2.1.4.2.1 Equations

The RIA is calculated from:

$$RIA = \left(\frac{RL \bullet BW}{q_1^* \bullet RE} - TBI\right) \bullet 10^3 \qquad (6)$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency (mg/kg•day)$^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

For organics, plant uptake is regressed against soil concentration; therefore the next step is to calculate RLC from:

$$RLC = \frac{RIA}{\Sigma(UC_i \bullet DC_i \bullet FC_i)} \qquad (7)$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(μg-pollutant/g-soil DW)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage-sludge-amended soil (unitless)

It should be noted that the units for UC_i in equation (7) differ from those in equation (2), because in this equation the concentration of pollutant in plant tissue is regressed against concentration of pollutant in soil, whereas in equation (2) plant tissue is regressed against the application rate of pollutants to the soil.

Finally, soil concentration RLC is converted to an annual application rate (RP_a) by considering the mass of soil (MS) and the decay series:

$$RP_a = RLC \cdot MS \cdot 10^{-9} \cdot [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1} \tag{8}$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application until equilibrium conditions are reached (yr)

The half-lives of dieldrin and chlordane indicate that these organic pollutants do not degrade. Thus, they are treated slightly differently from the other organics in that a cumulative pollutant application rate, not an annual application rate, is calculated from:

$$RP_c = RLC \cdot MS \cdot 10^{-9} \tag{9}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)

5.2.1.4.2.2 Input Parameters

5.2.1.4.2.2.1 Adjusted Reference Intake in Humans, RIA

As stated in Section 5.2.1.4.1.2.1, the values used to calculate RIAs are designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk. The definition and derivation of each of the parameters used to estimate RIA for nonthreshold-acting toxicants are further discussed in the following sections.

5.2.1.4.2.2.2 Risk Level, RL

Since by definition no "safe" level exists for exposure to nonthreshold toxicants, specification of a given risk level on which to base regulations is a matter of policy. For this risk assessment, RL was set at 10^{-4}. The RIA will; therefore, be the concentration that, for lifetime exposure, is calculated to have an upper-bound cancer risk of one case in 10,000 individuals exposed. This risk level refers to excess cancer risk that is over and above the background cancer risk in unexposed individuals.

5.2.1.4.2.2.3 Body Weight, BW

An adult body weight of 70 kg was used, as explained in Section 5.2.1.4.1.2.3.

5.2.1.4.2.2.4 Total Background Intake Rate of Pollutant, TBI

Because there is no available data, the TBI values for inorganics are assumed to be negligible.

5.2.1.4.2.2.5 Human Cancer Potency, q_1^*

The cancer potency value (q_1^*) represents the relationship between a specified carcinogenic dose and its associated degree of risk. The q_1^* is based on continual exposure of an individual to a specified concentration over a period of 70 years. Established EPA methodology for determining cancer potency values assumes that any degree of exposure to a carcinogen produces a measurable risk. The q_1^* value is the cancer risk (the proportion affected) per unit of dose; it is expressed in terms of risk per dose and is measured in units of milligrams of pollutant per kilogram of body weight per day of exposure $(mg/kg \cdot day)^{-1}$. The q_1^*s were taken from IRIS. When a q_1^* was not available in IRIS, the pending value was used, if applicable, or, if one had been previously approved but had been withdrawn, the former approved number was used. For aldrin/dieldrin, the q_1^* for dieldrin was used, and for DDE/DDD/DDT, the q_1^* for DDT was used. See Table 5.2.1-13 for a summary of the q_1^*s used in this risk assessment.

5.2.1.4.2.2.6 Relative Effectiveness of Ingestion Exposure, RE

As stated previously, an RE factor should be applied only where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the carcinogens, RE was set equal to 1.

5.2.1.4.2.2.7 Reference Concentration of Pollutant in Soil, RLC

Since plant uptake is assumed to be in direct proportion to the concentration of pollutant in soil, the allowable concentration of pollutant is given as the reference concentration of pollutant in soil.

TABLE 5.2.1-13

ORAL UPTAKE SLOPES FOR CARCINOGENS (mg/kg•day)

Pollutant	Oral Uptake Slope (q_1^*) (mg/kg•day)
Aldrin/Dieldrin	16 (based on dieldrin)[a]
Benzo(a)pyrene	7.3
Chlordane	1.3
DDT/DDE/DDD	0.34 (based on DDT)[b]
Heptachlor	4.5
Hexachlorobenzene	1.6
Hexachlorobutadiene	0.078
Lindane	1.33[c]
n-Nitrosodimethylamine	51
Polychlorinated biphenyls (PCBs)	7.7
Toxaphene	1.1
Trichloroethylene	0.011[d]

[a] The q_1^* for aldrin is 17, but aldrin is rarely found in sludges, so the q_1^* for dieldrin was used.
[b] The q_1^*s for DDD and DDE are .24 and .34, respectively.
[c] Pending.
[d] Withdrawn by EPA 7/1/92.

5.2.1.4.2.2.8 Uptake Response Slope of Pollutants in Plant Tissue for the Food Group, UC

Because very little data were available on the uptake of organic compounds by plants, the response slopes could not be calculated. They were therefore conservatively set to a default slope of 0.001.

5.2.1.4.2.2.9 Daily Dietary Consumption of the Food Group, DC

The daily dietary consumption of each food group is the same as that presented for the inorganic compounds in Section 5.2.1.4.1.2.7.

5.2.1.4.2.2.10 Fraction of Food Group Produced on Sewage Sludge-Amended Soil, FC

The fraction of each food group produced on sewage sludge-amended soil is the same for organic compounds as for inorganic compounds—2.5 percent. See Section 5.2.1.4.1.2.8 for a discussion of the derivation of this value.

5.2.1.4.2.2.11 Reference Annual Application Rate of Pollutant, RP_a

The reference annual application rate applies to organic compounds that degrade in the environment. The amount of pollutant in sludge that can be added to a hectare each year takes this degradation into account.

5.2.1.4.2.2.12 Assumed Mass of Dry Soil in Upper 15 cm, MS

Where sewage sludge is incorporated into the upper layer of soil, incorporation is usually accomplished by disking or chisel plowing of surface-applied sludge, or by directly injecting it into the soil. An assumption typically used is that sludge is mixed into the soil to a depth of 15 cm (6 in), and that the soil has a bulk density of 1.33 g/cm^3. This is based on the average density of clay and loam found in the root zone of the crop. Therefore, the dry mass of this upper layer of soil is $2 \cdot 10^9$ g DW/ha (Naylor and Loehr, 1982; Donahue et al., 1983).

5.2.1.4.2.2.13 Decay Rate Constant, k

Organic pollutants may be subject to some or all of the following loss processes: volatilization, degradation, and leaching. Modeling of these processes is extremely complex. A simpler means for estimating loss is based on empirical data from soil systems that have been monitored over time. Such data may be used to estimate a first-order decay rate constant for pollutants. Years of application, k, is calculated as a function of the empirically derived half-life of the pollutant in soil, $T_{0.5}$(yr), from the following equation:

$$k = \frac{\ln 2}{T_{0.5}} \qquad (10)$$

where:

k	=	first-order decay rate constant (yr^{-1})
ln	=	natural logarithm
$T_{0.5}$	=	half-life of pollutant in soil (yr)

The loss rate constant (k) is used in a decay series that represents pollutant loss from the soil. This series could be expanded indefinitely. It is therefore necessary to determine how many terms, n, to use. The ideal point to stop adding more terms is when additional terms make an insignificant change in the total sum of the series (i.e. the series has converged). The half-lives used to calculate the loss rate constants are presented in Table 5.2.1-14.

Years of Application, n. The number of terms, n, required to reach convergence can be determined from:

$$n = \frac{5.6}{k} \qquad (11)$$

TABLE 5.2.1-14

AEROBIC DEGRADATION OF POLLUTANTS

Pollutant	Decay Rates (days)
Aldrin	4.77[a]
Benzo(a)pyrene	0.48[g]
Chlordane	0[h]
DDT	0.04[i]
Dieldrin	0[a,b]
Heptachlor	6.02[c]
Hexachlorobenzene	0.12[d,e]
Hexachlorobutadiene	1.41[e,f]
Lindane	1.2[h]
Nitrosodimethylamine	5.1[j]
PCBs	0.063[k]
Toxaphene	1.2[l]
Trichloroethene	0.78[m]

[a]Castro and Yoshida, 1971.
[b]Howard, 1991.
[c]U.S. EPA. Pesticide and Industrial Chemical Risk Analysis and Hazard Assessment. PIRANHA, Version 2.0.
[d]Beck and Hansen, 1974.
[e]Howard et al., 1991.
[f]Zoeteman et al., 1980 and Tabak and Barth, 1978.
[g]Coover and Sims, 1987.
[h]Ellington et al., 1988.
[i]Stewart and Chisholm, 1971.
[j]Tate and Alexander, 1975.
[k]Fries, 1982.
[l]Consensus value agreed upon by the PRC at their March 8, 1991 meeting.
[m]Dilling et al., 1975.

where:

n	=	years of application until equilibrium conditions are reached (yr)
k	=	loss rate constant (yr^{-1})

In Equation 11, it can be deduced that, if n is greater than or equal to 5.6 divided by k, the final term, $e^{(1-a)k}$, will be less than 0.01, the effect on the concentration of pollutant in soil of further applications of sewage sludge will then be zero. A more practical explanation of this is that the rate of loss of pollutant from the soil becomes very nearly equal to the rate of application, and therefore soil concentration does not increase significantly. However, for this risk assessment the decision was made to set n at 100 years for consistency; for some organics the half-life is sufficiently long that convergence occurs after 100 years, while convergence occurs before 100 years for other organics. This assumption is conservative, given that the risk for humans in all pathways in which the HEI is a human (except Pathway 3: child eating sludge) is assessed for a 70-year lifetime based on the use of the RfD and the q_1^*, both of which are based on a 70-year lifetime exposure.

5.2.1.4.2.3 Input and Output Values

Input and output values are presented in Table 5.2.1-15.

5.2.1.4.2.4 Sample Calculations

As discussed in Section 5.2.1.4.2.1, there are two approaches for calculating risk assessment outputs for organics. The first is for organics that degrade over time. The following is a sample calculation for such an organic, benzo(a)pyrene.

TABLE 5.2.1-15

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 1

Aldrin/Dieldrin

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	16
RE	1
DE	1
MS	2E+09
RIA	0.438
RLC	140.012

RPc	280

Benzo(a)pyrene

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	7.3
RE	1
DE	1
MS	2E+09
k	0.48
RIA	0.959
RLC	306.875

RPa	230

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.1-15 (cont.)

Chlordane

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	1.3
RE	1
DE	1
MS	2E+09
RIA	5.385
RLC	1723.22

RPc	3400

DDT

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	0.34
RE	1
DE	1
MS	2E+09
k	0.04
RIA	20.588
RLC	6588.789

RPa	560

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.1-15 (cont.)

Heptachlor

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	4.5
RE	1
DE	1
MS	2E+09
k	6.024
RIA	1.556
RLC	497.820

RPa	990

Hexachlorobenzene

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	1.6
RE	1
DE	1
MS	2E+09
k	0.122
RIA	4.375
RLC	1400.118

RPa	320

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.1-15 (cont.)

Hexachlorobutadiene

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	0.078
RE	1
DE	1
MS	2E+09
k	1.406
RIA	89.744
RLC	28720.361

RPa	43000

Lindane

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	1.33
RE	1
DE	1
MS	2E+09
k	1.2
RIA	5.263
RLC	1684.352

RPa	2300

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.1-15 (cont.)

n-Nitrosodimethylamine

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	51
RE	1
DE	1
MS	2E+09
k	5.1
RIA	0.137
RLC	43.925

RPa	87

PCBs

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	7.7
RE	1
DE	1
MS	2E+09
k	0.063
RIA	0.909
RLC	290.934

RPa	37

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.1-15 (cont.)

Toxaphene

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	1.1
RE	1
DE	1
MS	2E+09
k	1.2
RIA	6.364
RLC	2036.535

RPa	2800

Trichloroethylene

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.025	0.00039
Leafy vegetables	0.001	1.9672	0.025	0.00005
Legumes	0.001	8.7462	0.025	0.00022
Root vegetables	0.001	1.5950	0.025	0.00004
Garden fruits	0.001	4.1517	0.025	0.00010
Peanuts	0.001	2.2538	0.025	0.00006
Grains and cereals	0.001	90.6802	0.025	0.00227
		sum UC*DC*FC		0.00312

RL	1.00E-04
BW	70
q1*	0.011
RE	1
DE	1
MS	2E+09
k	0.78
RIA	636.364
RLC	203653.47

RPa	220000

Notes:
Totals may not add due to rounding.
UC = uptake response slope of pollutant in plant tissue (µg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
DC = daily dietary consumption of food group (g-diet DW/day)
FC = fraction of food group produced on sewage sludge-amended soil (unitless)
RL = risk level (unitless)
BW = human body weight (kg)
q1* = human cancer potency (mg/kg-day)^(-1)
RE = relative effectiveness of ingestion exposure (unitless)
DE = exposure duration adjustment (unitless)
MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)

TABLE 5.2.1-15 (cont.)

k = loss rate constant (yr)^(-1)
RIA = adjusted reference intake of pollutant in humans (μg-pollutant/day)
RLC = reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)
RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

$$RIA = \left(\frac{RL \bullet BW}{q_1^* \bullet RE} - TBI\right) \bullet 10^3$$

$$= \left(\frac{0.0001 \bullet 70}{7.3 \bullet 1}\right) \bullet 10^3 \qquad (12)$$

$$= 0.959 \ \mu g\text{-benzo(a)pyrene/day}$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(mg/kg \bullet day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

For organics, plant uptake is regressed against soil concentration; therefore, the next step is to calculate RLC from:

$$RLC = \frac{RIA}{\Sigma(UC_i \bullet DC_i \bullet FC_i)}$$

$$= \frac{0.959}{0.003} \qquad (13)$$

$$= 306.875 \ \mu g\text{-benzo(a)pyrene/g-soil DW}$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(μg-pollutant/g-soil DW)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

Next, it is necessary to incorporate into the analysis pollutant loss from the soil. A first-order loss rate constant is derived from the pollutant half-life:

$$k = \frac{\ln 2}{T_{0.5}} = \frac{\ln 2}{1.44} = 0.48\,yr^{-1} \tag{14}$$

where:

k	=	first-order decay rate constant (yr^{-1})
ln	=	natural logarithm
$T_{0.5}$	=	half-life of pollutant in soil (yr)

Finally, soil concentration RLC is converted to an annual application rate by considering mass of soil (MS) and the 100-year decay series discussed above:

$$\begin{aligned} RP_a &= RLC \cdot MS \cdot 10^{-9} \cdot [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1} \\ &= 306.875 \cdot 2 \cdot 10^{9} \cdot 10^{-9} \cdot [1 + e^{-0.48} + e^{-2 \cdot 0.48} + ... + e^{(1-100) \cdot 0.48}]^{-1} \\ &= 230\ kg\text{-}benzo(a)pyrene/ha \cdot yr \end{aligned} \tag{15}$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (µg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/µg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application until equilibrium conditions reached (yr)

The second approach is for organics that do not degrade over time. The calculations are identical to the first approach for organics, until the final calculation. The difference between the two approaches is that the output of the second approach is a cumulative pollutant application rate of the pollutant, as shown for chlordane:

$$RP_c = RLC \cdot MS \cdot 10^{-9}$$

$$= 1723.22 \cdot (2 \cdot 10^9) \cdot 10^{-9} \quad (16)$$

$$= 3{,}400 \text{ kg-chlordane/ha}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)

5.2.2 Agricultural Pathway 2 (Human Toxicity from Plant Ingestion—Home Gardener)

5.2.2.1 Description of Pathway

Sewage Sludge → Soil → Plant → Human

This pathway evaluates the case in which the soil in a home garden has been amended with sewage sludge. The major difference between Pathways 1 and 2 is the fraction of food groups produced on sewage sludge-amended soil, represented by the variable FC. In addition, peanuts and dried legumes are not included, because it is unlikely that home gardeners would grow them.

5.2.2.2 Pollutants Evaluated

Like Agricultural Pathway 1, both the inorganic and organic pollutants were evaluated. See Pathway 1 for further discussion. The pollutants evaluated for this pathway are listed in Table 5.2.2-1.

5.2.2.3 Highly Exposed Individual

The HEI for this pathway is the home gardener who grows a major portion of his or her diet in soil that has been amended with sewage sludge.

5.2.2.4 Algorithm Development

5.2.2.4.1 Inorganics

Equations

The RIA for inorganics is derived as follows:

TABLE 5.2.2-1

POLLUTANTS EVALUATED FOR AGRICULTURAL PATHWAY 2

Inorganics	Organics
Arsenic	Aldrin/Dieldrin
Cadmium	Benzo(a)pyrene
Mercury	Chlordane
Nickel	DDD/DDE/DDT
Selenium	Heptachlor
Zinc	Hexachlorobenzene
	Hexachlorobutadiene
	Lindane
	n-Nitrosodimethylamine
	Polychlorinated biphenyls (PCBs)
	Toxaphene
	Trichloroethylene

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \quad (1)$$

where:

RIA	=	adjusted reference intake of pollutants in human beings (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

Then, RP_c is calculated from:

$$RP_c = \frac{RIA}{\Sigma(UC_i \cdot DC_i \cdot FC_i)} \quad (2)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(kg-pollutant DW/ha)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

Input Parameters

Adjusted Reference Intake, RIA. The values used to calculate RIAs are designed to protect the sensitive members of the population. The definition and derivation of each of the parameters used to estimate RIA for threshold-acting toxicants are further discussed in the following sections.

Oral Reference Dose, RfD. The same RfDs were used in this pathway as in Pathway 1 (see Table 5.2.1-3). Inorganics were assessed as threshold chemicals, and the RfDs were taken from IRIS (U.S. EPA, 1992h). For zinc, the recommended dietary allowance (RDA) was used instead of the RfD, because the RfD did not meet the RDA, which is required to maintain health. (For a more detailed discussion, see Section 5.2.1.4.1.2.2 in Pathway 1.)

Human Body Weight, BW. An adult body weight of 70 kg was used (see Section 5.2.1.4.1.2.3).

Relative Effectiveness of Ingestion Exposure, RE. An RE factor should be applied only where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the pollutants, RE was set equal to 1 (see Section 5.2.1.4.1.2.4).

Total Background Intake Rate of Pollutant from All Other Sources of Exposure, TBI. Humans are exposed to pollutants found in sewage sludge (e.g., cadmium, volatile organic compounds), even if no sewage sludge is applied to agricultural land. These sources include background levels (natural and/or anthropogenic) in drinking water, food, and air. When TBI is subtracted from the weight-adjusted RfD, the remainder defines the increment that can result from use or disposal of sewage sludge without exceeding the threshold. The TBIs used for adults are summarized in Table 5.2.1-4 in Pathway 1.

Daily Dietary Consumption of Food Group, DC. The Highly Exposed Individual is the home gardener who produces and consumes grains and cereals, potatoes, leafy vegetables, fresh legumes, root vegetables, and garden fruits; these are also consumed, but not produced, by the HEI in Pathway 1. In Pathway 1, the category of legume vegetables includes dried legumes (e.g., dried beans), and fresh legumes. For Pathway 2, only fresh legumes were included, since home gardeners do not usually grow the dried legumes they consume. To determine the consumption of fresh legumes, the EPA reanalysis of the FDA Revised Total Food Diet List (U.S. EPA, 1989a) was revisited. Those food items comprised of fresh or canned legumes were retained (e.g., lima beans, immature, frozen, boiled), while food items containing dried legumes (e.g., pinto beans, boiled from dried) were not included. Peanuts were not included in the crops grown and consumed by the HEI in Pathway 2, because home gardeners do not usually grow peanuts in their gardens. Sweet corn was added as a food group for home gardeners, because so many gardeners grow corn. In Pathway 1, sweet corn is included in the category of cereals and grains; for Pathway 2, the EPA reanalysis was reviewed (U.S. EPA, 1989a) and those items pertinent to sweet corn were identified. Sweet corn consumption was subtracted from the category of cereals and grains and treated as a separate category. This is because, for Pathway 2, the percentage of sweet corn, and of grains and cereals that are homegrown, differs. The two groups cannot, therefore, be combined.

Uptake Response Slope of Pollutants in Plant Tissue for the Food Group, UC. As explained above for Pathway 2, seven plant groups were evaluated: potatoes, leafy vegetables, fresh legumes, root vegetables, garden fruits, sweet corn, and grains and cereals. The uptake slopes for these plant groups are presented, by pollutant, in Table 5.2.2-2. The slopes were derived by using the same methodology used and described in Pathway 1. (See Section 5.2.1.4.1.2.6 for a detailed discussion of the methodology used to derive uptake slopes for plant groups.)

Fraction of Food Group Produced on Sewage Sludge-Amended Soil, FC. The U.S. Department of Agriculture (USDA) periodically conducts surveys of the annual consumption of homegrown foods. In the most recent (1978) study for which data are available, the annual consumption of homegrown foods was surveyed for three population groups: nonmetropolitan, suburban, and central city (USDA, 1982). The results of the survey are shown in Table 5.2.2-3. Of the food groups in this table, only three overlap with the food groups previously identified (see Table 5.2.1-10 in Pathway 1): potatoes, fresh vegetables, and flour and cereal (similar to the grains-and-cereals category in Pathway 1).

Although the home gardener (a nonmetropolitan resident) was identified as the highly exposed individual (HEI) for this pathway, the data in Table 5.2.2-3 represent the percent of food consumed by the total population (gardeners and nongardeners). Therefore, the data probably under-represent the percentage of the gardener's diet that is homegrown. Kaitz (1978b) found that 46 percent of households in the United States produced some of their own food. It is reasonable to assume that the data in Table 5.2.2-3 adequately represent the distribution of the types of homegrown food eaten by households that produce some of their own food. As a reasonable worst-case assumption, it was assumed that 100 percent of gardeners produce some of their own food. To increase the values in Table 5.2.2-3 so that they represent the percentage of each food group that is homegrown if 100 percent, instead of 46 percent, of the diet is homegrown, the values in Table 5.2.2-3 were multiplied by the ratio of 100/46 (2.17). The results of multiplying the figures in Table 5.2.2-3 by 2.17 are:

TABLE 5.2.2-2

UPTAKE SLOPES FOR INORGANIC POLLUTANTS BY PLANT GROUP, UC (μg-pollutant/g-plant tissue DW)(kg-pollutant/ha)

Plant Group	Pollutant					
	Arsenic	Cadmium	Mercury	Nickel	Selenium	Zinc
Grains and Cereals	0.013	0.018	0.043	0.005	0.001	0.050
Potatoes	0.002	0.004	0.001	0.005	0.021	0.012
Leafy Vegetables	0.018	0.182	0.004	0.016	0.008	0.125
Fresh Legumes	0.001	0.002	0.001	0.031	0.012	0.018
Root Vegetables	0.004	0.032	0.007	0.004	0.011	0.022
Garden Fruits	0.001	0.045	0.005	0.003	0.010	0.023
Sweet Corn	0.001	0.059	0.001	0.001	0.001	0.010

TABLE 5.2.2-3

ANNUAL CONSUMPTION OF HOMEGROWN FOODS
(percent homegrown)

	Nonmetropolitan[a]	Suburban[b]	Central City[c]
Milk, cream, cheese	3.1	0.3	0
Fats, oil	0.9	0	0
Flour, cereal	0.2	0	0
Meat	9.7	2.0	0.2
Poultry, fish	10.8	5.9	1.9
Eggs	7.9	2.2	0
Sugar, sweets	2.5	1.6	0.5
Potatoes, sweet potatoes	17.2	4.6	1.5
Vegetables (fresh, canned, frozen)	27.0	13.9	5.6
Fruit (fresh, canned, frozen)	9.8	5.5	2.0
Juice (vegetable, fruit)	3.8	1.3	0.4
Dried vegetables, fruit	7.7	4.0	0

[a]Nonmetropolitan = All U.S. areas not within a standard metropolitan statistical area (SMSA).

[b]Suburban = Generally within the boundaries of a SMSA, but not within legal limits of a central city SMSA.

[c]Central City = Populations of 50,000 or more and, main or core city within a SMSA.

Source: USDA, 1982.

Food Group	Percent Homegrown	
Potatoes, sweet potatoes	37.32	(17.2 x 2.17)
Vegetables (fresh, canned, frozen)	58.59	(27.0 x 2.17)
Flour, cereal	0.43	(0.2 x 2.17)

The percentage of homegrown vegetables (58.59 percent) was used to estimate the percentage of homegrown leafy vegetables, fresh legumes, root vegetables, garden fruit, and sweet corn. The value for potatoes (37.32 percent) was used to estimate the percentage of homegrown potatoes, and the value for flour, cereal (0.43 percent) was used to estimate the percentage of homegrown grains and cereals. These values represent the food consumption of a small segment of home gardeners who are at the high end of the consumption distribution. It would be difficult for most home gardeners to grow more than 59 percent of the vegetables they consume, given that the growing season in most parts of the country is considerably shorter than the entire year in which vegetables are consumed.

Input and Output Values

Table 5.2.2-4 presents the input and output values for inorganic compounds for Agricultural Pathway 2.

Sample Calculations

The following are sample calculations for inorganic pollutants for Agricultural Pathway 2. The pollutant used as an example is arsenic.

First, RIA is calculated to be:

TABLE 5.2.2-4

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 2

Arsenic

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.002	15.5954	0.37	0.0108
Leafy vegetables	0.018	1.9672	0.59	0.0214
Fresh legumes	0.001	3.2235	0.59	0.0021
Root vegetables	0.004	1.5950	0.59	0.0035
Garden fruits	0.001	4.1517	0.59	0.0035
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.013	89.0833	0.0043	0.0050
		sum UC*DC*FC		0.0472

RfD	0.0008
BW	70
RE	1
TBI	0.012
RIA	44

RPc	930

Cadmium

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.004	15.5954	0.37	0.0230
Leafy vegetables	0.182	1.9672	0.59	0.2112
Fresh legumes	0.002	3.2235	0.59	0.0036
Root vegetables	0.032	1.5950	0.59	0.0305
Garden fruits	0.045	4.1517	0.59	0.1104
Sweet corn	0.059	1.5969	0.59	0.0552
Grains and cereals	0.018	89.0833	0.0043	0.0070
		sum UC*DC*FC		0.4408

RfD	0.001
BW	70
RE	1
TBI	0.01614
RIA	53.86

RPc	120

Mercury

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.004	1.9672	0.59	0.0052
Fresh legumes	0.001	3.2235	0.59	0.0020
Root vegetables	0.007	1.5950	0.59	0.0066
Garden fruits	0.005	4.1517	0.59	0.0112
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.043	89.0833	0.0043	0.0164
		sum UC*DC*FC		0.0481

RfD	0.0003
BW	70
RE	1
TBI	0.0032
RIA	17.8

RPc	370

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.2-4 (cont.)

Nickel

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.005	15.5954	0.37	0.0289
Leafy vegetables	0.016	1.9672	0.59	0.0183
Fresh legumes	0.031	3.2235	0.59	0.0585
Root vegetables	0.004	1.5950	0.59	0.0035
Garden fruits	0.003	4.1517	0.59	0.0081
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.005	89.0833	0.0043	0.0021
		sum UC*DC*FC		0.1203

RfD	0.02
BW	70
RE	1
TBI	0.173
RIA	1227

RPc	10000

Selenium

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.021	15.5954	0.37	0.1199
Leafy vegetables	0.008	1.9672	0.59	0.0089
Fresh legumes	0.012	3.2235	0.59	0.0238
Root vegetables	0.011	1.5950	0.59	0.0100
Garden fruits	0.010	4.1517	0.59	0.0251
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.1891

RfD	0.005
BW	70
RE	1
TBI	0.115
RIA	235

RPc	1200

Zinc

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.012	15.5954	0.37	0.0671
Leafy vegetables	0.125	1.9672	0.59	0.1448
Fresh legumes	0.018	3.2235	0.59	0.0337
Root vegetables	0.022	1.5950	0.59	0.0206
Garden fruits	0.023	4.1517	0.59	0.0566
Sweet corn	0.010	1.5969	0.59	0.0092
Grains and cereals	0.050	89.0833	0.0043	0.0190
		sum UC*DC*FC		0.3509

RfD	0.21
BW	70
RE	1
TBI	13.42
RIA	1280

RPc	3600

Notes:
Totals may not add due to rounding.
UC = uptake response slope of pollutant in plant tissue (µg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
DC = daily dietary consumption of food group (g-diet DW/day)

TABLE 5.2.2-4 (cont.)

FC = fraction of food group produced on sewage sludge-amended soil (unitless)
RfD = oral reference dose (mg/kg-day)
BW = human body weight (kg)
RE = relative effectiveness of ingestion exposure (unitless)
TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RIA = adjusted reference intake of pollutant in humans (μg-pollutant/day)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3$$

$$= \left(\frac{0.0008 \cdot 70}{1} - 0.012\right) \cdot 10^3 \qquad (3)$$

$$= 44 \ \mu g\text{-arsenic/g} \cdot day$$

where:

RIA	=	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

Substituting the above value for RIA and the value for the $\Sigma(UC \cdot DC \cdot FC)$ as given in Table 5.2.2-4 into Equation 2, RP_c is calculated to be:

$$RP_c = \frac{RIA}{\Sigma(UC_i \cdot DC_i \cdot FC_i)}$$

$$= \frac{44}{0.0472} \qquad (4)$$

$$= 930 \text{ kg-arsenic/ha (rounded down to 2 significant figures)}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(kg-pollutant DW/ha)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

5.2.2.4.2 Organics

Equations

The RIA is calculated from:

$$RIA = \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI\right) \cdot 10^3 \quad (5)$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

For organics, plant uptake is regressed against soil concentration; therefore the next step is to calculate RLC from:

$$RLC = \frac{RIA}{\Sigma(UC_i \cdot DC_i \cdot FC_i)} \quad (6)$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(μg-pollutant/g-soil DW)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

It should be noted that the units for UC_i in this equation differ from those in equation (2), because in equation (4) the concentration of pollutant in plant tissue is regressed against concentration of pollutant in soil, whereas in equation (2) plant tissue is regressed against the application rate of pollutants to the soil.

Finally, soil concentration RLC is converted to an annual application rate (RP_a) by considering the mass of soil (MS) and the decay series as shown below:

$$RP_a = RLC \cdot MS \cdot 10^{-9} \cdot [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1} \quad (7)$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)

MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application until equilibrium conditions are reached (yr)

The half-lives of dieldrin and chlordane indicate that these organic pollutants do not degrade. Thus they are treated slightly differently from the other organics in that a cumulative pollutant application rate, not an annual application rate, is calculated from:

$$RP_c = RLC \cdot MS \cdot 10^{-9} \tag{8}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)

Input Parameters

Adjusted Reference Intake in Humans, RIA. The values used to calculate RIAs are designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk. The definition and derivation of each of the parameters used to estimate RIA for nonthreshold-acting toxicants are further discussed in the following sections.

Risk Level, RL. Since by definition no "safe" level exists for exposure to nonthreshold toxicants, specification of a given risk level on which to base regulations is a matter of policy. For this risk assessment, RL was set at 10^{-4}. The RIA will, therefore, be the concentration of the pollutant that is calculated to have an upper-bound cancer risk of one case in 10,000 individuals exposed for a lifetime. This risk level refers to excess cancer risk that is over and above the background cancer risk in unexposed individuals.

Body Weight, BW. In keeping with U.S. EPA policy, an adult body weight of 70 kg was used (see Section 5.2.1.4.1.2.3).

Total Background Intake Rate of Pollutant, TBI. No TBI values are available for organic compounds; the values were assumed to be negligible.

Human Cancer Potency, q_1^*. See Table 5.2.1-13 in Pathway 1 for the q_1^*s used. A complete discussion of the q_1^*s can be found in Section 5.2.1.4.2.2.5.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should be applied only where well-documented/referenced information is available concerning the contaminant's observed relative effectiveness. Since this information was not available for any of the carcinogens, RE was set equal to 1.

Reference Concentration of Pollutant in Soil, RLC. Since plant uptake is related to the concentration of pollutant in soil, the allowable concentration of pollutant is given as the reference concentration of pollutant in soil.

Uptake Response Slope of Pollutants in Plant Tissue for the Food Group, UC. Since very little data were available on the uptake of organic compounds by plants, the response slopes could not be calculated and were therefore conservatively set at a default slope of 0.001.

Daily Dietary Consumption of the Food Group, DC. The daily dietary consumption of each food group is the same as that presented for the inorganic compounds in Section 5.2.2.4.1, Daily Dietary Consumption of Food Group, DC.

Fraction of Food Group Produced on Sewage Sludge-Amended Soil, FC. The fraction of each food group produced on sewage sludge-amended soil is the same for organic compounds as for inorganic compounds: 37 percent for potatoes, 59 percent for vegetables, and 0.43 percent for flour and cereal (see Section 5.2.2.4.1, Fraction of Food Group Produced on Sewage Sludge-Amended Soil, FC).

Reference Annual Application Rate of Pollutant, RP_a. The reference annual application rate applies to organic compounds that degrade in the environment. The amount of pollutant in sludge that can be added to a hectare each year takes this degradation into account.

Assumed Mass of Dry Soil in Upper 15 cm, MS. The assumed mass of dry soil in the upper 15 cm is $2 \cdot 10^9$ g-soil DW/ha. (See Section 5.2.1.4.2.2.12 for a complete derivation of this value.)

Decay Rate Constant, k. See Section 5.2.1.4.2.2.13 in Pathway 1 for a complete discussion of this variable. The k values are presented in Table 5.2.1-14, also in Pathway 1.

Input and Output Values

Table 5.2.2-5 presents the input and output values for organic compounds for Agricultural Pathway 2.

Sample Calculations

As discussed in Section 5.2.1.4.2.1, there are two approaches for calculating risk assessment outputs for organics. The first is used for those organics that degrade over time, as shown by the following sample calculations for organic pollutants for Agricultural Pathway 2. The pollutant used is benzo(a)pyrene.

First, RIA is calculated to be:

$$\begin{aligned} RIA &= \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI\right) \cdot 10^3 \\ &= \left(\frac{0.0001 \cdot 70}{7.3 \cdot 1}\right) \cdot 10^3 \\ &= 0.959 \ \mu g\text{-benzo(a)pyrene/day} \end{aligned} \tag{9}$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

TABLE 5.2.2-5

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 2

Aldrin/Dieldrin

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	16
RE	1
DE	1
MS	2E+09
RIA	0.438
RLC	32.291

RPc	64

Benzo(a)pyrene

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	7.3
RE	1
DE	1
MS	2E+09
k	0.48
RIA	0.959
RLC	70.775

RPa	54

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.2-5 (cont.)

Chlordane

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	1.3
RE	1
DE	1
MS	2E+09
RIA	5.385
RLC	397.430

RPc	790

DDT

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	0.34
RE	1
DE	1
MS	2E+09
k	0.04
RIA	20.588
RLC	1519.587

RPa	130

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.2-5 (cont.)

Heptachlor

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	4.5
RE	1
DE	1
MS	2E+09
k	6.024
RIA	1.556
RLC	114.813

RPa	220

Hexachlorobenzene

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	1.6
RE	1
DE	1
MS	2E+09
k	0.122
RIA	4.375
RLC	322.912

RPa	75

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.2-5 (cont.)

Hexachlorobutadiene

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	0.078
RE	1
DE	1
MS	2E+09
k	1.406
RIA	89.744
RLC	6623.840

RPa	10000

Lindane

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	1.33
RE	1
DE	1
MS	2E+09
k	1.2
RIA	5.263
RLC	388.466

RPa	540

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.2-5 (cont.)

n-Nitrosodimethylamine

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	51
RE	1
DE	1
MS	2E+09
k	5.1
RIA	0.137
RLC	10.131

RPa	20

PCBs

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	7.7
RE	1
DE	1
MS	2E+09
k	0.063
RIA	0.909
RLC	67.099

RPa	8.5

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.2-5 (cont.)

Toxaphene

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	1.1
RE	1
DE	1
MS	2E+09
k	1.2
RIA	6.364
RLC	469.690

RPa	650

Trichloroethylene

Food Group	UC	DC	FC	UC*DC*FC
Potatoes	0.001	15.5954	0.37	0.0058
Leafy vegetables	0.001	1.9672	0.59	0.0012
Fresh legumes	0.001	3.2235	0.59	0.0019
Root vegetables	0.001	1.5950	0.59	0.0009
Garden fruits	0.001	4.1517	0.59	0.0024
Sweet corn	0.001	1.5969	0.59	0.0009
Grains and cereals	0.001	89.0833	0.0043	0.0004
		sum UC*DC*FC		0.0135

RL	1.00E-04
BW	70
q1*	0.011
RE	1
DE	1
MS	2E+09
k	0.78
RIA	636.364
RLC	46969.050

RPa	51000

Notes:
Totals may not add due to rounding.
UC = uptake response slope of pollutant in plant tissue (µg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
DC = daily dietary consumption of food group (g-diet DW/day)
FC = fraction of food group produced on sewage sludge-amended soil (unitless)
RL = risk level (unitless)
BW = human body weight (kg)
q1* = human cancer potency (mg/kg-day)^(-1)
RE = relative effectiveness of ingestion exposure (unitless)
DE = exposure duration adjustment (unitless)
MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)

TABLE 5.2.2-5 (cont.)

k = loss rate constant (yr)^(-1)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
RLC = reference concentration of pollutant in soil (µg-pollutant/g-soil DW)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)
RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

Then, RLC is calculated to be:

$$RLC = \frac{RIA}{\Sigma(UC_i \cdot DC_i \cdot FC_i)}$$

$$= \frac{0.959}{0.0135} \qquad (10)$$

$$= 70.775 \ \mu g\text{-benzo(a)pyrene/g-soil DW}$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(μg-pollutant/g-soil DW)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

Next, k is calculated to be:

$$k = \frac{\ln 2}{T_{0.5}} = \frac{\ln 2}{1.44} = 0.48 yr^{-1} \qquad (11)$$

where:

k	=	first-order decay rate constant (yr^{-1})
ln	=	natural logarithm
$T_{0.5}$	=	half-life of pollutant in soil (yr)

Finally, RP_a is calculated to be:

$$RP_a = RLC \cdot MS \cdot 10^{-9} \cdot [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1}$$

$$= 70.775 \cdot 2 \cdot 10^9 \cdot 10^{-9} \cdot [1 + e^{-0.48} + e^{-2 \cdot 0.48} + ... + e^{(1-100) \cdot 0.48}]^{-1} \qquad (12)$$

$$= 54 \ kg\text{-benzo(a)pyrene/ha} \cdot yr \text{ (rounded down to 2 significant figures)}$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application until equilibrium conditions reached (yr)

The second approach is used for organics that do not degrade over time. The calculations are identical to those used in the first approach for organics, until the final calculation. The difference between the two approaches is that the output of the second approach is a reference cumulative application rate of pollutant. The following calculation, using chlordane as an example, shows only the final step in the procedure.

RP_c is calculated to be:

$$\begin{aligned} RP_c &= RLC \cdot MS \cdot 10^{-9} \\ &= 397.430 \cdot (2 \cdot 10^{9}) \cdot 10^{-9} \\ &= 790 \text{ kg-chlordane/ha (rounded down to 2 significant figures)} \end{aligned} \tag{13}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^{9}$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)

5.2.3 Agricultural Pathway 3 (Human Toxicity from Sewage Sludge Ingestion—Child)

5.2.3.1 Description of Pathway

Sewage Sludge → Human

This pathway assesses the hazard to a child of ingesting undiluted sewage sludge.

5.2.3.2 Pollutants Evaluated

Even though some of the inorganic pollutants were eliminated for this pathway in the screening procedure, outlined in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sewage Sludge: Methods and Results* (U.S. EPA, 1985c), all of the metals were re-evaluated in the risk assessment for the final rule, at the request of EPA's Office of Solid Waste, which evaluates a comparable pathway for setting action levels for hazardous wastes. In addition, all 12 organic pollutants were assessed for this pathway. Table 5.2.3-1 lists the pollutants evaluated for this pathway.

5.2.3.3 Highly Exposed Individual

The HEI is the normal child between the ages of 1 and 6 who ingests sewage sludge from storage piles or from the soil surface for a maximum of 5 years. It is assumed that the sewage sludge is not diluted with soil when exposure occurs. The HEI is not a PICA child (a PICA child exhibits excessive hand-to-mouth activity), because it is assumed that parents of PICA children will take precautions to prevent their children from eating sewage sludge. However, protection for worst-case exposure is introduced by adjusting the value derived from the Integrated Uptake/Biokinetic model (IUBK) for lead (described later in this pathway) downward to provide additional protection.

TABLE 5.2.3-1

POLLUTANTS EVALUATED FOR AGRICULTURAL PATHWAY 3

Inorganics	Organics
Arsenic	Aldrin/Dieldrin
Cadmium	Benzo(a)pyrene
Chromium	Chlordane
Copper	DDT/DDE/DDD (total)
Lead	Lindane
Mercury	Heptachlor
Molybdenum	Hexachlorobenzene
Nickel	Hexachlorobutadiene
Selenium	n-Nitrosodimethylamine
Zinc	Polychlorinated biphenyls (PCBs)
	Toxaphene
	Trichloroethylene

5.2.3.4 Algorithm Development

5.2.3.4.1 Inorganics

Equations

The RIA for inorganics is derived as follows:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \qquad (1)$$

where:

RIA	=	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

Because this pathway considers the direct ingestion of sewage sludge, the reference concentration of pollutant in sewage sludge is calculated by dividing the adjusted reference intake of pollutant in humans by the product of a soil ingestion rate and a duration-of-exposure adjustment factor:

$$RSC = \frac{RIA}{I_s \cdot DE} \qquad (2)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
I_s	=	soil ingestion rate (g-soil DW/day)
DE	=	exposure duration adjustment (unitless)

Input Parameters

Adjusted Reference Intake of Pollutants in Humans (RIA). The values used to calculate RIAs are designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk.

Oral Reference Dose, RfD. Inorganics were assessed as threshold chemicals, and the RfDs were taken from IRIS (U.S. EPA, 1992h). The RfD for trivalent chromium was used, because EPA determined that chromium in sewage sludge and soils is generally in the trivalent (not hexavalent) state. According to an EPA publication, *Application of Sewage Sludge to Cropland: Appraisal of Potential Hazards of the Heavy Metals to Plants and Animals* (U.S. EPA, 1976c), hexavalent chromium is toxic to plants, but sludges contain little, if any, hexavalent chromium, because it is reduced to the trivalent state during the process of digesting sewage sludge. In soil, hexavalent chromium remains in a soluble form for a short time, but eventually it is reduced to trivalent chromium and then changed to forms having low solubility. This conclusion is also supported by the findings of Patterson and Kodukula (1984), who determined metal distributions in activated sewage-sludge systems. Similarly, the RfDs for inorganic mercury and for inorganic arsenic were used, since the organic forms of these metals are rarely found in sludge.

The RfD for inorganic arsenic for this pathway was 0.0008 mg/kg•day, based on hyperpigmentation, keratosis, and possible vascular complications following oral exposure to humans. The Agency's approved RfD is currently 0.0003 mg/kg•day. However, there was not a clear consensus among Agency scientists on the oral RfD. Strong scientific arguments can be made for various values, within a factor of 2 or 3 of the currently recommended RfD value (i.e., 0.0001 to 0.0008 mg/kg•day). Utilizing the flexibility offered by this range, EPA elected to use the least conservative value, 0.0008 mg/kg•day, as the most appropriate value to use in the risk assessment, because most of the model inputs, as well as the low probability of continuous exposure from this source as compared to other sources such as drinking water, are conservative.

For three inorganics (zinc, copper, and lead) RfDs were not used. For zinc, the recommended dietary allowance (RDA) was used, because the RfD did not meet the RDA, which is required to maintain health. RDAs are provided separately for adults, toddlers, and other specified groups. Since this pathway evaluates toddlers, the RDA for zinc for toddlers was used (10 mg/day), then it was divided by the appropriate body weight (16 kg) to yield 0.6 mg/kg•day. For copper, the RDA was used because an Agency-approved RfD was not available. Based on a RDA for children of 2 mg/day, the adjusted RDA is 0.125 mg/kg•day (2 ÷ 16 kg = 0.125). The RfDs and RDAs are summarized in Table 5.2.3-2.

For lead, neither an RfD nor an RDA was available. Consequently, EPA's integrated uptake biokinetic (IUBK) model, designed to predict levels of lead in the blood based on total exposure, was used. The Indoor Quality and Total Human Exposure Committee of EPA's Science Advisory Board (SAB) reviewed the IUBK model and concluded that it was sound and could be effectively applied for many current needs throughout the Agency.

In the proposed TSD, the effects on children of ingesting lead-contaminated sewage sludge were evaluated by extrapolating from cattle data. For the present risk assessment, EPA's Office of Research and Development (ORD) and its Office of Water (OW) both agreed to use the IUBK model instead of extrapolating from the cattle data.

Human Body Weight, BW. This pathway assesses children 1 to 6 years old. The corresponding body weight used was 16 kg.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should be applied only where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the pollutants, RE was set equal to 1.

Total Background Intake Rate of Pollutant from All Other Sources of Exposure, TBI. The TBIs (natural and/or anthropogenic) in drinking water, food, and air for toddlers are presented in Table 5.2.3-3. TBIs were available only for seven of the inorganics (arsenic,

TABLE 5.2.3-2

RfDS AND RDAS FOR AGRICULTURAL PATHWAY 3

Pollutant	RfD (mg/kg•day)	Route of Exposure (animal)	Most Sensitive Endpoint
Arsenic (inorganic)	0.0008	oral (human)	Hyperpigmentation, keratosis, and possible vascular complications
Cadmium	0.001	oral (human)	Proteinuria
$Chromium^{3+}$	1.0	oral (rat)	No effects[a]
Copper	0.125[b]	NA	NA
Mercury (inorganic)	0.0003	oral (rat)	Autoimmune effects
Molybdenum	0.005	Not available	Not available
Nickel	0.02	oral (rat)	Decreased body, organ weights
Selenium	0.005	oral (rat)	Selenosis (hair, nail loss, etc.)
Zinc	0.625[c]	NA	NA

[a]Based on a NOAEL.

[b]No RfD available, so the recommended dietary allowance (RDA) was used. The RDA for children is 2 mg/day (NAS, 1989, p.228). 2 mg/day ÷ 16 kg (body weight of a child) = 0.125 mg/kg•day.

[c]The RfD did not meet the minimum RDA. Therefore, the RDA was used in lieu of the RfD. The RDA for children is 10 mg/day (NAS, 1989, p.209). 10 mg/day ÷ 16 kg (body weight of a child) = 0.625 mg/kg•day.

NA=Not Applicable.

TABLE 5.2.3-3

TOTAL BACKGROUND INTAKE: TODDLERS
(mg/day)

Chemical	Air[a,b]	Diet	Water[a,c]	Total
Arsenic	0.002	0.002[d,e]	0.0005	0.0045
Cadmium	0.000056	0.0061[d]	0.002	0.008156
Chromium	0.0024	0.045[a]	0.002	0.0494
Mercury	0.00008	0.0007[d]	0.0005	0.00128
Nickel	0.0004	0.150[a]	0.005	0.1554
Selenium	0.0004	0.054[d]	0.005	0.0594
Zinc	negligible	6.50[a]	0.21	6.71

[a]Sources: Contractor Reports to EPA on Occurrence and Exposure in Relation to Drinking Water Regulations.

[b]Air intakes were generally reported for adults and were converted for toddlers by a ratio of: $\frac{8\ m^3/day}{20\ m^3/day} = 0.4$

[c]Water intakes were generally reported for adults and were converted for toddlers by a ratio of: $\frac{1\ l/day}{2\ l/day} = 0.5$

[d]Data from Dr. M. Bolger of FDA. Represents exposure for food and all liquids except drinking water from 1988 to present market-basket analysis.

[e]Dietary intake for total arsenic was reported as 0.0092 mg/day for 2-year-old children. Since approximately 80 percent of dietary arsenic is in the less toxic organic form, only 20 percent of the total is used to evaluate the effects of inorganic arsenic from dietary sources.

cadmium, chromium, mercury, nickel, selenium, and zinc). See Section 5.2.1.4.1.2.5 in Pathway 1 for a complete description of TBIs.

Sewage Sludge Ingestion Rate, I_s. The soil ingestion rate used was 0.2 g-soil DW/day, based on the 1989 EPA directive from the Office of Solid Waste and Emergency Response (OSWER) recommending this value for the children at highest risk (U.S. EPA, 1989d).

Exposure Duration Adjustment, DE. EPA's Office of Research and Development (ORD) expressed concern about the suitability of using RfDs based on lifetime exposure for evaluating the effects to children of ingesting inorganic pollutants in sewage sludge/soil mixtures. Scientists from ORD and the Office of Water re-evaluated the bases for the lifetime RfDs and proposed new values based on less-than-lifetime exposures. These new numbers were then submitted to the Agency's RfD Committee for approval. The Committee was unable to reach consensus on approving the new numbers, because there is no Agency method for calculating less-than-lifetime RfDs. There are plans for continuing these efforts in the future and, if completed in time, these new less-than-lifetime RfDs will be used by OW to evaluate inorganic pollutants for this pathway in future rule making. Since no EPA-approved method was available for adjusting exposure durations associated with RfDs before promulgating the Part 503 rule, the DE was set equal to 1.

Input and Output Values

Table 5.2.3-4 presents the input and output values for inorganic pollutants for Agricultural Pathway 3.

At the March 13, 1992, meeting, a consensus was reached among OW, ORD, the Office of Pesticides and Toxic Substances (OPTS), and the Office of Solid Waste and Emergency Response (OSWER) that the IUBK model should not cause a blood lead level to exceed 10 μg/dl and should protect a high percentage of the exposed population. Using a 30-percent absorption value, and a 95th percentile of the population distribution, the model generated an allowable soil lead concentration of 500 ppm. Because Superfund action levels range from 500

TABLE 5.2.3-4

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 3

Pollutant	RfD	RDA	BW	RE	TBI	RIA	Is	DE	RSC
Arsenic	0.0008		16	1	0.0045	8.3	0.2	1	41
Cadmium	0.001		16	1	0.008156	7.844	0.2	1	39
Chromium	1		16	1	0.0494	15950.6	0.2	1	79000
Copper		0.125	16	1	0	2000	0.2	1	10000
Lead	Based on EPA policy decision								300
Mercury	0.0003		16	1	0.00128	3.52	0.2	1	17
Molybdenum	0.005		16	1	0	80	0.2	1	400
Nickel	0.02		16	1	0.1554	164.6	0.2	1	820
Selenium	0.005		16	1	0.0594	20.6	0.2	1	100
Zinc		0.625	16	1	6.71	3290	0.2	1	16000

Notes:

Totals may not add due to rounding.

RfD = oral reference dose (mg/kg-day)

RDA = Recommended Dietary Allowance (mg/kg-day)

BW = human body weight (kg)

RE = relative effectiveness of ingestion exposure (unitless)

TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)

RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)

Is = soil ingestion rate (g-soil DW/day)

DE = exposure duration adjustment (unitless)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

to 1,000 ppm, EPA concluded that allowing concentrations of lead in soil up to the action level was insufficiently protective. The group therefore made a policy decision to set the allowable lead concentration in sewage sludge at 300 ppm for this pathway.

Several reasons support this decision. First, such action would provide an additional margin of safety with respect to contamination of soil by lead and any threat to the bodies of developing children. Because childhood ingestion of dirt is so widespread, and because the potential consequences are so severe, a high order of conservatism is warranted on this point, especially in the context of regulatory decisions authorizing the addition of lead, a threshold pollutant, to the environment. In addition, a 300-ppm soil concentration yielded an allowable concentration of lead in sludge that was widely consistent with current sewage sludge quality at all but a small number of POTWs. As a result, the social cost of an additional safety factor is small relative to the potential benefit.

Coincidentally, this is the same pollutant limit calculated by the Peer Review Committee on the basis of observing that body burdens (absorption) of animals fed up to 10 percent of their diet as sewage sludge did not change until the concentration of lead in the sewage sludge exceeded 300 ppm. These data provide further support for the appropriateness of the value chosen by the Agency.

Sample Calculations

The following is a sample calculation for inorganic pollutants for Agricultural Pathway 3. The pollutant used as an example is arsenic.

First, RIA is calculated from:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \qquad (3)$$

$$RIA = \left(\frac{0.0008 \cdot 16}{1} - 0.0045\right) \cdot 10^3 \quad (4)$$

$$RIA = 8.300 \ \mu g\text{-arsenic/day} \quad (5)$$

where:

RIA	=	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

Then, RSC is calculated from:

$$RSC = \frac{RIA}{I_s \cdot DE} \quad (6)$$

$$RSC = \frac{8.300}{0.2 \cdot 1} \quad (7)$$

$$RSC = 41 \ \mu g\text{-arsenic/g-sewage sludge DW (rounded down to 2 significant figures)} \quad (8)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge(μg-pollutant/g-sewage sludge DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
I_s	=	soil ingestion rate (g-soil DW/day)
DE	=	exposure duration adjustment (unitless)

5.2.3.4.2 Organics

Equations

The RIA is calculated from:

$$RIA = \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI \right) \cdot 10^3 \qquad (9)$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight (kg)
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Because this pathway considers the direct ingestion of sewage sludge, the reference calculation of pollutant in sewage sludge is calculated by dividing the adjusted reference intake of pollutant in humans by the product of a soil ingestion rate and a duration exposure adjustment factor:

$$RSC = \frac{RIA}{I_s \cdot DE} \qquad (4)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
I_s	=	soil ingestion rate (g-soil DW/day)
DE	=	exposure duration adjustment (unitless)

Degradation of organics is not considered in this pathway, because the sludge is not mixed with soil and is subject to little degradation in the environment.

Input Parameters

Adjusted Reference Intake in Humans, RIA. The values used to calculate RIAs are designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk. The definition and derivation of each of the parameters used to estimate RIA for nonthreshold-acting toxicants are further discussed in the following sections.

Risk Level, RL. Since, by definition, no "safe" level exists for exposure to nonthreshold agents, specification of a given risk level on which to base regulations is a matter of policy. For this risk assessment, RL was set at 10^{-4}. The RIA will therefore be the concentration that, for lifetime exposure, is calculated to have an upper-bound cancer risk of one case in 10,000 individuals exposed. This risk level refers to excess cancer risk over and above the background cancer risk in unexposed individuals.

Body Weight, BW. As with inorganics, the body weight used for toddlers was 16 kg.

Total Background Intake Rate of Pollutant, TBI. No TBI values are available for organic compounds; they were assumed to be negligible.

Human Cancer Potency, q_1*. See Table 5.2.1-13 in Pathway 1 for a summary of the q_1*s used in the risk assessment for land application. Section 5.2.1.4.2.2.5 explains the derivation of the q_1*s used.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should be applied only where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the carcinogens, RE was set equal to 1.

Sewage Sludge Ingestion Rate, I_s. The soil ingestion rate used was 0.2 g-soil DW/day based on the 1989 OSWER directive suggesting this value for the children at highest risk (U.S. EPA, 1989d).

Exposure Duration Adjustment, DE. An adjustment to the RIA was required, based on the brief duration (5 years) of this exposure. Values of q_1^* are usually calculated to represent a lifetime exposure. Adjusting cancer risk estimates in terms of duration of exposure is consistent with the method in which potency estimates, q_1^*, are derived, and has been used previously by EPA. The value was derived on the basis of duration of exposure divided by assumed lifetime, or 5 years/70 years = 0.07.

Input and Output Values

Table 5.2.3-5 presents the input and output values for organic pollutants for Agricultural Pathway 3.

Sample Calculations

The following is a sample calculation for organic pollutants for Agricultural Pathway 3. The pollutant used as an example is benzo(a)pyrene.

First, RIA is calculated from:

$$RIA = \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI\right) \cdot 10^3 \quad (11)$$

$$RIA = \left(\frac{0.0001 \cdot 16}{7.3 \cdot 1} - 0.00\right) \cdot 10^3 \quad (12)$$

$$RIA = 0.219\ \mu g\text{-benzo(a)pyrene/day} \quad (13)$$

where:

TABLE 5.2.3-5

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 3

	RL	BW	q1*	RE	RIA	Is	DE	RSC
Aldrin/Dieldrin	1.00E-04	16	16	1	0.1	0.2	0.0714	7.0
Benzo(a)pyrene	1.00E-04	16	7.3	1	0.219	0.2	0.0714	15
Chlordane	1.00E-04	16	1.3	1	1.231	0.2	0.0714	86
DDT	1.00E-04	16	0.34	1	4.706	0.2	0.0714	320
Heptachlor	1.00E-04	16	4.5	1	0.356	0.2	0.0714	24
Hexachlorobenzene	1.00E-04	16	1.6	1	1	0.2	0.0714	70
Hexachlorobutadiene	1.00E-04	16	0.078	1	20.51	0.2	0.0714	1400
Lindane	1.00E-04	16	1.33	1	1.203	0.2	0.0714	84
n-Nitrosodimethylamine	1.00E-04	16	51	1	0.031	0.2	0.0714	2.1
PCBs	1.00E-04	16	7.7	1	0.208	0.2	0.0714	14
Toxaphene	1.00E-04	16	1.1	1	1.455	0.2	0.0714	100
Trichloroethylene	1.00E-04	16	0.011	1	145.5	0.2	0.0714	10000

Notes:
Totals may not add due to rounding.
RL = risk level (unitless)
BW = human body weight (kg)
q1* = human cancer potency (mg/kg-day)^(-1)
RE = relative effectiveness of ingestion exposure (unitless)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
Is = soil ingestion rate (g-soil DW/day)
DE = exposure duration adjustment (unitless)
RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight (kg)
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Then, RSC is calculated from

$$RSC = \frac{RIA}{I_s \cdot DE} \quad (14)$$

$$RSC = \frac{0.219}{0.2 \cdot 0.0714} \quad (15)$$

$$RSC = 15\ \mu g\text{-pollutant/g-sewage sludge DW (rounded down to 2 significant figures)} \quad (16)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
I_s	=	soil ingestion rate (g-soil DW/day)
DE	=	exposure duration adjustment (unitless)

5.2.4 Agricultural Pathway 4 (Human Toxicity from Animal Products Produced from Animals Fed Forages Grown on Sewage Sludge-Amended Soil)

5.2.4.1 *Pathway Description*

Sewage Sludge → Soil → Plant → Animal → Human

In this pathway, animals ingest forage and grain produced on sewage sludge-amended soil. As the data show, the plant uptake of pollutants is related to concentration of the pollutants in the soil, and the subsequent uptake of pollutants in the plants by animals is related to the concentration of the pollutants in the plants. The animals are then ingested by humans who consume beef, pork, lamb, poultry, dairy products, and eggs.

5.2.4.2 *Pollutants Evaluated*

As discussed in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results* (U.S.EPA, 1985c), several inorganic and organic pollutants were recommended for further evaluation. All of these pollutants were evaluated for this pathway. Table 5.2.4-1 presents the pollutants evaluated for Agricultural Pathway 4.

5.2.4.3 *Highly Exposed Individual*

The highly exposed individuals are from a farm household raising a substantial percentage of their own meat and other animal products. The animals consume forage grown on sewage sludge-amended soil. The HEI is assumed to consume daily quantities of the various animal tissue food groups. It is assumed that the HEI is also exposed to a background intake of pollutant.

TABLE 5.2.4-1

POLLUTANTS EVALUATED FOR AGRICULTURAL PATHWAY 4

Inorganics	Organics
Cadmium	Aldrin/Dieldrin
Mercury	Chlordane
Selenium	DDE/DDD/DDT
Zinc	Heptachlor
	Hexachlorobenzene
	Lindane
	Polychlorinated Biphenyls (PCBs)
	Toxaphene

5.2.4.4 *Algorithm Development*

5.2.4.4.1 Inorganics

5.2.4.4.1.1 *Equations*

The RIA for inorganics is derived as follows:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \qquad (1)$$

where:

RIA	=	adjusted reference intake of pollutants in human beings (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Because this pathway involves the consumption of animal products by humans, the next equation in this analysis is a reference application rate of pollutant, RF (μg-pollutant/g-diet DW) as shown below:

$$RF = \frac{RIA}{\sum (UA_i \cdot DA_i \cdot FA_i)} \qquad (2)$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in animal tissue food group i (μg-pollutant/g-animal tissue DW) (μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of animal tissue food group i (g-animal tissue DW/day)
FA_i	=	fraction of food group i assumed to be derived from animals which ingest forage grown on sewage sludge-amended soil (unitless)

For inorganics, a cumulative reference application rate of pollutant, RP (kg-pollutant/ha) is calculated:

$$RP_c = \frac{RF}{UC} \quad (3)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
UC	=	uptake response slope of pollutant in forage crop (μg-pollutant/g forage DW) $(\text{kg-pollutant/ha})^{-1}$

5.2.4.4.1.2 Input Parameters

5.2.4.4.1.2.1 Adjusted Reference Intake of Pollutants in Human Beings, RIA

The values used to calculate the RIA are designed to protect the sensitive members of the population. The definition and derivation of each of the parameters used to estimate RIA for threshold-acting toxicants are further discussed in the following sections.

5.2.4.4.1.2.2 Oral Reference Dose, RfD

Inorganics were assessed as threshold chemicals and the RfDs were taken, when available, from IRIS (U.S. EPA, 1992h). The same RfDs used in Pathway 1 for cadmium, mercury, and selenium were used for this pathway. The recommended dietary allowance (RDA) was used for zinc instead of the RfD, because the RfD was less than the RDA, which is required to maintain health (see Table 5.2.1-3). (For a more detailed discussion, see Section 5.2.1.4.1.2.2 in Pathway 1.)

5.2.4.4.1.2.3 Human Body Weight, BW

An adult body weight of 70 kg was used as explained in Section 5.2.1.4.1.2.3.

5.2.4.4.1.2.4 Relative Effectiveness of Ingestion Exposure, RE

As stated previously, an RE factor should only be applied where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the pollutants, RE was set equal to 1.

5.2.4.4.1.2.5 Total Background Intake Rate of Pollutant from All Other Sources of Exposure, TBI

Humans are exposed to pollutants found in sewage sludge (e.g., cadmium, volatile organic compounds), even if no sewage sludge is applied to agricultural land. These sources include background levels (natural and/or anthropogenic) in drinking water, food, and air. When TBI is subtracted from the weight-adjusted RfD, the remainder defines the increment that can be added from sewage sludge use or disposal without exceeding the threshold. The TBIs used for adults are presented in Table 5.2.1-4 in Pathway 1.

5.2.4.4.1.2.6 Uptake Response Slope of Pollutant in Animal Tissue Food Group, UA

Animal tissue uptake slopes relate the concentration of pollutant in animal tissue to the concentration of pollutant in animal feed. In the proposed TSD (U.S. EPA, 1989f), the data were taken from an extensive literature search in which both primary and secondary sources were reviewed and the data in them were extracted for use in calculating animal uptake slopes. For this effort, the available literature of that cited in the TSD was obtained from EPA, and the data points were checked and corrected, if necessary. (Due to time constraints, studies not available through EPA were not reviewed.) The final data set is located in Appendix D.

From these studies, uptake slopes were calculated for each animal-tissue food group listed in Agricultural Pathway 1 (i.e., beef, beef liver, pork, lamb, poultry, dairy products, eggs). Uptake slopes are calculated, generally, by taking the geometric mean of appropriate studies. To calculate the geometric mean for a food group not represented in the data, appropriate surrogate data from comparable food groups having data were used. These steps are described in detail in the following subsections.

Data Extraction

The analysis for this pathway was performed assuming that human consumption of animal tissue occurs in the major food groups listed in Table 5.2.4-2. These food groups were included in the EPA Reanalysis of the Pennington diet as explained in Section 5.2.14.1.2.7. Data were extracted only for these food groups. Fats were evaluated for organic pollutants, because organics sequester predominantly in the fatty portions of tissue. Note that for liver and eggs the whole tissue is evaluated. This is because data for these tissues were reported for the whole tissue rather than the fatty portion.

The following information was recorded for each study:

- Species
- Number of animals studied
- Part of animal from which tissue samples were analyzed
- Number of tissue samples analyzed
- Form of chemical in animal feed
- Either concentration of pollutant in feed, or quantity of pollutant and feed consumed each day (from which feed concentration was calculated)
- Whether the above feed data were reported in terms of wet or dry weight
- Tissue concentration, and range of values if multiple readings were reported
- Any other pertinent information

TABLE 5.2.4-2

FOOD GROUPS CONSIDERED FOR HUMAN CONSUMPTION OF ANIMAL TISSUE

Food Groups for Inorganic Pollutants	Food Groups for Organic Pollutants
Beef	Beef fat
Beef liver	Beef liver
Lamb	Lamb fat
Pork	Pork fat
Poultry	Poultry fat
Dairy	Dairy fat
Eggs	Eggs

Calculation of Animal Uptake Slopes

To calculate an uptake slope of pollutant in animal tissue for each study from the resulting data set, the following methodology was adopted:

1. The concentration of pollutant in animal feed (μg-pollutant/g-feed) was either directly recorded, or was calculated by dividing the quantity of pollutant consumed each day by the quantity of feed consumed each day.

   Feed concentration was reported either in terms of wet weight, dry weight, or it was not specified. For the purposes of this analysis all data must be in dry weight. Because it was impossible to determine the moisture content of animal feed, no attempt was made to convert wet weight data to dry weight.

   Concentration of pollutant in feed is used as the denominator in calculating uptake slopes. Converting the feed data from wet to dry weight increases the concentration of pollutant in the feed (because the bulk weight of the feed decreases as moisture is removed), thereby decreasing the uptake slope. Thus not converting the data is a conservative measure. Although it would have been preferable to convert the data to dry weight, the lack of reliable information precluded carrying out such a calculation.

2. The concentration of pollutant in the animal tissue (μg-pollutant/g-animal tissue DW) was directly reported either as wet or dry weight. As with feed concentration, this analysis requires that the data be in terms of dry weight. Unlike the feed concentration data, moisture content of animal tissues is available from USDA (see Appendix D tables for specific sources). Conversions from wet to dry weight were carried out as follows:

$$\text{Dry Weight} = \frac{\text{Wet Weight}}{(1 - \text{moisture content})} \qquad (4)$$

3. The uptake response slope of pollutant in animal tissue food group, UA (μg-pollutant/g-animal tissue DW)(μg-pollutant/g-feed)$^{-1}$ was then calculated by regressing the concentration of pollutant in the animal tissue against the concentration of pollutant in the animal feed.

For each particular pollutant/food group combination (i.e., mercury uptake in poultry), the geometric mean of the uptake slopes from the individual studies was calculated and used to represent the uptake slope.

The consumption of beef, lamb, pork, and poultry includes consumption of organ meats as well as muscle. Since liver and kidney can sequester pollutants to a much higher degree than muscle, and liver and kidney are the most frequently eaten organ meats, uptake in liver and kidney was included.

The methodology adopted for incorporating the uptake of liver and kidney was to calculate a weighted geometric mean of muscle, liver, and kidney data in the ratio 50:5:3. These ratios are based on typical body weight ratios for these organs. If only liver, or only kidney data were available, the weighted mean included only that data. That is, if muscle and liver data were used the weighted mean was calculated with a ratio of 50:5, or if muscle and kidney data were used the ratio was 50:3. The following equation shows how the calculation was performed if all three data sets were used:

$$\text{weighted geometric mean} = \sqrt[58]{(\text{muscle data})^{50} \cdot (\text{liver data})^{5} \cdot (\text{kidney data})^{3}} \qquad (5)$$

Use of Surrogate Data from Comparable Food Groups

For some pollutant/food group combinations, little or no data were available. When this occurred it was necessary to use data from surrogate tissue groups. The following criteria, organized by food group, were followed in choosing the data used as the basis for calculating the uptake slopes. (Specific details of which studies were used for each food group/pollutant combination are given in the tables in Appendix D.)

Beef

1. Where muscle and kidney data were available, the weighted geometric mean of beef muscle and beef kidney data in the ratio of 50:3 (muscle:kidney) were used.
2. In the absence of kidney data, only beef muscle data were used.
3. In the absence of either muscle or kidney data, dairy data were substituted.

Beef Liver

1. Beef liver data were used where available.
2. Where no beef liver data were available, liver data from other animals were substituted.
3. For the pollutants where no liver data were available, the most conservative of either beef data, dairy data, or the geometric mean of beef and dairy data were used.

Lamb, Pork, and Poultry

1. Where possible, the weighted geometric mean of muscle, liver, and kidney data (in the ratio 50:5:3) for each food group were used. If either liver or kidney data were not available, the geometric mean of muscle and the available data were used instead (see equation 2).
2. If no data were available directly relating to the food group, the weighted mean of all other meat uptakes was substituted. If less than 15 uptake slopes were available from meat studies, dairy data were incorporated on an equal weighting with muscle.
3. If only beef and dairy data were available, the most conservative of either beef data, dairy data, or the geometric mean of beef and dairy data were used.

Dairy

1. Milk data were used where available.
2. If no milk data were available, data for beef were substituted.
3. If the number of studies used to calculate beef uptake was less than five, the geometric mean of all other meat groups was substituted. Note that the limiting number of studies is less than that for the criteria for pork. This is because dairy products are primarily derived from cattle.

Eggs

1. Egg data were used where available.

2. If no egg data were available, poultry data were substituted.

3. If neither of the above were available, the data used for dairy products were substituted.

The animal uptake slopes calculated are presented in Table 5.2.4-3 for each animal food group/inorganic pollutant pairing.

5.2.4.4.1.2.7 Daily Dietary Consumption of Animal Tissue Food Group, DA

Daily dietary consumption of animal-tissue food groups, DA, is determined using the same EPA dietary analysis (Estimated Lifetime Average Daily Food Intake) discussed for the daily dietary consumption of food group, DC, which was presented in Section 5.2.1.4.1.2.7 in Pathway 1. For this pathway, the relevant food groups are identical to those listed in Table 5.2.4-2. See Table 5.2.1-10 for the consumption figures for each of these food groups.

5.2.4.4.1.2.8 Fraction of Food Group Assumed to be Derived from Animals that Ingest Forage Grown on Sewage Sludge-Amended Soil, FA

The HEI for this pathway is a farm household raising a substantial percentage of their own meat and other animal products. Therefore, the values of FA are based on the annual consumption of homegrown foods on nonmetropolitan areas (i.e., all U.S. areas not within a SMSA). They are presented in Table 5.2.2-3. The FA value for poultry is 11 percent and for beef, beef liver, lamb, and pork it is 10 percent as shown in Table 5.2.2-3. The FA value used

TABLE 5.2.4-3

UPTAKE SLOPE OF INORGANIC POLLUTANTS IN ANIMAL TISSUE FOOD GROUPS, UA (µg-pollutant/g-animal tissue DW)/(µg-pollutant/g-diet DW)

Pollutant	Beef	Beef Liver	Lamb	Pork	Poultry	Dairy	Eggs
Cadmium	0.008	0.413	0.008	0.003	0.085	0.001	0.002
Mercury	0.004	0.262	0.024	0.024	0.024	0.020	0.020
Selenium	0.151	1.195	0.901	2.939	0.901	0.901	0.901
Zinc	0.006	0.003	1.106	0.002	0.007	0.005	0.007

for dairy products in this analysis is that used for the category of milk, cream, and cheese in Table 5.2.2-3 (i.e., 3 percent). For eggs, the FA value from Table 5.2.2-3 is 8 percent.

5.2.4.4.1.2.9 Uptake Response Slope of Pollutants in Forage, UC

The uptake slopes for forage were derived using the same methodology used and described in Pathway 1. See Section 5.2.1.4.1.2.6 for a detailed discussion. The geometric mean of the uptake slopes for each inorganic evaluated are: 0.07 for cadmium, 0.043 for mercury, 0.003 for selenium, and 0.048 for zinc.

5.2.4.4.1.3 Input and Output Values

Table 5.2.4-4 presents the input and qutput values for inorganic compounds for Agricultural Pathway 4.

5.2.4.4.1.4 Sample Calculations

The following are sample calculations for inorganics for Agricultural Pathway 4. The pollutant used as an example is cadmium.

First RIA is calculated to be:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \quad (6)$$

$$RIA = \left(\frac{0.001 \cdot 70}{1} - 0.01614\right) \cdot 10^3 \quad (7)$$

$$RIA = 53.86\ \mu g\text{-cadmium/day} \quad (8)$$

TABLE 5.2.4-4

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 4

Cadmium

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.008	19.2547	0.10	0.0145
Beef liver	0.413	0.8983	0.10	0.0371
Lamb	0.008	0.2008	0.10	0.0002
Pork	0.003	9.0543	0.10	0.0024
Poultry	0.085	6.7031	0.11	0.0627
Dairy	0.001	28.8679	0.03	0.0010
Eggs	0.002	8.3224	0.08	0.0012
		sum UA*DA*FA		0.1191

RfD	0.001
BW	70
RE	1
TBI	0.01614
UC	0.070
RIA	53.86
RF	452.061

RPc	6400

Mercury

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.004	19.2547	0.10	0.0076
Beef liver	0.262	0.8983	0.10	0.0235
Lamb	0.024	0.2008	0.10	0.0005
Pork	0.024	9.0543	0.10	0.0222
Poultry	0.024	6.7031	0.11	0.0181
Dairy	0.020	28.8679	0.03	0.0171
Eggs	0.020	8.3224	0.08	0.0132
		sum UA*DA*FA		0.1021

RfD	0.0003
BW	70
RE	1
TBI	0.0032
UC	0.043
RIA	17.8
RF	174.397

RPc	4000

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.4-4 (cont.)

Selenium

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.151	19.2547	0.10	0.2904
Beef liver	1.195	0.8983	0.10	0.1074
Lamb	0.901	0.2008	0.10	0.0181
Pork	2.939	9.0543	0.10	2.6610
Poultry	0.901	6.7031	0.11	0.6642
Dairy	0.901	28.8679	0.03	0.7802
Eggs	0.901	8.3224	0.08	0.5998
		sum UA*DA*FA		5.1210

RfD	0.005
BW	70
RE	1
TBI	0.115
UC	0.003
RIA	235
RF	45.889

RPc	15000

Zinc

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.006	19.2547	0.10	0.0107
Beef liver	0.003	0.8983	0.10	0.0002
Lamb	1.106	0.2008	0.10	0.0222
Pork	0.002	9.0543	0.10	0.0017
Poultry	0.007	6.7031	0.11	0.0054
Dairy	0.005	28.8679	0.03	0.0045
Eggs	0.007	8.3224	0.08	0.0049
		sum UA*DA*FA		0.0496

RfD	0.21
BW	70
RE	1
TBI	13.42
UC	0.048
RIA	1280
RF	25781.192

RPc	530000

Notes:
Totals may not add due to rounding.
UA = uptake slope of pollutant in animal tissue
(μg-pollutant/g-animal tissue DW)/(μg-pollutant/g-diet DW)
DA = daily dietary consumption of animal tissue food group (g-diet DW/day)
FA = fraction of food group assumed to be derived from animals which ingest sewage sludge (unitless)
RfD = oral reference dose (mg/kg-day)
BW = human body weight (kg)
RE = relative effectiveness of ingestion exposure (unitless)
TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
UC = uptake response slope of pollutant in forage (μg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
RIA = adjusted reference intake of pollutant in humans (μg-pollutant/day)
RF = reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

where:

RIA	=	adjusted reference intake of pollutants in human beings (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Then, RF is calculated to be:

$$RF = \frac{RIA}{\sum (UA_i \cdot DA_i \cdot FA_i)} \quad (9)$$

$$RF = \frac{53.86}{0.1191} \quad (10)$$

$$RF = 452.061\ \mu g\text{-cadmium/g-diet DW} \quad (11)$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in animal tissue food group i (μg-pollutant/g-animal tissue DW) (μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of animal tissue food group i (g-animal tissue DW/day)
FA_i	=	fraction of food group i assumed to be derived from animals that ingest forage grown on sewage sludge-amended soil (unitless)

Finally, RP_c is calculated to be:

$$RP_c = \frac{RF}{UC} \quad (12)$$

$$RP_c = \frac{452.061}{0.070} \quad (13)$$

$$RP_c = 6{,}400 \text{ kg-cadmium/ha (rounded down to 2 significant figures)} \tag{14}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
UC	=	uptake response slope of pollutant in forage crop (μg-pollutant/g forage DW) $(\text{kg-pollutant/ha})^{-1}$

5.2.4.4.2 Organics

5.2.4.4.2.1 Equations

The RIA is calculated from:

$$RIA = \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI\right) \cdot 10^3 \tag{15}$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(\text{mg/kg} \cdot \text{day})^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Because this pathway involves the consumption of animal products by humans, the next equation in this analysis is a reference application rate of pollutant, RF (μg-pollutant/g-diet DW) as shown below:

$$RF = \frac{RIA}{\sum (UA_i \cdot DA_i \cdot FA_i)} \tag{16}$$

where:

RF = reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA = adjusted reference intake in humans (μg-pollutant/day)
UA_i = uptake response slope of pollutant in animal tissue food group i (μg-pollutant/g-animal tissue DW)(μg-pollutant/g-diet DW)$^{-1}$
DA_i = daily dietary consumption of animal tissue food group i (g-animal tissue DW/day)
FA_i = fraction of food group i assumed to be derived from animals which ingest forage grown on sewage sludge-amended soil (unitless)

For organics, a reference concentration of pollutant in soil is calculated:

$$RLC = \frac{RF}{UC} \tag{17}$$

where:

RLC = reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RF = reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
UC = uptake response slope of pollutant in forage crop (μg-pollutant/g-forage DW)(μg-pollutant/g-soil)$^{-1}$

Finally, soil concentration, RLC, is converted to an annual application rate (RP_a) by considering the mass of soil (MS) and the decay series as shown below:

$$RP_a = RLC \bullet MS \bullet 10^{-9} \bullet [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1} \tag{18}$$

where:

RP_a = reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC = reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9} = conversion factor (kg/μg)
e = base of natural logarithms, 2.718 (unitless)
k = loss rate constant (yr^{-1})
n = years of application until equilibrium conditions are reached (yr)

The half-lives of dieldrin and chlordane indicate that these organic pollutants do not degrade. Thus they are treated slightly differently from the other organics in that a cumulative pollutant application rate, not an annual application rate, is calculated from:

$$RP_c = RLC \bullet MS \bullet 10^{-9} \tag{19}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9}	=	conversion factor (kg/μg)

5.2.4.4.2.2 Input Parameters

5.2.4.4.2.2.1 Adjusted Reference Intake in Humans, RIA

The values used to calculate RIAs are designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk. The definition and derivation of each of the parameters used to estimate RIA for nonthreshold-acting toxicants are further discussed in the following sections.

5.2.4.4.2.2.2 Risk Level, RL

Since by definition no "safe" level exists for exposure to nonthreshold agents, specification of a given risk level on which to base regulations is a matter of policy. For this risk assessment, RL was set at 10^{-4}, so the RIA will be the concentration that, for lifetime exposure, is calculated to have an upper-bound cancer risk of one case in 10,000 individuals exposed. This risk level refers to excess cancer risk that is over and above the background cancer risk in unexposed individuals.

5.2.4.4.2.2.3 Body Weight, BW

In keeping with U.S. EPA policy, an adult body weight of 70 kg was used as explained in Section 5.2.1.4.1.2.3.

5.2.4.4.2.2.4 Human Cancer Potency, q_1^*

This variable is described in detail in Pathway 1 in Section 5.2.1.4.2.2.5. See Table 5.2.1-13, also in Pathway 1, for a summary of the q_1^*s used in the risk assessment for land application.

5.2.4.4.2.2.5 Relative Effectiveness of Ingestion Exposure, RE

As stated previously, an RE factor should only be applied where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the carcinogens, RE was set equal to 1.

5.2.4.4.2.2.6 Total Background Intake Rate of Pollutant, TBI

No TBI values are available for organic compounds; they were assumed to be negligible.

5.2.4.4.2.2.7 Reference Concentration of Pollutant in Diet, RF

Animal uptake is in direct proportion to the concentration of pollutant in food. RLC relates the adjusted reference intake in humans (RIA) to animal uptake of pollutants and human dietary consumption.

5.2.4.4.2.2.8 Uptake Response Slope of Pollutant in Animal Tissue Food Group, UA

Animal tissue uptake slopes relate the concentration of pollutant in animal tissue to its concentration in animal feed. The derivation of the uptake slopes is described in detail in Section 5.2.4.4.1.2.6 in this pathway. The slopes derived for organic pollutants are presented in Table 5.2.4-5.

TABLE 5.2.4-5

UPTAKE SLOPE OF ORGANIC POLLUTANTS IN ANIMAL TISSUE FOOD GROUPS, UA (µg-pollutant/g-animal tissue DW)/(µg-pollutant/g-diet DW)

Pollutant	Beef (fat)	Beef Liver	Lamb (fat)	Pork (fat)	Poultry (fat)	Dairy (fat)	Eggs
Aldrin/Dieldrin	2.156	2.873	1.553	7.143	45.753	12.880	33.422
Chlordane	0.071	0.071	0.071	0.071	0.071	0.060	0.060
DDT	2.800	12.891	2.289	7.357	81.597	5.601	9.767
Heptachlor	3.718	12.362	0.853	3.398	3.398	12.362	12.362
Hexachlorobenzene	3.482	6.461	8.353	6.383	8.834	6.461	3.042
Hexachlorobutadiene	3.482	6.461	8.353	6.383	8.834	6.461	3.042
Lindane	1.117	1.117	1.117	1.117	1.117	1.117	1.117
PCBs	4.215	6.664	6.664	6.664	6.664	10.536	10.536
Toxaphene	18.653	18.653	18.653	18.653	18.653	18.653	18.653

5.2.4.2.2.9 Daily Dietary Consumption of the Food Group, DA

Since organics sequester in the fat and liver, the food groups assessed were: beef fat, total beef liver and liver fat, lamb fat, pork fat, poultry fat, dairy fat, and eggs. The daily dietary consumption of each of these food groups can be found in Table 5.2.1-10 in Pathway 1.

5.2.4.4.2.2.10 Fraction of Food Group Assumed to be Derived from Animals that Ingest Forage Grown on Sewage Sludge-Amended Soil, FA

The fraction of food group i derived from animals that ingest forage assumed to be grown on sewage sludge-amended soil, FA are the same as for inorganics: 0.10 for beef, beef liver, lamb, and pork; 0.11 for poultry; 0.03 for dairy; and 0.08 for eggs.

5.2.4.4.2.2.11 Reference Concentration of Pollutant in Soil, RLC

Since plant uptake is related to the concentration of pollutant in soil as discussed in Pathway 1, Section 5.2.1.4.1.2.6, the allowable concentration of pollutant is given as the reference concentration of pollutant in soil.

5.2.4.4.2.2.12 Uptake Response Slope of Pollutants in Forage, UC

As very little data were available on the uptake of organic compounds by plants, the response slopes could not be calculated and were therefore conservatively set to a default slope of 0.001.

5.2.4.4.2.2.13 Reference Annual Application Rate of Pollutant, RP_a

The reference annual application rate applies to organic compounds that degrade in the environment. The amount of pollutant in sludge that can be added to a hectare each year takes this degradation into account.

5.2.4.4.2.2.14 Mass of Dry Soil in Upper 15 cm, MS

The assumed mass of dry soil in the upper 15 cm is $2 \cdot 10^9$ g-soil DW/ha. (See Section 5.2.1.4.2.2.12 for a complete description of the derivation of this value.)

5.2.4.4.2.2.15 Decay Rate Constant, k

See Pathway 1, Section 5.2.1.4.2.2.13 for a complete description of this variable. The values used for k are presented in Table 5.2.1-14, also in Pathway 1.

5.2.4.4.2.3 Input and Output Values

Table 5.2.4-6 presents the input and output values for organic compounds for Agricultural Pathway 4.

5.2.4.4.2.4 Sample Calculations

As discussed previously, two approaches are used for organic pollutants. The first, for those organics that degrade over time, is shown by the following sample calculations. The pollutant used as an example is heptachlor.

First, RIA is calculated from:

TABLE 5.2.4-6

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 4

Aldrin/Dieldrin

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	2.156	15.4977	0.10	3.3413
Beef liver (incl. fat)	2.873	1.1438	0.10	0.3286
Lamb (fat)	1.553	0.2080	0.10	0.0323
Pork (fat)	7.143	12.7299	0.10	9.0928
Poultry (fat)	45.753	1.3403	0.11	6.7455
Dairy (fat)	12.880	18.1252	0.03	7.0037
Eggs	33.422	8.3224	0.08	22.2519
		sum UA*DA*FA		48.7959

RL	1.00E-04
BW	70
q1*	16
RE	1
UC	0.001
MS	2E+09
RIA	0.438
RF	0.009
RLC	8.966

RPc	17

Chlordane

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	0.071	15.4977	0.10	0.1096
Beef liver (incl. fat)	0.071	1.1438	0.10	0.0081
Lamb (fat)	0.071	0.2080	0.10	0.0015
Pork (fat)	0.071	12.7299	0.10	0.0900
Poultry (fat)	0.071	1.3403	0.11	0.0104
Dairy (fat)	0.060	18.1252	0.03	0.0324
Eggs	0.060	8.3224	0.08	0.0396
		sum UA*DA*FA		0.2916

RL	1.00E-04
BW	70
q1*	1.3
RE	1
UC	0.001
MS	2E+09
RIA	5.385
RF	18.466
RLC	18465.936

RPc	36000

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.4-6 (cont.)

DDT/DDE/DDD

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	2.800	15.4977	0.10	4.3390
Beef liver (incl. fat)	12.891	1.1438	0.10	1.4745
Lamb (fat)	2.289	0.2080	0.10	0.0476
Pork (fat)	7.357	12.7299	0.10	9.3652
Poultry (fat)	81.597	1.3403	0.11	12.0301
Dairy (fat)	5.601	18.1252	0.03	3.0453
Eggs	9.767	8.3224	0.08	6.5025
		sum UA*DA*FA		36.8043

RL	1.00E-04
BW	70
q1*	0.34
RE	1
UC	0.001
MS	2E+09
k	0.04
RIA	20.588
RF	0.559
RLC	559.397

RPa	48

Heptachlor

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	3.718	15.4977	0.10	5.7617
Beef liver (incl. fat)	12.362	1.1438	0.10	1.4139
Lamb (fat)	0.853	0.2080	0.10	0.0177
Pork (fat)	3.398	12.7299	0.10	4.3250
Poultry (fat)	3.398	1.3403	0.11	0.5009
Dairy (fat)	12.362	18.1252	0.03	6.7218
Eggs	12.362	8.3224	0.08	8.2304
		sum UA*DA*FA		26.9716

RL	1.00E-04
BW	70
q1*	4.5
RE	1
UC	0.001
MS	2E+09
k	6.024
RIA	1.556
RF	0.058
RLC	57.674

RPa	110

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.4-6 (cont.)

Hexachlorobenzene

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	3.482	15.4977	0.10	5.3962
Beef liver (incl. fat)	6.461	1.1438	0.10	0.7390
Lamb (fat)	8.353	0.2080	0.10	0.1737
Pork (fat)	6.383	12.7299	0.10	8.1254
Poultry (fat)	8.834	1.3403	0.11	1.3024
Dairy (fat)	6.461	18.1252	0.03	3.5132
Eggs	3.042	8.3224	0.08	2.0255
		sum UA*DA*FA		21.2754

RL	1.00E-04
BW	70
q1*	1.6
RE	1
UC	0.001
MS	2E+09
k	0.122
RIA	4.375
RF	0.206
RLC	205.637

RPa	48

Lindane

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	1.117	15.4977	0.10	1.7315
Beef liver (incl. fat)	1.117	1.1438	0.10	0.1278
Lamb (fat)	1.117	0.2080	0.10	0.0232
Pork (fat)	1.117	12.7299	0.10	1.4223
Poultry (fat)	1.117	1.3403	0.11	0.1647
Dairy (fat)	1.117	18.1252	0.03	0.6075
Eggs	1.117	8.3224	0.08	0.7439
		sum UA*DA*FA		4.8209

RL	1.00E-04
BW	70
q1*	1.33
RE	1
UC	0.001
MS	2E+09
k	1.2
RIA	5.263
RF	1.092
RLC	1091.733

RPa	1500

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.4-6 (cont.)

PCBs

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	4.215	15.4977	0.10	6.5318
Beef liver (incl. fat)	6.664	1.1438	0.10	0.7622
Lamb (fat)	6.664	0.2080	0.10	0.1386
Pork (fat)	6.664	12.7299	0.10	8.4828
Poultry (fat)	6.664	1.3403	0.11	0.9825
Dairy (fat)	10.536	18.1252	0.03	5.7289
Eggs	10.536	8.3224	0.08	7.0147
		sum UA*DA*FA		29.6415

RL	1.00E-04
BW	70
q1*	7.7
RE	1
UC	0.001
MS	2E+09
k	0.063
RIA	0.909
RF	0.031
RLC	30.670

RPa	4.3

Toxaphene

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	18.653	15.4977	0.10	28.9079
Beef liver (incl. fat)	18.653	1.1438	0.10	2.1335
Lamb (fat)	18.653	0.2080	0.10	0.3880
Pork (fat)	18.653	12.7299	0.10	23.7452
Poultry (fat)	18.653	1.3403	0.11	2.7501
Dairy (fat)	18.653	18.1252	0.03	10.1427
Eggs	18.653	8.3224	0.08	12.4191
		sum UA*DA*FA		80.4865

RL	1.00E-04
BW	70
q1*	1.1
RE	1
UC	0.001
MS	2E+09
k	1.2
RIA	6.364
RF	0.079
RLC	79.065

RPa	120

TABLE 5.2.4-6 (cont.)

Notes:

Totals may not add due to rounding.

UA = uptake slope of pollutant in animal tissue
(μg-pollutant/g-animal tissue DW)/(μg-pollutant/g-diet DW)

DA = daily dietary consumption of animal tissue food group (g-diet DW/day)

FA = fraction of food group assumed to be derived from animals which ingest sewage sludge (unitless)

RL = risk level (unitless)

BW = human body weight (kg)

q1* = human cancer potency (mg/kg-day)^(-1)

RE = relative effectiveness of ingestion exposure (unitless)

UC = uptake response slope of pollutant in forage (μg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)

MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)

k = loss rate constant (yr)^(-1)

RIA = adjusted reference intake of pollutant in humans (μg-pollutant/day)

RF = reference concentration of pollutant in diet (μg-pollutant/g-diet DW)

RLC = reference concentration of pollutant in soil (μg-pollutant/g-soil DW)

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

$$RIA = \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI\right) \cdot 10^3 \quad (20)$$

$$RIA = \left(\frac{0.0001 \cdot 70}{4.5 \cdot 1} - 0.00\right) \cdot 10^3 \quad (21)$$

$$RIA = 1.556\ \mu g\text{-heptachlor/day} \quad (22)$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Next, RF is calculated to be:

$$RF = \frac{RIA}{\sum (UA_i \cdot DA_i \cdot FA_i)} \quad (23)$$

$$RF = \frac{1.556}{26.972} \quad (24)$$

$$RF = 0.058\ \mu g\text{-heptachlor/g-dietDW} \quad (25)$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in animal tissue food group i (μg-pollutant/g-animal tissue DW)(μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of animal tissue food group i (g-animal tissue DW/day)

FA_i = fraction of food group i assumed to be derived from animals that ingest forage grown on sewage sludge-amended soil (unitless)

Next, RLC is calculated to be:

$$RLC = \frac{RF}{UC} \tag{26}$$

$$RLC = \frac{0.058}{0.001} \tag{27}$$

$$RLC = 57.674\ \mu g\text{-heptachlor/g-soil DW} \tag{28}$$

where:

RLC = reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RF = reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
UC = uptake response slope of pollutant in forage crop (μg-pollutant/g-forage DW)(μg-pollutant/g-soil)$^{-1}$

Finally, RP_a is calculated to be:

$$RP_a = RLC \cdot MS \cdot 10^{-9} \cdot [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1} \tag{29}$$

$$RP_a = 57.674 \cdot 2 \cdot 10^{9} \cdot 10^{-9} \cdot [1 + e^{-6.023} + e^{-2 \cdot 6.023} + ... + e^{(1-100) \cdot 6.023}]^{-1} \tag{30}$$

$$RP_a = 110\ \text{kg-heptachlor/ha} \cdot \text{yr (rounded down to 2 significant figures)} \tag{31}$$

where:

RP_a = reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC = reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9} = conversion factor (kg/μg)
e = base of natural logarithms, 2.718 (unitless)
k = loss rate constant (yr^{-1})
n = years of application until equilibrium conditions are reached (yr)

The second approach is for those organics that do not degrade over time. The calculations are identical to the first approach for organics up until the final calculation. The difference between the two approaches is that the output of the second approach is a reference cumulative application rate of pollutant. The following calculation, using chlordane as an example, shows only the final step in the procedure, where RP_c is calculated to be:

$$RP_c = RLC \cdot MS \cdot 10^{-9} \tag{32}$$

$$RP_c = 18{,}466 \cdot 2 \cdot 10^{9} \cdot 10^{-9} \tag{33}$$

$$RP_c = 36{,}000 \text{ kg-chlordane/yr (rounded down to 2 significant figures)} \tag{34}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9}	=	conversion factor (kg/μg)

5.2.5 Agricultural Pathway 5 (Human Toxicity from Consumption of Animal Products Produced from Animals that Incidentally Ingest Sewage Sludge)

5.2.5.1 *Description of Pathway*

Sewage Sludge → Animal → Human

This pathway involves the application of sewage sludge to the land, the direct ingestion of this sewage sludge by animals, and, finally, the consumption of contaminated animal tissue by humans.

A grazing animal can be exposed to direct ingestion of sewage sludge by two quite different methods. The first involves direct ingestion of sewage sludge by livestock, when sewage sludge has been surface-applied to pasture crops. Livestock can ingest sewage sludge adhering to the crops or lying on the soil surface. Alternatively, sewage sludge can be injected into the soil or mixed with the plow-layer soil, and the grazing livestock ingest the soil-sewage sludge mixture. Exposure will be maximized when sewage sludge is ingested directly with no dilution with soil, and hence this exposure scenario is considered in this analysis.

It is assumed that only a small percentage of the grazing livestock's diet is sewage sludge, and that not all of the animal tissue consumed by the HEI is derived from livestock that have been feeding on sewage sludge-amended soil.

Background pollutant intake by the HEI (i.e., the ingestion of pollutants from all sources other than that associated with the application of sewage sludge to the land), is taken into consideration in the equations for this pathway.

5.2.5.2 *Pollutants Evaluated*

As discussed in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results* (EPA, 1985c), 11 pollutants remained for analysis when the incremental ranking was completed. In addition, because data for selenium and zinc were available, they were evaluated, too. The pollutants shown in Table 5.2.5-1 were all evaluated for this pathway.

5.2.5.3 *Highly Exposed Individual*

The analysis developed for this pathway is designed to assist in setting pollutant loading limits to protect a highly exposed human consuming the tissue of foraging animals that have incidentally ingested undiluted sewage sludge. The HEI is assumed to consume daily quantities of the various animal-tissue food groups as determined by EPA's Estimated Lifetime Average Daily Food Intake. The HEI is also assumed to be exposed to a background intake of pollutant.

5.2.5.4 *Algorithm Development*

5.2.5.4.1 Inorganics

Equations

Because this pathway involves the direct ingestion of sewage sludge by animals, the output of the analysis is a reference concentration of pollutant in sewage sludge, RSC. To calculate RSC, the adjusted reference intake of pollutant in humans, RIA (μg-pollutant/day) is divided by a function of factors that relate to the exposure of livestock to sewage sludge, the uptake of a pollutant in the animal tissue, and the human consumption of this tissue. These factors are the uptake response slope of pollutant in the animal-tissue food group i, UA_i (μg-pollutant/g-animal tissue DW)(μg-pollutant/g-diet DW)$^{-1}$, the daily dietary consumption of the animal tissue food group i, DA_i (g-animal tissue DW/day), and the fraction of food group i assumed to be derived from animals that ingest sewage sludge, FA_i (unitless). This conversion generates an overall reference feed concentration of pollutant, RF (μg-pollutant/g-diet DW) for forage animals. Because sewage sludge constitutes only a small portion of the animals' diet, RF

TABLE 5.2.5-1

POLLUTANTS EVALUATED FOR AGRICULTURAL PATHWAY 5

Inorganics	Organics
Cadmium	Aldrin/Dieldrin
Mercury	Chlordane
Selenium	DDT/DDE/DDD
Zinc	Heptachlor
	Hexachlorobenzene
	Hexachlorobutadiene
	Lindane
	Polychlorinated biphenyls (PCBs)
	Toxaphene

is then divided by the fraction of diet that is sewage sludge, FS (g-sewage sludge DW/g-soil DW) to calculate RSC. Because the sewage sludge is directly ingested, there is no difference in calculations between organic and inorganic pollutants. As discussed above, the first step in the algorithm is the calculation of RIA.

For inorganics RIA is calculated from:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \tag{1}$$

where:

RIA	=	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

$$RF = \frac{RIA}{\sum (UA_i \cdot DA_i \cdot FA_i)} \tag{2}$$

where:

RF	=	reference feed concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in the animal tissue food group i (μg-pollutant/g-animal tissue DW)(μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of the animal tissue food group i (g-animal tissue DW/day)
FA_i	=	fraction of food group i assumed to be derived from animals that ingest sewage sludge (unitless).

Because this pathway involves the direct ingestion of sewage sludge by animals, the output of the analysis is a reference concentration of pollutant in sewage sludge, RSC, calculated from:

$$RSC = \frac{RF}{FS} \qquad (3)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RF	=	reference feed concentration of pollutant in diet (μg-pollutant/g-diet DW)
FS	=	fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)

Input Parameters

Adjusted Reference Intake of Pollutants in Humans, RIA. The values used to calculate RIAs are designed to protect the sensitive members of the population. The definition and derivation of each of the parameters used to estimate RIA for threshold-acting toxicants are further discussed in the following sections.

Oral Reference Dose, RfD. The same RfDs were used in this pathway as in Pathway 1 (see Table 5.2.1-3). Inorganics were assessed as threshold chemicals and the RfDs were taken from IRIS (U.S. EPA, 1992h). (For a more detailed discussion, see Section 5.2.1.4.1.2.2 in Pathway 1).

Human Body Weight, BW. An adult body weight of 70 kg was used as explained in Section 5.2.1.4.1.2.3.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should only be applied where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the pollutants, RE was set equal to 1.

Total Background Intake Rate of Pollutant from All Other Sources of Exposure, TBI. Humans are exposed to pollutants found in sewage sludge (e.g., cadmium, mercury), even if no sewage sludge is applied to agricultural land. These sources include background levels (natural and/or anthropogenic) in drinking water, food, and air. When TBI is subtracted from the weight-adjusted RfD, the remainder defines the increment that can be added from sewage sludge use or disposal without exceeding the threshold. The TBIs used for adults are presented in Table 5.2.1-4 in Pathway 1.

Uptake Response Slope of Pollutant in the Animal Tissue Food Group, UA. Animal tissue uptake slopes relate the concentration of pollutant in animal tissue to the concentration in the animals' feed. The original data were taken from an extensive literature search. The methodology for calculating uptake slopes for each feed/tissue combination depends on how the data were presented in the literature. Uptake slopes for each food group are, generally, the geometric mean of the uptake slopes from a number of feed/tissue combinations. For a complete discussion of the derivation of these numbers, see Section 5.2.4.4.1. The data used are presented in Appendix D. For hexachlorobutadiene, no data were available, so the uptake slope for hexachlorobenzene was used based on the similar toxicology of these pollutants.

Daily Dietary Consumption of the Animal Tissue Food Group, DA. For this pathway, only dietary consumption of animals that graze was considered. Thus consumption of beef, beef liver, lamb, and dairy products was retained in the analysis. Since pigs and poultry (e.g., ducks, chickens) do not graze and would not, therefore, be directly exposed to sludge applied to land, pork, poultry, and eggs were not included in the analysis. The same values of DA were used for this pathway as were previously presented for Pathway 4. See Table 5.2.1-10 for the consumption figures for each of these food groups.

Fraction of Food Group Assumed to be Derived From Animals That Ingest Sewage Sludge, FA. The HEI for this pathway is a farm household raising a substantial percentage of its own meat and other animal products. Therefore, as in Pathway 4, the values of FA are based on the annual consumption of homegrown foods in nonmetropolitan areas [i.e., all U.S. areas not within a Standard Metropolitan Statistical Area (SMSA) (SMSA is explained further in the glossary located at the front of this document)]. They are presented in Table 5.2.2-3. The FA value for beef, beef liver, and lamb is that shown for meat in Table 5.2.2-3 (i.e., 10 percent). The value used for dairy products in this analysis is the value for the category consisting of milk, cream, and cheese in Table 5.2.2-3 (i.e., 3 percent).

Fraction of Animal Diet That is Sewage Sludge, FS. The fraction of sewage sludge ingested (adhering to plants and/or directly from the soil surface) by grazing cattle averaged over a season is 2.5 percent (Chaney et al., 1987a; Bertrand et al., 1981). These data are derived from cattle feces' studies, where livestock were not allowed to graze on pasture during sewage sludge application or for a 21-day period thereafter. However, given that in any 1 year, the maximum fraction of a farm treated with sewage sludge is approximately 33 percent (based on discussions with regulatory officials in several states), and if one assumes the cattle are rotated among several pasture fields, the actual fraction of the diet that is sewage sludge (chronic lifetime model approach) will be lower than the 2.5 percent assumed.

Cattle grazing on land treated with sewage sludge compost that was applied the previous growing season have been shown to ingest approximately 1.0 percent sewage sludge (Decker et al., 1980a). When a weighted average is calculated from these two values of sewage sludge ingestion (i.e., 0.67 x 2.5 + 0.33 x 1.0), the long-term average sewage sludge in the diet is 1.5 percent (Chaney at el., 1991a).

Input and Output Values

The input and output values for inorganics for Agricultural Pathway 5 are listed in Table 5.2.5-2.

TABLE 5.2.5-2

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 5

Cadmium

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.008	19.2547	0.10	0.0145
Beef liver	0.413	0.8983	0.10	0.0371
Lamb	0.008	0.2008	0.10	0.0002
Dairy	0.001	28.8679	0.03	0.0010
		sum UA*DA*FA		0.0528

RfD	0.001
BW	70
RE	1
TBI	0.01614
FS	0.015
RIA	53.86
RF	1020.556

RSC	68000

Mercury

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.004	19.2547	0.10	0.0076
Beef liver	0.262	0.8983	0.10	0.0235
Lamb	0.024	0.2008	0.10	0.0005
Dairy	0.020	28.8679	0.03	0.0171
		sum UA*DA*FA		0.0487

RfD	0.0003
BW	70
RE	1
TBI	0.0032
FS	0.015
RIA	17.8
RF	365.714

RSC	24000

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.5-2 (cont.)

Selenium

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.151	19.2547	0.10	0.2904
Beef liver	1.195	0.8983	0.10	0.1074
Lamb	0.901	0.2008	0.10	0.0181
Dairy	0.901	28.8679	0.03	0.7802
		sum UA*DA*FA		1.1960

RfD	0.005
BW	70
RE	1
TBI	0.115
FS	0.015
RIA	235
RF	196.487

RSC	13000

Zinc

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.006	19.2547	0.10	0.0107
Beef liver	0.003	0.8983	0.10	0.0002
Lamb	1.106	0.2008	0.10	0.0222
Dairy	0.005	28.8679	0.03	0.0045
		sum UA*DA*FA		0.0377

RfD	0.21
BW	70
RE	1
TBI	13.42
FS	0.015
RIA	1280
RF	33970.494

RSC	2200000

Notes:
Totals may not add due to rounding.
UA = uptake slope of pollutant in animal tissue (µg-pollutant/g-animal tissue DW)/(µg-pollutant/g-diet DW)
DA = daily dietary consumption of animal tissue food group (g-diet DW/day)
FA = fraction of food group assumed to be derived from animals which ingest sewage sludge (unitless)
RfD = oral reference dose (mg/kg-day)
BW = human body weight (kg)
RE = relative effectiveness of ingestion exposure (unitless)
TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
FS = fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
RF = reference concentration of pollutant in diet (µg-pollutant/g-diet DW)
RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

Sample Calculations

The following are sample calculations for inorganics for Agricultural Pathway 5. The pollutant used as an example is cadmium.

First, RIA is calculated to be:

$$RIA = \left(\frac{RfD \bullet BW}{RE} - TBI\right) \bullet 10^3 \tag{4}$$

$$RIA = \left(\frac{0.001 \bullet 70}{1} - 0.01614\right) \bullet 10^3 \tag{5}$$

$$RIA = 53.86\ \mu g\text{-cadmium/day} \tag{6}$$

where:

RIA	=	adjusted reference intake of pollutants in human beings (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Then, RF is calculated to be:

$$RF = \frac{RIA}{\sum (UA_i \bullet DA_i \bullet FA_i)} \tag{7}$$

$$RF = \frac{53.86}{0.0528} \tag{8}$$

$$RF = 1020.556\ \mu g\text{-cadmium/g-dietDW} \tag{9}$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in animal tissue food group i (μg-pollutant/g-animal tissue DW) (μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of animal tissue food group i (g-animal tissue DW/day)
FA_i	=	fraction of food group i assumed to be derived from animals that ingest forage grown on sewage sludge-amended soil (unitless)

Finally, RSC is calculated to be:

$$RSC = \frac{RF}{FS} \tag{10}$$

$$RSC = \frac{1020.556}{0.015} \tag{11}$$

$$RSC = 68{,}000\ \mu g\text{-cadmium/g-sewage sludge DW (rounded down to 2 significant figures)} \tag{12}$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RF	=	reference feed concentration of pollutant in diet (μg-pollutant/g-diet DW)
FS	=	fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)

5.2.5.4.2 Organics

For organics RIA is calculated from:

$$RIA = \left(\frac{RL \bullet BW}{q_1^* \bullet RE} - TBI\right) \bullet 10^3 \tag{13}$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

RF is calculated from:

$$RF = \frac{RIA}{\Sigma(UA_i \cdot DA_i \cdot FA_i)} \qquad (14)$$

where:

RF	=	reference feed concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in the animal tissue food group i (μg-pollutant/g-animal tissue DW)(μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of the animal tissue food group i (g-animal tissue DW/day)
FA_i	=	fraction of food group i assumed to be derived from animals that ingest sewage sludge (unitless).

RSC is calculated from:

$$RSC = \frac{RF}{FS} \qquad (15)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RF	=	reference feed concentration of pollutant in diet (μg-pollutant/g-diet DW)
FS	=	fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)

Input Parameters

Adjusted Reference Intake in Humans, RIA. The values used to calculate RIAs are designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk. The definition and derivation of each of the parameters used to estimate RIA for nonthreshold-acting toxicants are further discussed in the following sections.

Risk Level, RL. Since by definition no "safe" level exists for exposure to nonthreshold agents, specification of a given risk level on which to base regulations is a matter of policy. For this risk assessment, RL was set at 10^{-4}, so the RIA will be the concentration for lifetime exposure that is calculated to have an upper-bound cancer risk of one case in 10,000 individuals exposed. This risk level refers to excess cancer risk that is over and above the background cancer risk in unexposed individuals.

Body Weight, BW. In keeping with U.S. EPA policy, an adult body weight of 70 kg was used as explained in Section 5.2.1.4.1.2.3.

Human Cancer Potency, q_1*. This variable is described in detail in Pathway 1, Section 5.2.1.4.2.2.5. See Table 5.2.1-13, also in Pathway 1, for a summary of the q_1*s used in the risk assessment for land application.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should only be applied where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the carcinogens, RE was set equal to 1.

Total Background Intake Rate of Pollutant, TBI. No TBI values are available for organic compounds; they were assumed to be negligible.

Reference Concentration of Pollutant in Soil, RF. Since animal uptake is related to the concentration of pollutant in sludge the allowable concentration of pollutant in animal products is given as the reference concentration of pollutant in diet.

Uptake Response Slope of Pollutant in the Animal Tissue Food Group, UA. Animal uptake of pollutants from sludge is represented by the uptake response slopes, which relate the concentration of pollutant in animal tissue to the concentration in the sludge. The method by which these uptake slopes were calculated is presented in Pathway 4, Section 5.2.4.4.1.2.6. The resultant slopes can be found in the table of input and output values for organics, Table 5.2.5-3.

Daily Dietary Consumption of the Animal Tissue Food Group, DA. For this pathway, only dietary consumption of animals that graze were considered. Thus only consumption of beef, beef liver, lamb, and dairy products were retained in the analysis. Values of DA were used for this pathway as were previously presented. Since organics sequester in the liver and in fat, the food groups used were beef fat, total beef liver and liver fat, lamb fat, and dairy fat. No animal uptake study gave separate uptake numbers for uptake in beef liver fat, so the combined uptake in the liver and liver fat was used. See Table 5.2.1-10 in Pathway 1 for the consumption figures for these four food groups.

Fraction of Food Group Assumed to be Derived From Animals That Ingest Sewage Sludge, FA. As in Pathway 4, the values of FA come from the annual consumption of homegrown foods in nonmetropolitan areas (i.e., all U.S. areas not within a SMSA). They are presented in Table 5.2.2-3. The values for beef, beef liver, and lamb are those shown for meat in Table 5.2.2-3 (i.e., 10 percent), while the value used for dairy products in this analysis is the value for milk, cream, cheese in Table 5.2.2-3 (i.e., 3 percent).

Fraction of Animal Diet That is Sewage Sludge, FS. The fraction of sewage sludge (adhering to plants and/or directly from the soil surface) by grazing cattle is 2.5 percent (Chaney et al., 1987a; Bertrand et al., 1981). Cattle grazing on land treated with sewage sludge compost applied the previous growing season ingest approximately 1.0 percent sewage sludge (Decker et al., 1980). When a weighted average is calculated from these two values of sewage sludge

TABLE 5.2.5-3

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 5

Aldrin/Dieldrin

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	2.156	15.4977	0.10	3.3413
Beef liver (incl. fat)	2.873	1.1438	0.10	0.3286
Lamb (fat)	1.553	0.2080	0.10	0.0323
Dairy (fat)	12.880	18.1252	0.03	7.0037
		sum UA*DA*FA		10.7058

RL	1.00E-04
BW	70
q1*	16
RE	1
FS	0.015
RIA	0.438
RF	0.041

RSC	2.7

Chlordane

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	0.071	15.4977	0.10	0.1096
Beef liver (incl. fat)	0.071	1.1438	0.10	0.0081
Lamb (fat)	0.071	0.2080	0.10	0.0015
Dairy (fat)	0.060	18.1252	0.03	0.0324
		sum UA*DA*FA		0.1515

RL	1.00E-04
BW	70
q1*	1.3
RE	1
FS	0.015
RIA	5.385
RF	35.538

RSC	2300

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.5-3 (cont.)

DDT/DDE/DDD

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	2.800	15.4977	0.10	4.3390
Beef liver (incl. fat)	12.891	1.1438	0.10	1.4745
Lamb (fat)	2.289	0.2080	0.10	0.0476
Dairy (fat)	5.601	18.1252	0.03	3.0453
		sum UA*DA*FA		8.9065

RL	1.00E-04
BW	70
q1*	0.34
RE	1
FS	0.015
RIA	20.588
RF	2.312

RSC	150

Heptachlor

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	3.718	15.4977	0.10	5.7617
Beef liver (incl. fat)	12.362	1.1438	0.10	1.4139
Lamb (fat)	0.853	0.2080	0.10	0.0177
Dairy (fat)	12.362	18.1252	0.03	6.7218
		sum UA*DA*FA		13.9153

RL	1.00E-04
BW	70
q1*	4.5
RE	1
FS	0.015
RIA	1.556
RF	0.112

RSC	7.4

Hexachlorobenzene

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	3.482	15.4977	0.10	5.3962
Beef liver (incl. fat)	6.461	1.1438	0.10	0.7390
Lamb (fat)	8.353	0.2080	0.10	0.1737
Dairy (fat)	6.461	18.1252	0.03	3.5132
		sum UA*DA*FA		9.8221

RL	1.00E-04
BW	70
q1*	1.6
RE	1
FS	0.015
RIA	4.375
RF	0.445

RSC	29

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.5-3 (cont.)

Hexachlorobutadiene

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	3.482	15.4977	0.10	5.3962
Beef liver (incl. fat)	6.461	1.1438	0.10	0.7390
Lamb (fat)	8.353	0.2080	0.10	0.1737
Dairy (fat)	6.461	18.1252	0.03	3.5132
		sum UA*DA*FA		9.8221

RL	1.00E-04
BW	70
q1*	0.078
RE	1
FS	0.015
RIA	89.744
RF	9.137

RSC	600

Lindane

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	1.117	15.4977	0.10	1.7315
Beef liver (incl. fat)	1.117	1.1438	0.10	0.1278
Lamb (fat)	1.117	0.2080	0.10	0.0232
Dairy (fat)	1.117	18.1252	0.03	0.6075
		sum UA*DA*FA		2.4901

RL	1.00E-04
BW	70
q1*	1.33
RE	1
FS	0.015
RIA	5.263
RF	2.114

RSC	140

PCBs

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	4.215	15.4977	0.10	6.5318
Beef liver (incl. fat)	6.664	1.1438	0.10	0.7622
Lamb (fat)	6.664	0.2080	0.10	0.1386
Dairy (fat)	10.536	18.1252	0.03	5.7289
		sum UA*DA*FA		13.1615

RL	1.00E-04
BW	70
q1*	7.7
RE	1
FS	0.015
RIA	0.909
RF	0.069

RSC	4.6

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.2.5-3 (cont.)

Toxaphene

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	18.653	15.4977	0.10	28.9079
Beef liver (incl. fat)	18.653	1.1438	0.10	2.1335
Lamb (fat)	18.653	0.2080	0.10	0.3880
Dairy (fat)	18.653	18.1252	0.03	10.1427
			sum UA*DA*FA	41.5722

RL	1.00E-04
BW	70
q1*	1.1
RE	1
FS	0.015
RIA	6.364
RF	0.153

RSC	10

Notes:
Totals may not add due to rounding.
UA = uptake slope of pollutant in animal tissue (μg-pollutant/g-animal tissue DW)/(μg-pollutant/g-diet DW)
DA = daily dietary consumption of animal tissue food group (g-diet DW/day)
FA = fraction of food group assumed to be derived from animals which ingest sewage sludge (unitless)
RL = risk level (unitless)
BW = human body weight (kg)
q1* = human cancer potency (mg/kg-day)^(-1)
RE = relative effectiveness of ingestion exposure (unitless)
FS = fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)
RIA = adjusted reference intake of pollutant in humans (μg-pollutant/day)
RF = reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RSC = reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)

ingestion (i.e., 0.67 x 2.5 + 0.33 x 1.0), the long-term average sewage sludge in the diet is 1.5 percent (Chaney et al., 1991a). This is the same value used for this pathway for inorganics.

Input and Output Values

The input and output values for organics for Agricultural Pathway 5 are listed in Table 5.2.5-3.

Sample Calculations

The following are sample calculations for organics for Agricultural Pathway 5. The pollutant used as an example is heptachlor.

First RIA is calculated to be:

$$RIA = \left(\frac{RL \bullet BW}{q_1^* \bullet RE} - TBI\right) \bullet 10^3 \qquad (16)$$

$$RIA = \left(\frac{0.0001 \bullet 70}{4.5 \bullet 1} - 0.00\right) \bullet 10^3 \qquad (17)$$

$$RIA = 1.556\ \mu g\text{-heptachlor/day} \qquad (18)$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(mg/kg \bullet day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Then, RF is calculated to be:

$$RF = \frac{RIA}{\sum(UA_i \cdot DA_i \cdot FA_i)} \quad (19)$$

$$RF = \frac{1.556}{13.915} \quad (20)$$

$$RF = 0.112\ \mu g\text{-heptachlor/g-dietDW} \quad (21)$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in animal tissue food group i (μg-pollutant/g-animal tissue DW) (μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of animal tissue food group i (g-animal tissue DW/day)
FA_i	=	fraction of food group i assumed to be derived from animals that ingest forage grown on sewage sludge-amended soil (unitless)

Finally, RSC is calculated to be:

$$RSC = \frac{RF}{FS} \quad (22)$$

$$RSC = \frac{0.112}{0.015} \quad (23)$$

$$RSC = 7.4\ \mu g\text{-heptachlor/g-sewage sludge DW} \quad (24)$$

(rounded down to 2 significant figures)

where:

RSC = reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)

RF = reference feed concentration of pollutant in diet (μg-pollutant/g-diet DW)

FS = fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)

5.2.6 Agricultural Pathway 6 (Animal Toxicity from Plant Consumption)

5.2.6.1 Description of Pathway

Sewage Sludge → Soil → Plant → Animal

This pathway protects animals that ingest plants (forage and grain) grown on sewage sludge-amended soil.

5.2.6.2 Pollutants Evaluated

As discussed in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results* (U.S. EPA, 1985c), all pollutants except cadmium, copper, molybdenum, selenium, and zinc were screened out during the initial evaluation. Since the original screening was completed, further research indicates that arsenic, chromium, nickel, and lead are also a concern to animals consuming plants grown on sewage sludge-amended soils. Therefore, the following pollutants were evaluated: arsenic, cadmium, chromium, copper, lead, molybdenum, nickel, selenium, and zinc (see Table 5.2.6-1).

5.2.6.3 Highly Exposed Individual (HEI)

The HEI is the most sensitive/most exposed herbivorous livestock that consumes plants grown on sewage sludge-amended soil. It is assumed that 100 percent of the livestock diet consists of forage grown on sewage sludge-amended land, and that the animal is exposed to a background pollutant intake. The animal of concern varies by pollutant, and thus, where a sensitive species has been identified for a pollutant, the species is identified in the section specific to each pollutant.

TABLE 5.2.6-1

POLLUTANTS EVALUATED FOR AGRICULTURAL PATHWAY 6

Inorganics
Arsenic
Cadmium
Chromium
Copper
Lead
Molybdenum
Nickel
Selenium
Zinc

5.2.6.4 Algorithm Development

5.2.6.4.1 Equations

For pathways that consider herbivorous animals consuming plants either as the target organism, or as an intermediate member of the food chain, the endpoint of the analysis is a reference application rate of pollutant, RP (kg-pollutant/ha). To calculate RP, it is first necessary to determine a reference concentration of pollutant in forage, RF (μg-pollutant/g-forage DW). RF is the allowable concentration of pollutant in the diet ingested as a result of the application of sewage sludge to the land. RF is calculated by subtracting the background concentration of pollutant in forage, BC (μg-pollutant/g-forage DW), from the maximum allowable pollutant concentration in the diet [i.e., the threshold pollutant intake level, TPI (μg-pollutant/g-diet DW)]. To make the connection between animal intake and plant uptake, RP is then calculated by dividing RF by the uptake slope of forage, UC (μg-pollutant/g-forage DW)(kg-pollutant/ha)$^{-1}$.

As discussed above, RF is calculated by subtracting BC from TPI, thus:

$$RF = TPI - BC \qquad (1)$$

where:

RF = reference concentration of pollutant in forage (μg-pollutant/g-forage DW)
TPI = threshold pollutant intake level (μg-pollutant/g-diet DW)
BC = background concentration of pollutant in forage (μg-pollutant/g-forage DW)

For inorganics, which are the only pollutants considered in this pathway, a cumulative application rate of pollutant, RP, is calculated by dividing RF by UC, thus:

$$RP = \frac{RF}{UC} \qquad (2)$$

where:

RP = reference application rate of pollutant (kg-pollutant/ha)
RF = reference concentration of pollutant in forage (μg-pollutant/g-forage DW)
UC = uptake slope of forage (μg-pollutant/g-forage DW)(kg-pollutant/ha)$^{-1}$

5.2.6.4.2 Input Parameters

Threshold Pollutant Intake Level, TPI

For each pollutant, the available literature was reviewed in order to estimate the maximum intake of a pollutant that would not cause a toxic effect to a most sensitive/most exposed herbivorous animal. Unlike the reference intake of pollutant in humans, which is expressed as an allowable daily intake of pollutant, the TPI is expressed as an allowable concentration of pollutant in the animals' diet. Threshold pollutant intake levels are taken directly from recommendations by the National Academy of Science (NAS, 1980e), except in the cases of copper, molybdenum, selenium, and zinc; their derivation is described next. TPI values are presented in Table 5.2.6-2.

Copper. The NAS recommended a maximum intake level of 25 μg-pollutant/g-diet DW, which was derived from an experiment in which copper salts were fed to sheep with low dietary zinc. When excessive bioavailable copper is chronically present in animal diets, copper accumulates to a toxic level in the liver. At that point, other stresses can trigger a hemolytic crisis and injury or death. Many sheep have been poisoned when they grazed in fields to which fertilizers or pesticides had been applied because the copper level in the ingested diet was the combined amount of copper both in and on the forage. Further, zinc in forage interferes with copper absorption by livestock, so forage containing excessive zinc can induce copper deficiency in livestock fed diets low in copper. Forage grown on sewage sludge-amended soils has a normal or increased concentration of zinc.

A few studies have been conducted in which test animals were fed forage crops grown on sewage sludge-amended soils (e.g., Bray et al., 1985; Dowdy et al., 1983a,b; and Dowdy et al., 1984). Data are available from goat and sheep feeding studies in which corn silage grown on sewage sludge-amended soil constituted greater than 90 percent of the animals' diet. The silage, which was grown on sewage sludge-amended plots, contained elevated levels of cadmium, copper, and zinc. However, the livestock did not have increased levels of copper in the liver, which is the pattern observed when toxic levels of copper salts are ingested. Similarly in a 90-day feeding study, cattle fed forage grown on soils amended with 224 mt/ha of sludge compost (resulting in a

TABLE 5.2.6-2

TPI VALUES FOR AGRICULTURAL PATHWAY 6

Pollutant	(TPI) Threshold Pollutant Intake Level (μg-pollutant/g-diet DW)
Arsenic	50
Cadmium	10
Chromium	3,000
Copper	50
Lead	30
Molybdenum	10
Nickel	100
Selenium	2.3
Zinc	600

somewhat increased concentration of copper in the crop), did not have increased levels of copper in the liver. This was also observed when guinea pigs were fed Swiss chard containing a high concentration of copper (Chaney et al., 1987b). Further, there have been no findings of livestock toxicity due to copper as a result of ingesting forage crops grown on sewage sludge-amended soils, reported in the literature. Chaney et al. (1987a) noted that no toxicity was found in sheep grazed an entire season in pastures treated with swine manure containing high levels of copper, even though dietary copper reached over 100 mg/kg.

The data on which NAS based its recommended maximum tolerable concentration of copper in feed for sheep, 25 μg-copper/g-diet DW, are from studies in which sheep were fed copper salts (as discussed above). Copper salts are more toxic than nonsalt forms of copper and results from studies in which copper salts were used are not representative of conditions found in fields treated with sewage sludge. Nevertheless, so little data are available that the data should not be ignored.

Therefore, the TPI for copper has been set at the geometric mean of the NAS recommended concentration (25 μg-copper/g-diet DW) and the data from Chaney et al. (1987a) (100 mg/kg); the TPI is 50 μg-copper/g-diet DW.

Molybdenum. Excessive soil molybdenum in neutral pH soils can poison livestock through uptake by forage crops (Logan and Chaney, 1983). The toxicity mechanism is well-characterized: molybdenum is transformed in the rumen to thiomolybdate, which binds copper and prevents both copper absorption from the intestines and copper utilization within the animal. The most sensitive livestock are cattle and sheep, which are deficient in copper since the increased diet molybdenum further interferes with copper utilization in the animal (NAS, 1980c; Mills and Davis, 1987).

Forage crops grown on sewage sludge-amended soils are not copper deficient, and would not promote a worse-than-normal molybdenum toxicity. Rather, sewage sludge-fertilized crops (at cumulative sewage sludge loadings at which molybdenum applications might be of importance) would have normal to somewhat enriched copper levels depending on soil and sewage sludge properties. Therefore, the impact of increased soil molybdenum is reduced considerably in sewage sludge-amended soils as compared to copper deficient soils.

Ingestion by ruminants of forage shows that ingestion of cured forage from high-molybdenum areas is less toxic than the same forage grazed in a succulent state (Mills and Davis, 1987). The higher the energy level of the diet, the more sulfide is produced in the rumen, accentuating formation of thiomolybdate which causes the actual toxic effect of molybdenum by inducing copper deficiency. Accordingly, the form of molybdenum, as well as the forage type and crop species, must be taken into consideration when relating dietary levels of molybdenum to the degree of toxicity to ruminants.

The NAS (1980c) evaluated low-level chronic molybdenum toxicity to the most sensitive livestock (beef cattle) and concluded that 5 to 10 ppm (μg/g) molybdenum, which is the dose that has been weakly associated with impaired bone development in young horses and cattle, was the critical level. It must be emphasized that substantially higher levels of molybdenum are tolerated in the presence of adequate copper and inorganic sulfate (sulfate inhibits molybdate absorption in the intestine). Forages grown on sewage sludge-amended soils (high cumulative rates) have normal copper and sulfate concentrations, so the higher recommended permissible concentration of about 10 μg-molybdenum/g-forage is more appropriate. A large body of data on the toxicity of forages grown on soil naturally high in molybdenum (not molybdenum salt additions to diets) and containing toxic concentrations of ɔdenum supports the use of 10 μg-molybdenum/g-forage assuming the diet contains a no:..... copper concentration (NAS, 1980c, Table 1, page 5).

Based on the above considerations the TPI for molybdenum has been set at 10 μg/g.

Selenium. Moxon (1937) determined that there was no observed adverse effects when chickens were fed 2 μg-selenium/g-diet DW in the form of seleniferous corn, barley, and wheat. At 2.5 μg-selenium/g-diet DW, however, many hatched chicks had wiry down and increased mortality was observed. The TPI has been set at 2.3 μg-selenium/g-diet DW, the geometric mean of these two values. This value is higher than the NAS (1980b) recommendation of 2 μg-selenium/g-diet, although the NAS noted that there was little demonstrated toxicity to livestock until chronic diets contained about 5 μg-selenium/g-diet. The TPI for selenium has thus been set at 2.3 μg-selenium/g-diet DW.

Zinc. There have been no findings of toxicity to livestock from zinc in forage crops grown on sewage sludge-amended soils reported in the available literature. This is likely a result of the plateau response of plant zinc concentration to sewage sludge-applied zinc, such that a high concentration of zinc cannot be reached in crops unless substantial phytotoxicity has occurred. Data from Bray et al. (1985), Dowdy et al. (1983a, b), and Dowdy et al. (1984), are from goat and sheep feeding studies in which corn silage grown on sewage sludge-amended soil constituted greater than 90 percent of the animals' diet. Although the silage contained elevated levels of cadmium, copper, and zinc, the livestock did not have increased levels of zinc in the liver (the pattern observed when toxic levels of zinc are fed). Similarly, forage grown on soils amended with 224 mt/ha of sewage sludge compost and fed to cattle had a somewhat increased zinc content, but no accumulated zinc was found in cattle in a feeding study lasting over 90 days with the conserved forage. Further, when guinea pigs were fed Swiss chard, which was grown on acidic soil amended with sludge and contained a high concentration of zinc, no accumulation of zinc was found in the liver of the guinea pigs (Chaney et al., 1987b).

Dietary copper levels have been repeatedly shown to interact with zinc toxicity to livestock. Excessive copper in crops or copper salts directly fed can induce zinc deficiency in livestock fed diets low in zinc. (The potential toxicity of inorganic zinc salts is invariably greater than the same element present in plant tissue.) Although forages grown on sewage sludge-amended soils can have highly increased zinc concentrations under conditions of very low soil pH and high cumulative sludge applications, these same forages have increased concentrations of copper, not deficient levels of copper. Thus, forages grown on sewage sludge-treated soil are not deficient in copper and do not cause zinc-induced copper deficiency in animals ingesting forages grown on sewage sludge-amended soils.

Although many studies with zinc salts fed to cattle with normal dietary copper intake found no toxicity until 1,000 μg-zinc/g-diet DW, and nonruminants fed high levels of zinc salts in normal diets had no toxicity until zinc concentration exceeded 1,000 μg-zinc/g-diet DW, to maintain a conservative analysis, the TPI for forage zinc is concluded to be 600 μg-zinc/g-diet DW.

Background Concentration of Pollutant in Forage, BC

Background concentrations in forage are calculated by taking the geometric mean of pollutant concentrations in forage crops grown in soil to which sewage sludge has not been added (see Appendix C, Plant Uptake Tables, Table C-9). In the case of molybdenum, increasing pH causes an increase in plant response, therefore only the neutral studies were utilized in the calculation of the geometric mean.

Uptake Slope of Forage, UC

Plant uptake of pollutants (see Section 5.2.1.4.1.2.6 in Agricultural Pathway 1) is defined by a single uptake slope for each plant/pollutant combination. Uptake is assumed to be linear in all cases, with zero plant concentration when soil concentration is zero. Plant uptake is reported either in terms of a pollutant loading rate per hectare, or in terms of a soil concentration. Conversion between the two reporting methods relies upon the assumption that the mass of dry soil in one hectare of land is $2 \cdot 10^9$ g-soil DW. Forage crop uptake slopes in this analysis are calculated by regressing forage crop plant tissue pollutant concentration against pollutant application rate per hectare.

Uptake slopes for each pollutant for each plant group are derived by calculating the geometric mean from a large number of studies. The data from these studies is presented in Appendix C, Plant Uptake Tables.

5.2.6.5 Input and Output Values

The input and output values for this pathway are summarized in Table 5.2.6-3.

TABLE 5.2.6-3

INPUT AND OUTPUT VALUES
FOR AGRICULTURAL PATHWAY 6

Pollutant	TPI	BC	RF	UC	RPc
Arsenic	50	0.304	49.696	0.030	1600
Cadmium	10	0.225	9.775	0.070	140
Chromium	3000	**		**	
Copper	50	5.842	44.158	0.012	3700
Lead	30	2.204	27.796	0.002	11000
Molybdenum	10	2.084	7.916	0.423	18
Nickel	100	0.696	99.304	0.055	1800
Selenium	2.3	0.055	2.245	0.003	790
Zinc	600	17.372	582.628	0.048	12000

Notes:
** No data
Totals may not add due to rounding.
TPI = threshold pollutant intake level (μg-pollutant/g-diet DW)
BC = background concentration of pollutant in forage (μg-pollutant/g-plant tissue DW)
RF = reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
UC = uptake slope of pollutant in forage (μg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

5.2.6.6 Sample Calculations

The following are sample calculations for Agricultural Pathway 6. The pollutant used as an example is zinc:

First, RF is calculated to be:

$$RF = TPI - BC \tag{3}$$

$$RF = 600 - 17.372 \tag{4}$$

$$RF = 582.628\ \mu g\text{-}zinc/g\text{-}forage DW \tag{5}$$

where:

RF = reference concentration of pollutant in forage (μg-pollutant/g-forage DW)
TPI = threshold pollutant intake level (μg-pollutant/g-diet DW)
BC = background concentration of pollutant in forage (μg-pollutant/g-forage DW)

Next, RP_c is calculated to be:

$$RP = \frac{RF}{UC} \tag{6}$$

$$RP = \frac{582.628}{0.048} \tag{7}$$

$$RP = 12{,}000\ kg\text{-}zinc/ha\ \text{(rounded down to 2 significant figures)} \tag{8}$$

where:

RP = reference application rate of pollutant (kg-pollutant/ha)
RF = reference concentration of pollutant in forage (μg-pollutant/g-forage DW)
UC = uptake slope of forage (μg-pollutant/g-forage DW)(kg-pollutant/ha)$^{-1}$

5.2.7 Agricultural Pathway 7 (Animal Toxicity from Sewage Sludge Ingestion)

5.2.7.1 Description of Pathway

Sewage Sludge → Animal

This pathway involves the application of sewage sludge to the land and the direct ingestion of this sewage sludge by animals. A grazing animal can be exposed to direct ingestion of sewage sludge by two quite different methods. The first involves direct ingestion of sewage sludge by livestock, where sewage sludge has been surface-applied to pasture crops. Livestock can ingest sewage sludge adhering to the crops or lying on the soil surface. It is assumed that each year the grazing livestock are exposed to freshly applied sewage sludge with no time for dissipation of the organic chemicals. Alternatively, sewage sludge can be injected into the soil or mixed with the plow-layer soil, and the grazing livestock will ingest the soil-sewage sludge mixture. Exposure will be maximized when sewage sludge is directly ingested, and hence this exposure route is considered in this analysis. It is assumed that only a small percentage of the grazing livestock's diet is sewage sludge.

5.2.7.2 Pollutants Evaluated

As discussed in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results* (U.S. EPA, 1985c), all pollutants except copper and iron were screened out during the initial evaluation. Since the original screening was completed, further research indicates that iron is not a problem to animals incidentally eating sludge (see Section 4.2) and that arsenic, cadmium, chromium, lead, molybdenum, nickel, selenium, and zinc are also of concern for animals incidentally ingesting sludge. Table 5.2.7-1 presents the pollutants evaluated.

TABLE 5.2.7-1

POLLUTANTS EVALUATED FOR AGRICULTURAL PATHWAY 7

Inorganics
Arsenic
Cadmium
Chromium
Copper
Lead
Molybdenum
Nickel
Selenium
Zinc

5.2.7.3 Highly Exposed Individual (HEI)

The HEI for this pathway is herbivorous livestock, which incidentally consumes sewage sludge adhering to forage crops and/or sewage sludge on the soil surface. It is assumed that the percent of sewage sludge in the livestock diet is 1.5 percent and that the animal is exposed to a background pollutant intake. The animal of concern varies by pollutant, and, thus, where a sensitive species has been identified for a pollutant, the species is identified in the individual sections for each pollutant.

5.2.7.4 Algorithm Development

5.2.7.4.1 Equations

As for Pathway 5, because the ingestion of sludge results in the highest rate of pollutant ingestion, the endpoint of this analysis is a reference concentration of pollutant in sewage sludge, RSC (μg-pollutant/g-sewage sludge DW). To calculate RSC, it is first necessary to determine a reference concentration of pollutant in diet, RF (μg-pollutant/g-diet DW). RSC is calculated by dividing RF by the fraction of animal diet that is sewage sludge, FS (g-sewage sludge DW/g-diet DW). RF is calculated by subtracting the background concentration of pollutant in soil, BS (μg-pollutant/g-soil DW) from the threshold pollutant intake level, TPI (μg-pollutant/g-diet DW).

Because this pathway relates to the ingestion of soil, RF is calculated by subtracting BS from TPI, thus:

$$RF = TPI - BS \qquad (1)$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
TPI	=	threshold pollutant intake level (μg-pollutant/g-diet DW)
BS	=	background concentration of pollutant in soil (μg-pollutant/g-soil DW)

For inorganics, which are the only pollutants considered in this pathway, RSC is calculated by dividing RF by FS, thus:

$$RSC = \frac{RF}{FS} \tag{2}$$

where:

RSC = reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RF = reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
FS = fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)

5.2.7.4.2 Input Parameters

Threshold Pollutant Intake Level, TPI (μg-pollutant/g-diet DW)

For each pollutant, the available literature was reviewed to estimate the maximum intake of a pollutant that would not cause a toxic effect to a most sensitive/most exposed herbivorous animal. Unlike the reference intake of pollutant in humans, which is expressed as an allowable daily intake of pollutant, the TPI in this pathway is referenced in the literature as an allowable pollutant concentration in the animals' diet.

Threshold pollutant intake levels are taken directly from recommendations by the National Academy of Science (NAS, 1980e), except in the cases of copper, molybdenum, selenium, and zinc, and are listed in Table 5.2.7-2. The sources of the threshold pollutant intake levels for these four pollutants are discussed in Section 5.2.6.4.2, Pathway 6.

Background Concentration of Pollutant in Soil, BS (μg-pollutant/g-soil DW)

As discussed in Pathway 9, BS may be the natural background concentration or may result from other pollution sources. Since inorganics are considered, for the purposes of this

TABLE 5.2.7-2

THRESHOLD POLLUTANT INTAKE LEVEL FOR PATHWAY 7

Pollutant	TPI[a]
Arsenic	50
Cadmium	10
Chromium	3,000
Copper	50
Lead	30
Molybdenum	10
Nickel	100
Selenium	2.3
Zinc	600

[a]μg-pollutant/g-diet DW

analysis, never to be lost from the soil, the application of sewage sludge to the land is limited by the total allowable concentration of pollutants on a cumulative basis. Where background levels are significant compared to the maximum allowable pollutant concentration, the allowable pollutant loading from sewage sludge will be noticeably reduced. Soil background levels are listed in Table 5.2.7-3.

Fraction of Animal Diet that Is Sewage Sludge, FS (g-sewage sludge DW/g-diet DW)

The fraction of sludge ingested (adhering to plants and/or directly from the soil surface) by grazing cattle has been estimated to be 2.5 percent averaged over a season (Chaney et al., 1987a; Bertrand et al., 1981). These data are derived from cattle feces studies, where livestock were not allowed to graze in pastures during sludge application or for a 21-day period after application. However, given that (based on discussions with regulatory officials in several states) in any 1 year, the maximum fraction of a farm treated with sludge is approximately 33 percent, if it is assumed that the cattle are rotated among several pasture fields, the actual fraction of the diet that is sludge will be lower than the 2.5 percent assumed.

Cattle grazing on land treated with sludge compost that was applied during the previous growing season have been shown to ingest approximately 1.0 percent sludge (Decker et al., 1980a). When a weighted average is calculated from these two values of sludge ingestion (i.e., 0.67 x 2.5 + 0.33 x 1.0), the long-term average percent of sludge in diet is estimated to be 1.5 (Chaney et al., 1991a).

5.2.7.5 Input and Output Values

The input and output values for this pathway are presented in Table 5.2.7-4.

TABLE 5.2.7-3

BACKGROUND CONCENTRATION OF POLLUTANTS IN SOIL FOR PATHWAY 7

Pollutant	BS[a]
Arsenic	3
Cadmium	0.2
Chromium	100
Copper	19
Lead	11
Molybdenum	2
Nickel	18
Selenium	0.21
Zinc	54

[a]μg-pollutant/g-soil DW

TABLE 5.2.7-4

INPUT AND OUTPUT VALUES FOR AGRICULTURAL PATHWAY 7

Pollutant	TPI	BS	RF	FS	RSC
Arsenic	50	3	47	0.015	3100
Cadmium	10	0.2	9.8	0.015	650
Chromium	3000	100	2900	0.015	190000
Copper	50	19	31	0.015	2000
Lead	30	11	19	0.015	1200
Molybdenum	10	2	8	0.015	530
Nickel	100	18	82	0.015	5400
Selenium	2.3	0.21	2.09	0.015	130
Zinc	600	54	546	0.015	36000

Notes:
Totals may not add due to rounding.
TPI = threshold pollutant intake level (µg-pollutant/g-diet DW)
BS = background concentration of pollutant in soil (µg-pollutant/g-soil DW)
RF = reference concentration of pollutant in diet (µg-pollutant/g-diet DW)
FS = fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)
RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

5.2.7.6 Sample Calculations

The following are sample calculations for Agricultural Pathway 7. The pollutant used as an example is arsenic.

First, RF is calculated to be:

$$RF = TPI - BS \quad (3)$$

$$RF = 50 - 3.0 \quad (4)$$

$$RF = 47\ \mu g\text{-arsenic/g-diet DW} \quad (5)$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
TPI	=	threshold pollutant intake level (μg-pollutant/g-diet DW)
BS	=	background concentration of pollutant in soil (μg-pollutant/g-soil DW)

Then, RSC is calculated to be:

$$RSC = \frac{RF}{FS} \quad (6)$$

$$RSC = \frac{47}{0.015} \quad (7)$$

$$RSC = 3{,}100\ \mu g\text{-arsenic/g-sewage sludge DW} \quad (8)$$

(rounded down to two significant figures)

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
FS	=	fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)

5.2.8 Agricultural Pathway 8 (Plant Toxicity in Plants Grown on Sewage-Sludge-Amended Soil)

5.2.8.1 Description of Pathway

Sewage Sludge → Soil → Plant

This pathway evaluates the toxic effects of sewage sludge application on the growth of plants (phytotoxicity). Uptake of pollutants is assumed to occur through plant roots.

5.2.8.2 Pollutants Evaluated

Table 5.2.8-1 presents the pollutants evaluated for Agricultural Pathway 8.

Organics are not assessed, because organic compounds in sewage sludge occur at extremely low concentrations and are rarely taken up by plants in quantities that exceed background levels.

Seven metals found in sludge (i.e., cadmium, chromium, copper, lead, nickel, selenium, and zinc) have been identified as potentially phytotoxic. The technical references report decreases in plant growth and accumulation of cadmium, chromium, copper, nickel, lead, and zinc in crops grown on sludge-treated fields. The limited data that illustrate reductions in yields suggest that plant phytotoxicity can and does occur from land application of sewage sludge under conditions of environmental stress (i.e., low soil pH and high application rates of sludges containing high concentrations of metals). No study investigated whether detrimental metal-related biochemical processes had taken place in plants grown on sludge-treated soils. Thus there is no unequivocal evidence that metals introduced through land application of municipal wastewater sludge cause phytotoxicity. However, since cadmium, chromium, copper, nickel, and zinc are phytotoxic and can accumulate in sludge-treated soils, it is prudent to control input of these metals during land application of municipal sludges. Four pollutants were evaluated for this pathway: chromium, copper, nickel, and zinc.

TABLE 5.2.8-1

POLLUTANTS EVALUATED FOR AGRICULTURAL PATHWAY 8

Inorganics
Chromium
Copper
Nickel
Zinc

5.2.8.3 Definition of Phytotoxicity

Phytotoxicity occurs when a substance accumulates in plant tissue to a level that affects optimal growth and development of the plant. The two conditions usually associated with phytotoxicity are abnormal morphology in new growth, and retardation of growth and/or reduction in yield. The degree of phytotoxicity increases with the extent and duration of exposure.

To unequivocally confirm phytotoxicity, three conditions must be met: identification of toxicants in the growth medium, significant reduction in yields, and identification of a biochemical mechanism responsible for the plant injury.

Carlson et al. (1975), Loneragan et al. (1987), and Poschenrieder et al. (1989), among others, have shown that metals induce phytotoxicity by:

- Altering the plant's water relations, thereby causing water stress and wilting
- Increasing the permeability of the root cell plasma membrane, thereby causing roots to become leaky and less selective in the uptake of constituents from the growth medium
- Inhibiting photosynthesis and respiration
- Adversely affecting the activities of metabolic enzymes.

Although their biochemical mechanisms are not thoroughly understood, these observed disorders are associated with metal-induced phytotoxicity.

For the purpose of establishing standards, phytotoxicity must be defined in quantifiable terms. Abnormal morphological symptoms are precursors of yield reduction, which ultimately is the most important measure of phytotoxicity for agronomic species, since it affects the profitability of producing crops. Yield reduction is used here to define phytotoxicity. The level of yield reduction considered indicative of phytotoxicity is arguable, since spatial and temporal variations in crop yield are often large and may exceed 50 percent. Since it is possible to discern much smaller changes in yield from well-controlled field experiments, reduction of more than 50 percent in yield is here defined as a LOAEL. Ideally, LOAELs should be obtained from long-term field studies in which reduction in yield was assessed subsequent to the application of sewage sludge. Therefore, the literature was reviewed. The relevant studies are summarized in the next section.

5.2.8.4 Long-Term Field Data

The threshold phytotoxic concentration of pollutant in plant tissue, TPC (μg-pollutant/g-plant tissue DW), is the rate associated with yield reduction. Yield reduction from land application of sludge has been demonstrated in the field when one of two conditions exist. In the first condition, sludges with very high metal concentrations were used and sensitive crops suffered phytotoxicity (Williams, 1975; Marks et al., 1980; Chaney et al., 1978; Sheaffer et al., 1981; Berrow and Burridge, 1981). These types of sludges are no longer produced. In the second condition, phytotoxicity occurred when the soil pH was extremely low (because of oxidation and leaching of organic nitrogen and sulfur), and elevated concentrations of ammonium nitrate were present due to high cumulative sludge applications (Lutrick et al., 1982; King and Morris, 1972; Giordano et al., 1975; Williams, 1980; Bolton, 1975). In these studies, increasing the pH completely corrected phytotoxicity.

In natural soil systems, as the pH decreases below 5.5 a rapid, exponential increase in soluble aluminum and manganese occurs. This increase plays havoc with plant growth and development in most species (Pearson and Adams, 1967). Therefore, growers need to maintain soil pH greater than 5.5 for normal crop production in order to prevent phytotoxicity from aluminum and manganese.

In a long-term field experiment, researchers evaluated phytotoxicity in strongly acidic soils containing high cumulative loadings of metals. Four sludge treatments were applied annually from 1968 to 1981, approximately 3,800 kg-zinc/ha; 200 kg-cadmium/ha; 900 kg-copper/ha; 250 kg-nickel/ha; 2,100 kg-chromium/ha; and 750 kg-lead/ha were applied with the maximum rate of sludge (approximately 800 mt DW) (Hinesly and Hansen, 1984). Corn was grown each year on the plots, which varied in pH from 4.9 to 7.2. The year-to-year variation in yield in the control plots (3.5 to 9 mt/ha) made it difficult to summarize field data across years. Thus, yield variations as a result of treatment within years was evaluated.

Phytotoxicity to corn, even under these extreme loading rates and low pH, was not demonstrated. In most years, increased yields were observed on plots treated with sludge as compared to fertilized controls. Since corn is not a sensitive crop, phytotoxicity might have occurred in a more sensitive crop. However in a growth chamber experiment in which swiss chard was grown in the soil/sludge mixture from these plots, the yield of swiss chard was comparable for soil treated with sludge compared to soil not treated with sludge (Mahler and Ryan, 1982). In a companion study, Mahler et al. (1987) evaluated 11 sites where sludge application rates ranged from 100 to 2,000 mt DW/ha; with metal loading rates of 1,200 kg-copper/ha; 1,200 kg-zinc/ha; and 1,000 kg-nickel/ha. They found no difference in the yield of swiss chard or corn between the control soil and the sludge-amended soil.

In a separate field experiment where the maximum rate of sludge application was 410 mt DW/ha, the yield of soybeans and wheat was either unaffected or increased by sludge treatment for all years but one (Hinesly and Hansen, 1984). In 1972, the highest rate of sludge application was associated with a decreased yield of soybeans, which the authors attributed to phosphorous toxicity. However, the pH of the soil was 5.0, and the levels of manganese and zinc were also high, so it is difficult to determine the cause. However, further addition of sludge did not aggravate the situation. Even where twice as much sludge was applied in 1978 as in 1972 and the pH was 5.1, yield was not suppressed. Thus, it is apparent that phytotoxicity from cadmium, copper, chromium, nickel, and zinc is not a dramatic problem even under fairly extreme conditions.

Yield reduction from land application of sludge has only been observed in combination with low soil pH or with sludges containing very high concentrations of metals. The presence of either condition makes the findings irrelevant for setting metal limits for land application of municipal wastewater sewage sludge. Since all the field observations are NOAELs the long-term data from field experiments cannot be used to develop LOAELs.

For this pathway where plants are the target organisms, the endpoint of the analysis is a cumulative reference application rate of pollutant, RP_c (kg-pollutant/ha), which is the amount of the inorganic pollutant that can be applied without phytotoxic effects. Two approaches were used to determine RP_c and the most conservative result was chosen for each metal. In Approach 1, the probability approach, the phytotoxic threshold of corn, a relatively insensitive species, was determined for each of the inorganic pollutants of concern. (See Table 5.2.8-2 for plant species sensitivity.) In Approach 2, the plant tissue concentration associated with potential phytotoxicity in sensitive crops (leafy vegetables) was obtained from the literature. Then the plant response curves (UC) and background concentrations (BC) of pollutants in leafy vegetables from Pathway 1 were utilized to calculate a loading rate associated with the phytotoxic plant tissue concentration.

5.2.8.5 Approach 1: Probability Approach Based on Short-term Experiments

In this approach, RP_c, the reference cumulative application rate of pollutant (kg-pollutant/ha) was derived from the literature. Short-term experiments were utilized to develop a plant concentration of pollutant associated with phytotoxicity (PT_{50}). To establish this association in each plant group an exhaustive search of the scientific literature was conducted, using several computerized databases; and 271 technical journal articles were identified on topics discussing metal accumulation by plants and subsequent phytotoxicity. The information contained in these articles was sorted according to metal (chromium, copper, nickel, and zinc), source of the metal input in the study (inorganic soluble metal salts, metal-spiked sludge, or sludge), metal loadings, culturing methods (hydroponic, pot, or field), soil pH, plant species, metal concentration accumulated in plant tissue, and growth response (deficiency, normal, or phytotoxicity) (see Appendix E). Although most studies were on agronomic plants (e.g., lettuce, corn), several studies included plants not typically cultivated: *Rudbeckia hirta* (black-eyed susan), *Schizachyrium scoparium* (little bluestem), and *Quercus rubra* (red oak). They were no more sensitive than sensitive agronomic plants such as swiss chard and lettuce. Thus, the use of agronomic plant species should provide protection for noncultivated plants, too.

TABLE 5.2.8-2

RELATIVE SENSITIVITY OF CROPS TO SLUDGE-APPLIED HEAVY METALS
(CHANEY AND HUNDEMANN, UNPUBLISHED)[a]

Very Sensitive[b]	Sensitive[c]	Tolerant[d]	Very Tolerant[e]
Chard	Mustard	Cauliflower	Corn
Lettuce	Kale	Cucumber	Sudangrass
Redbeet	Spinach	Zucchini squash	Smooth bromegrass
Carrot	Broccoli	Flatpea	'Merlin' red fescue
Turnip	Radish	Oat	
Peanut	Tomato	Orchardgrass	
Ladino clover	Marigold	Japanese bromegrass	
Alsike clover	Zigzag, Red, Kura and Crimson clover	Switchgrass	
Crownvetch		Red top	
'Arc' alfalfa	Alfalfa	Buffelgrass	
White sweetclover	Korean lespedeza	Tall fescue	
Yellow sweetclover	Sericea lespedeza	Red fescue	
Weeping lovegrass	Blue lupin	Kentucky bluegrass	
Lehman lovegrass	Birdsfoot trefoil		
Deer tongue	Hairy vetch		
	Soybean		
	Snapbean		
	Timothy		
	Colonial bentgrass		
	Perennial ryegrass		
	Creeping bentgrass		

[a]Sassafras sandy loam amended with a highly stabilized and leached digested sludge containing 5300 mg Zn, 2400 mg Cu, 320 mg Ni, 390 mg Mn, and 23 mg Cd/kg dry sludge. At 5 percent sludge, maximum cumulative recommended applications of Zn and Cu are made.
[b]Injured at 10 percent of a high metal sludge at pH 6.5 and at pH 5.5.
[c]Injured at 10 percent of a high metal sludge at pH 5.5, but not at pH 6.5.
[d]Injured at 25 percent high metal sludge at pH 5.5, but not at pH 6.5, and not at 10 percent sludge at pH 5.5 or 6.5.
[e]Not injured even at 25 percent sludge, pH 5.5.

Source: Logan and Chaney, 1983

The cause-and-effect relationship between the metal concentrations in plant tissues and the resulting plant growth retardation was established by pooling data of the same plant species and the same metal from all pertinent studies. Growth retardation was defined as the percentage reduction in the biomass of the total plant compared to that of the untreated control. This methodology assumes that short-term reduction in shoot growth translates into reduced yield at maturity. Further, since data are not stratified by the method of cultivation, this approach implicitly assumes that cultivation does not affect the relationship between the metal concentration in soil and the metal concentration in plant tissue, and subsequent growth reduction.

To ensure that the growth retardation could be attributed only to one metal, short-term (2- to 6-week) laboratory studies were reviewed and data were used only from those studies in which one metal element, usually in the form of soluble metal salt, was added to the growth medium. Shoot weight was used to measure percent growth retardation and by inference, phytotoxicity. Recognizing that plants grown in the field often recover from the phytotoxicity observed in the early stages of growth and suffer no adverse effect at maturity, the phytotoxicity threshold level (PT_{50}) of metal in plant tissue measured in short-term studies was conservatively assumed to equal the concentration associated with phytotoxicity in mature plants. Therefore, the short-term studies were used to establish the phytoxicity threshold—the concentration of each metal in the tissue of each plant group—associated with 50 percent reduction in biomass.

The relationship between the concentration of metal in soil and the associated concentration of metal in plants grown on sludge-amended fields is not adequately modeled by the uptake of metals by plants grown in hydroponic solution or pots to which soluble metal salts have been added. Therefore, the empirical relationship between soil metal loading and the resulting metal concentration in plant tissue was established based on data from sludge/field experiments conducted under various agricultural conditions across the United States. These data are summarized in Appendix F.

Probability analyses were conducted to determine whether application of sewage sludge would result in metal levels exceeding PT_{50} in plant tissue. For each metal, the observed sludge loading rates were divided into loading ranges (e.g., 0 to 100 kg/ha). Assuming the metal concentrations in plants observed at each metal loading range follow a lognormal distribution and that phytotoxicity occurs if the plant tissue concentration exceeds the predetermined phytotoxicity threshold, (the PT_{50} determined by reviewing data from short-term studies) a calculation was made to determine the probability that the metal concentrations in plants grown on soils within a given metal loading range will exceed the phytotoxic threshold.

Once the level of tolerable risk (defined as the probability of exceeding PT_{50}) is selected, an appropriate metal loading limit can be determined. The acceptable probability level (level of tolerable risk) for plant tissue metal concentrations to exceed the phytotoxic threshold was set at 0.01. So it was acceptable to exceed the phytotoxic threshold 1 time out of every 100. Because confidence in the probability calculations increases with more data, the computations were based on corn, which is not a sensitive plant species, but it is the crop most widely grown at land application sites for which there are ample data, making it a logical choice for this analysis.

The following procedure was used to compute the probabilities that corn grown on sludge-treated soils would exceed the phytotoxic threshold.

Assumptions:

- The observations are independent and random.
- Within a metal loading range, the data (metal contents in plant tissue) follow a lognormal distribution.

Procedure:

- Use only data from field investigations where plants were grown on municipal sludge-treated soils.
- Arrange the data (X_i for i = i .... n) according to ascending order of the corresponding metal loading rate.
- Select appropriate loading ranges and divide the data accordingly.
- Calculate probability for each loading range.
- Transform X_i in a loading range to $Y_i = \ln X_i$.

- Calculate the mean (μ) and standard deviation (σ) for Y_i.

$$\mu = \frac{\sum_{i=1}^{n} Y_i}{n} \qquad (1)$$

$$\sigma = \sqrt{\frac{\Sigma(X_i - \mu)^2}{n}} \qquad (2)$$

- Compute the Z parameter for a normal distribution

$$Z = \frac{(Y - \mu)}{\sigma} \qquad (3)$$

Y is the natural logarithmic value of the phytotoxicity threshold (Y = ln PT).

- Probability (P) for metal contents of plant (Y_i) to be less than or equal to the threshold (Y), $Y_i \leq Y$, may be determined by entering the Z value onto a standard normal distribution table.

- The probability for metal content of plant to exceed the threshold is then equal to 1.

- Repeat the computation for each loading range and level of phytotoxicity threshold.

Based on this analysis, the probability of applying sludge at any particular loading rate could be determined. Thus the probability of applying sludge at a loading rate associated with phytoxicity could also be determined. As long as this probability was less than 0.01, the loading rate could be applied without risk of exceeding the phytotoxicity threshold. The entire data set was used to determine the highest loading rate having a less then 0.01 chance of exceeding the tolerance threshold. This loading rate is the allowable loading rate derived by Approach 1.

5.2.8.6 Approach 2: LOAELs for Sensitive Crops

5.2.8.6.1 Equation

In Approach 2 the reference cumulative application rate of pollutant, RP_c (kg/ha), is:

$$RP_c = \frac{TPC - BC}{UC} \qquad (4)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
TPC	=	threshold phytotoxic concentration of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)
BC	=	background concentration of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)
UC	=	uptake slope of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)(kg-pollutant/ha)$^{-1}$.

5.2.8.6.2 Threshold Phytotoxic Concentration, TPC

The TPC, the concentration of pollutant in plant tissue associated with phytotoxicity, is a more sensitive indicator of damage than 50 percent reduction in yield (PT_{50}), which was used in Approach 1. Further, Approach 1 was based on data for corn, which is a species that is not very sensitive to metal in soil. Consequently, applying loading rates based on corn may reduce yield in more sensitive species such as lettuce, bush beans, and swiss chard. This concern prompted a literature search to obtain the concentration in sensitive plant species associated with the lowest observed adverse effect level (LOAEL), which is a more sensitive indicator than yield reduction.

5.2.8.6.3 Background Concentration of Pollutant in Plant Tissue, BC

Background concentrations in plants are calculated by taking the geometric mean of the concentration in each plant group grown in soil to which sewage sludge has not been added (see

Appendix C, Plant Uptake Tables). The background concentrations, by pollutant and plant group, are shown in the input/output table, Table 5.2.8-7.

5.2.8.6.4 Uptake Slope of Pollutant in Plant Tissue, UC

The plant response slope (UC from Pathway 1) for leafy vegetables was utilized to back calculate the soil loading associated with the TPC. (See Section 5.2.1.4.1.2.6 in Agricultural Pathway 1 for a complete discussion of plant uptake of pollutants, UC.) (The data used to calculate the uptake slopes are presented in Appendix C, Plant Uptake Tables.) Uptake is assumed to be linear in all cases, with zero plant concentration when soil concentration is zero. For each study, the plant uptake slopes were calculated by regressing the pollutant concentration in the plant against the pollutant application rate per hectare. Then the studies are allocated to plant groups based on the plants studied. Uptake slopes for each pollutant for each plant group were derived by calculating the geometric mean of uptake slopes from the applicable studies. The uptake slopes for leafy vegetables are shown in the input/output table, Table 5.2.8-7. The plant group leafy vegetables, includes studies on pollutant uptake in such plants as lettuce, swiss chard, cabbage, collard greens, and spinach.

5.2.8.7 Zinc

5.2.8.7.1 Approach 1

Based on data from short-term experiments, the relationship between the concentration of zinc in leaf tissue and the percent growth retardation for corn was fitted by nonlinear regression to either a parabolic or logarithmic function model. Although the data were derived from several sources, they are described reasonably well by these models (R^2 between 0.78-0.85). The zinc concentration in the leaf tissue of corn corresponding to PT_{50} is 1,975 μ-zinc/g-plant tissue DW.

The probability that corn grown on sludge-treated soils would exceed PT_{50} (1,975 μg-zinc/g-plant tissue DW) was computed for 12 loading ranges (see Table 5.2.8-3). An acceptable probability of reaching the tolerance threshold was set at 0.01 (1 chance in 100). At cumulative loadings of less than 50 kg-zinc/ha, the probability of exceeding a tolerance threshold of 1,975 μg zinc/g-plant tissue DW (corresponding to 50 percent growth retardation, PT_{50}) is less than 0.0001. If the cumulative loading rate is increased to 2,500 to 3,500 kg-zinc/ha, the probability that the zinc concentration in the corn leaf would exceed the PT_{50} is still <0.0001. Therefore, based on the PT_{50} at least 3,500 kg-zinc/ha may be added through sludge application without causing a significant phytotoxic effect in corn.

5.2.8.7.2 Approach 2

Because corn is not the most sensitive crop, the approach utilized by the Peer Review Committee (PRC, 1989) was followed for lettuce, one of the most sensitive crops (Logan and Chaney, 1983). In lettuce, the first detectable yield reduction occurs at a foliar tissue concentration of 400 μg-zinc/g-plant tissue DW (Logan and Chaney, 1983); this is the TPC. Substituting the geometric mean of the uptake slopes for zinc uptake in leafy vegetables (0.125 μg-zinc/g-plant tissue DW)(kg-pollutant/ha)$^{-1}$ and the background concentration for zinc in leafy vegetables (46.962 μg-zinc/g-tissue DW) into equation 1 (see Section 5.2.8.3.1), RP_c for zinc is calculated as follows:

$$RP_c = \frac{TPC - BC}{UC} = \frac{400 - 47.0}{0.125} = 2{,}800 \text{ kg-zinc/ha (rounded down to two significant figures)} \qquad (5)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
TPC	=	threshold phytotoxic concentration of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)
BC	=	background crop concentration (μg-pollutant/g-tissue DW)
UC	=	uptake slope of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)(kg-pollutant/ha)$^{-1}$

TABLE 5.2.8-3

PROBABILITY OF ZINC IN CORN GROWN ON SLUDGE-TREATED SOILS EXCEEDING THE PHYTOTOXICITY TOLERANCE THRESHOLD

Zinc Loading Range		Probability of Exceeding Tolerance Treshold
(kg/ha)	Number of Observations	PT_{50} 1,975 μg/g
0	51	<0.0001
0-50	16	<0.0001
50-100	28	<0.0001
100-150	16	<0.0001
150-200	14	<0.0001
200-300	22	<0.0001
300-400	19	<0.0001
400-500	14	<0.0001
500-750	19	<0.0001
750-1,000	8	<0.0001
1,000-1,500	17	<0.0001
1,500-2,500	12	0.0020
2,500-3,500	10	<0.0001

This is within the upper loading limit of the probability approach (2,500 to 3,500 kg-zinc/ha), and therefore appears to be an appropriate limit.

5.2.8.8 Copper

5.2.8.8.1 Approach 1

Although phytotoxicity of copper has been extensively reported, data suitable to delineate the cause-and-effect relationship between concentration of copper in leaf tissue and the extent of retardation of plant growth are sparse. Based on limited data, data for corn indicate a negative dose-response relationship, while data for bush beans and snap beans indicate a positive dose-response relationship. In corn yield was unaffected by plant tissue concentrations up to 40 μg-copper/g-plant tissue DW in a hydroponic study in which cupric sulfate was used, (Lexmond and Vorn, 1981). In a pot experiment in which cupric sulfate salts and spiked sewage sludge were added to soil, the PT_{50} for corn was 7 μg-copper/g-plant tissue DW (MacLean and Dekker, 1978).

The phytotoxic threshold was based on corn, but the discrepancy in data made it difficult to select an appropriate value. According to the diagnostic criteria for plant nutrition and soil fertility, plants containing 7 μg-copper/g-plant tissue DW in the leaf tissue have barely adequate amounts of copper for optimal growth (Bould et al., 1984; Chapman, 1966; Jones and Eck, 1973). Therefore, it is unlikely that copper could have caused the decrease in yield at 7 μg-copper/g-plant tissue DW observed by MacLean and Dekker (1978). Further, most data on more sensitive species indicate that tissue concentrations must exceed 7 μg-copper/g-plant tissue DW for phytotoxicity to occur. Even corn grown on soils not receiving sludge have a 0.59 probability of exceeding 7 μg-copper/g-plant tissue DW. Thus, the data of Lexmond and Vorn (1981) appear to be more appropriate for establishing the copper phytotoxicity threshold for corn. The NOAEL identified by Lexmond and Vorn (1981) (40 μg-copper/g-plant tissue DW) was used as the PT_{50}. The probability that copper levels in plant tissue will exceed this concentration is less than 0.0001 for cumulative loading rates up to 1,550 kg-copper/ha, the highest loading rate reported in the literature (see Table 5.2.8-4). Plants can probably tolerate a higher cumulative

TABLE 5.2.8-4

PROBABILITY OF COPPER IN CORN GROWN IN SLUDGE-TREATED SOILS EXCEEDING THE PHYTOTOXICITY TOLERANCE THRESHOLD

Copper Loading (kg/ha)	Number of Observations	Probability of Exceeding Tolerance Threshold 40 µg/g[a]
0	42	<0.0001
0-100	52	<0.0001
100-200	28	<0.0001
200-300	21	<0.0001
300-400	17	<0.0001
400-500	10	<0.0001
500-1,550	35	<0.0001

[a]Tolerance thresholds of 40 µg/g correspond to the PT_{50} for copper.

limit but the available data are limited, and the upper boundary of the safe loading limit for copper cannot be definitively determined.

5.2.8.8.2 Approach 2

Data were found in the literature on two sensitive species—bush beans and snap beans. In bush beans experiments conducted in hydroponic culture (Cha and Wallace, 1989; Daniels et al., 1972; and Daniels and Struckmeyer, 1973), indicated that the PT_{50} for copper concentration in leaf tissue was 60 μg-copper/g-plant tissue DW. In a hydroponic study in which cupric sulfate was used, yield was unaffected in bush beans in concentrations up to 40 μg-copper/g-plant tissue DW (MacLean and Dekker, 1978).

Yield reductions in snap beans were noted when concentrations in the trifoliate seedlings increased to 30 μg-copper/g-plant tissue DW. For snap beans in a field study where $CuSO_4$ and $Cu(OH)_2$ were applied, severe toxicity was observed at tissue concentrations in excess of 40 μg-copper/g-plant tissue DW (Walsh et al., 1972); this is the TPC. The RP_c was calculated using the TPC for snap beans, and the uptake and background concentration data for leafy vegetables, as shown below:

$$\begin{aligned} RP_c &= \frac{TPC - BC}{UC} \\ &= \frac{40 - 6.72}{0.013} \qquad (6) \\ &= 2{,}500 \text{ kg-copper/ha (rounded down to two significant figures)} \end{aligned}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
TPC	=	threshold phytotoxic concentration of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)
BC	=	background crop concentration (μg-pollutant/g-plant tissue DW)
UC	=	uptake slope of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)(kg-pollutant/ha)$^{-1}$

This is somewhat higher than the results from the probability approach, which yielded 1,550 kg-copper/ha. The more conservative result, 1,550 kg-copper/ha, was chosen as the final result.

5.2.8.9 Chromium and Nickel

5.2.8.9.1 Approach 1

Two sets of data establish the phytotoxicity of corn for chromium and nickel. The data suggest that the metal concentration required for normal growth in plant tissue falls into a relatively narrow range. Plant injuries caused by chromium and nickel rise rapidly, becoming acute as the concentrations of chromium and nickel in leaf tissue exceed the normal growth ranges. The leaf tissue concentrations corresponding to PT_{50} are 3.0 μg-nickel/g-plant tissue DW for nickel and 5.9 μg-chromium/g-plant tissue for chromium. They were identified by interpolating the data points in the most critical concentration region.

The probability that nickel levels in plant tissue will exceed the PT_{50} of 3.0 μg-pollutant/g-plant tissue (in the loading range 0 to 100 kg/ha) is 0.0136 (see Table 5.2.8-5). As the nickel loading increases, however, the concentration of nickel in corn grown on sludge-treated soil decreases. Consequently, as cumulative loadings increase, the probabilities of nickel concentrations in corn leaf exceeding the PT_{50} decrease. (In fact, the probability of exceeding the threshold is smaller for plants grown in sludge-treated soils than in soils not treated with sludge.) When the loading range is increased to 100 to 425 nickel kg/ha, the probability of exceeding the PT_{50} drops to 0.0045. Since this probability should continue to drop as the load increases, phytotoxicity due to nickel probably should not occur under normal agronomic practice. If the maximum loadings used are representative of the upper boundary, 425 kg-nickel/ha can be safely applied without affecting corn yields.

For chromium, the probability of exceeding the PT_{50} (5.9 μg-chromium/g-plant tissue) (in the loading range of 0 to 30 kg/ha) is 0.1190 (see Table 5.2.8-6). As with nickel, the probability decreases as the load increases. When the loading range increases to 100 to 1,000 kg/ha, the

TABLE 5.2.8-5

PROBABILITY OF CORN GROWN IN SLUDGE-TREATED SOILS EXCEEDING THE NICKEL PHYTOTOXICITY THRESHOLD

Loading Range (kg/ha)	Observations	Probability of Exceeding Tolerance Threshold 3.0 μg/g[a]
0	28	0.0427
0-100	116	0.0136
100-425	40	0.0045

[a]Tolerance thresholds of 3.0 μg/g corresponds to the PT_{50} for nickel.

TABLE 5.2.8-6

PROBABILITY OF CORN GROWN ON SLUDGE-TREATED SOILS EXCEEDING THE CHROMIUM PHYTOTOXICITY TOLERANCE THRESHOLD

Loading Range (kg/ha)	Observation	Probability of Exceeding Tolerance Threshold 5.9 μg/g[a]
0-30	9	0.1190
100-1,000	31	0.0721
1,000-3,000	17	0.0188

[a]Tolerance thresholds of 5.0 μg/g corresponds to the PT_{50} for chromium.

probability decreases to 0.0721. At the highest loading range reported in the literature, 1,000 to 3,000 kg/ha, the probability drops to 0.0188. If the maximum loadings are representative of the upper boundary, 3,000 kg-chromium/ha can be safely applied without affecting corn yields.

Approach 2

As with zinc and copper, the Approach 2 was used for nickel. (Approach 2 was not used for chromium as no data were available.) The TPC for nickel occurs at significantly higher tissue concentrations than the PT_{50} (3.0 μg-nickel/g-plant tissue) (Chapman, 1966; Adriano, 1987). The typical concentration of nickel in plant tissue is approximately 10 μg-nickel/g-plant tissue DW. For healthy plants grown on serpentine soils, the nickel concentration of leaf tissue in corn may reach up to 40 to 50 μg-nickel/g-plant tissue DW (Wallace et al. 1977). These data indicate that the PT_{50} for nickel is unlikely to be 3.0 μg-nickel/g-plant tissue. Therefore, the lower limit of 40 μg-nickel/g-plant tissue for corn was used as the TPC for nickel based on the data from Wallace et al. (1977). This TPC for corn was used with the uptake and background concentration data for leafy vegetables, as shown below:

$$RP_c = \frac{TPC - BC}{UC} = \frac{40 - 1.69}{0.016} \qquad (7)$$

$$= 2{,}400 \text{ kg-nickel/ha (rounded down to two significant figures)}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
TPC	=	threshold phytotoxic concentration of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)
BC	=	background crop concentration (μg-pollutant/g-plant tissue DW)
UC	=	uptake slope of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)(kg-pollutant/ha)$^{-1}$

This result is much greater than the upper limits of the probability approach (425 kg-nickel/ha) so the latter was used as the RP_c.

5.2.8.7 Input and Output Values

Table 5.2.8-7 summarizes the limits calculated from Approach 1, the probability approach. The input and output data for the PRC approach, Approach 2, are summarized in Table 5.2.8-8. The limits for this pathway are the lower of Approach 1 and 2, and they are summarized in Table 5.2.8-9.

TABLE 5.2.8-7

PROBABILITY ANALYSIS RESULTS FOR AGRICULTURAL PATHWAY 8

Pollutant	RPc
Chromium	3000
Copper	1500
Nickel	420
Zinc	3500

Note:
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

TABLE 5.2.8-8

INPUT AND OUTPUT VALUES FROM RISK ASSESSMENT FOR AGRICULTURAL PATHWAY 8

Pollutant	TPC	BC	UC	RPc
Chromium				N/A
Copper	40	6.715	0.013	2500
Nickel	40	1.687	0.016	2400
Zinc	400	46.962	0.125	2800

Notes:
Totals may not add due to rounding.
TPC = threshold phytotoxic concentration of pollutant (μg-pollutant/g-plant tissue DW)
BC = background concentration of pollutant in plant tissue (μg-pollutant/g-plant tisue DW)
UC = uptake slope of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

TABLE 5.2.8-9

LIMITING RESULT FOR AGRICULTURAL PATHWAY 8

Pollutant	RPc
Chromium	3000
Copper	1500
Nickel	420
Zinc	2800

Note:
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

5.2.9 Agricultural Pathway 9 (Toxicity to Soil Organisms)

5.2.9.1 Description of Pathway

Sewage Sludge → Soil → Soil Organisms

This pathway assesses the application of sewage sludge to the land, and the ingestion by soil organisms of sewage sludge incorporated into soil.

5.2.9.2 Pollutants Evaluated

As discussed in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results* (EPA, 1985c), all pollutants except copper were screened out during the initial evaluation. Since the original screening was completed, no information indicates that this decision should be altered. Therefore, copper was the only pollutant assessed for this pathway.

5.2.9.3 Highly Exposed Individual

The analysis developed for this pathway is designed to assist in setting pollutant loading limits that protect the most exposed/most sensitive soil organisms. No field data currently indicate the level at which copper becomes toxic to soil organisms. However, Hartenstein et al. (1980c) routinely produced earthworms in soil containing sewage sludge, thereby providing a limited source of data. There is no evidence that earthworms are the most sensitive species; however, because of the lack of data for other species, the criteria for this pathway have been set using earthworm data. As will be evident later, the criteria are based on a No Observed Adverse Effect Level (NOAEL) for the earthworm, *Eisenia foetida*.

5.2.9.4 Algorithm Development

Since only copper is analyzed in this pathway, this section will not contain a separate section for organics.

5.2.9.4.1 Equations

Because the diet of soil organisms is soil, threshold pollutant intake levels are in terms of soil concentration. Rather than equating these data to an input such as a reference dose (e.g., in Pathway 1, sewage sludge → soil → plant → human), the data are equated directly to the reference concentration of pollutant in soil, RLC (μg-pollutant/g-soil DW). Thus, the only calculation that is required is to consider the background concentration of pollutant in soil, BS (μg-pollutant/g-soil DW), and to convert the soil concentration to the reference cumulative application rate of pollutant, RP_c (kg-pollutant/ha), as in the following equation:

$$RP_c = (RLC - BS) \cdot MS \cdot 10^{-9} \quad (1)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
BS	=	background concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)

5.2.9.4.2 Input Parameters

Reference Cumulative Application Rate of Pollutant in Soil, RP_c

Since the diet of soil organisms is soil, the allowable concentration of pollutant in their diet is given as the reference cumulative application rate of pollutant in soil.

Reference Concentration of Pollutant in Soil, RLC

At the present time, there are no data from sewage sludge studies conducted in the field that indicate the level at which copper becomes toxic to soil organisms. However, studies carried out by Hartenstein et al. (1980b) indicate that *E. foetida* feeding on nonamended waste-activated sewage sludge with copper concentrations of up to 1,500 μg-copper/g-sewage sludge DW showed no toxic effect over a feeding period exceeding 4 months. Given this information, sewage sludge-amended soils with a copper concentration of 1,500 μg-copper/g-soil DW can be considered as not causing any adverse effects.

Background Concentration of Pollutant in Soil, BS

The background soil concentration, BS, is the sum of the natural background concentration and the background pollution. The background concentration of copper in soil is 19.0 μg-copper/g-soil DW (see Table 5.2.1-5 in Agricultural Pathway 1).

Assumed Mass of Dry Soil in Upper 15 cm, MS

Sewage sludge is usually incorporated into the upper layer of soil is by disking or chisel-plowing surface-applied sludge, or by directly injecting it into the soil. Sludge is mixed into the soil to a depth of 15 cm, and the soil has a bulk density of 1.33 g/cm^3. Therefore, the dry mass of this upper layer of soil is $2 \cdot 10^9$ g DW/ha. (See Section 5.2.1.4.2.2.12.)

5.2.9.5 Input and Output Values

The criteria for this pathway are based on a No Observed Adverse Effect Level (NOAEL) for the earthworm, *Eisenia foetida*. Many studies have shown that copper is toxic to earthworms. However, most of these studies report the use of ionic copper salts, which are not typical of chemical conditions in sewage sludge-amended agricultural soils. Bound metals, as found in sewage sludge, are far less bioavailable than their ionic counterparts. The data for ionic salts are thus not suitable for determining intake by soil organisms. A study by Van Rhee (1977) was considered unacceptable, because it considered the application of copper-containing fungicides; the reported decline in population could have been due to any number of toxic compounds in the fungicide formulation.

Table 5.2.9-1 summarizes input and output values for this pathway.

5.2.9.6 Sample Calculations

Substituting the input parameters into equation 1, the reference application rate of pollutant, RP_c, for copper is calculated to be:

$$\begin{aligned} RP_c &= (RLC - BS) \cdot MS \cdot 10^{-9} \\ &= (1500 - 19.0) \cdot (2 \times 10^9) \cdot 10^{-9} \qquad (2) \\ &= 2900 \text{ kg-copper/ha (rounded down to two significant figures)} \end{aligned}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
BS	=	background concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9}	=	conversion factor (kg/μg)

5.2.9.7 Toxicity of Cadmium to Soil Organisms

Starting in the 1980s, studies by McGrath, Brookes, Giller, and their associates identified apparent adverse effects of sludge-applied heavy metals on the soil microbial biomass and on the *Rhizobium* strain that forms nodules in white clover and related species (Brookes and McGrath, 1984; Brookes et al., 1986b; Giller et al., 1989; McGrath, Brookes, and Giller, 1988; McGrath, Hirsch, and Giller, 1988). In a long-term experiment (the Woburn Market Garden Experiment), about 766 kg/ha of sewage sludge having moderately high metal concentrations (averages for metals were about 3,000μg-zinc/g; 1,300 μg-copper/g; 200 μg-nickel/g; 100 μg-cadmium/g; 900 μg-lead/g; and 1,000 μg-chromium/g; McGrath, 1984) was applied to field plots of vegetable crops on a sandy soil from 1942 to 1961. The soil microbe populations were examined more than 20 years after the final application of sludge. No legume had been grown since 1942. The researchers found that the application of sludge caused selection in these soils of a strain of *Rhizobium leguminosarum*, biovar *trifolli*, which formed nodules on white clover. However, the nodules were ineffective *Rhizobium* strain, and no phytotoxicity occurred to the white clover if nitrogen fertilizer was added to the pots. Further, inoculation of the plots with an effective strain allowed normal nodulation of white clover, although the population of effective strains in the soil declined after inoculation. Further, *Rhizobia* for other legume species have not been found to be inhibited by soil metals at levels below those that caused significant phytotoxicity (soybean: Heckman et al., 1986, 1987a, 1987b; Kinkle et al., 1987; and alfalfa: Angle and Chaney, 1991; Angle et al., 1988; El-Aziz et al., 1991).

In addition to the inhibiting of nitrogen fixation by this strain of *Rhizobium*, nitrogen fixation by blue-green algae was also inhibited on these plots and on some other high-metal soils (Brookes, McGrath, and Heijnen, 1986a). Nitrogen fixation by free-living bacteria was also inhibited on high-metal mine soils (Rother, Millbank, and Thornton, 1982a).

Many other studies have failed to show inhibition of microbial activity on sludge-amended soils (e.g., Minnich and McBride, 1986; Rother, Millbank, and Thornton, 1982b). Angle and coworkers have conducted some work on evaluating the metal tolerance of U.S. strains of white clover *Rhizobium*. These strains were found to be less sensitive than the strains described by McGrath (Angle et al., unpublished). Angle has found effective strains in nodules of white and red clover growing in farmers' fields in the vicinity of Palmerton, Pennsylvania, zinc smelter, in soils with higher zinc and cadmium levels than in the Woburn study. It is apparent that these studies on white clover *Rhizobium* versus other soil microbes, including other strains of white clover *Rhizobium*, conflict as to the toxicity of soil metals to soil microbes. In attempting to explain the adverse effects of applying sludge on the Woburn plots, it has been hypothesized that the finding may have resulted from the very light texture of the soil, the somewhat high level of metals in the sludge used, and/or the long period of exposure without reinoculation of the soil. When sowing white clover, the simple inoculation of seeds (a common agronomic practice) allows normal nodulation and nitrogen fixation. Further research is clearly needed in order to locate the causative agent and to determine whether the observations represent an adverse effect.

TABLE 5.2.9-1

INPUT AND OUTPUT VALUES FOR AGRICULTURAL PATHWAY 9

Pollutant	RLC	BS	MS
Copper	1500	19.0	2E+09

RPc
2900

Notes:
Totals may not add due to rounding.
RLC = reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
BS = background concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

5.2.10 Agricultural Pathway 10 (Toxicity to Soil Organism Predators)

5.2.10.1 Pathway Description

Sewage Sludge → Soil → Soil Organisms → Soil Organism Predator

This pathway involves the application of sewage sludge to the land, the ingestion of sewage sludge by soil organisms, and the consumption of soil organisms by predators. The sewage sludge may, or may not, be incorporated into the soil.

5.2.10.2 Pollutants Evaluated

As discussed in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results* (EPA, 1985), all pollutants except cadmium, lead, zinc, and aldrin/dieldrin were screened out during the initial evaluation. Since the original screening was completed, additional information indicates that zinc and aldrin/dieldrin are no longer a concern to predators of soil organisms but that PCBs are. Therefore the three pollutants evaluated for this pathway are: cadmium, lead, and PCBs.

5.2.10.3 Highly Exposed Individual

The analysis developed for this pathway is designed to assist in setting pollutant loading limits that protect the most sensitive/most exposed predator of soil organisms. Of concern in this pathway, therefore, are sensitive wildlife that consume soil organisms that have been feeding on sewage sludge-amended soil. No predator of soil organisms has been singled out as being particularly sensitive to cadmium and lead. The literature indicates, however, that insectivorous small mammals (shrews and moles) are the best sentinels for both inorganic and organic contaminants, and they are thus assumed to be the most exposed. This is not the case for PCBs, where there is clear evidence that chickens are the most sensitive species.

5.2.10.4 Algorithm Development

5.2.10.4.1 Inorganics

Equations

As with a number of other pathways, it is necessary to determine a reference concentration of pollutant in soil, RLC (μg-pollutant/g-soil DW), such that the reference application rate of pollutant, RP (kg-pollutant/ha), can be calculated for each pollutant.

To calculate RLC, it is necessary to consider the following four factors: the threshold pollutant intake level, TPI (μg-pollutant/g-diet DW); the fraction of diet considered to be soil organisms, FD (g-soil organisms DW/g-diet DW); a bioavailability factor, BAV (unitless); and a bioaccumulation factor, BACC (μg-pollutant/g-soil organisms DW)(μg-pollutant/g-soil DW)$^{-1}$.

The simplest way to conceptualize the development of the algorithm is to consider that the product of soil concentration, the BAV, and the BACC, is the concentration of pollutant in soil organisms that is consumed by a predator:

$$\begin{matrix}\text{soil organism}\\ \text{pollutant concentration}\end{matrix} = \begin{matrix}\text{soil}\\ \text{concentration}\end{matrix} \cdot BAV \cdot BACC \qquad (1)$$

When this equation is rearranged to solve for the soil concentration, the following equation is derived:

$$\begin{matrix}\text{soil}\\ \text{concentration}\end{matrix} = \frac{\begin{matrix}\text{soil organism}\\ \text{pollutant concentration}\end{matrix}}{BAV \cdot BACC} \qquad (2)$$

This equation, however, assumes that 100 percent of the diet of the predator is contaminated soil organisms. This is not a suitable assumption for chronic exposure. Including the soil organisms fraction of the diet, and replacing the soil organisms pollutant concentration with a maximum allowable pollutant concentration in the diet (i.e., TPI), the pollutant soil concentration now represents RLC. The equation thus becomes:

$$RLC = \frac{TPI}{FD \cdot BAV \cdot BACC} \quad (3)$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
TPI	=	threshold pollutant intake level (μg-pollutant/g-diet DW)
FD	=	fraction of diet considered to be soil organisms (g-soil organisms DW/g-diet DW)
BAV	=	bioavailability factor (unitless)
BACC	=	bioaccumulation factor (μg-pollutant/g-soil organisms DW)(μg-pollutant/g-soil DW)$^{-1}$

For inorganics, a reference cumulative application rate of pollutant, RP_c is then calculated:

$$RP_c = (RLC - BS) \cdot MS \cdot 10^{-9} \quad (4)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
BS	=	background concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9}	=	conversion factor (kg/μg)

Input Parameters

Threshold Pollutant Intake Level, TPI. For each pollutant, the available literature was reviewed to estimate the maximum intake of a pollutant that would not cause a toxic effect to a most sensitive/most exposed predator. Unlike the reference intake of pollutant in humans, which is expressed as an allowable daily intake of pollutant (e.g., in Pathway 5, sewage sludge → soil → animal → human), the TPI in this pathway is referenced in the literature as an allowable concentration of pollutant in the predator's diet.

Fraction of Diet Considered to be Soil Organisms, FD. For all the pollutants analyzed in this pathway, birds and mammals are at risk if they consume earthworms/soil as a significant part of their diet. Exposed wildlife species are not presumed to consume earthworms as 100 percent their of diet. This level might be appropriate for considering acute exposure, but it is not appropriate for chronic exposure to a toxicant. After considering maximum chronic consumption of earthworms by wildlife (see review by MacDonald, 1983), 33 percent was selected as the fraction of earthworms in the predator's diet.

Bioavailability Factor, BAV. Pollutants in sewage sludge/soil mixtures are not 100 percent bioavailable for uptake by organisms. Complex mechanisms bind chemicals within the sludge/soil matrix, thus restricting uptake. In addition, pollutants ingested as part of the diet can further restrict uptake. For example, water-borne soluble lead salts have high bioavailability: fasting humans can absorb as much as 80 percent of soluble lead salts. However, when consumed with food, the absorption of lead salts is decreased to about 5 percent (James et al., 1985). This finding can be applied to other species. When wildlife consumes earthworms, the earthworms already have soil in their guts. Due to the adsorptive properties of soil, the bioavailability of the pollutants in the soil can be substantially decreased.

Bioaccumulation Factor, BACC. In previous pathways, uptake from one medium to another was considered through the use of an uptake slope. The bioaccumulation factor serves a similar purpose, because it describes the concentration that will be present in earthworms because of a specific concentration of bioavailable pollutant in the soil.

Background Concentration of Pollutant in Soil, BS. For the purposes of this analysis, inorganics are considered never to be lost from the soil. The application of sewage sludge to the land is therefore limited by the cumulative total permissible concentration of pollutants. Where background levels are significant compared to the maximum concentration of allowable pollutant concentration, the allowable pollutant loading from sewage sludge will be noticeably reduced.

Assumed Mass of Dry Soil in Upper 15 cm, MS. This analysis assumes that sewage sludge is mixed into the soil to a depth of 15 cm and that the soil has a bulk density of 1.33 g/cm^3. Therefore, the dry mass of this upper layer of soil is $2 \cdot 10^9$ g/ha. (See Section 5.2.1.4.2.2.1.2 for a complete discussion of this variable.)

Input and Output Values

Cadmium. Research has demonstrated that soil cadmium constitutes a risk to birds and mammals that ingest earthworms as a significant part of their diet, because earthworms bioaccumulate cadmium to concentrations above that in the soils in which they live. Although some crops absorb cadmium to high concentrations, there is no evidence that herbivorous wildlife are at higher risk from eating crops growing on cadmium-rich soils amended with sewage sludge than are omnivorous wildlife eating earthworms living in the soils.

Beyer et al. (1991) noted that a number of studies have found earthworms with high cadmium levels, because sewage sludge has been used to amend soil. It is not uncommon to find up to 100 μg-cadmium/g-earthworm DW for soil-purged worms.

Threshold Pollutant Intake Level, TPI. The threshold pollutant intake level for cadmium equals 100 μg-cadmium/g-diet DW. Because of the short biological half-life of cadmium in rodents and birds, 100 μg-cadmium/g-diet DW can be tolerated by sensitive individuals. It should be noted that a threshold cadmium intake level of 0.5 μg-cadmium/g-diet was recommended by the National Academy of Science (NAS, 1980); however, this TPI was based on cadmium concentration in liver and kidney consumed by humans. It is therefore not appropriate for this analysis.

Bioavailability Factor, BAV. In studies in which pigs were fed sludge-cadmium and salt-cadmium, levels of cadmium in pig kidney indicated that a reasonable figure for bioavailability of cadmium in sludge is 21.4 percent (Osuna et al., 1981). In studies of the effects of chemically feeding earthworms to Japanese quail, Stoewsand et al. (1986) and Pimental et al. (1984) found no adverse effects in feeding 60 percent control or 50 percent cadmium-enriched earthworms (dry weight basis). This suggests that worm cadmium has low bioavailability. The bioavailability factor for cadmium is thus assumed to be 21.4 percent.

Bioaccumulation Factor, BACC. The bioaccumulation factor for cadmium equals 10 (μg-cadmium/g-soil organisms DW)(μg-cadmium/g-soil DW)$^{-1}$ for soil-purged earthworms. The bioaccumulation ratio of worm:soil for cadmium is about 10 for purged worms, and about 5 to 6 for nonpurged worms. Nonpurged worms contained 45 percent soil (DW basis), so the worm tissue provides about 93 percent of the cadmium, while soil provides about 7 percent. Since the predator of soil organisms consumes nonpurged earthworms, the bioaccumulation factor is set at 6, based on these data.

Calculations For Standard Methodology

Substituting the relevant input parameters into Equation 3, the reference concentration of pollutant in soil (RLC) for cadmium is calculated to be:

$$RLC = \frac{TPI}{FD \bullet BAV \bullet BACC} = \frac{100}{0.33 \bullet 0.214 \bullet 6} = 236\ \mu g\text{-cadmium/g-soil DW} \quad (5)$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
TPI	=	threshold pollutant intake level (μg-pollutant/g-diet DW)
FD	=	fraction of diet considered to be soil organisms (g-soil organisms DW/g-diet DW)
BAV	=	bioavailability factor (unitless)
BACC	=	bioaccumulation factor (μg-pollutant/g-soil organisms DW)(μg-pollutant/g-soil DW)$^{-1}$

Substituting the relevant input parameters and this value for RLC into Equation 4, the reference cumulative application rate of pollutant, RP_c for cadmium is calculated to be:

$$RP_c = (RLC - BS) \bullet MS \bullet 10^{-9} \quad (6)$$

$$RP_c = (236 - 0.2) \bullet 2 \bullet 10^{9} \bullet 10^{-9} \quad (7)$$

$$RP_c = 470\,\text{kg-cadmium/ha (rounded down to 2 significant figures)} \quad (8)$$

where:

RP_c	=	reference application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
BS	=	background concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9}	=	conversion factor (kg/μg)

Table 5.2.10-1 summarizes input and output values for the standard methodology for calculating RP_c for cadmium.

Alternative Approaches for Cadmium

Approach 1. Among other studies reporting a correlation between use of sewage sludge to amend soil and toxicity to wildlife species, Hegstrom and West (1989) looked at tissue metals in several species of small mammals from forest sites that received sludge applications. They collected insectivorous Towbridge's shrews (*Sorex towbridgii*), shrew-moles (*Neurotrichus gibbsi*), and granivorous deer mice (*Peromyscus maniculatus*) from sludge-treated and control sites at Pack Forest, where Seattle sludge had been surface-applied at 51 mt/ha several years earlier. Heavy metals were higher in tissues of Towbridge's shrews from the sludge-treated areas than from control sites, and accumulations were much higher than in the other species studied.

A second set of shrews was collected from forested sites that had received much higher cumulative applications in order to identify any kidney or liver lesions that might result from sludge use. Despite the high levels of heavy metals found in the tissues of Towbridge's shrews (mean = 126 mg cadmium/kg DW), no lesions were found in their organs. Of course, this concentration is far below the level expected to cause the first health effect in mammals (696 mg cadmium/kg whole kidney DW, see below).

To estimate transfer from soil to kidney as a basis for limiting applications of sewage sludge containing cadmium, the following calculations were made: 51 mt-sewage sludge DW/ha was applied to forest sites where shrews were sampled. The sewage sludge applied in the studies contained 50 ppm cadmium; 2,000 ppm zinc; 900 ppm copper; and 1,200 ppm lead. This

TABLE 5.2.10-1

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR AGRICULTURAL PATHWAY 10, FROM STANDARD METHODOLOGY

Pollutant	TPI	FD	BAV	BACC	BS	MS		RLC
Cadmium	100	0.33	0.214	6	0.2	2E+09		236.0
Lead	150	0.33	0.4	0.45	11.0	2E+09		2525.3

RPc
470
5000

Notes:

Totals may not add due to rounding.

TPI = threshold pollutant intake level (μg-pollutant/g-diet DW)

FD = fraction of diet assumed to be soil biota (g-soil biota DW/g-diet DW)

BAV = bioavailability factor (unitless)

BACC = bioaccumulation factor (μg-pollutant/g-soil biota DW)/(μg-pollutant/g-soil DW)

BS = background concentration of pollutant in soil (μg-pollutant/g-soil DW)

MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)

RLC = reference concentration of pollutant in soil (μg-pollutant/g-soil DW)

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

application resulted in 2.55 kg-cadmium/ha being applied. If the sewage sludge were mixed with the 15-cm plow layer, the resulting soil concentration would be 1.26 μg-cadmium/g-soil DW. But in this forest, the sewage sludge is not mixed with the plow layer; it is applied to the litter layer, which lies on the soil surface. Because the sewage sludge is not mixed with the soil plow layer, and because the litter layer has a low bulk density (approximately one-half that of soil) due to its organic nature, the mixed zone of litter and sludge is probably about 50 percent sewage sludge or greater (dry matter basis). Further, these soils are strongly acidic, which prevents earthworms from living in them. Thus, other macrofauna such as arthropods are involved in degrading the litter layer. In the absence of earthworms, these organisms are the prey for shrews. The arthropods reside in the surface litter layer which consists of approximately 50 percent sewage sludge. On an area-wide basis this is equivalent to 1,000 mt/ha in the soil-sludge mixture, not to the 50 mt/ha applied, because, as discussed above, the density of litter is one-half that of soil. Thus, the litter-sludge mixture contains 25.5 μg-cadmium/g-soil DW. The cadmium concentrations in whole shrew kidneys were 33 μg-cadmium/g-whole kidney DW (25-43, N=66) on sludged plots, and 9 μg-cadmium/g-whole kidney DW (8-10, N=50) on equivalent forested control sites. The increment in kidney cadmium due to sludge utilization was 24 μg-cadmium/g-whole kidney DW.

The concentration of cadmium in the whole kidney has to be related to the potential toxic level in the kidney cortex (200 μg-cadmium/g-kidney cortex FW). This value is considered a measure of the lowest cadmium concentration that can cause tubular dysfunction in sensitive individuals for many animal species. To relate the toxicity level of cadmium in the kidney cortex to the concentration in the whole kidney the conversion factor of 1.25 for whole kidney-cadmium concentration to kidney cortex-cadmium concentration for humans (Svartengren et al., 1986) is used:

$$\frac{200\ \mu\text{g-cadmium}}{\text{g-kidney cortex FW}} \bullet \frac{1}{1.25}\left(\frac{\mu\text{g-cadmium}}{\text{g-whole kidney}}\right)\left(\frac{\text{g-kidney cortex}}{\mu\text{g-cadmium}}\right) = \frac{160\ \mu\text{g-cadmium}}{\text{g-whole kidney FW}} \qquad (9)$$

To complete this calculation, kidney-FW must be converted to kidney-DW. In the absence of specific data for shrews, the arithmetic mean of the solids content for beef, calf, hog, and lamb kidney (USDA, 1975), 23 percent solids, was used. Thus:

$$\frac{160\ \mu g\text{-cadmium}}{g\text{-whole kidney FW}} \cdot \frac{1.00\ gFW}{0.23\ gDW} = \frac{696\ \mu g\text{-cadmium}}{g\text{-whole kidney DW}} \qquad (10)$$

Then the slope for (shrew kidney-cadmium):(soil-cadmium)[(24 μg-cadmium/g-whole kidney-DW)/(25.5 μg-cadmium/g-soil DW) = 0.941] is divided into the tolerable concentration of cadmium in the whole kidney on a dry-weight basis:

$$\frac{696\ \mu g\text{-cadmium/g-whole kidney DW}}{941(\mu g\text{-cadmium/g-whole kidney DW})(\mu g\text{-cadmium/g-soil DW})^{-1}} \qquad (11)$$

$$= 740\ \mu g\text{-cadmium/g-soil DW}$$

Thus, a concentration of 740 μg-cadmium/g-soil DW is the level at which sensitive shrews would be expected to display the first effect (on kidney function) of dietary cadmium exposure. A value for RP_c is calculated by using this value for RLC in equation 4:

$$RP_c = (RLC - BS) \cdot MS \cdot 10^{-9} \qquad (12)$$

$$RP_c = (740 - 0.2) \cdot 2 \cdot 10^{9} \cdot 10^{-9} \qquad (13)$$

$$RP_c = 1{,}400\ \text{kg-cadmium/ha (rounded down to 2 significant figures)} \qquad (14)$$

where:

RP_c	=	reference application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
BS	=	background concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ (g-soil DW/ha) = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)

Approach 2. A limited number of shrew-moles was sampled by Hegstrom and West (1989) on plots having received similar applications of sewage sludge. The kidney from the control animals contained 5 μg-cadmium/g-whole kidney DW, while the animals exposed to sewage sludge had 65 (33-128) μg-cadmium/g-whole kidney DW in their kidneys. Dividing the slope for (shrew kidney-cadmium):(soil-cadmium)[(60 μg-cadmium/g-whole kidney DW)/(25.5 μg-

cadmium/g-soil DW) = 2.35] into the tolerable concentration of cadmium in whole kidney on a dry-weight basis calculated in Approach 1, gives:

$$\frac{696\ \mu g\text{-cadmium/g-whole kidney DW}}{2.35(\mu g\text{-cadmium/g-whole kidney DW})(\mu g\text{-cadmium/g-soil DW})^{-1}} \tag{15}$$

$$= 296\ \mu g\text{-cadmium/g-soil DW}$$

Thus, a concentration of 296 μg-cadmium/g-soil DW is the level at which sensitive shrews would be expected to display the first effect on kidney function due to dietary cadmium exposure. A value for RP_c is calculated by using this value for RLC in equation 4:

$$RP_c = (RLC - BS) \bullet MS \bullet 10^{-9} \tag{16}$$

$$RP_c = (296 - 0.2) \bullet 2 \bullet 10^{9} \bullet 10^{-9} \tag{17}$$

$$RP_c = 590\,\text{kg-cadmium/ha (rounded down to 2 significant figures)} \tag{18}$$

where:

RP_c	=	reference application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
BS	=	background concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \bullet 10^9$ (g-soil DW/ha) = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)

Approach 3. Moles are another mammal that consume large quantities of earthworms. Ma (1987) examined cadmium transfer to mole kidney at four sites in the vicinity of a zinc smelter where the soils were contaminated with both zinc and cadmium. Earthworms were present in the soils. Soil cadmium reached 9.2 mg/kg, and zinc reached 1,015 mg/kg at the most contaminated site. The increase in kidney cadmium was 25.7 (μg-cadmium/g-whole kidney DW)(μg-cadmium/g-soil DW)$^{-1}$ (mean of 31.2, 28.0, and 17.8 for sites 1, 2, and 3). Dividing this slope into the tolerable concentration of cadmium in whole kidney on a dry-weight basis calculated in Approach 1, gives:

$$25.7(\mu g\text{-cadmium/g-whole kidney DW})(\mu g\text{-cadmium/g-soil DW})^{-1} \qquad (19)$$

$$=27.1\ \mu g\text{-cadmium/g-soil DW}$$

Thus, a concentration of 27.1 μg-cadmium/g-soil DW is the level at which sensitive moles would be expected to display the first effect of dietary cadmium exposure on kidney function. A value for RP_c is calculated by using this value for RLC in equation 4:

$$RP_c = (RLC - BS) \bullet MS \bullet 10^{-9} \qquad (20)$$

$$RP = (27.1 - 0.2) \bullet 2 \bullet 10^{9} \bullet 10^{-9} \qquad (21)$$

$$RP_c = 53\,\text{kg-cadmium/ha (rounded down to 2 significant figures)} \qquad (22)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
BS	=	background concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \bullet 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)

This study also requires some further comments. Ma sampled at a depth of 10 cm, thereby analyzing the mineral soil below the litter layer, ignoring the collection of smelter emissions in the organic layer on top of the mineral layer. In the vicinity of U.S. smelters, the surface organic layer contains much higher cadmium concentrations than the subsurface mineral layer. For example, in an untilled profile 2.5 km distant from a 90-year-old zinc smelter in Palmerton, Pennsylvania, the 0 to 2 cm organic layer contained 68.9 μg-cadmium/g, while the 2 to 10 cm mineral soil contained only 12 μg-cadmium/g-soil DW; thus the concentration of cadmium in the surface layer was 5.7 times higher than in the underlying subsurface layer (Chaney et al., 1984). Given this information, the 53 kg-cadmium/ha calculated from Ma's data could easily have been 306 kg-cadmium/ha if the correct soil material had been sampled. Nevertheless, because it is uncertain what Ma's results might have been had sampling been conducted differently, the limit for this approach will remain at 53 kg-cadmium/ha.

Table 5.2.10-2 summarizes the outputs for the various approaches for cadmium and indicates the limiting result.

Lead

Since crops do not bioaccumulate lead to any greater concentration than the soils in which they grow, it has been concluded that, if lead in soil represents a risk to birds and mammals, it will be a risk to those that ingest earthworms/soil as a significant part of their diet. There is little evidence of significant bioaccumulation of lead by soil organisms to concentrations above that in the soils in which they live. Thus, it seems unlikely that soil lead moves through this food chain.

Threshold Pollutant Intake Level, TPI. The threshold pollutant intake level for lead equals 150 μg-lead/g-diet DW. Beyer et al. (1991) noted that birds that consume earthworms can tolerate approximately 150 μg-lead/g-diet DW.

Bioavailability Factor, BAV. The bioavailability factor for lead is estimated as 0.4. Chaney et al. (1989) estimated that soil-lead bioavailability ranged from 20 percent at the 1,000 ppm soil-lead level to 70 percent at the 10,000 ppm soil-lead level. Concentrations in sewage sludge would typically be at the lower end of this scale, but (to remain conservative) a bioavailability factor of 40 percent was used.

Bioaccumulation Factor, BACC. The bioaccumulation factor for lead is estimated as 0.45 (μg-lead/g-soil organisms DW)(μg-lead/g-soil DW)$^{-1}$. No bioaccumulation of lead was found in worms; the ratio of lead in nonpurged worms to lead in soil was 0.45.

Input and output values for lead are summarized in Table 5.2.10-1.

Lead—Other Studies. Other studies conducted using rodents exposed to high lead soils indicate that 2,500 μg-lead/g-soil DW may be too high for rodents that live in the field. In particular, Haschek et al. (1979) found histopathologic lesions in several species sampled in old

TABLE 5.2.10-2

OUTPUT VALUES FOR CADMIUM FOR AGRICULTURAL PATHWAY 10

	RPc
Standard methodology	470
Alternative Approach 1	1400
Alternative Approach 2	590
Alternative Approach 3	53
Limiting result	53

Note:
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

orchards that had been sprayed with lead arsenate pesticides over many years. Soil-lead levels in 0-8 cm depth samples for two orchards studied were 1,342 and 6,326 ppm (Elfving et al., 1978). Considering that soil residues of lead from orchard sprays are largely in the surface 2 cm, however, the surface soil lead may have been considerably higher than these reported values. It may be fair to multiply the reported concentrations by 4 to account for dilution of the surface (0 to 2 cm) soil lead in the depth samples. Multiplication by 4 would make both the soil concentrations higher than that determined above for the criteria limit. Compared to these data, therefore, the criteria limit is conservative.

Ma (1989) found excessive kidney lead in shrews living on a shooting range that contained very high soil-lead levels. No limit can be estimated from the data.

In conclusion, no studies have been found in which wildlife exhibited toxic effects at levels at, or below, the criteria limit determined.

5.2.10.4.2 Organics

Equations

The development of the equations is the same for organics as for inorganics until the final equation that calculates application rate of pollutants. The reason for the difference is that organics typically degrade in soil, and therefore a reference annual application rate, RP_a is calculated from:

$$RP_a = RLC \cdot MS \cdot 10^{-9} \cdot [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1} \quad (23)$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	($2 \cdot 10^9$ g-soil DW/ha) = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application (yr)

Input Parameters

Loss Rate Constant, k (yr^{-1}). For a complete discussion of this variable, see Section 5.2.1.4.2.2.13 in Pathway 1. The values used for k are presented in Table 5.2.1-14, also in Pathway 1.

Input and Output Values

Polychlorinated Biphenyls, PCBs

In order to estimate the maximum soil concentration of PCBs that protects the most sensitive/most exposed predators of soil organisms, the available literature was reviewed. Research has demonstrated that lipophilic organic compounds, such as PCBs, constitute a risk to birds and mammals that ingest earthworms as a significant part of their diet, because earthworms bioaccumulate these compounds to concentrations above that in the soils in which they live.

Threshold Pollutant Intake Level, TPI. The threshold pollutant intake level for PCB equals 5 μg-PCB/g-diet DW. Beyer et al. (1991) noted that 5 μg PCB/g-diet DW in chronic diets of chickens was the lowest concentration at which toxicity was observed in mammals or birds (Lillie et al., 1974; see also Eisler, 1986; McLane and Hughes, 1980; Peakall, 1986; Peakall and Peakall, 1973; Platonow and Reinhart, 1973; Tori and Peterle, 1983). Other data from earthworm-consuming wildlife did not indicate injury until the PCB concentration in the diet greatly exceeded 5 μg/g (Eisler, 1986).

Bioavailability Factor, BAV. For the purposes of this analysis, the conservative assumption was made that the bioavailability of PCBs is 100 percent.

Bioaccumulation Factor, BACC. The bioaccumulation factor for PCB, calculated as the geometric mean from a number of studies, equals 3.69 (μg-PCB/g-soil organisms DW)(μg-PCB/g-soil DW)$^{-1}$ (see Beyer et al., 1991; Kreis et al., 1987; Tarradellas et al., 1982; and Marquenie et al., 1987).

Loss Rate Constant, k. Based on aerobic degradation rate in soil, the loss rate constant for PCB is estimated as 0.063 yr^{-1} (see Table 5.2.1-14).

Years of Application, n. As with all degradation equations in this analysis, the equation is carried out to 100 years.

Input and Output Values

Table 5.2.10-3 summarizes the input and output values for PCBs for this pathway.

Sample Calculations

Substituting the relevant input parameters into Equation 3, the reference concentration of pollutant in soil, RLC, for PCBs is calculated:

$$RLC = \frac{TPI}{FD \bullet BAV \bullet BACC} \qquad (24)$$

$$RLC = \frac{5}{0.33 \bullet 1 \bullet 3.69} \qquad (25)$$

$$RLC = 4.106\ \mu g\text{-}PCBs/g\text{-}soil\ DW \qquad (26)$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
TPI	=	threshold pollutant intake level (μg-pollutant/g-diet DW)
FD	=	fraction of diet considered to be soil organisms (g-soil organisms DW/g-diet DW)
BAV	=	bioavailability factor (unitless)
BACC	=	bioaccumulation factor (μg-pollutant/g-soil organisms DW)(μg-pollutant/g-soil DW)$^{-1}$

TABLE 5.2.10-3

INPUT AND OUTPUT VALUES
FOR AGRICULTURAL PATHWAY 10

Pollutant	TPI	FD	BAV	BACC	BS	MS	k	RLC
PCBs	5	0.33	1	3.69	0.2	2E+09	0.064	4.106

RPa
0.50

Notes:

Totals may not add due to rounding.

TPI = threshold pollutant intake level (µg-pollutant/g-diet DW)

FD = fraction of diet assumed to be soil biota (g-soil biota DW/g-diet DW)

BAV = bioavailability factor (unitless)

BACC = bioaccumulation factor (µg-pollutant/g-soil biota DW)/(µg-pollutant/g-soil DW)

BS = background concentration of pollutant in soil (µg-pollutant/g-soil DW)

MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)

k = loss rate constant (yr)^(-1)

RLC = reference concentration of pollutant in soil (µg-pollutant/g-soil DW)

RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

Substituting the relevant input parameters and this value for RLC into Equation 5, the reference annual application rate of pollutant, RP_a, for PCBs is calculated to be:

$$RP_a = RLC \bullet MS \bullet 10^{-9} \bullet [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1} \qquad (27)$$

$$RP_a = 4.06 \bullet 2x10^9 \bullet 10^{-9} \bullet [1 + e^{-0.0633} + e^{-2 \bullet 0.0633} + ... + e^{(1-100) \bullet 0.0633}]^{-1} \qquad (28)$$

$$RP_a = 4.06 \bullet 2 \bullet [0.0643]^{-1} \text{ kg-PCBs/ha} \bullet \text{yr} \qquad (29)$$

$$RP_a = 0.50 \text{ kg-PCBs/ha} \bullet \text{yr} \qquad (30)$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	($2 \bullet 10^9$ g-soil DW/ha) = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application (yr)

5.2.11 Agricultural Pathway 11 (Human Exposure Through Inhalation of Particulates Resuspended by Tilling Sewage Sludge)

5.2.11.1 Description of Pathway

Sewage Sludge → Soil → Airborne Dust → Human

This pathway evaluates the impact of particles that have been resuspended by the tilling dewatered sewage sludge into the soil. The particles are inhaled by a tractor operator.

5.2.11.2 Pollutants of Concern

Table 5.2.11-1 lists the organic and inorganic compounds assessed by this pathway.

5.2.11.3 Highly Exposed Individual (HEI)

The HEI for this pathway is the tractor driver tilling the field. It is assumed that the distance from the driver to the soil surface is 1 meter. It is also assumed that this HEI will not be exposed to more than 10 mg/m^3 of total dust. For dust levels at or above this level, the American Conference of Governmental Industrial Hygienists (ACGIH) recommends that individuals work within a closed cab.

5.2.11.4 Algorithm Development

5.2.11.4.1 Equations

The reference application rate of pollutant, RP (kg-pollutant/ha), is calculated as a function of the 10 mg/m^3 total dust concentration, the National Institute of Occupational Safety and Health (NIOSH) recommended standard for each contaminant (see Table 5.2.11-2), and the mass of soil into which sewage sludge is incorporated. The calculations are based on the

TABLE 5.2.11-1

POLLUTANTS OF CONCERN FOR AGRICULTURAL PATHWAY 11

Inorganics	Organics
Arsenic	Aldrin/Dieldrin
Cadmium	DDT/DDE/DDD
Chromium	Polychlorinated biphenyls (PCBs)
Lead	
Mercury	
Nickel	

TABLE 5.2.11-2

NIOSH RECOMMENDED OCCUPATIONAL HEALTH STANDARDS

Pollutant	Standard ($\mu g/m^3$)
Aldrin/Dieldrin	150 TWA[a]
Arsenic	2 (15 min)
Cadmium	40 TWA
Chromium	25 TWA
DDT	500 TWA
Lead	50 (8 hr) TWA
Mercury	50 TWA
Nickel	15 TWA
PCBs	1 TWA

[a]Time-weighted average (TWA) in NIOSH recommendations is based on a 10-hour exposure unless otherwise noted.

assumption that sewage sludge is incorporated to a depth of 15 cm, and that the sewage sludge and soil are well mixed. This assumption results in the following relationship among the maximum concentration of pollutant in dust, the NIOSH standard, and the ACGIH recommendation for maximum total dust exposure:

$$MDC = \frac{NIOSH}{TDA} \cdot 10^{6} \qquad (1)$$

where:

MDC	=	Maximum concentration of pollutant in dust (mg-pollutant/g-soil DW)
NIOSH	=	NIOSH recommended health standard (mg/m^3)
TDA	=	ACGIH total dust standard = (10 mg/m^3 soil)
10^6	=	conversion factor (mg/g)

NIOSH/TDA gives the ratio of the total pollutant to total dust such that, at the TDA limit, the maximum quantity of pollutant in the dust is the NIOSH limit. For example, if TDA = 15 mg/m^3, and if DDT has a NIOSH standard of 0.5 mg/m^3, the concentration can be no more than 0.5/15, or 1/30th of the total dust. RP is then calculated by multiplying MDC by the mass of dry soil in the upper 15 cm, thus:

$$RP = MDC \cdot MS \cdot 10^{-9} \qquad (2)$$

where:

RP	=	Reference application rate of pollutant (kg-pollutant/ha)
MDC	=	Maximum concentration of pollutant in dust (mg-pollutant/g-soil DW)
MS	=	Assumed mass of dry soil in upper 15 cm ($2 \cdot 10^9$ g-soil DW/ha)
10^{-9}	=	conversion factor (kg/mg)

5.2.11.4.2 Input Parameters

NIOSH Health Standard

The NIOSH values given in Table 5.2.11-2 were selected to determine the maximum allowable concentration of pollutant in sewage sludge. These concentrations in sewage sludge do not result in violations of the occupational health standards.

ACGIH Total Dust Standard, TDA

ACGIH recommends a limit of 10 mg/m^3 as the total dust exposure to the worker. At higher dust levels, it recommends use of an enclosed cab to prevent exposure of the worker to excessive dust levels.

5.2.11.5 Input and Output Values

Table 5.2.11-3 summarizes the NIOSH values and calculated RP outputs for each pollutant.

5.2.11.6 Sample Calculations

Following are sample calculations for aldrin/dieldrin:

$$MDC = 0.15 \cdot \frac{1}{10} \cdot 10^6 \quad (3)$$

$$MDC = 15{,}000 \text{ mg-pollutant/kg-soil DW} \quad (4)$$

$$RP = 15{,}000 \cdot 2 \cdot 10^9 \cdot 10^{-9} \quad (5)$$

$$RP = 30{,}000 \text{ kg-pollutant/ha} \quad (6)$$

TABLE 5.2.11-3

INPUT AND OUTPUT VALUES FOR AGRICULTURAL PATHWAY 11

Pollutant	NIOSH Std.	TDA	MS		MDC	RPc
Arsenic	0.002	10	2E+09		200	400
Cadmium	0.040	10	2E+09		4000	8000
Chromium	0.025	10	2E+09		2500	5000
Lead	0.050	10	2E+09		5000	10000
Mercury	0.050	10	2E+09		5000	10000
Nickel	0.015	10	2E+09		1500	3000
Aldrin/Dieldrin	0.150	10	2E+09		15000	30000
DDT	0.500	10	2E+09		50000	100000
PCBs	0.001	10	2E+09		100	200

Notes:
NIOSH standard is a time weighted average (TWA) based on 10 hour exposure, except for arsenic and lead where TWA is based on 15 minutes and 8 hours, respectively.
Totals may not add due to rounding.
NIOSH Std. =NIOSH recommended health standard (mg/m^3)
TDA = ACGIH total dust standard (mg/m^3-soil)
MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
MDC = maximum concentration of pollutant in dust (µg-pollutant/g-soil DW)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

5.2.12 Agricultural Pathway 12 (Human Toxicity from Ingestion of Contaminated Surface Water and Fish)

5.2.12.1 Description of Pathway

Sewage Sludge → Soil → Surface Water → Human

Pathway 12 evaluates the effects on humans of applying sewage sludge to the land. The effects occur when soil erodes and contaminates surface water. Humans are assumed to drink 2 liters/per day of water and to eat 0.04 kg/day of fish from the contaminated water.

5.2.12.2 Pollutants Evaluated

All of the pollutants of concern were evaluated; they are listed in Table 5.2.12-1.

5.2.12.3 Highly Exposed Individual

The Highly Exposed Individual (HEI) for Pathway 12 is assumed to eat 0.04 kg/day of fish and to drink 2 liters/per day of water from surface water contaminated with pollutants eroded from sewage sludge-amended soils.

5.2.12.4 Algorithm Development

Pollutants are lost from soil by erosion, which releases pollutants into surface water; by volatilization into air; by leaching into ground water; and by degradation. Degradation is not further evaluated here because the pollutants no longer pose a hazard once they have degraded. The remaining three processes are treated as three separate pathways: Pathway 12 (surface water), Pathway 13 (air), and Pathway 14 (ground water).

TABLE 5.2.12-1

POLLUTANTS EVALUATED FOR AGRICULTURAL PATHWAY 12

Inorganics	Organics
Arsenic	Benzene
Cadmium	Benzo(a)pyrene
Chromium	Bis(2-ethylhexyl)phthalate
Copper	Chlordane
Lead	DDT/DDD/DDE
Mercury	Lindane
Nickel	n-Nitrosodimethylamine
	Polychlorinated biphenyls (PCBs)
	Toxaphene
	Trichloroethylene

While the reference application rates are derived separately for these three pathways, the calculations begin with the mass balance calculations, which partition pollutant loss from the sludge management area (SMA) to surface water, to air, and to ground water. The calculations are integrated so that pollutant mass is conserved. The results are then used in calculating the reference application rate for each pollutant of concern for Pathways 12, 13, and 14.

For organic pollutants, the methodology is designed to derive reference application rates such that sewage sludge can be applied indefinitely without exceeding reference concentrations in water or air. It is based on the worst-case assumption that equilibrium may eventually be reached between the annual loading of pollutant to a site and the total annual loss of pollutant through all competing loss processes. This equilibrium and accumulation of pollutant in soil are discussed in Appendix G. Based on that predicted equilibrium and the partitioning of pollutant among loss processes, the maximum annual reference application rate of pollutant (kg-pollutant/ha•yr) is calculated for the surface water pathway.

For metals, equilibrium is not necessarily achieved. The reference application rates are expressed as cumulative loadings of pollutant (kg-pollutant/ha). The concentration of metals in soil on the site is expected to increase with repeated applications until metal concentrations reach maximum allowable levels. The practice of applying sewage sludge to land is then discontinued. The reference application rates for surface water are based on the maximum predicted average concentration of pollutant in surface water over 70 years.

For both metals and organic pollutants, the approach to deriving the reference application rate consists of four steps:

- Preparing a mass balance of pollutant loss, i.e., calculating the relative rates at which pollutant is removed from the site by each of four competing loss processes (erosion, leaching, volatilization, and degradation).
- Determining the reference concentration of pollutant in the medium.
- Determining the pollutant concentration in the medium resulting from a unit loading (kg-pollutant/ha) of sewage sludge at the site.

- Deriving reference application rates by dividing the reference concentration in the medium by the concentration predicted per unit loading or per sewage sludge concentration.

5.2.12.4.1 Mass Balance

Losses of pollutant through leaching, volatilization, erosion, and degradation are assumed to be first-order with respect to the residual concentration of the pollutant in treated soil. Mass balance calculations begin with estimating of loss coefficients for each of these competing loss processes.

Pollutant Loss to Erosion

Annual losses to erosion are calculated based on an average rate of soil loss (8.5 mt/ha•yr) derived by USDA for agricultural land (USDA, 1987). If pollutant is evenly incorporated into the mixing zone, annual loss of pollutant from this layer is described by the following first-order loss process:

$$K_{ero} = \frac{d_{ero}}{d_i} \tag{1}$$

where:

K_{ero}	=	loss rate coefficient for erosion (yr^{-1})
d_{ero}	=	depth of soil eroded from site each year (m/yr)
d_i	=	depth of incorporation for sewage sludge (m, equivalent to kg/m^2 for a unit concentration of the pollutant in treated soil)

Pollutant Loss to Volatilization

For organic pollutants, estimates of volatile emissions are based on equations provided by Hwang and Falco (1986). After minor changes in units and names of variable from the original version, the primary equation is:

$$Na = \frac{2\,t_e\,\theta_e\,D_{ei}\,C_a}{\sqrt{\pi\,\alpha_i\,t_e}} \qquad (2)$$

where:

Na	=	total emissions from the soil surface over time interval t_e (kg/m^2)
t_e	=	duration of emissions (sec)
θ_e	=	effective porosity of soil (unitless)
D_{ei}	=	intermediate variable to be defined below (m^2/sec)
C_a	=	vapor concentration of pollutant in air-filled pore space of treated soil (kg/m^3)
α_i	=	intermediate variable to be defined below (m^2/sec)

Certain of the variables used in Equation 2 are further defined below:

$$D_{ei} = 10^{-4}\,D_{ca}\,\theta_e^{1/3} \qquad (3)$$

where:

D_{ei}	=	intermediate variable for Equation 2 (m^2/sec)
10^{-4}	=	conversion factor (m^2) (cm^2)$^{-1}$
D_{ca}	=	the molecular diffusivity of pollutant vapor in air (cm^2/sec)
θ_e	=	effective porosity of soil (unitless)

Hwang and Falco estimate C_a with the relation:

$$C_a = \frac{41\,H}{KD\,C_s} \qquad (4)$$

where:

C_a	=	vapor concentration of pollutant in air-filled pore space of treated soil (kg/m^3)
41	=	conversion factor (m^3/m^3) (atm-m^3/mol)$^{-1}$ at approximately 298 K
H	=	Henry's Law constant for the pollutant (atm•m^3/mol)
KD	=	equilibrium partition coefficient for the pollutant in soil (m^3/kg)
C_s	=	concentration of adsorbed pollutant in treated soil (kg/kg)

Of interest for these calculations is the relationship between the total concentration of pollutant in treated soil (in dissolved, adsorbed, or vapor phase) and the concentration in vapor phase within the soil's pore space. As discussed in Appendix H, this relationship can be described by:

$$C_a = \frac{C_t}{\left(\frac{BD\,KD}{\dot{H}}\right) + \left(\frac{\theta_w}{\dot{H}}\right) + \theta_a} \tag{5}$$

where:

C_a	=	vapor concentration of pollutant in air-filled pore space of treated soil (kg/m^3)
C_t	=	total concentration of pollutant in treated soil (kg/m^3)
BD	=	bulk density of soil in mixing zone (kg/m^3)
KD	=	equilibrium partition coefficient for the pollutant in soil (m^3/kg)
$\dot{H}$	=	nondimensional Henry's Law constant for the pollutant
θ_w	=	water-filled porosity of soil (unitless)
θ_a	=	air-filled porosity of soil (unitless)

The nondimensional Henry's Law constant is defined as:

$$\dot{H} = \frac{H}{RT} \tag{6}$$

and:

$\dot{H}$	=	nondimensional Henry's Law constant for the pollutant
H	=	Henry's Law constant for the pollutant ($atm \cdot m^3/mol$)
R	=	ideal gas constant (8.21×10^{-5} $atm \cdot m^3/K \cdot mol$)
T	=	temperature (K)

Other variables used in Equation 2 are:

$$\alpha_i = \frac{D_{ei}}{1 + \kappa S} \tag{7}$$

where:

α_i	=	intermediate variable for Equation 2 (m^2/sec)
D_{ei}	=	intermediate variable for Equation 2 (m^2/sec)
κ	=	intermediate variable for Equation 2 (unitless)
S	=	intermediate variable for Equation 2 (unitless)

and where:

$$\kappa = \frac{\rho_{ss} KD}{\dot{H}} \tag{8}$$

where:

κ	=	intermediate variable for Equation 2 (unitless)
ρ_{ss}	=	particle density of sewage sludge-soil mixture (kg/m^3)
KD	=	equilibrium partition coefficient for the pollutant in soil (m^3/kg)
$\dot{H}$	=	nondimensional Henry's Law constant for the pollutant

and where:

$$S = \frac{1-\theta_e}{\theta_e} \tag{9}$$

where:

S	=	intermediate variable for Equation 2 (unitless)
θ_e	=	effective porosity of soil (unitless)

These equations provide an estimate of total emissions from an uncovered layer of contaminated soil as a function of time and of the initial concentration of pollutant. As is evident from Equation 2, however, the process described is not first-order with respect to pollutant concentration. For consistency with methods used to estimate losses for other pathways, Equation 2 is evaluated for t_e equal to 1 year, and the results are used to estimate a loss coefficient for approximating the loss process as exponential with respect to time. Losses predicted for the first year are divided into the total mass of pollutant in soil to estimate the approximate fraction of available pollutant lost per unit of time. For a unit concentration (1 kg/m^3) of the pollutant in soil, the mass of pollutant beneath 1 square meter of soil surface (kg/m^2) is equal to the volume of treated soil beneath a square meter of surface (m^3 per m^2), which is equal to the depth of incorporation (m). The estimated loss rate (kg/m^2•yr) is converted to a comparable comparable first-order loss coefficient (yr^{-1}) as:

$$K_{vol} \approx -\ln\left(1 - \frac{Na_y}{d_i\, C_t}\right) \tag{10}$$

where:

K_{vol}	=	loss rate coefficient for volatilization, used to approximate loss function described by Equation 2 (yr^{-1})
Na_y	=	emissions from the soil surface in first year ($kg/m^2 \cdot yr$)
d_i	=	depth of incorporation for sewage sludge (m, equivalent to kg/m^2 for a unit concentration of the pollutant in treated soil)
C_t	=	total concentration of pollutant in treated soil ($kg \cdot pollutant/m^3$)

Because Equation 2 was derived by assuming the column of contaminated soil is of infinite depth, it can predict loss greater than 100 percent within a year for a relatively shallow layer of treated soil and a relatively volatile pollutant. For such cases, Equation 10 cannot be evaluated, and the rate coefficient is estimated from predicted emissions in the first second:

$$K_{vol} \approx -3.2 \times 10^7 \ln\left(1 - \frac{Na_s}{d_i}\right) \tag{11}$$

where:

K_{vol}	=	loss rate coefficient for volatilization, used to approximate loss function described by Equation 2 (yr^{-1})
3.2×10^7	=	conversion factor (sec) $(yr)^{-1}$
Na_s	=	emissions from the soil surface in first second ($kg/m^2 \cdot sec$)
d_i	=	depth of incorporation for sewage sludge (m, equivalent to kg/m^2 for a unit concentration of the pollutant in treated soil)

Pollutant Loss to Leaching

Appendices H and I describe the derivation of a first-order coefficient for losses to leaching. This coefficient is calculated as:

$$K_{lec} = \frac{NR}{(BD\,KD + \theta_w + \dot{H}\,\theta_a)\,d_i} \tag{12}$$

where:

K_{lec}	=	loss rate coefficient for leaching (yr^{-1})
NR	=	annual recharge to ground water beneath the SMA (m/yr)
BD	=	bulk density of soil in mixing zone (kg/m^3)
KD	=	equilibrium partition coefficient for the pollutant in soil (m^3/kg)
θ_w	=	water-filled porosity of soil (unitless)

H	=	nondimensional Henry's Law constant for the pollutant
θ_a	=	air-filled porosity of soil (unitless)
d_i	=	depth to which sewage sludge is incorporated into soil (m)

Individual Loss Processes as Fraction of Total Loss

These three loss rate coefficients are combined with an estimated loss coefficient for degradation of the pollutant in treated soil (K_{deg}), obtained from the scientific literature (see Appendix J), to yield a coefficient for the total rate at which the pollutant is lost from soil:

$$K_{tot} = K_{lec} + K_{vol} + K_{ero} + K_{deg} \tag{13}$$

where:

K_{tot}	=	total loss rate for the pollutant in treated soil (yr^{-1})
K_{lec}	=	loss rate coefficient for leaching (yr^{-1})
K_{vol}	=	loss rate coefficient for volatilization (yr^{-1})
K_{ero}	=	loss rate coefficient for erosion (yr^{-1})
K_{deg}	=	loss rate coefficient for degradation (yr^{-1})

The ratio of each individual coefficient to the total then describes the fraction of pollutant loss caused by each individual process:

$$f_{lec} = \frac{K_{lec}}{K_{tot}} \quad f_{vol} = \frac{K_{vol}}{K_{tot}} \quad f_{ero} = \frac{K_{ero}}{K_{tot}} \quad f_{deg} = \frac{K_{deg}}{K_{tot}} \tag{14}$$

where:

f_{lec}	=	fraction of total loss caused by leaching (unitless)
K_{lec}	=	loss rate coefficient for leaching (yr^{-1})
K_{tot}	=	total loss rate for the pollutant in treated soil (yr^{-1})
f_{vol}	=	fraction of total loss caused by volatilization (unitless)
K_{vol}	=	loss rate coefficient for volatilization (yr^{-1})
f_{ero}	=	fraction of total loss caused by erosion (unitless)
K_{ero}	=	loss rate coefficient for erosion (yr^{-1})
f_{deg}	=	fraction of total loss caused by degradation (unitless)
K_{deg}	=	loss rate coefficient for degradation (yr^{-1})

5.2.12.4.2 Calculating the Reference Application Rate

For carcinogenic pollutants, the calculations begin by using the human cancer potency to calculate a reference intake:

$$RI = \frac{RL}{q_1^*} \tag{15}$$

where:

RI	=	reference intake for carcinogen (mg/kg•day)
RL	=	risk level (risk of developing cancer per lifetime of exposure)
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$

For noncarcinogenic pollutants, the reference intake is equal to the oral reference dose (RfD) established by the U.S. EPA, minus total background intake from sources other than sewage sludge.

This reference intake is used to calculate a reference concentration of the pollutant in surface water. The HEI is assumed to be exposed through ingesting both contaminated fish and contaminated water:

$$EXP_{sw} = \frac{C_{sw}\ BCF\ FM\ P_f\ I_f + C_{sw}\ I_w}{BW} \tag{16}$$

where:

EXP_{sw}	=	dose of pollutant received through surface water pathway (mg/kg•day)
C_{sw}	=	concentration of pollutant in surface water (mg/l)
BCF	=	pollutant-specific bioconcentration factor (l/kg)
FM	=	pollutant-specific food chain multiplier (unitless)
P_f	=	ratio of pollutant concentration in the edible portion of fish to concentration in whole fish (unitless)
I_f	=	daily consumption of fish (kg/day)
I_w	=	daily consumption of water (l/day)
BW	=	body weight (kg)

To derive a reference water concentration for the pollutant in surface water, RI is substituted for EXP_{sw} and RC_{sw} is substituted for C_{sw}. After rearranging,

$$RC_{sw} = \frac{RI\ BW}{BCF\ FM\ P_f\ I_f + I_w} \qquad (17)$$

where:

RC_{sw}	=	reference water concentration for surface water (mg/l)
RI	=	reference intake for carcinogen (mg/kg•day)
BW	=	body weight (kg)
BCF	=	pollutant-specific bioconcentration factor (l/kg)
FM	=	pollutant-specific food chain multiplier (unitless)
P_f	=	ratio of pollutant concentration in the edible portion of fish to concentration in whole fish (unitless)
I_f	=	daily consumption of fish (kg/day)
I_w	=	daily consumption of water (l/day)

Where acute or chronic freshwater criteria for pollutants have been determined for aquatic life, the smaller of these two values and of the value calculated above is used as the reference water concentration.

Concentrations of pollutant in surface water must be related to concentrations in eroded soil. Once the eroded soil enters the stream, the pollutant partitions between the solid and the liquid compartments in the stream. The concentration of pollutant in water is related to the concentration of pollutant in the eroded soil entering the stream as:

$$C_{sw} = \frac{C_{sed}}{KD_{sw} + \left(\frac{P_l}{P_s}\right)\left(\frac{1}{\rho_w}\right)} \qquad (18)$$

where:

C_{sw}	=	concentration of pollutant in surface water (mg/l)
C_{sed}	=	dry weight concentration of pollutant in eroded soil (mg/kg)
KD_{sw}	=	partitioning coefficient between solids and liquids within the stream (l/kg)
P_l	=	percent liquid in the water column (unitless, by mass)
P_s	=	percent solids in the water column (unitless, by mass)
ρ_w	=	density of water (kg/l)

For metals, a partition coefficient for the pollutant is derived by using an equation from U.S. EPA (1982c):

$$KD_{sw} = \alpha TSS^{\beta} \tag{19}$$

where:

KD_{sw}	=	partition coefficient between solids and liquids within the stream (l/kg)
α, β	=	pollutant-specific empirical constants
TSS	=	total suspended solids content of the stream (mg/l)

The dimensionless ratio P_l / P_s is calculated as:

$$\frac{P_l}{P_s} \approx \frac{\rho_w}{TSS\ 10^{-6}} \tag{20}$$

where:

P_l	=	percent liquid in the water column (unitless, by mass)
P_s	=	percent solids in the water column (unitless, by mass)
ρ_w	=	density of water (kg/l)
TSS	=	total suspended solids content of the stream (mg/l)
10^{-6}	=	conversion factor (kg) $(mg)^{-1}$

The reference dry-weight concentration of pollutant in eroded soil (RC_{sed}) can be derived by substituting RC_{sw} for C_{sw} in Equation 18 and rearranging,

$$RC_{sed} = RC_{sw}\left[KD_{sw} + \left(\frac{P_l}{P_s}\right)\left(\frac{1}{\rho_w}\right)\right] \tag{21}$$

where:

RC_{sed}	=	reference concentration of pollutant for soil eroding into stream (mg/kg)
RC_{sw}	=	reference water concentration for surface water (mg/l)
KD_{sw}	=	partition coefficient between solids and liquids within the stream (l/kg)
P_l	=	percent liquid in the water column (unitless, by mass)
P_s	=	percent solids in the water column (unitless, by mass)
ρ_w	=	density of water (kg/l)

The next step is to determine how eroded soil from the sludge management area (SMA) is diluted by soil from the (untreated) remainder of the watershed. A dilution factor describes the fraction of the stream's sediment originating in the SMA:

$$DF = \frac{A_{sma}\ ME_{sma}\ S_{sma}}{(A_{sma}\ ME_{sma}\ S_{sma}) + (A_{ws} - A_{sma})\ ME_{ws}\ S_{ws}} \tag{22}$$

where:

DF = dilution factor (unitless)
A_{sma} = area affected by sewage-sludge management (ha)
ME_{sma} = estimated rate of soil loss for the SMA (kg/ha•yr)
S_{sma} = sediment delivery ratio for the SMA (unitless)
A_{ws} = area of the watershed (ha)
ME_{ws} = estimated rate of soil loss for the watershed (kg/ha•yr)
S_{ws} = sediment delivery ratio for the watershed (unitless)

The sediment delivery ratio for the SMA is calculated with the following empirical relationship for delivery of eroded soil from the SMA to the stream (Mills et al., 1982):

$$S_{sma} = 0.77\ (L_{sma})^{-0.22} \tag{23}$$

where:

S_{sma} = sediment delivery ratio for the SMA (unitless)
0.77 = empirical constant
L_{sma} = distance between the SMA and the receiving water body (m)
0.22 = empirical constant

The sediment delivery ratio for the watershed is calculated as (Vanoni, 1975):

$$S_{ws} = 0.872\ (A_{ws})^{-0.125} \tag{24}$$

where:

S_{ws} = sediment delivery ratio for the watershed (unitless)
0.872 = empirical constant
A_{ws} = area of the watershed (ha)
0.125 = empirical constant

If it is assumed that the rates of soil erosion from the SMA and from the remainder of the watershed are the same, ME_{ws} and ME_{sma} cancel from the equation, and the dilution factor can be calculated as:

$$DF = \frac{A_{sma}\ S_{sma}}{A_{sma}\ S_{sma} + (A_{ws} - A_{sma})S_{ws}} \tag{25}$$

where:

DF = dilution factor (unitless)
A_{sma} = area affected by sewage sludge management (ha)
S_{sma} = sediment delivery ratio for the SMA (unitless)
A_{ws} = area of the watershed (ha)
S_{ws} = sediment delivery ratio for the watershed (unitless)

If all pollutants in stream sediment are assumed to originate in the SMA, this same fraction also describes the ratio between the average concentration of pollutant in sediment entering the stream and the average concentration in soil eroding from the SMA:

$$C_{sed} = DF\ C_{sma} \tag{26}$$

or:

$$C_{sma} = \frac{C_{sed}}{DF} \tag{27}$$

where:

C_{sed} = dry-weight concentration of pollutant in eroded soil for (mg/kg)
DF = dilution factor (unitless)
C_{sma} = average pollutant concentration for soil eroding from the SMA (mg/kg)

RC_{sed} is substituted for C_{sed} and RC_{sma} for C_{sma} to derive a reference soil concentration for soil eroding from the SMA:

$$RC_{sma} = \frac{RC_{sed}}{DF} \tag{28}$$

where:

RC_{sma} = reference pollutant concentration for soil eroding from the SMA (mg/kg)
RC_{sed} = reference concentration of pollutant for soil eroding into stream (mg/kg)
DF = dilution factor (unitless)

The final step of the calculation is to use earlier results from mass balance calculations to relate the maximum allowable concentration of pollutant in eroded soil to the reference annual pollutant loading for the SMA. This step uses the estimated fraction of annual pollutant loss attributable to erosion and the mass of soil lost from the site each year. For organic pollutants,

$$RP_a = \frac{RC_{sma} \cdot ME_{sma} \cdot 10^{-6}}{f_{ero}} \quad (29)$$

where:

RP_a	=	reference annual application rate of pollutant (kg/ha•yr)
RC_{sma}	=	reference pollutant concentration in soil eroding from the SMA (mg/kg)
ME_{sma}	=	estimated rate of soil loss for the SMA (kg/ha•yr)
10^{-6}	=	conversion factor (kg) $(mg)^{-1}$
f_{ero}	=	fraction of total loss caused by erosion (unitless)

Annual soil erosion from the site can be calculated from the bulk density of treated soil and the estimated average rate of loss of agricultural soil in the U.S:

$$ME_{sma} = 10{,}000\ d_e\ BD \quad (30)$$

where:

ME_{sma}	=	estimated rate of soil loss for the SMA (kg/ha•yr)
10,000	=	conversion factor (kg/m^2) $(kg/ha)^{-1}$
d_e	=	depth of soil eroded from site each year (m/yr)
BD	=	bulk density of soil in mixing zone (kg/m^3)

The calculations differ slightly for metals, for which criteria are expressed as cumulative loadings of pollutant. As discussed in Appendix G, concentrations of metals in the soil are assumed to increase over time as pollutant accumulates in the soil, and, after the last application of sewage sludge, to decrease through erosion. Since the HEI's exposure continues for a lifetime, criteria for metals are calculated based on maximum estimated average losses of pollutant through erosion for a period equal to the human life expectancy.

For the years in which sewage sludge is applied, pollutant is assumed to be loaded once per year, and lost at a continuous first-order rate (K_{tot}). The outcome of combined loading and losses (for an arbitrary loading of 1 kg/ha•yr) is calculated numerically as:

$$M_t = 0 \qquad (t=0)$$
$$M_t = (M_{t-1} + 1)\ e^{-K_{tot}} \qquad (1 \le t \le N) \quad (31)$$

where:

M_t = mass of pollutant in soil at end of year t (kg/ha)
K_{tot} = total loss rate coefficient for the pollutant in treated soil (yr^{-1})
N = number of years in which sewage sludge is applied

After the last application, no further loading of pollutant to soil takes place, but pollutant continues to be depleted:

$$M_{LS} = M_N e^{-K_{tot}(LS-N)} \qquad (32)$$

where:

M_{LS} = mass of pollutant at end of individual lifetime (kg/ha)
M_N = mass of pollutant after N applications (kg/ha)
K_{tot} = total loss rate coefficient for the pollutant in treated soil (yr^{-1})
LS = human life expectancy (yr)
N = number of years in which sewage sludge is applied

The fraction of total cumulative loading lost in the human lifespan is independent of the assumed application rate, and can be calculated as:

$$f_{ls} = 1 - \frac{M_{LS}}{N \cdot 1} \qquad (33)$$

where:

f_{ls} = fraction of total cumulative loading lost in human lifetime (unitless)
M_{LS} = mass of pollutant at end of individual lifetime (kg/ha)
N = number of years in which sewage sludge is applied
1 = sewage sludge application rate (kg/ha•yr)

The final step in the calculations for a metal is identical to the corresponding step for organic pollutants, except that the mass of soil eroding per year is multiplied by the life expectancy to calculate the total mass of soil lost in that period. This value is multiplied by the reference soil concentration and converted to kilograms to yield the maximum mass of pollutant allowed to be lost to erosion per hectare of site, which is adjusted for the fraction of total loading lost to erosion and the fraction of cumulative loading lost within the human lifespan, to derive the reference loading rate of pollutant to treated land:

$$RP_c = \frac{RC_{sma}\ ME_{sma}\ LS\ 10^{-6}}{f_{ero}\ f_{ls}} \tag{34}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg/ha)
RC_{sma}	=	reference pollutant concentration for soil eroding from the SMA (mg/kg)
ME_{sma}	=	estimated rate of soil loss for the SMA (kg/ha•yr)
LS	=	human life expectancy (yr)
10^{-6}	=	conversion factor (kg) $(mg)^{-1}$
f_{ero}	=	fraction of total loss caused by erosion (unitless)
f_{ls}	=	fraction of total cumulative loading lost in human lifetime (unitless)

5.2.12.5 Input and Output Values

Output values are presented in Table 5.2.12-2. Input values for parameters used in the sample equations are found in Tables 5.2.12-3 and 5.2.12-4.

5.2.12.6 Sample Calculations for PCBs

Calculations for PCBs follow the procedure outlined in Section 5.2.12.4.

5.2.12.6.1 Mass Balance

Mass balance calculations for PCBs begin by estimating loss rate coefficients for leaching, volatilization, and erosion. See Appendix J for a discussion of the loss rate coefficient for degradation.

TABLE 5.2.12-2

REFERENCE APPLICATION RATES FOR POLLUTANTS (RPs)

PATHWAY 12

Pollutant	RP
Arsenic	86,000[a]
Benzene	Unlimited[b]
Benzo(a)pyrene	1.3[b]
Bis(2-ethylhexyl)phthalate	Unlimited[b]
Cadmium	63,000[a]
Chlordane	5.3[b]
Chromium	Unlimited[a]
Copper	Unlimited[a]
DDT/DDD/DDE	1.2[b]
Lead	Unlimited[a]
Lindane	2,100[b]
Mercury	1,100[a]
Nickel	Unlimited[a]
n-Nitrosodimethylamine	29,000[b]
PCBs	0.34[b]
Toxaphene	5.0[b]
Trichloroethylene	Unlimited[b]

[a]kg-pollutant/ha
[b]kg-pollutant/ha•year

Note: All RPs rounded **down** to two significant digits.

TABLE 5.2.12-3

SITE PARAMETERS FOR SAMPLE EQUATIONS

Parameter	Value	Units	Source
A_{msa}	1,074	ha	NSSS
A_{ws}	440,300	ha	U.S. EPA, 1990a
BD	1,400	kg/m^3	Chaney, 1992
d_c	0.00060	m/yr	U.S.D.A., 1987
DF	0.0066	unitless	
d_i	0.15	m	U.S. EPA, 1987a
L_{msa}	10	m	Policy
N	20	yr	U.S. EPA, 1983
NR	0.5	m/yr	U.S. EPA, 1986a
ρ_{ss}	2,650	kg/m^2	
ρ_w	1	kg/l	
t_c	3.2×10^7	sec	
TSS	16	mg/l	STORET database
Θ_s	0.2	unitless	
Θ_c	0.4	unitless	Carsel and Parrish, 1988
Θ_w	0.2	unitless	

Note: Appendix J discusses these and other parameter values.

TABLE 5.2.12-4

POLLUTANT-SPECIFIC PARAMETERS FOR SAMPLE EQUATIONS

	PCBs	Arsenic	Units	Source
BCF	3.1×10^4	350	kg^{-1}	Table J-12
BW	70	70	kg	
D_{ca}	0.06	NA	cm^2/sec	
FM	10	1	unitless	Table J-12
H	3.2×10^{-4}	NA	$atm\text{-}m^3/mol$	
I_f	0.04	0.04	kg/day	Javitz, 1980
I_w	2	2	1/day	
KD	15.1	0.019	m^3/kg	Table J-4
KD_{sw}	1,510	63,668	m_3/kg	Table J-3
LS	70	70	yr	
P_f	0.5	1	unitless	
q_1^*	7.7	1.75	$(mg/kg \bullet day)^{-1}$	
R	8.2×10^{-5}	8.21×10^{-5}	$(atm \bullet m^3/mol)$	
RL	10^{-4}	10^{-4}	$lifetime^{-1}$	
T	288	NA	°K	U.S. EPA, 1986a

Note: Appendix J discusses these and other parameter values.

Pollutant Loss to Erosion

Based on an assumed bulk density of 1,400 kg/m^3 for treated soil, 8.5 metric tons of soil lost to erosion per hectare annually is equivalent to a depth of about 0.00060 m of eroded soil. The rate of pollutant loss to erosion is therefore calculated as:

$$
\begin{aligned}
K_{ero} &= \frac{d_e(m/yr)}{d_i(m)} \\
&= \frac{0.00060(m/yr)}{0.15(m)} \\
&= 0.004(yr^{-1})
\end{aligned}
\qquad (35)
$$

where:

K_{ero}	=	loss rate coefficient for erosion (yr^{-1})
d_e	=	depth of soil eroded from site each year (m/yr)
d_i	=	depth of incorporation for sewage sludge (m)

Pollutant Loss to Volatilization

Based on the work of Hwang and Falco (1986), volatile emissions from treated soil are calculated as in Equation 2. A first-order loss rate coefficient for volatilization is estimated from this equation.

Before calculating Equation 2, a number of intermediate variables used in that equation must first be calculated:

$$
\begin{aligned}
D_{ei} &= D_{ai}(cm^2/sec)\ 0.0001(m^2/cm^2)\ \theta_e^{1/3} \\
&= (0.06)(0.0001)(0.4^{1/3}) \\
&= 4.2\times10^{-6}(m^2/sec)
\end{aligned}
\qquad (36)
$$

where:

D_{ei}	=	intermediate variable for Equation 2
D_{ca}	=	the molecular diffusivity of the pollutant in air (cm^2/sec)
0.0001	=	conversion factor (m^2) $(cm^2)^{-1}$
θ_e	=	effective porosity of soil (unitless)

To calculate the concentration of PCBs in the air-filled pore, a nondimensional Henry's Law constant for PCBs is calculated:

$$\dot{H} = \frac{H(atm \cdot m^3/mol)}{R(m^3 \cdot atm/K \cdot mol)\ T(°K)} = \frac{(3.2\times10^{-4})}{(8.21\times10^{-5})(288)} = 0.014 \qquad (37)$$

where:

$\dot{H}$	=	nondimensional Henry's Law constant (unitless)
H	=	Henry's Law constant for the pollutant (atm•m^3/mol)
R	=	ideal gas constant (atm•m^3/mol)
T	=	temperature (K)

For a unit concentration (1 kg/m^3) of PCBs in treated soil, the concentration in air-filled pore space is then calculated:

$$C_a = \frac{C_t(kg/m^3)}{\left(\frac{BD(kg/m^3)\ KD(m^3/kg)}{\dot{H}}\right) + \left(\frac{\theta_w}{\dot{H}}\right) + \theta_a} = \frac{1}{\frac{(1400)(15.1)}{(0.014)} + \frac{(0.2)}{(0.014)} + (0.2)} = 6.6\times10^{-7}(kg/m^3) \qquad (38)$$

where:

C_a	=	vapor concentration of pollutant in air-filled pore space of treated soil (kg/m^3)
C_t	=	total concentration of pollutant in treated soil (kg/m^3)
BD	=	bulk density of soil in mixing zone (kg/m^3)

KD	=	equilibrium partition coefficient for the pollutant (m^3/kg)
$\dot{H}$	=	nondimensional Henry's Law constant
θ_w	=	water-filled porosity of soil (unitless)
θ_a	=	air-filled porosity of soil (unitless)

Other intermediate variables needed for Equation 2 are:

$$\kappa = \frac{\rho_{ss}(kg/m^3)\,KD(m^3/kg)}{\dot{H}} = \frac{(2650)(15.1)}{(0.014)} = 2.9\times10^6 \tag{39}$$

where:

κ	=	intermediate variable for Equation 2
ρ_{ss}	=	particle density of sewage sludge-soil mixture (kg/m^3)
KD	=	equilibrium partition coefficient for the pollutant (m^3/kg)
$\dot{H}$	=	nondimensional Henry's Law constant

and:

$$S = \frac{1-\theta_e}{\theta_e} = \frac{1-(0.4)}{(0.4)} = 1.5 \tag{40}$$

where:

S	=	intermediate variable for Equation 2
θ_e	=	effective porosity of soil (unitless)

and:

$$\alpha_1 = \frac{D_{ei}(m^2/sec)}{1+\kappa S} = \frac{(4.2\times10^{-6})}{1+(2.9\times10^6)(1.5)} = 9.8\times10^{-13}(m^2/sec) \tag{41}$$

where:

α_i	=	intermediate variable (m^2/sec)
D_{ei}	=	intermediate variable (m^2/sec)
κ	=	intermediate variable (unitless)
S	=	intermediate variable (unitless)

These results are substituted into Equation 2 to estimate the mass of pollutant emitted in the first year:

$$Na_y = \frac{2\, t_e(sec)\ \theta_e\ D_{ei}(m^2/sec)\ C_a(kg/m^3)}{\sqrt{\pi\ \alpha_i(m^2/sec)\ t_e(sec)}}$$

$$= \frac{2\ (3.2\times10^7)\ (0.4)\ (4.2\times10^{-6})\ (6.6\times10^{-7})}{\sqrt{(3.14)\ (9.7\times10^{-13})\ (3.2\times10^7)}} \qquad (42)$$

$$= 0.0072\,(kg/m^2\bullet yr)$$

where:

Na_y	=	emissions from the soil surface in first year ($kg/m^2\bullet yr$)
t_e	=	duration of emissions (sec)
θ_e	=	effective porosity of soil (unitless)
D_{ei}	=	intermediate variable (m^2/sec)
C_a	=	vapor concentration of pollutant in air-filled pore space of treated soil (kg/m^3)
α_i	=	intermediate variable (m^2/sec)

The estimated loss rate (in $kg/m^2\bullet yr$) is next converted into a comparable first-order loss coefficient (yr^{-1}):

$$K_{vol} = -\ln\left(1 - \frac{Na_y}{d_i}\right)$$

$$= -\ln\left(1 - \frac{(0.0072)}{(0.15)}\right) \qquad (43)$$

$$= 0.049\,(yr^{-1})$$

where:

K_{vol}	=	loss rate coefficient for volatilization (yr^{-1})
Na_y	=	emissions from the soil surface in first year ($kg/m^2\bullet yr$)
d_i	=	depth of incorporation for sewage sludge (m)

Pollutant Loss to Leaching

Using the value for $\dot{H}$ calculated in Equation 37, a rate coefficient for loss of PCBs to leaching is calculated:

$$
\begin{aligned}
K_{lec} &= \frac{NR(m/yr)}{\left[BD(kg/m^3)\,KD(m^3/kg) + \theta_w + \dot{H}\,\theta_a\right]\,d_i(m)} \\
&= \frac{(0.5)}{[(1400)(15.1) + (0.2) + (0.014)(0.2)](0.15)} \\
&= 1.6\times10^{-4}(yr^{-1})
\end{aligned}
\tag{44}
$$

where:

K_{lec}	=	loss rate coefficient for leaching (yr^{-1})
NR	=	annual recharge to ground water beneath the SMA (m/yr)
BD	=	bulk density of soil in mixing zone (kg/m^3)
KD	=	equilibrium partition coefficient for the pollutant (m^3/kg)
θ_w	=	water-filled porosity of soil (unitless)
$\dot{H}$	=	nondimensional Henry's Law constant (unitless)
θ_a	=	air-filled porosity of soil (unitless)
d_i	=	depth of incorporation for sewage sludge (m)

Individual Loss Processes as Fraction of Total Loss

These three loss rate coefficients for PCBs (K_{lec}, K_{vol}, K_{ero}) are combined with an estimated loss coefficient for pollutant degradation (K_{deg}) in treated soil to yield a coefficient for the total rate at which pollutant is lost from soil:

$$
\begin{aligned}
K_{tot} &= K_{lec}(yr^{-1}) + K_{vol}(yr^{-1}) + K_{ero}(yr^{-1}) + K_{deg}(yr^{-1}) \\
&= (1.6\times10^{-4}) + (0.049) + (0.004) + (0.063) \\
&= 0.12(yr^{-1})
\end{aligned}
\tag{45}
$$

where:

K_{tot}	=	total loss rate for the pollutant in treated soil (yr^{-1})
K_{lec}	=	loss rate coefficient for leaching (yr^{-1})
K_{vol}	=	loss rate coefficient for volatilization (yr^{-1})
K_{ero}	=	loss rate coefficient for erosion (yr^{-1})

K_{deg} = loss rate coefficient for degradation (yr^{-1})

The values for K_{lec}, K_{vol}, and K_{ero} are calculated above. The value for K_{deg} is listed in Table J-7 in Appendix J.

The ratio of each individual coefficient to the total then describes the fraction of pollutant loss caused by each individual process:

$$f_{lec} = \frac{K_{lec}(yr^{-1})}{K_{tot}(yr^{-1})} = \frac{(1.6\times10^{-4})}{(0.12)} = 0.0014$$

$$f_{vol} = \frac{K_{vol}(yr^{-1})}{K_{tot}(yr^{-1})} = \frac{(0.049)}{(0.12)} = 0.41 \qquad (46)$$

$$f_{ero} = \frac{K_{ero}(yr^{-1})}{K_{tot}(yr^{-1})} = \frac{(0.004)}{(0.12)} = 0.035$$

$$f_{deg} = \frac{K_{deg}(yr^{-1})}{K_{tot}(yr^{-1})} = \frac{(0.063)}{(0.12)} = 0.54$$

where:

f_{lec} = fraction of total loss caused by leaching (unitless)
K_{lec} = loss rate coefficient for leaching (yr^{-1})
K_{tot} = total loss rate for the pollutant in treated soil (yr^{-1})
f_{vol} = fraction of total loss caused by volatilization (unitless)
K_{vol} = loss rate coefficient for volatilization (yr^{-1})
f_{ero} = fraction of total loss caused by erosion (unitless)
K_{ero} = loss rate coefficient for erosion (yr^{-1})
f_{deg} = fraction of total loss caused by degradation (unitless)
K_{deg} = loss rate coefficient for degradation (yr^{-1})

5.2.12.6.2 Reference Application Rate for PCBs

For carcinogenic pollutants, the calculations for determining the reference application rate begin by using the pollutant's potency for causing human cancer to calculate a reference intake:

$$RI = \frac{RL}{q_1^*(kg \cdot day/mg)} \tag{47}$$

$$= \frac{10^{-4}}{7.7}$$

$$= 1.3 \times 10^{-5} (mg/kg \cdot day)$$

where:

RI	=	reference intake for carcinogen (mg/kg•day)
RL	=	risk level (unitless)
q_1^*	=	human cancer potency for PCBs $(mg/kg \cdot day)^{-1}$

A reference water concentration for PCBs in surface water is calculated:

$$RC_{sw} = \frac{RI(mg/kg \cdot day)\ \ BW(kg)}{BCF(l/kg)\ \ FM\ \ P_f\ \ I_f(kg/day)\ +\ I_w(l/day)} \tag{48}$$

$$= \frac{(1.3 \times 10^{-5})(70)}{(3.1 \times 10^4)(10)(0.5)(0.04)\ +\ (2)}$$

$$= 1.5 \times 10^{-7}\ (mg/l)$$

where:

RC_{sw}	=	reference water concentration for surface water (mg/l)
RI	=	reference intake for carcinogen (mg/kg•day)
BW	=	body weight (kg)
BCF	=	pollutant-specific bioconcentration factor (l/kg)
FM	=	pollutant-specific food chain multiplier (unitless)
P_f	=	percent of pollutant concentration in the edible portion of fish (unitless)
I_f	=	daily consumption of fish (kg/day)
I_w	=	daily consumption of water (l/day)

The water concentration is next related to the concentration of pollutant in the eroded soil entering the stream. The ratio P_i / P_s is calculated:

$$\frac{P_l}{P_s} \approx \frac{\rho_w(kg/l)}{TSS(mg/l) \times 10^{-6}(kg/mg)}$$

$$= \frac{(1)}{(16) \times 10^{-6}} \qquad (49)$$

$$= 62{,}500(unitless)$$

where:

P_l	=	percent liquid in the water column (unitless, by mass)
P_s	=	percent solids in the water column (unitless, by mass)
ρ_w	=	density of pure water (1 kg/l)
TSS	=	total suspended solids content of the stream (mg/l)
10^{-6}	=	conversion factor (kg) $(mg)^{-1}$

The reference dry-weight concentration of pollutant in eroded soil (RC_{sed}) is derived:

$$RC_{sed} = RC_{sw}(mg/l)\left[KD_{sw}(kg/l) + \left(\frac{P_l(unitless)}{P_s(unitless)}\right)\left(\frac{1}{\rho_w(kg/l)}\right)\right]$$

$$= (1.5\times10^{-7})\ [(1{,}510) + (62{,}500)\ (1)] \qquad (50)$$

$$= 9.4\times10^{-3}(mg/kg)$$

where:

RC_{sed}	=	reference concentration of pollutant for soil eroding into stream (mg/kg)
RC_{sw}	=	reference water concentration for surface water (mg/l)
KD_{sw}	=	partitioning coefficient between solids and liquids in the stream (l/kg)
P_l	=	percent liquid in the water column (unitless, by mass)
P_s	=	percent solids in the water column (unitless, by mass)
ρ_w	=	density of pure water (1 kg/l)

The sediment delivery ratio for the SMA is calculated from an empirical relationship for delivery of eroded soil from the SMA to the stream:

$$S_{sma} = 0.77\ [L_{sma}(m)]^{-0.22}$$

$$= 0.77\ (10)^{-0.22} \qquad (51)$$

$$= 0.46(unitless)$$

where:

S_{sma}	=	sediment delivery ratio for the SMA (unitless)
0.77	=	empirical constant
L_{sma}	=	distance between the SMA and the receiving water body (m)
0.22	=	empirical constant

The sediment delivery ratio for the watershed is calculated:

$$\begin{aligned} S_{ws} &= 0.87\ [A_{ws}(ha)]^{-0.125} \\ &= (0.87)\ (440{,}300)^{-0.125} \\ &= 0.17\,(\text{unitless}) \end{aligned} \tag{52}$$

where:

S_{ws}	=	sediment delivery ratio for the watershed (unitless)
0.87	=	empirical constant
A_{ws}	=	area of the watershed (ha)
0.125	=	empirical constant

The dilution factor is calculated as:

$$\begin{aligned} DF &= \frac{A_{sma}(ha)\ S_{sma}(\text{unitless})}{A_{sma}(ha)\ S_{sma}(\text{unitless}) + [A_{ws}(ha) - A_{sma}(ha)]\ S_{ws}(\text{unitless})} \\ &= \frac{(1074)(0.46)}{(1074)(0.46) + [(440{,}300) - (1074)](0.17)} \\ &= 0.0066\,(\text{unitless}) \end{aligned} \tag{53}$$

where:

DF	=	dilution factor (unitless)
A_{sma}	=	area affected by sewage sludge management (ha)
S_{sma}	=	sediment delivery ratio for the SMA (unitless)
A_{ws}	=	area of the watershed (ha)
S_{ws}	=	sediment delivery ratio for the watershed (unitless)

A reference soil concentration for soil eroding from the SMA is calculated as:

$$RC_{sma} = \frac{RC_{sed}(mg/kg)}{DF(unitless)}$$

$$= \frac{(9.4x10^{-3})}{(0.0066)} \quad (54)$$

$$= 1.43 \ (mg/kg)$$

where:

RC_{sma}	=	reference pollutant concentration for soil eroding from the SMA (mg/kg)
RC_{sed}	=	reference pollutant concentration for soil eroding into the stream (mg/kg)
DF	=	dilution factor (unitless)

Annual soil erosion from the site is calculated from the bulk density of treated soil, and from the estimated average rate of loss of agricultural soil in the U.S:

$$ME_{sma} = 10{,}000(m^2/ha) \ d_e(m/yr) \ BD(kg/m^3)$$

$$= 10{,}000 \ (0.00060) \ (1{,}400) \quad (55)$$

$$= 8{,}400(kg/ha \bullet yr)$$

where:

ME_{sma}	=	estimated rate of soil loss to erosion for the SMA (kg/ha•yr)
10,000	=	conversion factor $(kg/m^2)\ (kg/ha)^{-1}$
d_e	=	depth of soil eroded from site each year (m/yr)
BD	=	bulk density of soil in mixing zone (kg/m^3)

The final step of the calculation is to determine the reference application rate from the reference concentration of pollutant in eroded soil, using the value for f_{ero} calculated in Section 5.2.12.5.1:

$$RP_a = \frac{RC_{sma}(mg/kg) \ \ ME_{sma}(kg/ha \bullet yr) \ \ 10^{-6}(kg/mg)}{f_{ero}(unitless)}$$

$$= \frac{(1.43) \ (8{,}400) \ 10^{-6}}{(0.033)} \quad (56)$$

$$= 0.348(kg/ha \bullet yr)$$

where:

RP_a = reference annual pollutant loading (kg/ha•yr)
RC_{sma} = reference pollutant concentration for soil eroding from the SMA (mg/kg)
ME_{sma} = estimated rate of soil loss to erosion from the SMA (kg/ha•yr)
10^{-6} = conversion factor (kg) $(mg)^{-1}$
f_{ero} = fraction of total loss caused by erosion (unitless)

5.2.12.7 Sample Calculations for Arsenic

Calculations for arsenic follow the procedure outlined in Section 5.2.12.4.

5.2.12.7.1 Mass Balance

Mass balance calculations for arsenic begin by using parameter values from Table 5.2.12-2 to estimate loss coefficients for erosion and leaching. Arsenic is not lost to vaporization and degradation.

Pollutant Loss to Erosion

The rate of pollutant loss to erosion is calculated as:

$$K_{ero} = \frac{d_e(m/yr)}{d_i(m)} = \frac{0.00060\,(m/yr)}{0.15\,(m)} = 0.0040\,(yr^{-1}) \qquad (57)$$

where:

K_{ero} = fraction of available pollutant lost to erosion each year (yr^{-1})
d_e = depth of soil eroded from site each year (m/yr)
d_i = depth of incorporation for sewage sludge (m)

Pollutant Loss To Leaching

A coefficient for the rate of loss to leaching is calculated as:

$$K_{lec} = \frac{NR}{\left[BD(kg/m^3)\ KD(m^3/kg) + \theta_w + \dot{H}\ \theta_a \right] d_i(m)}$$

$$= \frac{(0.5)}{[(1400)\ (0.02) + (0.2) + (0)\ (0.2)]\ (0.15)} \qquad (58)$$

$$= 0.118(yr^{-1})$$

where:

K_{lec}	=	loss rate coefficient for leaching (yr^{-1})
NR	=	annual recharge to ground water beneath the SMA (m/yr)
BD	=	bulk density of soil in mixing zone (kg/m^3)
KD	=	equilibrium partition coefficient for the pollutant (m^3/kg)
θ_w	=	water-filled porosity of soil (unitless)
$\dot{H}$	=	nondimensional Henry's Law constant for the pollutant
θ_a	=	air-filled porosity of soil (unitless)
d_i	=	depth of incorporation for sewage sludge soil (m)

Individual Loss Processes as Fraction of Total Loss

The sum of these two coefficients represents the total rate at which arsenic is lost from treated soil:

$$K_{tot} = K_{lec}(yr^{-1}) + K_{ero}(yr^{-1})$$

$$= (0.118) + (0.0040) \qquad (59)$$

$$= 0.122(yr^{-1})$$

where:

K_{tot}	=	total loss rate for the pollutant in treated soil (yr^{-1})
K_{lec}	=	first-order loss rate through leaching (yr^{-1})
K_{ero}	=	fraction of available pollutant lost to erosion each year (yr^{-1})

The fraction of total loss attributable to each process is then:

$$f_{lec} = \frac{K_{lec}}{K_{tot}} = \frac{0.118\,(yr^{-1})}{0.122\,(yr^{-1})} = 0.967 \qquad (60)$$

where:

f_{lec}	=	fraction of total loss caused by leaching (unitless)
K_{lec}	=	first-order loss rate through leaching (yr^{-1})
K_{tot}	=	total loss rate for the pollutant in treated soil (yr^{-1})

and:

$$f_{ero} = \frac{K_{ero}}{K_{tot}} = \frac{0.004\,(yr^{-1})}{0.122\,(yr^{-1})} = 0.033 \qquad (61)$$

where:

f_{ero}	=	fraction of total loss caused by erosion (unitless)
K_{ero}	=	fraction of available pollutant lost to erosion each year (yr^{-1})
K_{tot}	=	total loss rate for the pollutant in treated soil (yr^{-1})

5.2.12.7.2 Reference Application Rate

For carcinogenic pollutants, the calculations begin by using the human cancer potency to calculate a reference intake. For arsenic:

$$RI = \frac{RL}{q_1^* (kg \cdot day/mg)}$$

$$= \frac{(10^{-4})}{(1.75)} \qquad (62)$$

$$= 5.7 \times 10^{-5} (mg/kg \cdot day)$$

where:

RI	=	reference intake for carcinogen (mg/kg•day)
RL	=	risk level (risk of developing cancer per lifetime of exposure)
q_1^*	=	human cancer potency for arsenic $(mg/kg \cdot day)^{-1}$

A reference water concentration for arsenic in surface water is calculated as:

$$RC_{sw} = \frac{RI(mg/kg \cdot day)\ BW(kg)}{BCF(l/kg)\ FM\ P_f\ I_f(kg/day) + I_w(l/day)}$$

$$= \frac{(5.7 \times 10^{-5})(70)}{(350)(1)(1)(0.04) + (2)} \qquad (63)$$

$$= 2.5 \times 10^{-4} (mg/l)$$

where:

RC_{sw}	=	reference water concentration for surface water (mg/l)
RI	=	reference intake for carcinogen (mg/kg•day)
BW	=	body weight (kg)
BCF	=	pollutant-specific bioconcentration factor (l/kg)
FM	=	pollutant-specific food chain multiplier (unitless)
P_f	=	ratio of pollutant concentration in the edible portion of fish to concentration in whole fish (unitless)
I_f	=	daily consumption of fish (kg/day)
I_w	=	daily consumption of water (l/day)

The partitioning of arsenic between dissolved and adsorbed phases in the stream estimated as:

$$KD_{sw} = \alpha [TSS (mg/l)]^{\beta}$$

$$= (480{,}000)(16)^{(-0.7286)} \qquad (64)$$

$$= 63{,}668 (l/kg)$$

where:

KD_{sw}	=	partition coefficient for pollutant in stream (m^3/kg)
α, β	=	pollutant-specific empirical constants
TSS	=	total suspended solids content of the stream (mg/l)

The reference dry-weight concentration of arsenic in eroded soil is:

$$RC_{sed} = RC_{sw}(mg/l)\left[KD_{sw}(l/kg) + \left(\frac{P_l}{P_s}\right)\left(\frac{1}{\rho_w}\right)(l/kg)\right]$$
$$= (2.5\times10^{-4})[(63{,}668) + (62{,}500)(1)]$$
$$= 31.5(mg/kg) \qquad (65)$$

where:

RC_{sed}	=	reference concentration of pollutant for all soil eroding into stream (mg/kg)
RC_{sw}	=	reference water concentration for surface water (mg/l)
KD_{sw}	=	partition coefficient for pollutant in stream (m^3/kg)
P_l	=	percent liquid in the water column (unitless, by mass)
P_s	=	percent solids in the water column (unitless, by mass)
ρ_w	=	density of water (kg/l)

A reference soil concentration for soil eroding from the SMA is calculated as:

$$RC_{sma} = \frac{RC_{sed}(mg/kg)}{DF(unitless)}$$
$$= \frac{(31.5)}{(0.0066)} \qquad (66)$$
$$= 4.8\times10^3(mg/kg)$$

where:

RC_{sma}	=	reference pollutant concentration for soil eroding from the SMA (mg/kg)
RC_{sed}	=	reference pollutant concentration for all soil entering the stream (mg/kg)
DF	=	dilution factor (unitless)

For the years in which sewage sludge is applied, arsenic is assumed to be loaded once per year at an arbitrary rate of 1 kg/ha•yr, and lost at the rate of (K_{tot}). The outcome of combined loading and losses is calculated numerically as:

$$M_t = 0 \qquad (t=0)$$
$$M_t = (M_{t-1} + 1)\, e^{-K_{tot}} \qquad (1 \le t \le N) \qquad (67)$$

where:

M_t	=	mass of pollutant in soil at end of year t (kg/ha)
N	=	number of years in which sewage sludge is applied
K_{tot}	=	total loss rate for the pollutant in treated soil (yr^{-1})

After 20 applications with an annual loss rate of about 12 percent, arsenic has reached a concentration about seven times higher than its annual loading to soil. After the last application, no further loading of pollutant to soil takes place, but pollutant continues to be depleted:

$$\begin{aligned} M_{LS} &= M_N(kg/ha)\ e^{-K_{tot}\,(LS-N)} \\ &= 7.0\ e^{-0.122\,(70-20)} \\ &= 0.016(kg/ha) \end{aligned} \qquad (68)$$

where:

M_{LS}	=	mass of pollutant at end of individual lifetime (kg/ha)
M_N	=	mass of pollutant after N applications (kg/ha)
K_{tot}	=	total loss rate for the pollutant in treated soil (yr^{-1})
LS	=	human life expectancy (assumed to be 70 years)
N	=	number of years in which sewage sludge is applied

The fraction of the total, cumulative loading lost in the human lifespan is independent of the assumed application rate. It can be calculated as:

$$\begin{aligned} f_{ls} &= 1 - \frac{M_{LS}\,(kg/ha)}{N(yr)\ 1(kg/ha \bullet yr)} \\ &= 1 - \frac{0.016}{20 \times 1} \\ &= 0.9992 \end{aligned} \qquad (69)$$

where:

f_{ls}	=	fraction of total cumulative loading lost in human lifetime (unitless)
M_{LS}	=	mass of pollutant at end of individual lifetime (kg/ha)
N	=	number of years in which sewage sludge is applied
1	=	loading rate for arsenic (kg/ha•yr)

The final step in the calculations is to derive the reference cumulative application rate of arsenic to treated land using the value for Me_{sma} calculated in Section 5.2.12.6.2:

$$RP_c = \frac{RC_{sma}(mg/kg)\ ME_{sma}(kg/ha \bullet yr)\ LS\ (yr)\ 10^{-6}(kg/mg)}{f_{ero}\ f_{ls}}$$

$$= \frac{(4.8\times10^{5})\ (8,400)\ (70)\ 10^{-6}}{(0.033)\ (0.9992)} \quad (70)$$

$$= 8.6\times10^{4}(kg/ha)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg/ha)
RC_{sma}	=	reference pollutant concentration for soil eroding from the SMA (mg/kg)
ME_{sma}	=	estimated rate of soil loss to erosion from the SMA (kg/ha•yr)
LS	=	human life expectancy (yr)
10^{-6}	=	conversion factor $(kg)(mg)^{-1}$
f_{ero}	=	fraction of total loss caused by erosion (unitless)
f_{ls}	=	fraction of total cumulative loading lost in human lifetime (unitless)

5.2.13 Air Pathway

5.2.13.1 Description of Pathway

Sewage Sludge → Soil → Air → Human

Pathway 13 evaluates the effects on humans of breathing pollutants that volatilize from sewage sludge applied to the land.

5.2.13.2 Pollutants Evaluated

All of the pollutants of concern were evaluated for this pathway. Table 5.2.13-1 lists the pollutants evaluated for Pathway 13. Criteria for the air pathway are derived for organic pollutants only. EPA concluded that the movement of metals through this pathway is negligible, because the metals do not volatilize at ambient air temperatures.

5.2.13.3 Highly Exposed Individual

The Highly Exposed Individual (HEI) for the air pathway is assumed to live at the downwind boundary of the Sludge Management Area (SMA) and to breathe 20 m^3/day of air contaminated with volatile pollutants from sewage sludge.

5.2.13.4 Algorithm Development

This section describes the methodology used to derive the reference application rate of pollutant for land application sites for the air pathway. Pathway 13 begins with the mass balance calculations previously presented for Pathway 12 (see Section 5.2.12.4). The fraction of pollutant lost through volatilization (f_{vol}) is then used in calculating the reference application rate of pollutant for the air pathway. Sample calculations are performed for PCBs.

TABLE 5.2.13-1

POLLUTANTS OF CONCERN FOR AGRICULTURAL PATHWAY 13

Organics
Benzene
Benzo(a)pyrene
Bis (2-ethylhexyl) phthalate
Chlordane
DDT/DDD/DDE
Lindane
n-Nitrosodimethylamine
Polychlorinated Biphenyls (PCBs)
Toxaphene
Trichloroethylene

For organic pollutants, the methodology is designed to derive a reference application rate of pollutant such that sewage sludge can be applied indefinitely without exceeding reference concentrations for water or air. It is based on the worst-case assumption that equilibrium may eventually be reached between the annual loading of pollutant to a site and the total annual loss through all competing loss processes. This equilibrium and accumulation of pollutant in soil are discussed in Appendix G. Based on that predicted equilibrium and the partitioning of pollutant among loss processes, the reference annual pollutant loading (kg/ha•yr) is calculated for the air pathway.

5.2.13.4.1 Mass Balance

The ratio of the loss rate coefficient for volatilization to the total loss rate for the pollution in treated soil describes the fraction of pollutant loss to volatilization:

$$f_{vol} = \frac{K_{vol}}{K_{tot}} \qquad (1)$$

where:

f_{vol} = fraction of total loss caused by volatilization (unitless)
K_{vol} = loss rate coefficient for volatilization (yr^{-1})
K_{tot} = total loss rate for the pollutant in treated soil (yr^{-1})

5.2.13.4.2 Reference Application Rate of Pollutant

For each pollutant, a reference air concentration is first established based on the pollutant's cancer potency:

$$RC_{air} = \frac{RL \cdot BW \cdot 1000}{I_a \cdot q_1^*} \qquad (2)$$

where:

RC_{air} = reference air concentration for pollutant ($\mu g/m^3$)
RL = risk level (incremental risk of cancer per lifetime)
BW = body weight (kg)

1000	=	conversion factor (mg) (μg)$^{-1}$
I_a	=	inhalation volume (m^3/day)
q_1^*	=	human cancer potency (mg/kg•day)$^{-1}$

The next step is to relate releases of volatilized pollutant from the site to the expected concentration in ambient air. The model used to describe transport of pollutant from a land application site is described by the U.S. EPA (1987e) and is based on equations described in *Environmental Science and Engineering* (1985). A source-receptor ratio is calculated to relate the concentration of pollutant in ambient air at the HEI's location (μg/m^3) to the rate at which pollutant is emitted from the treated soil (μg/m^2•sec):

$$SRR = 2.032 \frac{A\ v}{(r' + X_y)\ \omega\ \sigma_z} \qquad (3)$$

where:

SRR	=	source-receptor ratio (sec/m)
2.032	=	empirical constant
A	=	area of SMA (m^2)
v	=	vertical term (unitless)
r'	=	distance from the center of the site to the receptor (m)
x_y	=	lateral virtual distance (m)
ω	=	wind speed (m/sec)
σ_z	=	standard deviation of the vertical distribution of concentrations (m)

The vertical term (v) is a function of source height, height of the mixing layer, and σ_z. Under stable conditions, the height of the mixing layer is assumed to be infinite; for a pollutant release height of zero, v = 1. The lateral virtual distance is the distance from a virtual point source to the SMA, such that the angle θ subtended by the SMA's width is 22.5°. This distance is calculated as:

$$x_y = \sqrt{\frac{A}{\pi}} \cot\left(\frac{\theta}{2}\right) \qquad (4)$$

where:

x_y	=	lateral virtual distance (m)
A	=	area of SMA (m^2)
θ	=	22.5°

The standard deviation of the vertical distribution of concentration (σ_z) is defined by an atmospheric stability class and the distance from the center of the site to the receptor. Based on values for parameters a and b, listed for "stable" atmospheric conditions in Table 5.2.13-2, σ_z is calculated as:

$$\sigma_z = a\, x^b \tag{5}$$

where:

σ_z	=	standard deviation of the vertical distribution of concentrations (m)
a	=	empirical constant
x	=	distance from center of SMA to the receptor (km)
b	=	empirical constant

and:

$$x = \frac{\sqrt{A} \cdot 10^{-3}}{2} \tag{6}$$

where:

x	=	distance from center of site to the receptor (km)
A	=	area of SMA (m^2)
10^{-3}	=	conversion factor (m)$(km)^{-1}$

The source-receptor ratio is combined with the reference air concentration to calculate a reference annual flux of pollutant:

$$RF_{air} = \frac{RC_{air}\ 316}{SRR} \tag{7}$$

where:

RF_{air}	=	reference annual flux of pollutant emitted from the site (kg/ha•yr)
RC_{air}	=	reference air concentration for pollutant ($\mu g/m^3$)
316	=	conversion factor ($\mu g/m^2 \cdot c$) $(kg/ha \cdot yr)^{-1}$
SRR	=	source-receptor ratio (sec/m)

For organic pollutants, the site is assumed to be at equilibrium between annual loadings and total annual losses. Annual releases of pollutant to volatilization are therefore predicted by the product of f_{vol} and annual loadings. A reference application rate of pollutant is therefore calculated from the reference flux as:

TABLE 5.2.13-2

PARAMETERS USED TO CALCULATE σ_z[a]

Pascal Stability Category	x (km)	a	b
Stable	0.10 - 0.20	15.209	0.81558
	0.21 - 0.70	14.457	0.78407
	0.71 - 1.00	13.953	0.68465
	1.01 - 2.00	13.953	0.63227
	2.01 - 3.00	14.823	0.54503
	3.01 - 7.00	16.187	0.46490
	7.01 - 15.00	17.836	0.41507
	15.01 - 30.00	22.651	0.32681
	30.01 - 60.00	27.084	0.27436
	> 60.00	34.219	0.21716

[a] Source: *Environmental Science and Engineering*, 1985. The standard deviation of the vertical distribution of pollutant concentration in air, σ_z (m), is calculated as $\sigma_z = ax^b$. A conversion factor to change (km) to (m) is figured into the empirical constants a and b.

$$RP_a = \frac{RF_{air}}{f_{vol}} \quad (8)$$

where:

RP_a = reference application rate of pollutant (kg/ha•yr)
RF_{air} = reference annual flux of pollutant emitted from the site (kg/ha•yr)
f_{vol} = fraction of total loss caused by volatilization (unitless)

5.2.13.5 Output Values

Output values are presented in Table 5.2.13-3.

5.2.13.6 Sample Calculations for PCBs

5.2.13.6.1 Mass Balance

Calculations for PCBs follow the procedure outlined in 5.2.13.4. Input values for parameters used in the sample equations are found in Tables 5.2.13-4 and 5.2.13-5.

Calculations for PCBs begin with the mass balance equations that assign pollutant losses to erosion, volatilization, leaching (see Section 5.2.12.5.1), and degradation (see Appendix J). The fraction of pollutant lost to the air pathway (f_{vol}) is expressed as :

$$f_{vol} = \frac{K_{vol}(yr^{-1})}{K_{tot}(yr^{-1})} = \frac{(0.049)}{(0.012)} = 0.42 \quad (9)$$

where:

f_{vol} = fraction of total loss caused by volatilization (unitless)
K_{vol} = loss rate coefficient for volatilization
K_{tot} = total loss rate for the pollutant in treated soil (yr^{-1})

TABLE 5.2.13-3

REFERENCE APPLICATION RATES FOR POLLUTANTS (RPs)

PATHWAY 13

Pollutant	RP[a]
Benzene	160
Benzo(a)pyrene	3,500
Bis(2-ethylhexyl)phthalate	Unlimited
Chlordane	3.9
DDT/DDD/DDE	45
Lindane	110
n-Nitrosodimethylamine	22
PCBs	1.5
Toxaphene	120
Trichloroethylene	420

[a]kg-pollutant/ha•year

Note: All RPs rounded **down** to two significant digits.

TABLE 5.2.13-4

SITE PARAMETER VALUES USED IN SAMPLE EQUATIONS

Symbol	Value
a	13.953 (unitless)
A	1.1×10^7 m^2
b	0.63227 (unitless)
r′	1,639 m
v	1 (unitless)
ω	4.5 m/sec
x	1.639 km
x_y	9,295 m

Note: Appendix J discusses these and other parameter values.

TABLE 5.2.13-5

PARAMETER VALUES USED IN SAMPLE EQUATIONS FOR PCBs

Parameter	Value
BW	70 (kg)
I_a	20 (m^3/day)
q_1^*	7.7 $(mg/kg \cdot day)^{-1}$
RL	10^{-4}

Note: Appendix J discussed these and other parameter values.

5.2.13.6.2 Reference Application Rate for PCBs

To calculate the reference application rate for PCBs, a reference air concentration is first established, based on cancer potency:

$$RC_{air} = \frac{RL \; BW(kg) \; 1{,}000(\mu g/mg)}{I_a(m^3/day) \; q_1^*(kg \cdot day/mg)} \tag{10}$$

$$= \frac{10^{-4} \cdot 70 \cdot 1{,}000}{20 \cdot 7.7}$$

$$= 0.045(\mu g/m^3)$$

where:

RC_{air}	=	reference air concentration for pollutant ($\mu g/l$)
RL	=	risk level (incremental risk of cancer per lifetime)
BW	=	body weight (kg)
1,000	=	conversion factor $(\mu g)(mg)^{-1}$
I_a	=	inhalation volume (m^3/day)
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$

To relate this reference concentration to a rate of volatile emissions from treated land, a source-receptor ratio is calculated from a vertical term, a lateral virtual distance, and the standard deviation of the vertical distribution of concentrations. The vertical term (v) is a function of source height, height of the mixing layer, and σ_z. Under stable conditions the height of the mixing layer is assumed to be infinite; and for a pollutant release height of zero, v = 1. The lateral virtual distance is the distance from a virtual point source to the SMA, such that the angle θ subtended by the SMA width is 22.5°. This distance is calculated as:

$$x_y\,(m) = \sqrt{\frac{A(m^2)}{\pi}} \cot\left(\frac{\theta}{2}\right) \tag{11}$$

$$= \sqrt{\frac{1.1 \times 10^7}{3.14}} \cot\left(\frac{22.5°}{2}\right)$$

$$= 9{,}295\ (m)$$

where:

x_y	=	lateral virtual distance (m)
A	=	area of SMA (m^2)
θ	=	22.5°

The standard deviation of the vertical distribution of concentration (σ_z) is defined by an atmospheric stability class and the distance from the center of the SMA to the receptor. Based on values for the "stable" class in Table 5.2.13-2, the value of σ_z is calculated as:

$$\sigma_z = 13.953\ (1.639)^{0.63227} = 19\,(m) \quad (12)$$

where:

σ_z	=	standard deviation of the vertical distribution of concentrations (m)
a	=	empirical constant
b	=	empirical constant

and:

$$x(km) = \frac{\sqrt{A(m^2)} \bullet 10^{-3}(m/km)}{2} = \frac{\sqrt{1.1x10^7} \bullet 10^{-3}}{2} = 1.639\,(km) \quad (13)$$

where:

x	=	distance from the center of the SMA to the receptor (km)
A	=	area of SMA (m^2)
10^{-3}	=	conversion factor (m) $(km)^{-1}$

Using these results, a source-receptor ratio is calculated to relate the concentration of pollutant in ambient air at the HEI's location ($\mu g/m^3$) to the rate at which that pollutant is emitted from the treated soil ($\mu g/m^2 \bullet sec$):

$$SRR = 2.032 \frac{A(m^2)\ v}{\left[r'(m) + x_y(m)\right] \omega(m/sec)\ \sigma_z(m)}$$

$$= 2.032 \frac{(1.1 \times 10^7)(1)}{[(1,639) + (9,295)](4.5)(19)} \tag{14}$$

$$= 23\,(sec/m)$$

where:

SRR	=	source-receptor ratio (sec/m)
2.032	=	empirical constant
A	=	area of SMA (m^2)
v	=	vertical term (unitless)
r'	=	distance from the center of the site to the receptor (m)
x_y	=	lateral virtual distance (m)
ω	=	wind speed (m/sec)
σ_z	=	standard deviation of the vertical distribution of concentrations (m)

The source-receptor ratio is combined with the reference air concentration to calculate a reference annual flux of pollutant:

$$RF_{air} = \frac{RC_{air}(ug/m^3)\ 316}{SRR(sec/m)}$$

$$= \frac{(0.045)\ 316}{(23)} \tag{15}$$

$$= 0.61\,(kg/ha \bullet yr)$$

where:

RF_{air}	=	reference annual flux of pollutant emitted from the site (kg/ha•yr)
RC_{air}	=	reference air concentration for pollutant ($\mu g/m^3$)
316	=	conversion factor ($\mu g/m^2 \bullet sec$) $(kg/ha \bullet yr)^{-1}$
SRR	=	source-receptor ratio (sec/m)

A reference application rate for PCBs is then calculated from the reference flux as:

$$RP_a = \frac{RF_{air}(kg/ha \cdot yr)}{f_{vol}} \qquad (16)$$

$$= \frac{(0.61)}{(0.41)}$$

$$= 1.5 (kg/ha \cdot yr)$$

where:

RP_a	=	reference application rate of pollutant (kg/ha•yr)
RF_{air}	=	reference annual flux of pollutant emitted from the site (kg/ha•yr)
f_{vol}	=	fraction of total loss caused by volatilization (unitless)

5.2.14 Ground Water Pathway

5.2.14.1 Description of Pathway

Sewage Sludge → Soil → Ground Water → Human

Pathway 14 evaluates the effects of sewage sludge application to the land, the leaching of pollutants from soil into ground water, and the subsequent drinking of contaminated well water by humans.

5.2.14.2 Pollutants Evaluated

All of the pollutants of concern were evaluated for Pathway 14; they are listed in Table 5.2.14-1.

5.2.14.3 Highly Exposed Individual

The Highly Exposed Individual (HEI) for the ground water pathway is a human drinking water from wells contaminated with pollutants leaching to ground water from sewage sludge-amended soil.

5.2.14.4 Algorithm Development

This section describes the methodology used to derive criteria for land application sites for the ground water pathway. While the criteria are derived separately for exposure through the pathways for surface water, air, and ground water, the calculations have been integrated so that pollutant mass is conserved. Pathway 14 begins with a summary of the mass balance calculations that partition pollutant loss from the SMA through soil erosion, volatilization, leaching, and degradation. The results of these calculations are then used in calculating the reference

TABLE 5.2.14-1

POLLUTANTS EVALUATED FOR AGRICULTURAL PATHWAY 14

Inorganics	Organics
Arsenic	Benzene
Cadmium	Benzo(a)pyrene
Chromium	Bis(2-ethylhexyl)phthalate
Copper	Chlordane
Lead	DDT/DDD/DDE
Mercury	Lindane
Nickel	n-Nitrosodimethylamine
	Polychlorinated biphenyls (PCBs)
	Toxaphene
	Trichloroethylene

application rate based on leaching and subsequent contamination of ground water. Sample calculations are performed using PCBs as a representative organic pollutant and arsenic as a representative metal.

For organic pollutants, the methodology is designed to derive application rates such that sewage sludge can be applied indefinitely without exceeding reference concentrations in water or air. It is based on the worst-case assumption that equilibrium may eventually be reached between the annual loading of pollutant to a site and the total annual loss of pollutant through all competing loss processes. This equilibrium and accumulation of pollutant in soil are discussed in Appendix G. Based on that predicted equilibrium and the partitioning of pollutant among loss processes, the reference application rate (kg/ha•yr) is calculated for the ground water pathway.

For metals, equilibrium is not necessarily achieved and criteria are expressed as cumulative loadings (kg/ha). The concentration of metals in soil on the site is expected to increase with repeated applications, until the practice of land application is discontinued when metal concentrations reach maximum allowable levels.

Reference application rates for the ground water pathway are based on the highest concentrations of pollutant expected at the well within 300 years from the date of the first application of sewage sludge.

For both metals and organic pollutants, the approach to deriving criteria consists of four steps:

- Prepare a mass balance of pollutant loss, i.e., calculate the relative rates at which pollutant is removed from the site by each of four competing loss processes (erosion, leaching, volatilization, and degradation).
- Determine the reference concentration of pollutant in the ground water.
- Determine the pollutant concentration in ground water at the well location resulting from a unit loading (kg/ha) of sewage sludge at the site.

- Derive reference application rates by dividing the reference concentration in ground water by the concentration predicted per unit loading or sewage sludge concentration.

5.2.14.4.1 Mass Balance

Calculations for the ground water pathway begin with the mass balance equations that assign pollutant losses to erosion, volatilization, leaching (see Section 5.2.12.4.1), and degradation (see Appendix J). Leaching is the process through which pollutants move into the ground water from sewage sludge applied to land. The fraction of pollutant lost to leaching (f_{lec}) is expressed as the ratio of the loss rate coefficient for leaching to the total loss rate for the pollutant in treated soil:

$$f_{lec} = \frac{K_{lec}}{K_{tot}} \qquad (1)$$

where:

f_{lec} = fraction of total loss caused by leaching (unitless)
K_{lec} = loss rate coefficient for leaching (yr^{-1})
K_{tot} = total loss rate for the pollutant in treated soil (yr^{-1})

5.2.14.4.2 Calculating the Reference Application Rate

Calculations of the reference application rate for this pathway begin with the derivation of a reference ground water concentration (RC_{gw}). For carcinogens, RC_{gw} is calculated as:

$$RC_{gw} = \frac{RL\,BW}{q_1^*\,I_w} \qquad (2)$$

where:

RC_{gw} = reference water concentration (mg/l)
RL = risk level (incremental risk of cancer per lifetime, unitless)
BW = body weight (kg)
q_1^* = human cancer potency $(mg/kg\cdot day)^{-1}$
I_w = daily consumption of water (l/day)

For metals, the reference concentration is based on the maximum contaminant level (MCL) for the pollutant adjusted for an assumed background concentration in well water:

$$RC_{gw} = MCL - C_b \tag{3}$$

where:

RC_{gw} = reference water concentration (mg/l)
MCL = maximum contaminant level in drinking water, established by the U.S. EPA (mg/l)
C_b = background concentration of the pollutant in well water (mg/l)

For organic pollutants, reference application rates are calculated so that sewage sludge can be applied indefinitely without exceeding reference concentrations. The modeling of ground water contamination is therefore based on an annual loading of pollutant that is sustained for the entire 300 years of the simulation. For metals, sewage sludge is assumed to be applied for 20 years, followed by an inactive period in which pollutant is depleted from the treated soil. To simulate potential contamination of ground water for metals, the loading of pollutant into the unsaturated zone is linearized into a pulse of constant magnitude to represent the maximum annual loss of pollutant (kg/ha•yr) occurring over the 300-year simulation period modeled. The duration of that pulse is calculated so that pollutant mass is conserved. For land application sites, the rate of maximum loss will occur in the year immediately following the last application of sewage sludge, since the concentration of pollutant at the site reaches its peak at that time. As explained in Appendix G, this peak rate could be maintained for a maximum length of time described by:

$$TP = \frac{N}{1-e^{(-K_{tot} \cdot N)}} \tag{4}$$

where:

TP = length of square wave in which maximum total loss rate of pollutant (kg/ha•yr) depletes total mass of pollutant applied to site (yr)
N = number of consecutive years in which sewage sludge is applied to site (yr)
K_{tot} = total loss rate for the pollutant in treated soil (yr^{-1})

The next step is to relate the concentration of pollutant in well water to the concentration in leachate from the land application site. Two mathematical models are combined to calculate an expected ratio between these two concentrations. The Vadose Zone Flow and Transport finite element module (VADOFT) from the RUSTIC model (U.S. EPA, 1989c,e) is used to estimate flow and transport through the unsaturated zone, and the AT123D analytical model (Yeh, 1981) is used to estimate pollutant transport through the saturated zone.

VADOFT allows consideration of multiple soil layers, each with homogeneous soil characteristics. Within the unsaturated zone, the attenuation of organic pollutants is predicted based on longitudinal dispersion, an estimated retardation coefficient derived from an equilibrium partition coefficient, and a first-order rate of pollutant degradation. The model executes in two steps: results from the unsaturated zone flow and transport module are passed as input to the saturated zone module. The input requirements for the unsaturated zone module include various site-specific and geologic parameters and the rate of ground water recharge in the area of the site. It is assumed that the flux of pollutant mass into the top of the unsaturated zone beneath a land application site can be represented by results from the mass-balance calculations described above. Results from analysis of the unsaturated zone give the flow velocity and concentration profiles for each pollutant of interest. These velocities and concentrations are evaluated at the water table, converted to a mass flux, and used as input to the saturated zone module.

The flow system in the vertical column is solved with VADOFT, which is based on an overlapping representation of the unsaturated and saturated zones. The water flux at the soil/liquid interface is specified for the bottom of the impoundment, which defines the top of the unsaturated zone in the model. In addition, a constant pressure-head boundary condition is specified for the bottom of the unsaturated zone beneath the lagoon. This pressure-head is chosen to be consistent with the expected pressure-head at the bottom of the saturated zone. Transport in the unsaturated zone is determined using the Darcy velocity (v_d) and saturation profiles from the flow simulation. From these, the transport velocity profile can be determined.

Although limited to one-dimensional flow and transport, the use of a rigorous finite-element model in the unsaturated zone allows consideration of depth-variant physical and chemical processes that would influence the mass flux entering the saturated zone. Among the more important of these processes are advection (which is a function of the Darcy velocity, saturation, and porosity), mass dispersion, adsorption of the leachate onto the solid phase, and both chemical and biological degradation.

To represent a variably saturated soil column, the model divides the column into a finite-element grid consisting of a series of one-dimensional elements connected at nodal points. Elements can be assigned different properties for the simulation of flow in a heterogenous system. The model generates the grid from user-defined zones; the user defines the homogeneous properties of each zone, the zone thickness and the number of elements per zone, and the code automatically divides each zone into a series of elements of equal length. The governing equation is approximated using the Galerkin finite element method, and then it is solved iteratively for the dependent variable (pressure-head), subject to the chosen initial and boundary conditions. Solution of the series of nonlinear simultaneous equations generated by the Galerkin scheme is accomplished by either Picard iteration, a Newton-Raphson algorithm, or a modified Newton-Raphson algorithm. Once the finite element calculation converges, the model yields estimated values for all the variables at each of the discrete nodal points. A detailed description of the solution scheme is found in U.S. EPA (1989e).

For the present application, the simulation is based on the estimated mass flux of pollutant into the top of the soil column, and a zero concentration boundary condition at the bottom of the saturated zone. Sewage sludge is assumed to be applied for 20 consecutive years, followed by an inactive period in which pollutant is depleted from the land by leaching, volatilization, erosion, and degradation. To simulate potential contamination of ground water, the loading of pollutant into the unsaturated zone beneath the application site is "linearized" into a pulse of constant magnitude (TP) to represent the maximum annual loss of pollutant (kg/ha•yr) occurring over the 300-year simulation period modeled. The duration of that pulse is calculated so that pollutant mass is conserved.

This result is used to prepare inputs for VADOFT, which predicts the concentration of pollutant at the water table. The mass flux of pollutant into the saturated zone is evaluated at the water table based on the derived concentration distribution and the Darcy velocity. The resulting mass flux from the VADOFT simulation is used as input for the AT123D model, which simulates pollutant transport through the aquifer. It is represented as a mass flux boundary condition applied over a rectangular area representative of the land application site. The transient nature of the flux is represented by time-dependent levels interpolated from the results generated by the VADOFT simulation of the unsaturated zone.

AT123D estimates the transport of pollutant through the saturated soil zone. As in calculations for the unsaturated zone, degradation of organic pollutants is assumed to be first-order during transport through the aquifer. Speciation and complexation reactions are ignored for metals, leading to the possible over- or underestimation of expected concentrations of metals in ground water at the location of a receptor well. Detailed descriptions of the AT123D model are provided by U.S. EPA (1986e) and by Yeh (1981) and will not be repeated here. In general, the model provides an analytical solution to the basic advective-dispersive transport equation. One advantage of AT123D is its flexibility: the model allows the user up to 450 options and is capable of simulating a wide variety of configurations of source release and boundary conditions. For the current application, AT123D uses the source term and other input parameters to predict maximum concentrations of pollutant within 300 years in a receptor well at the downgradient edge of the site. The ratio of the concentration in well water to the concentration in leachate is defined as:

$$f_{wel} = \frac{C_{wel}}{C_{lec}} \qquad (5)$$

where:

f_{wel}	=	ratio of predicted concentration of pollutant in well to concentration in leachate (unitless)
C_{wel}	=	predicted concentration of the pollutant in well (mg/l)
C_{lec}	=	unit concentration of the pollutant in leachate (mg/l)

Because calculations in both the VADOFT and AT123D components of the ground water pathway model are linear with respect to pollutant concentration in leachate beneath the site, this ratio can be used to back-calculate a reference concentration of pollutant in this leachate:

$$RC_{lec} = \frac{RC_{gw}}{f_{wel}} \qquad (6)$$

where:

RC_{lec}	=	reference concentration of pollutant in leachate beneath the land application site (mg/l)
RC_{gw}	=	reference water concentration (mg/l)
f_{wel}	=	ratio of predicted concentration of pollutant in well to concentration in leachate (unitless)

Multiplying this reference concentration (mg/l) by the assumed fluid flux (net recharge in m/yr) and adjusting units yields the reference flux of pollutant mass from the site:

$$RF_{gw} = 10\ RC_{lec}\ NR \tag{7}$$

where:

RF_{gw}	=	reference annual flux of pollutant beneath the site (kg/ha•yr)
10	=	conversion factor ([mg•m]/l) $(kg/ha)^{-1}$
RC_{lec}	=	reference concentration of pollutant in leachate beneath the land application site (mg/l)
NR	=	annual recharge to ground water beneath the SMA (m/yr)

This reference flux must be related to the annual or cumulative loading of pollutant to the soil. At steady state, the annual loading of an organic pollutant will equal combined annual losses through leaching, volatilization, erosion, and degradation. The fraction lost to leaching (f_{lec}) was determined in the mass balance calculation described above. A reference annual application rate of pollutant can be derived by applying this ratio in reverse:

$$RP_a = \frac{RF_{gw}}{f_{lec}} \tag{8}$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RF_{gw}	=	reference annual flux of pollutant beneath the site (kg/ha•yr)
f_{lec}	=	fraction of total loss caused by leaching (unitless)

For metals, application of sewage sludge is assumed to end after 20 years. With repeat applications, concentrations of the metal increase at the site as the metal accumulates in treated soil. After the last application, concentrations decline exponentially as a result of leaching and soil erosion. The reference cumulative application rate of pollutant is derived by first calculating a total reference mass of pollutant loaded into the unsaturated zone, and dividing by the fraction of total pollutant loading lost to leaching:

$$RP_c = \frac{RF_{gw} TP}{f_{lec}} \tag{9}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RF_{gw}	=	reference annual flux of pollutant beneath the site (kg/ha•yr)
TP	=	length of square wave in which maximum total loss rate of pollutant (kg/ha•yr) depletes total mass of pollutant applied to site (yr)
f_{lec}	=	fraction of total loss caused by leaching (unitless)

5.2.14.5 Output Values

Output values are presented in Table 5.2.14-2.

5.2.14.6 Sample Calculations for PCBs

Calculations for PCBs follow the procedure outlined in Section 5.2.12.4. Input values for parameters used in the sample equations are found in Table 5.2.14-3.

5.2.14.6.1 Mass Balance

Calculations for PCBs begin with the mass balance equations that assign pollutant losses to erosion, volatilization, leaching, and degradation (see Section 5.2.12.5.1). The fraction of pollutant lost to leaching (f_{lec}) is expressed as the ratio of the rate loss coefficient for leaching to the total:

TABLE 5.2.14-2

REFERENCE APPLICATION RATES FOR POLLUTANTS (RPs)

PATHWAY 14

Pollutant	RP
Arsenic	1,200[a,c]
Benzene	Unlimited
Benzo(a)pyrene	Unlimited
Bis(2-ethylhexyl)phthalate	Unlimited
Cadmium	Unlimited
Chlordane	Unlimited
Chromium	12,000[a,c]
Copper	Unlimited
DDT/DDD/DDE	Unlimited
Lead	Unlimited
Lindane	Unlimited
Mercury	Unlimited
Nickel	13,000[a,c]
n-Nitrosodimethylamine	0.56[b,c]
PCBs	Unlimited
Toxaphene	Unlimited
Trichloroethylene	Unlimited

[a]kg-pollutant/ha
[b]kg-pollutant/ha•year
[c]Rounded **down** to two significant digits

TABLE 5.2.14-3

INPUT PARAMETER VALUES USED IN SAMPLE EQUATIONS

	PCBs	Arsenic	Units
BW	70	70	kg
C_b	NA	0.0032	mg/l
C_{lsc}	1	1	mg/l
C_{wel}	2.0×10^{-11}	0.0041	mg/l
I_w	2	2	1/day
RL	10^{-4}	NA	unitless
q_1^*	7.7	1.75	$(mg/kg \cdot day)^{-1}$
MCL	NA	0.05	mg/l
NR	0.5	0.5	m/yr
TP	NA	22	yr

Note: Appendix J discusses these and other parameter values.

$$f_{lec} = \frac{K_{lec}(yr^{-1})}{K_{tot}(yr^{-1})} = \frac{(1.6\times10^{-4})}{(0.12)} = 0.0013 \qquad (10)$$

where:

f_{lec}	=	fraction of total loss caused by leaching (unitless)
K_{lec}	=	loss rate coefficient for leaching (yr^{-1})
K_{tot}	=	total loss rate for the pollutant in treated soil (yr^{-1})

5.2.14.6.2 Reference Application Rate for PCBs

A reference ground water concentration for PCBs is calculated as:

$$RC_{gw}(mg/l) = \frac{RL\ BW(kg)}{q_1{*}(kg\cdot day/mg)\ I_w(l/day)} = \frac{(10^{-4})(70)}{(7.7)(2)} = 4.5\times10^{-4}(mg/l) \qquad (11)$$

where:

RC_{gw}	=	reference water concentration (mg/l)
RL	=	risk level (incremental risk of cancer per lifetime, unitless)
BW	=	body weight (kg)
$q_1{*}$	=	human cancer potency for PCBs $(mg/kg\cdot day)^{-1}$
I_w	=	rate of water ingestion (l/day)

With input parameter values discussed in Section 5.2.14.4.2 and in Appendix G, the VADOFT and AT123D components of the ground water pathway model predict the maximum concentration in ground water at the downgradient edge of the site within 300 years (based on a unit concentration of 1 mg/l in leachate). The ratio of these two concentrations is:

$$f_{wel} = \frac{C_{wel}(mg/l)}{C_{lec}(mg/l)}$$

$$= \frac{(2.0\times10^{-11})}{(1)} \qquad (12)$$

$$= 2.0\times10^{-11}$$

where:

f_{wel}	=	ratio of predicted concentration in well to concentration in leachate (unitless)
C_{wel}	=	predicted concentration of the pollutant in well (mg/l)
C_{lec}	=	unit concentration of the pollutant in leachate (mg/l)

This ratio is used to back-calculate a reference concentration of pollutant in leachate. Because the ratio is extremely low for PCBs, the reference concentration for leachate is higher than physically possible:

$$RC_{lec} = \frac{RC_{gw}(mg/l)}{f_{wel}}$$

$$= \frac{(4.5\times10^{-4})}{(2.0\times10^{-11})} \qquad (13)$$

$$= 2.3\times10^{7}(mg/l)$$

where:

RC_{lec}	=	reference concentration of pollutant in leachate from the land application site (mg/l)
RC_{gw}	=	reference water concentration (mg/l)
f_{wel}	=	ratio of predicted concentration in well to concentration in leachate (unitless)

Multiplying this reference concentration (mg/l) by the known fluid flux (net recharge m/yr), and adjusting units, yields the reference flux of pollutant mass from the site:

$$RF_{gw} = RC_{lec}(mg/l)\ NR(m/yr)\cdot 10$$

$$= (2.3\times10^{7})\ (0.5)\ 10 \qquad (14)$$

$$= 1.2\times10^{8}(kg/ha\cdot yr)$$

where:

RF_{gw}	=	reference annual flux of pollutant beneath the site (kg/ha•yr)
RC_{lcc}	=	reference concentration of pollutant in leachate beneath the land application site (mg/l)
NR	=	annual recharge to ground water beneath the SMA (m/yr)
10	=	conversion factor [(mg•m)/l] $(kg/ha)^{-1}$

A reference annual application rate of the pollutant is derived by adjusting this flux for the fraction of pollutant lost to leaching:

$$RP_a = \frac{RF_{gw}(kg/ha \bullet yr)}{f_{lcc}} = \frac{(1.2\times10^8)}{(0.0014)} = 8.5\times10^{10}(kg/ha \bullet yr) \quad (15)$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RF_{gw}	=	reference annual flux of pollutant beneath the site (kg/ha•yr)
f_{lcc}	=	fraction of total loss caused by leaching (unitless)

It is clear from this result that no conceivable application rate or concentration of PCBs in sewage sludge would be expected to result in concentrations of PCBs in well water above the reference water concentration.

5.2.14.7 Sample Calculations for Arsenic

Calculations for arsenic follow the procedure outlined in Section 5.2.12.4.

5.2.14.7.1 Mass Balance

Calculations for arsenic begin with the mass balance equations that assign pollutant losses to erosion and leaching (see Section 5.2.12.6.1). The fraction of pollutant lost to leaching (f_{lcc}) is expressed as the ratio of the rate loss coefficient for leaching, to the total loss rate for the pollutant in treated soil:

$$f_{lec} = \frac{K_{lec}}{K_{tot}} = \frac{0.12\,(yr^{-1})}{0.124\,(yr^{-1})} = 0.97 \qquad (16)$$

where:

f_{lec}	=	fraction of total loss caused by leaching (unitless)
K_{lec}	=	loss rate coefficient for leaching (yr^{-1})
K_{tot}	=	total loss rate for the pollutant in treated soil (yr^{-1})

5.2.14.7.2 Reference Application Rate for Arsenic

For input parameters for this section, see Table 5.2.14-3. The reference water concentration for arsenic is derived by subtracting an average background concentration from the maximum contaminant level:

$$RC_{gw} = MCL\,(mg/l) - C_b\,(mg/l) = 0.05 - 0.0032 = 0.047\ (mg/l) \qquad (17)$$

where:

RC_{gw}	=	reference water concentration (mg/l)
MCL	=	maximum contaminant level in drinking water, established by the U.S. EPA (mg/l)
C_b	=	background concentration of the pollutant in well water (mg/l)

The VADOFT and AT123D components of the model predict the maximum concentration in ground water at the downgradient edge of the site within 300 years (based on a unit concentration of 1 mg/l in leachate). The ratio of these two concentrations is:

$$f_{wel} = \frac{C_{wel}(mg/l)}{C_{lec}(mg/l)}$$

$$= \frac{(0.0041)}{(1)} \quad (18)$$

$$= 0.0041$$

where:

f_{wel} = ratio of predicted concentration in well to concentration in leachate (unitless)
C_{wel} = predicted concentration of the pollutant in well (mg/l)
C_{lec} = unit concentration of the pollutant in leachate (mg/l)

This ratio is used to back-calculate a reference concentration of pollutant in leachate:

$$RC_{lec} = \frac{RC_{gw}(mg/l)}{f_{wel}}$$

$$= \frac{(0.047)}{(0.0041)} \quad (19)$$

$$= 11.44\ (mg/l)$$

where:

RC_{lec} = reference concentration of pollutant in leachate beneath the land application site (mg/l)
RC_{gw} = reference water concentration (mg/l)
f_{wel} = ratio of predicted concentration in well to concentration in leachate (unitless)

Multiplying this reference concentration by the known fluid flux, and adjusting units, yields the reference flux of pollutant mass from the site:

$$RF_{gw} = RC_{lec}(mg/l)\ NR(m/yr) \cdot 10$$

$$= (11.44)\ (0.5)\ 10 \quad (20)$$

$$= 57.2\ (kg/ha \cdot yr)$$

where:

RF_{gw} = reference annual flux of pollutant beneath the site (kg/ha•yr)
RC_{lec} = reference concentration of pollutant in leachate beneath the land application site (mg/l)

NR	=	annual recharge to ground water beneath the SMA (m/yr)
10	=	conversion factor [(mg•m)/l] $(kg/ha)^{-1}$

A reference cumulative application rate of the pollutant is derived by adjusting this flux for the fraction of pollutant lost to leaching and the duration of the square wave (see Appendix G for the calculations of TP for arsenic):

$$RP_c = \frac{RF_{gw}(kg/ha \cdot yr)\ TP(yr)}{f_{lec}} = \frac{(57.2)\ (21.9)}{(0.97)} = 1{,}295\,(kg/ha) \quad (21)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RF_{gw}	=	reference annual flux of pollutant beneath the site (kg/ha•yr)
TP	=	length of square wave in which maximum total loss rate of pollutant (kg/ha•yr) depletes total mass of pollutant applied to site (yr)
f_{lec}	=	fraction of total loss caused by leaching (unitless)

5.3 APPLICATION OF SEWAGE SLUDGE ON NONAGRICULTURAL LAND

Application of sewage sludge on nonagricultural land is defined as the use of sewage sludge on land that is not ordinarily used for raising edible crops. The types of practices within this category include forest applications, both remote and suburban, where periodic grazing may occur; soil reclamation, both remote from and near to human habitation; and public contact sites, including parks, picnic areas, golf courses, cemeteries, highway median strips, and urban landscaping.

Three categories were chosen for defining different practices that encompass application to nonagricultural land: forest land, soil reclamation sites, and public contact sites. These are described below.

Forest Land

Sewage sludge is applied as a fertilizer, then reapplied in future years as needed based on nitrogen requirements. Sewage sludge is sprayed onto forest land (either over or under the canopy) and not tilled into the soil. (This does not preclude incorporation or injection, but the model assumes surface application, the most conservative method.) Sites are accessible to the public (including children) in accordance with restrictions on public access based on die-off of pathogens. If the applier intends to meet Class A pathogen requirements, there are no restrictions on public access.

Crops that are ingested by humans or animals are not purposely grown on forest land. However, edible wild plants and mushrooms can be consumed by humans, and domestic animals may graze on forest land. Also, wild animals live on forest lands, and hunting is permitted in accordance with state regulations.

Soil Reclamation

Wastewater sludge is added to disturbed lands in a single application (or in multiple applications over a short period of time) for purposes of building topsoil and providing fertilizer to enhance ground cover. Application rates are not limited by the site's ability to assimilate nitrogen. Sewage sludge is applied by depositing and spreading, with or without disking; spraying, with or without disking; or injecting beneath the subsurface. Soil reclamation areas are available for public access (including access by children) in accordance with restrictions on public access based on die-off of pathogens.

No food crops directly ingested by humans are cultivated on soil reclamation areas. As with forest land, edible wild plants can be consumed by humans, and domestic animals may graze on soil reclamation land. The number of mushrooms would be limited by the small amount of carbon sources in a soil reclamation site. Because ground cover is usually a grass, it is reasonable to allow feed crops for domestic animals to be grown on reclamation areas. Hunting is also permitted, as on forest sites.

Public Contact Sites

Wastewater sludge is applied in single or multiple year applications to enrich and fertilize the soil on sites such as golf courses, parks, picnic areas, campuses, playgrounds, cemeteries, and highway medians. Sewage sludge is applied by depositing and spreading, with or without disking; spraying, with or without disking; or injecting beneath the subsurface. Ground cover varies with type of site, but includes grasses, shrubs, a few trees, and flowers.

Edible wild plants, such as mushrooms, can also grow on these sites. The number of mushrooms would be limited by the small amount of carbon sources in public contact sites. Public contact sites to which sewage sludge is applied are typically smaller than reclamation sites; the small size limits the number of animals that are exposed, and hunting on most public contact sites is prohibited because the public uses them.

The pathways assessed are summarized in Table 5.3-1.

TABLE 5.3-1

ENVIRONMENTAL PATHWAYS OF CONCERN IDENTIFIED FOR APPLICATION OF SEWAGE SLUDGE TO NONAGRICULTURAL LAND[a]

Pathway	Description of HEI
1. Sewage Sludge → Soil → Plant → Human	A person who regularly harvests wild plants from forest land, soil reclamation areas, and public contact sites amended with sewage sludge.
3. Sewage Sludge → Human	Child who plays unattended in sewage sludge applied to forest land or soil reclamation sites, and who ingests sewage sludge daily for 2 years.
3. Sewage Sludge → Human	Child who plays unattended in sewage sludge applied to public contact sites, and who ingests sewage sludge daily for 5 years.
4. Sewage Sludge → Soil → Plant → Animal → Human	A hunter of herbivores that live in forests or on soil reclamation sites. The hunter preserves meat for consumption throughout the year.
5. Sewage Sludge → Animal → Human	Consumer of domestic animals that ingest sewage sludge in sewage sludge-amended forests and soil reclamation sites.
6. Sewage Sludge → Soil → Plant → Animal	A small herbivore that lives its entire life in a sewage sludge-amended area feeding on seeds and small plants close to the sewage sludge-soil layer in the forest and in public contact sites. Domestic animals that graze the grasses growing on sewage sludge-amended soil reclamation sites.
7. Sewage Sludge → Animal	Domestic animals that ingest sewage sludge applied to forest and soil reclamation sites.
8. Sewage Sludge → Soil → Plant	Plants grown in sewage sludge-amended soil in forests and public contact sites.
9. Sewage Sludge → Soil → Soil Organisms	Soil organisms living in sewage sludge-amended soil in forests, soil reclamation sites, and public contact sites.
10. Sewage Sludge → Soil → Soil Organism → Soil Organism Predator	Animals eating soil organisms that live in sewage sludge-amended soil in forests, soil reclamation sites, and public contact sites.
12. Sewage Sludge → Soil → Surface Water → Human	Water Quality Criteria for the receiving water for a person who eats 0.04 kg/day of fish and drinks 2 liters water/day.

TABLE 5.3-1 (cont.)

Pathway	Description of HEI
13. Sewage Sludge → Soil → Air → Human	Human breathing volatile pollutants from sewage sludge.
14. Sewage Sludge → Soil → Ground Water → Human	Human drinking water from wells contaminated with pollutants leaching from sewage sludge-amended soil to ground water.

[a]Note: Pathway 2 (home gardener) was excluded for nonagricultural land, as was Pathway 11 (tractor operator).

5.3.1 Nonagricultural Pathway 1 (Human Toxicity From Plant Consumption)

5.3.1.1 Description of Pathway

Sewage Sludge → Soil → Plant → Human

This pathway is important wherever humans can consume wild plants grown in forests, on reclaimed lands, or on public contact sites that have been amended with sewage sludge. Food crops from this pathway that are directly ingested by humans grow wild, or the crops are grown specifically to harvest for feed for animals. An individual might harvest wild plants (berries or mushrooms) from forest land, reclaimed land, or public contact sites amended with sewage sludge. Sites are available for public access in accordance with restrictions on public access based on because of die-off of pathogens.

5.3.1.2 Pollutants Evaluated

Table 5.3.1-1 lists the organic and inorganic compounds assessed for forest land, soil reclamation sites, and public contact sites.

5.3.1.3 Highly Exposed Individual

Forest Land

It is assumed that the major plants consumed from a forest will be berries and mushrooms. When sewage sludge is applied to forest land, the Highly Exposed Individual (HEI) is a person who regularly harvests edible wild berries and mushrooms from forest land amended with sewage sludge. This food is preserved by drying, freezing, or canning and is available for consumption throughout the year. It is assumed that the HEI continues this practice for 70 years on a site that has reached the cumulative loading limit.

TABLE 5.3.1-1

POLLUTANTS EVALUATED FOR NONAGRICULTURAL PATHWAY 1

Inorganics	Organics
Arsenic	Aldrin/Dieldrin
Cadmium	Benzo(a)pyrene
Mercury	Chlordane
Nickel	DDT/DDE/DDD
Selenium	Heptachlor
Zinc	Hexachlorobenzene
	Hexachlorobutadiene
	Lindane
	n-Nitrosodimethylamine
	Polychlorinated Biphenyls (PCBs)
	Toxaphene
	Trichloroethylene

Reclamation Sites

Assuming there is public access to a soil reclamation site, the HEI is a person who harvests edible wild berries and mushrooms on a regular basis. The quantities of berries consumed from these sites are the same as from forest land. Mushroom consumption is not expected to significantly increase exposure, because the low productivity of mushrooms in this type of site is expected to be low, so mushroom consumption was not included.

Public Contact Sites

The HEI for public contact sites is the same as that for soil reclamation sites. Although the size of the treated area is generally smaller, some berries are usually available on these sites. Again, relatively low production of mushrooms is expected.

5.3.1.4 Algorithm Development

5.3.1.4.1 Inorganics

Equations

The RIA for inorganics is derived as follows:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \qquad (1)$$

where:

RIA	=	adjusted reference intake of pollutants in human beings (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

Then, RP_c is calculated from:

$$RP_c = \frac{RIA}{\Sigma(UC_i \cdot DC_i \cdot FC_i)} \qquad (2)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(kg-pollutant DW/ha)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

Input Parameters

Adjusted Reference Intake, RIA. The values used to calculate RIAs are designed to protect the sensitive members of the population. The definition and derivation of each of the parameters used to estimate RIA for threshold-acting toxicants are further discussed in the following sections.

Oral Reference Dose, RfD. The same RfDs were used in this pathway as in Agricultural Pathway 1 (see Table 5.3.1-3). Inorganics were assessed as threshold-acting chemicals, and the RfDs were taken from IRIS (U.S. EPA, 1992h). The recommended dietary allowance (RDA) was used for zinc instead of the RfD, because the RfD did not meet the RDA, which is required to maintain health. (For a more detailed discussion, see Section 5.2.1.4.1.2.2 in Agricultural Pathway 1).

Human Body Weight, BW. An adult body weight of 70 kg was used, as explained in Section 5.2.1.4.1.2.3 in Agricultural Pathway 1.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should be applied only where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the carcinogens, RE was set equal to 1.

Total Background Intake Rate of Pollutant from All Other Sources of Exposure, TBI. Humans are exposed to pollutants found in sewage sludge (e.g., cadmium, volatile organic compounds), even if no sewage sludge is applied to agricultural land. These sources include background levels (natural and/or anthropogenic) in drinking water, food, and air. When TBI is subtracted from the weight-adjusted RfD, the remainder defines the increment that can result from use or disposal of sewage sludge without exceeding the threshold. The TBIs used for adults are summarized in Table 5.3.1-4 in Agricultural Pathway 1.

Uptake Response Slope of Pollutants in Plant Tissue, UC. The potential of mushrooms to bioaccumulate mercury and cadmium has been demonstrated both in sewage sludge-amended media and in natural environments (Chaney, 1991b). However, only small amounts of the mercury in mushrooms are in the highly toxic methyl-mercury form. This, coupled with low ingestion (assumed at 0.6 g DW/day), indicates that mercury should not be a practical limit on using sewage sludge on forest land. Some mushrooms also accumulate cadmium. However, cadmium bioavailability in these mushrooms appears to be quite low, and there is no evidence that mushrooms containing cadmium from a soil/sewage sludge mixture would become a significant source of dietary cadmium intake for humans (Chaney, 1991b). Other potential toxic elements in sewage sludge (e.g., nickel, zinc, and lead), are not accumulated to toxic levels in mushrooms (Zabowski and Zasoski, 1984). Thus, since no data were available, metal intake from mushrooms is not included in this pathway analysis.

Since no data were available for berries, the uptake slopes for pollutants in garden fruits, described in detail in Agricultural Pathway 1, were used for inorganics.

Daily Dietary Consumption of Food Group, DC. Normal mushroom consumption is estimated at 0.078 g/day from the Estimated Lifetime Average Daily Food Intake (from Table 5.3.1-10). However, forest lands potentially offer the opportunity for gathering mushrooms in relatively large amounts. Although the largest portion would probably be ingested fresh, they can be dried or frozen for use throughout the year. It is relatively easy to pick enough mushrooms to consume an average of 2 cups per week, or 6.5 gallons annually. This is equivalent to about 0.6 g DW/day, which, to be conservative, was the value used for DC.

Consumption of fruits similar to berries (e.g., blueberries, cherries, strawberries) is estimated at 2.6 g/day, using the data developed by Pennington (1983). The Estimated Lifetime Average Daily Food Intake was developed for each fruit using the procedure described in Agricultural Pathway 1. The intakes for the three fruits were summed to yield 2.6 g/day. Berries can be very prolific at or near forest land, and it is easy to pick large quantities. For example, a person could consume a half cup of fresh berries 1 to 2 days per week (e.g., a daily serving of 1/8th of a pie, cereal with berries, or juice). A half-cup 1.5 days per week is equivalent to 170 g wet weight, or about 17 g dry weight (DW) per week or an average daily ingestion rate of 2.6 g/day. Therefore, 2.6 g DW/day was used.

Fraction of Food Group Produced on Sludge-Amended Soil, FC. It is assumed that the fraction of berries and mushrooms grown on sewage sludge-amended soil, FC, is 25 percent, a reasonable worst-case assumption. Although it is expected that prolific growth of berries can occur at spots throughout a sludge site, probably most of the picking will be done in the buffer strips along roads (aside from sites entirely without sludge). Here, only a portion of the berries bordering the application area is grown in sewage sludge-amended soil. Similarly, mushrooms will be picked in both nonsludge areas and buffer strips.

Input and Output Values

Tables 5.3.1-2 and 5.3.1-3 present the input and output values for inorganic compounds for Nonagricultural Pathway 1.

TABLE 5.3.1-2

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY 1, FOREST LAND

Arsenic

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00093

RfD	0.0008
BW	70
RE	1
TBI	0.012
RIA	44

RPc	47000

Cadmium

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.045	2.5952	0.25	0.02924

RfD	0.001
BW	70
RE	1
TBI	0.01614
RIA	53.86

RPc	1800

Mercury

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.005	2.5952	0.25	0.00296

RfD	0.0003
BW	70
RE	1
TBI	0.0032
RIA	17.8

RPc	6000

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-2 (cont.)

Nickel

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.003	2.5952	0.25	0.00214

RfD	0.02
BW	70
RE	1
TBI	0.173
RIA	1227

RPc	570000

Selenium

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.010	2.5952	0.25	0.00666

RfD	0.005
BW	70
RE	1
TBI	0.115
RIA	235

RPc	35000

Zinc

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.023	2.5952	0.25	0.01498

RfD	0.21
BW	70
RE	1
TBI	13.42
RIA	1280

RPc	85000

Notes:
Totals may not add due to rounding.
UC = uptake response slope of pollutant in plant tissue (μg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
DC = daily dietary consumption of food group (g-diet DW/day)
FC = fraction of food group produced on sewage sludge-amended soil (unitless)
RfD = oral reference dose (mg/kg-day)
BW = human body weight (kg)
RE = relative effectiveness of ingestion exposure (unitless)

TABLE 5.3.1-2 (cont.)

TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RIA = adjusted reference intake of pollutant in humans (μg-pollutant/day)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

TABLE 5.3.1-3

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY 1, SOIL RECLAMATION SITES AND PUBLIC CONTACT SITES

Arsenic

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00093

RfD	0.0008
BW	70
RE	1
TBI	0.012
RIA	44

RPc	47000

Cadmium

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.045	2.5952	0.25	0.02924

RfD	0.001
BW	70
RE	1
TBI	0.01614
RIA	53.86

RPc	1800

Mercury

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.005	2.5952	0.25	0.00296

RfD	0.0003
BW	70
RE	1
TBI	0.0032
RIA	17.8

RPc	6000

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-3 (cont.)

Nickel

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.003	2.5952	0.25	0.00214

RfD	0.02
BW	70
RE	1
TBI	0.173
RIA	1227

RPc	570000

Selenium

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.010	2.5952	0.25	0.00666

RfD	0.005
BW	70
RE	1
TBI	0.115
RIA	235

RPc	35000

Zinc

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.023	2.5952	0.25	0.01498

RfD	0.21
BW	70
RE	1
TBI	13.42
RIA	1280

RPc	85000

Notes:
Totals may not add due to rounding.
UC = uptake response slope of pollutant in plant tissue
(µg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
DC = daily dietary consumption of food group (g-diet DW/day)
FC = fraction of food group produced on sewage sludge-amended soil (unitless)
RfD = oral reference dose (mg/kg-day)
BW = human body weight (kg)

TABLE 5.3.1-3 (cont.)

RE = relative effectiveness of ingestion exposure (unitless)
TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

Sample Calculations

The following calculations show the derivation of the risk assessment output for Nonagricultural Pathway 1, Forest Land, Soil Reclamation Sites, and Public Contact Sites. The pollutant used as an example is arsenic.

First, RIA is calculated to be:

$$\begin{aligned} RIA &= \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \\ &= \left(\frac{0.0008 \cdot 70}{1} - 0.012\right) \cdot 10^3 \qquad (3) \\ &= 44\ \mu g\text{-arsenic/g} \cdot day \end{aligned}$$

where:

RIA	=	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

Then, RP_c is calculated to be:

$$\begin{aligned} RP_c &= \frac{RIA}{\Sigma(UC_i \cdot DC_i \cdot FC_i)} \\ &= \frac{44}{0.00093} \qquad (4) \\ &= 47{,}000\ kg\text{-arsenic/ha (rounded down to 2 significant figures)} \end{aligned}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(kg-pollutant DW/ha)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

5.3.1.4.2 Organics

Equations

The RIA is calculated from:

$$RIA = \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI \right) \cdot 10^3 \quad (5)$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

For organics, plant uptake is regressed against soil concentration; therefore the next step is to calculate RLC from:

$$RLC = \frac{RIA}{\Sigma(UC_i \cdot DC_i \cdot FC_i)} \quad (6)$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(μg-pollutant/g-soil DW)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

It should be note that the units for UC_i in this equation differ from those in equation (2) because in this equation the concentration of pollutant in plant tissue is regressed against the concentration of pollutant in soil, whereas in equation (2) plant tissue is regressed against the application rate of pollutants to the soil.

Finally, soil concentration RLC is converted to an annual application rate (RP_a) by considering the mass of soil (MS) and the decay series as shown below:

$$RP_a = RLC \cdot MS \cdot 10^{-9} \cdot [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1} \tag{7}$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9}	=	conversion factor (kg/μg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application until equilibrium conditions are reached (yr)

The half-lives of dieldrin and chlordane indicate that these organic pollutants do not degrade. Thus, they are treated slightly differently from the other organics in that a cumulative pollutant application rate, not an annual application rate, is calculated from:

$$RP_c = RLC \cdot MS \cdot 10^{-9} \tag{8}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9}	=	conversion factor (kg/μg)

Input Parameters

Adjusted Reference Intake in Humans, RIA. The values used to calculate RIAs are designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk. The definition and derivation of each of the parameters used to estimate RIA for nonthreshold-acting toxicants are further discussed in the following sections.

Risk Level, RL. Since by definition no "safe" level exists for exposure to nonthreshold agents, specification of a given risk level on which to base regulations is a matter of policy. For this risk assessment, RL was set at 10^{-4}. The RIA will therefore be the concentration that, for lifetime exposure, is calculated to have an upper-bound cancer risk of one case in 10,000 individuals exposed. This risk level refers to excess cancer risk that is over and above the background cancer risk in unexposed individuals.

Body Weight, BW. In keeping with U.S. EPA policy, an adult body weight of 70 kg was used (see Section 5.2.1.4.1.2.3 in Agricultural Pathway 1).

Human Cancer Potency, q_1*. The cancer potency value (q_1*) represents the relationship between a specified carcinogenic dose and its associated degree of risk. The q_1* is based on continual exposure of an individual to a specified concentration over a period of 70 years. Established EPA methodology for determining cancer potency values assumes that any degree of exposure to a carcinogen produces a measurable risk. The q_1* value is the cancer risk (to the proportion affected) per unit of dose; it is expressed in terms of risk per dose and is measured in units of milligrams of pollutant per kilogram of body weight per day of exposure $(mg/kg \cdot day)^{-1}$. The q_1*s were taken from IRIS. When a q_1* was not available in IRIS, the pending value was used, if applicable, or, if one had been previously approved but had been withdrawn, the formerly approved number was used. See Table 5.2.1-13 in Agricultural Pathway 1 for a summary of the q_1*s used in the risk assessment for land application.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should be applied only where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the carcinogens, RE was set equal to 1.

Total Background Intake Rate of Pollutant, TBI. No TBI values are available for organic compounds; they were assumed to be negligible.

Reference Concentration of Pollutant in Soil, RLC. Since plant uptake of a pollutant is in direct proportion to the concentration of pollutant in soil, the allowable concentration of pollutant is given as the reference concentration of pollutant in soil.

Uptake Response Slope of Pollutants in Plant Tissue for the Food Group, UC. Little is known about transfer of organic compounds to berries and mushrooms. It is expected that, like most other crops studied, minimal plant uptake occurs and that the only transfer mechanism is volatilization. Therefore, the default uptake response slopes of 0.001 μg-pollutant/g-plant tissue DW $(kg\text{-}pollutant/ha)^{-1}$ was used for both berries and mushrooms.

Daily Dietary Consumption of the Food Group, DC. The daily dietary consumption of each food group is the same as that presented for the inorganic compounds.

Fraction of Food Group Produced on Sewage Sludge-Amended Soil, FC. The fraction of each food group produced on sewage sludge-amended soil is the same for organic compounds as for inorganic compounds: 25 percent.

Reference Annual Application Rate of Pollutant, RP. The reference annual application rate applies to organic compounds that degrade in the environment. The amount of pollutant in sludge that can be added to a hectare each year takes this degradation into account.

Assumed Mass of Dry Soil in Upper 15 cm, MS. The assumed mass of dry soil in the upper 15 cm is $2x10^9$ g-soil DW/ha. (See Section 5.2.1.4.2.2.12 in Agricultural Pathway 1 for a complete description of the derivation of this value.)

Decay Rate Constant, k. For a complete description of this variable, see Section 5.2.1.4.2.2.13 in Agricultural Pathway 1. The values of k used are summarized in Table 5.2.1-14, also in Agricultural Pathway 1.

Input and Output Values

Tables 5.3.1-4 and 5.3.1-5 present the input and output values for organic compounds for Nonagricultural Pathway 1.

TABLE 5.3.1-4

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY 1, FOREST LAND

Aldrin/Dieldrin

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
		sum UC*DC*FC		0.00080

RL	1.00E-04
BW	70
q1*	16
RE	1
DE	1
MS	2E+09
RIA	0.438
RLC	547.697

RPc	1000

Benzo(a)pyrene

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
		sum UC*DC*FC		0.00080

RL	1.00E-04
BW	70
q1*	7.3
RE	1
DE	1
MS	2E+09
k	0.48
RIA	0.959
RLC	1200.431

RPa	910

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-4 (cont.)

Chlordane

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
			sum UC*DC*FC	0.00080

RL	1.00E-04
BW	70
q1*	1.3
RE	1
DE	1
MS	2E+09
RIA	5.385
RLC	6740.881

RPc	13000

DDT

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
			sum UC*DC*FC	0.00080

RL	1.00E-04
BW	70
q1*	0.34
RE	1
DE	1
MS	2E+09
k	0.04
RIA	20.588
RLC	25773.955

RPa	2200

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-4 (cont.)

Heptachlor

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
			sum UC*DC*FC	0.00080

RL	1.00E-04
BW	70
q1*	4.5
RE	1
DE	1
MS	2E+09
k	6.024
RIA	1.556
RLC	1947.365

RPa	3800

Hexachlorobenzene

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
			sum UC*DC*FC	0.00080

RL	1.00E-04
BW	70
q1*	1.6
RE	1
DE	1
MS	2E+09
k	0.122
RIA	4.375
RLC	5476.965

RPa	1200

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-4 (cont.)

Hexachlorobutadiene

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
			sum UC*DC*FC	0.00080

RL	1.00E-04
BW	70
q1*	0.078
RE	1
DE	1
MS	2E+09
k	1.406
RIA	89.744
RLC	112348.01

RPa	160000

Lindane

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
			sum UC*DC*FC	0.00080

RL	1.00E-04
BW	70
q1*	1.33
RE	1
DE	1
MS	2E+09
k	1.2
RIA	5.263
RLC	6588.831

RPa	9200

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-4 (cont.)

n-Nitrosodimethylamine

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
			sum UC*DC*FC	0.00080

RL	1.00E-04
BW	70
q1*	51
RE	1
DE	1
MS	2E+09
k	5.1
RIA	0.137
RLC	171.826

RPa	340

PCBs

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
			sum UC*DC*FC	0.00080

RL	1.00E-04
BW	70
q1*	7.7
RE	1
DE	1
MS	2E+09
k	0.063
RIA	0.909
RLC	1138.071

RPa	140

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

Toxaphene

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
		sum UC*DC*FC		0.00080

RL	1.00E-04
BW	70
q1*	1.1
RE	1
DE	1
MS	2E+09
k	1.2
RIA	6.364
RLC	7966.495

RPa	11000

Trichloroethylene

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065
Mushrooms	0.001	0.6	0.25	0.00015
		sum UC*DC*FC		0.00080

RL	1.00E-04
BW	70
q1*	0.011
RE	1
DE	1
MS	2E+09
k	0.78
RIA	636.364
RLC	796649.52

RPa	860000

Notes:
Totals may not add due to rounding.
UC = uptake response slope of pollutant in plant tissue (µg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
DC = daily dietary consumption of food group (g-diet DW/day)
FC = fraction of food group produced on sewage sludge-amended soil (unitless)
RL = risk level (unitless)
BW = human body weight (kg)
q1* = human cancer potency (mg/kg-day)^(-1)
RE = relative effectiveness of ingestion exposure (unitless)
DE = exposure duration adjustment (unitless)

TABLE 5.3.1-4 (cont.)

MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
k = loss rate constant (yr)^(-1)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
RLC = reference concentration of pollutant in soil (µg-pollutant/g-soil DW)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)
RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

TABLE 5.3.1-5

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY I, SOIL RECLAMATION SITES AND PUBLIC CONTACT SITES

Aldrin/Dieldrin

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	16
RE	1
DE	1
MS	2E+09
RIA	0.438
RLC	674.322

RPc	1300

Benzo(a)pyrene

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	7.3
RE	1
DE	1
MS	2E+09
k	0.48
RIA	0.959
RLC	1477.966

RPa	1100

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-5 (cont.)

Chlordane

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	1.3
RE	1
DE	1
MS	2E+09
RIA	5.385
RLC	8299.346

RPc	16000

DDT

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	0.34
RE	1
DE	1
MS	2E+09
k	0.04
RIA	20.588
RLC	31732.792

RPa	2700

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-5 (cont.)

Heptachlor

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	4.5
RE	1
DE	1
MS	2E+09
k	6.024
RIA	1.556
RLC	2397.589

RPa	4700

Hexachlorobenzene

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	1.6
RE	1
DE	1
MS	2E+09
k	0.122
RIA	4.375
RLC	6743.218

RPa	1500

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-5 (cont.)

Hexachlorobutadiene

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	0.078
RE	1
DE	1
MS	2E+09
k	1.406
RIA	89.744
RLC	138322.426

RPa	200000

Lindane

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	1.33
RE	1
DE	1
MS	2E+09
k	1.2
RIA	5.263
RLC	8112.142

RPa	11000

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-5 (cont.)

n-Nitrosodimethylamine

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	51
RE	1
DE	1
MS	2E+09
k	5.1
RIA	0.137
RLC	211.552

RPa	420

PCBs

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	7.7
RE	1
DE	1
MS	2E+09
k	0.063
RIA	0.909
RLC	1401.188

RPa	170

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.1-5 (cont.)

Toxaphene

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	1.1
RE	1
DE	1
MS	2E+09
k	1.2
RIA	6.364
RLC	9808.317

RPa	13000

Trichloroethylene

Food Group	UC	DC	FC	UC*DC*FC
Berries	0.001	2.5952	0.25	0.00065

RL	1.00E-04
BW	70
q1*	0.011
RE	1
DE	1
MS	2E+09
k	0.78
RIA	636.364
RLC	980831.745

RPa	1000000

Notes:
Totals may not add due to rounding.
UC = uptake response slope of pollutant in plant tissue (µg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
DC = daily dietary consumption of food group (g-diet DW/day)
FC = fraction of food group produced on sewage sludge-amended soil (unitless)
RL = risk level (unitless)
BW = human body weight (kg)
q1* = human cancer potency (mg/kg-day)^(-1)
RE = relative effectiveness of ingestion exposure (unitless)
DE = exposure duration adjustment (unitless)

TABLE 5.3.1-5 (cont.)

MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
k = loss rate constant (yr)^(-1)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
RLC = reference concentration of pollutant in soil (µg-pollutant/g-soil DW)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)
RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

Sample Calculations

There are two approaches for calculating risk assessment outputs for organics. The first is for those organics that degrade over time. The following is a sample calculation for Nonagricultural Pathway 1, Forest Land. The pollutant used as an example is benzo(a)pyrene.

First, RIA is calculated to be:

$$\begin{aligned} RIA &= \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI\right) \cdot 10^3 \\ &= \left(\frac{0.0001 \cdot 70}{7.3 \cdot 1}\right) \cdot 10^3 \\ &= 0.959 \ \mu g\text{-benzo(a)pyrene/day} \end{aligned} \tag{9}$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Next, RLC is calculated to be:

$$\begin{aligned} RLC &= \frac{RIA}{\Sigma(UC_i \cdot DC_i \cdot FC_i)} \\ &= \frac{0.959}{0.00080} \\ &= 1200.461 \ \mu g\text{-benzo(a)pyrene/g-soil DW} \end{aligned} \tag{10}$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(μg-pollutant/g-soil DW)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)

FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

Next, it is necessary to incorporate into the analysis pollutant loss from the soil. To do this, a first-order loss rate constant is derived from the pollutant half-life:

$$k = \frac{\ln 2}{T_{0.5}} = \frac{\ln 2}{1.44} = 0.48\,yr^{-1} \quad (11)$$

where:

k	=	first-order decay rate constant (yr^{-1})
ln	=	natural logarithm
$T_{0.5}$	=	half-life of pollutant in soil (yr)

Finally, RP_a is calculated to be:

$$\begin{aligned} RP_a &= RLC \cdot MS \cdot 10^{-9} \cdot [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1} \\ &= 1200.431 \cdot 2 \cdot 10^9 \cdot 10^{-9} \cdot [1 + e^{-0.48} + e^{-2 \cdot 0.48} + ... + e^{(1-100) \cdot 0.48}]^{-1} \quad (12) \\ &= 910 \text{ kg-benzo(a)pyrene/ha} \cdot \text{yr (rounded down to 2 significant figures)} \end{aligned}$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application until equilibrium conditions reached (yr)

The second approach is for organics that do not degrade over time. The calculations are identical to the first approach for organics, until the final calculation. The difference between the two approaches is that the output of the second approach is a cumulative pollutant application rate, as shown with data for chlordane:

$$\begin{aligned} RP_c &= RLC \cdot MS \cdot 10^{-9} \\ &= 6740.881 \cdot (2 \cdot 10^9) \cdot 10^{-9} \quad (13) \\ &= 13{,}000 \text{ kg-chlordane/ha (rounded down to 2 significant figures)} \end{aligned}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9}	=	conversion factor (kg/μg)

There are two approaches for calculating risk assessment outputs for organics. The first is for those organics that degrade over time. The following is a sample calculation for Nonagricultural Pathway 1, Soil Reclamation Sites and Public Contact Sites. The pollutant used as an example is benzo(a)pyrene.

First, RIA is calculated to be:

$$RIA = \left(\frac{RL \bullet BW}{q_1{*} \bullet RE} - TBI\right) \bullet 10^3$$
$$= \left(\frac{0.0001 \bullet 70}{7.3 \bullet 1}\right) \bullet 10^3 \qquad (14)$$
$$= 0.959 \ \mu g\text{-benzo(a)pyrene/day}$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(mg/kg \bullet day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Next, RLC is calculated to be:

$$RLC = \frac{RIA}{\Sigma(UC_i \bullet DC_i \bullet FC_i)}$$
$$= \frac{0.959}{0.00065} \qquad (15)$$
$$= 1477.966 \ \mu g\text{-benzo(a)pyrene/g-soil DW}$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UC_i	=	uptake response slope of pollutants in plant tissue for the food group i (μg-pollutant/g-plant tissue DW)(μg-pollutant/g-soil DW)$^{-1}$
DC_i	=	daily dietary consumption of the food group i (g-diet DW/day)
FC_i	=	fraction of food group i produced on sewage sludge-amended soil (unitless)

Next, it is necessary to incorporate pollutant loss from the soil into the analysis. To do this a first order loss rate constant is derived from the pollutant half life, as shown below:

$$k = \frac{\ln 2}{T_{0.5}} = \frac{\ln 2}{1.44} = 0.48\,yr^{-1} \tag{16}$$

where:

k	=	first-order decay rate constant (yr^{-1})
ln	=	natural logarithm
$T_{0.5}$	=	half-life of pollutant in soil (yr)

Finally, RP_a is calculated to be:

$$RP_a = RLC \bullet MS \bullet 10^{-9} \bullet [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1}$$

$$= 1477.966 \bullet 2 \bullet 10^9 \bullet 10^{-9} \bullet [1 + e^{-0.48} + e^{-2 \bullet 0.48} + ... + e^{(1-100) \bullet 0.48}]^{-1} \tag{17}$$

$$= 1{,}100 \text{ kg-benzo(a)pyrene/ha} \bullet \text{yr (rounded down to 2 significant figures)}$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9}	=	conversion factor (kg/μg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application until equilibrium conditions reached (yr)

The second approach is for organics that do not degrade over time. The calculations are identical to the first approach for organics until the final calculation. The difference between the two approaches is that the output of the second approach is a cumulative pollutant application rate, as shown with data for chlordane:

$$
\begin{aligned}
RP_c &= RLC \cdot MS \cdot 10^{-9} \\
&= 8299.346 \cdot (2 \cdot 10^{9}) \cdot 10^{-9} \qquad (18) \\
&= 16{,}000 \text{ kg-chlordane/ha (rounded down to 2 significant figures)}
\end{aligned}
$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
10^{-9}	=	conversion factor (kg/μg)

5.3.2 Nonagricultural Pathway 2

Nonagricultural Pathway 2 (the home gardener) was not analyzed because it is not an appropriate nonagricultural pathway (home gardens do not exist in forests, reclamation sites, or public contact sites).

5.3.3 Nonagricultural Pathway 3 (Human Toxicity from Soil Consumption)

5.3.3.1 Description of Pathway

Sewage Sludge → Human

This pathway assesses the hazard to a child of ingesting undiluted sewage sludge.

5.3.3.2 Pollutants Evaluated

Table 5.3.3-1 lists the inorganic and organic compounds evaluated for this pathway.

5.3.3.3 Highly Exposed Individual

Forest Land

The HEI for this pathway is a child who plays unattended in forest land on which sewage sludge has been applied and who ingests sewage sludge on a daily basis for a 2-year period. This pathway is appropriate for families who live near amended forest sites and whose children play in the forest. The number of individuals in this category is expected to be small. This HEI is similar to the HEI for agricultural use, except that it is assumed a child will not be unattended before the age of 4 for a long enough time to travel through the buffer zone (an assumed minimum of 30 m), to enter into the area on which sludge has been applied, and to ingest the sludge.

Soil Reclamation Sites

The potential for an HEI to exist near reclaimed soil areas is similar to that for forest land. Therefore, the same assumptions have been made as for forest land.

TABLE 5.3.3-1

POLLUTANTS EVALUATED FOR NONAGRICULTURAL PATHWAY 3

Inorganics	Organics
Arsenic	Aldrin/Dieldrin
Cadmium	Benzo(a)pyrene
Chromium	Chlordane
Copper	DDT/DDE/DDD
Lead	Heptachlor
Mercury	Hexachlorobenzene
Molybdenum	Hexachlorobutadiene
Nickel	Lindane
Selenium	n-Nitrosodimethylamine
Zinc	Polychlorinated Biphenyls (PCBs)
	Toxaphene
	Trichloroethylene

Public Contact Sites

Public contact sites include sites having a high potential for occupancy (parks) and those with a low potential for occupancy (highway medians, roadside cemeteries). To be conservative, the HEI is chosen for the high-occupancy practice. A child's contact with sludge occurs during play in the park, which can occur daily. It is assumed that this practice results in exposure very similar to that for the comparable agricultural scenario and that there will be a 5-year exposure period. Therefore, the limits calculated for Agricultural Pathway 3 were used.

5.3.3.4 Algorithm Development

5.3.3.4.1 Inorganics

Equations

The RIA for inorganics is derived as follows:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI \right) \cdot 10^3 \qquad (1)$$

where:

RIA	=	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

Because this pathway considers the direct ingestion of sewage sludge, the reference concentration of pollutant in sewage sludge is calculated by dividing the adjusted reference intake of pollutant in humans by the product of a soil ingestion rate and a duration-of-exposure adjustment factor:

$$RSC = \frac{RIA}{I_s \bullet DE} \qquad (2)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
I_s	=	soil ingestion rate (g-soil DW/day)
DE	=	exposure duration adjustment (unitless)

Input Parameters

Adjusted Reference Intake in Humans, RIA. The values used to calculate RIAs are and designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk. The definition and derivation of each of the parameters used to estimate RIA for nonthreshold-acting toxicants are further discussed in the following sections.

Oral Reference Dose, RfD. Inorganics were assessed as threshold chemicals, and the RfDs were taken from IRIS (U.S. EPA, 1992h). As for Agricultural Pathway 3, the RfD for trivalent chromium was used, because EPA determined that chromium in sewage sludge and soils is generally in the trivalent, not hexavalent, state. See Agricultural Pathway 3, Section 5.2.3.4.1 for a more complete discussion. See Agricultural Pathway 1, Section 5.2.1.4.1.2.2 for a complete discussion on RfDs. The RfDs and RDAs are summarized in Table 5.3.3-2.

For lead, a RfD was not available and a RDA was inappropriate (lead intake is antagonistic to maintaining health). Consequently, EPA's integrated uptake biokinetic (IUBK) model, designed to predict blood lead levels based on total exposure, was used. The Indoor Quality and Total Human Exposure Committee of EPA's Science Advisory Board (SAB) reviewed the IUBK model and concluded that it was sound and could be effectively applied for many current needs.

TABLE 5.3.3-2

RfDS AND RDAS FOR NONAGRICULTURAL PATHWAY 3

Pollutant	RfD (mg/kg•day)	Route of Exposure (animal)	Most Sensitive Endpoint
Arsenic (inorganic)	0.0008	oral (human)	Hyperpigmentation, keratosis, and possible vascular complications
Cadmium	0.001	oral (human)	Proteinuria
$Chromium^{3+}$	1.0	oral (rat)	No effects[a]
Copper	0.105, 0.125[b]	NA	NA
Mercury (inorganic)	0.0003	oral (rat)	Autoimmune effects
Molybdenum	0.005	oral (human)	Increased uric acid levels
Nickel	0.02	oral (rat)	Decreased body and organ weights
Selenium	0.005	oral (rat)	Selenosis (hair, nail loss, etc.)
Zinc	0.526, 0.625[c]	NA	NA

[a]Based on a NOAEL.

[b]No RfD available, so the recommended dietary allowance (RDA) was used. The RDA for children is 2 mg/day (NAS, 1989, p.228). 2 mg/day ÷ 19 kg (body weight of a child age 4 to 6) = 0.105 mg/kg•day for forest and reclamations sites, 2 mg/day ÷ 16 kg (body weight of a child age 1 to 5) = 0.125 mg/kg•day.

[c]The RfD did not meet the minimum RDA. Therefore, the RDA was used in lieu of the RfD. The RDA for children is 10 mg/day (NAS, 1989, p.209). 10 mg/day ÷ 19 kg (body weight of a child age 4 to 6) = 0.526 mg/kg•day for forest and reclamation sites, 10 mg/day ÷ 16 kg (body weight of a child age 1 to 5) = 0.625 mg/kg•day.

NA: Not Applicable

In the proposed Technical Support Document (U.S. EPA, 1989f), the effects on children of ingesting lead-contaminated sewage sludge were evaluated by extrapolating from data on cattle. For the present risk assessment, both EPA's Office of Research and Development (ORD) and Office of Water (OW) agreed to use the IUBK model instead of extrapolating from the cattle data.

Human Body Weight, BW. This pathway assesses children 4 to 6 years old. The corresponding body weight used was 19 kg.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should be applied only where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the pollutants, RE was set equal to 1.

Total Background Intake Rate of Pollutant from All Other Sources of Exposure, TBI. The TBIs (natural and/or anthropogenic) in drinking water, food, and air for toddlers are presented in Table 5.2.3-3. TBIs were available only for seven of the inorganics: arsenic, cadmium, chromium, mercury, nickel, selenium, and zinc. Since TBIs were not available for copper and molybdenum, a background of 0 was used in the calculations. See Pathway 1 for a complete description of TBIs.

Sewage Sludge Ingestion Rate, I_s. The soil ingestion rate used was 0.2 g-soil DW/day, based on the 1989 EPA directive from the Office of Solid Waste and Emergency Response (OSWER) recommending this value for the children at highest risk (U.S. EPA, 1989d).

Exposure Duration Adjustment, DE. EPA's Office of Research and Development (ORD) expressed concern about the suitability of using RfDs based on lifetime exposure for evaluating the effects to children of ingesting inorganic pollutants in sewage-sludge/soil mixtures. Scientists from ORD and the Office of Water re-evaluated the bases for the lifetime RfDs and proposed new values based on less-than-lifetime exposures. These new numbers were then submitted to the Agency's RfD Committee for approval. The Committee was unable to reach consensus on approving the new numbers, because there is at present no Agency method for calculating less-than-lifetime RfDs. There are plans for continuing these efforts in the future and, if completed in time, these new less-than-lifetime RfDs will be used by OW to evaluate metallic pollutants for this pathway in Round II rule making. Since no EPA-approved method was available for adjusting exposure durations associated with RfDs, the DE was set equal to 1.

Input and Output Values

Tables 5.3.3-3 and 5.3.3-4 present the input and output values for inorganic pollutants for Nonagricultural Pathway 3, for forest land and soil reclamation sites, and for public contact sites, respectively.

At the meeting held March 13, 1992, a consensus was reached among OW, ORD, the Office of Pesticides and Toxic Substances (OPTS), and the Office of Solid Waste and Emergency Response (OSWER) that the IUBK model should not cause a blood lead level to exceed 10 μg/dl and should protect a high percentage of the exposed population. Using a 30-percent absorption value and a 95th percentile of the population distribution, an allowable soil concentration of 500 ppm of lead was generated by the model. Because lead levels that trigger Superfund action range from 500 to 1,000 ppm, it was felt that allowing soil concentrations of lead to reach the action level was insufficiently protective. The group therefore made a policy decision to set the allowable lead concentration in sewage sludge at 300 ppm for this pathway.

Several reasons support this decision. First, such action would provide an additional margin of safety with respect to lead contamination of soil and any threat to the bodies of developing children. Because childhood ingestion of dirt is so widespread and the potential consequence so severe, a high order of conservatism is warranted on this point, especially in the context of regulatory decisions authorizing the addition of a threshold pollutant, lead, to the environment. In addition, a 300-ppm soil concentration yielded an allowable lead concentration in sludge that was widely consistent with current sewage sludge quality at all but a small number of publicly owned treatment works (POTWs). As a result, the social cost of an additional safety factor is small, relative to the potential benefit.

TABLE 5.3.3-3

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY 3, FOREST LAND AND SOIL RECLAMATION SITES

Pollutant	RfD	RDA	BW	RE	TBI	RIA	Is	DE	RSC
Arsenic	0.0008		19	1	0.0045	10.700	0.2	1	53
Cadmium	0.001		19	1	0.008156	10.844	0.2	1	54
Chromium	1		19	1	0.0494	18950.600	0.2	1	94000
Copper		0.105	19	1	0	2000.000	0.2	1	10000
Lead	Based on EPA policy decision								300
Mercury	0.0003		19	1	0.00128	4.420	0.2	1	22
Molybdenum	0.005		19	1	0	95.000	0.2	1	470
Nickel	0.02		19	1	0.1554	224.600	0.2	1	1100
Selenium	0.005		19	1	0.0594	35.600	0.2	1	170
Zinc		0.526	19	1	6.71	3290.000	0.2	1	16000

Notes:

Totals may not add due to rounding.

RfD = oral reference dose (mg/kg-day)

RDA = Recommended Dietary Allowance (mg/kg-day)

BW = human body weight (kg)

RE = relative effectiveness of ingestion exposure (unitless)

TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)

RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)

Is = soil ingestion rate (g-soil DW/day)

DE = exposure duration adjustment (unitless)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

TABLE 5.3.3-4

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY 3, PUBLIC CONTACT SITES

Pollutant	RfD	RDA	BW	RE	TBI	RIA	Is	DE	RSC
Arsenic	0.0008		16	1	0.0045	8.300	0.2	1	41
Cadmium	0.001		16	1	0.008156	7.844	0.2	1	39
Chromium	1		16	1	0.0494	15950.600	0.2	1	79000
Copper		0.125	16	1	0	2000.000	0.2	1	10000
Lead	Based on EPA policy decision								300
Mercury	0.0003		16	1	0.00128	3.520	0.2	1	17
Molybdenum	0.005		16	1	0	80.000	0.2	1	400
Nickel	0.02		16	1	0.1554	164.600	0.2	1	820
Selenium	0.005		16	1	0.0594	20.600	0.2	1	100
Zinc		0.625	16	1	6.71	3290.000	0.2	1	16000

Notes:

Totals may not add due to rounding.

RfD = oral reference dose (mg/kg-day)

RDA = Recommended Dietary Allowance (mg/kg-day)

BW = human body weight (kg)

RE = relative effectiveness of ingestion exposure (unitless)

TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)

RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)

Is = soil ingestion rate (g-soil DW/day)

DE = exposure duration adjustment (unitless)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

Coincidentally, this is the same pollutant limit calculated by the Peer Review Committee, based on the observation that body burdens (absorption) of animals fed up to 10 percent of their diet as sewage sludge did not change until the concentration of lead in the sewage sludge exceeded 300 ppm (300 μg/g). These data provide further support for the appropriateness of the value chosen by the Agency.

Sample Calculations

The following is a sample calculation for inorganic pollutants for Nonagricultural Pathway 3, Forest Land and Soil Reclamation Sites. The pollutant used as an example is arsenic.

First, RIA is calculated from:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \quad (3)$$

$$RIA = \left(\frac{0.0008 \cdot 19}{1} - 0.0045\right) \cdot 10^3 \quad (4)$$

$$RIA = 10.700 \ \mu g\text{-arsenic/day} \quad (5)$$

where:

RIA	=	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

RSC is then calculated from:

$$RSC = \frac{RIA}{I_s \cdot DE} \quad (6)$$

$$RSC = \frac{10.700}{0.2 \cdot 1} \qquad (7)$$

$$RSC = 53\ \mu g\text{-arsenic/g-sewage sludge DW (rounded down to 2 significant figures)} \qquad (8)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
I_s	=	soil ingestion rate (g-soil DW/day)
DE	=	exposure duration adjustment (unitless)

The following is a sample calculation for inorganic pollutants for Nonagricultural Pathway 3, Public Contact Sites. The pollutant used as an example is arsenic.

First, RIA is calculated from:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \qquad (9)$$

$$RIA = \left(\frac{0.0008 \cdot 16}{1} - 0.0045\right) \cdot 10^3 \qquad (10)$$

$$RIA = 8.300\ \mu g\text{-arsenic/day} \qquad (11)$$

where:

RIA	=	adjusted reference intake of pollutants in humans (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
RE	=	relative effectiveness of ingestion exposure (unitless)
10^3	=	conversion factor (μg/mg)

RSC is then calculated from:

$$RSC = \frac{RIA}{I_s \bullet DE} \quad (12)$$

$$RSC = \frac{8.300}{0.2 \bullet 1} \quad (13)$$

$$RSC = 41\ \mu g\text{-arsenic/g-sewage sludge DW (rounded down to 2 significant figures)} \quad (14)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
I_s	=	soil ingestion rate (g-soil DW/day)
DE	=	exposure duration adjustment (unitless)

5.2.3.4.2 Organics

Equations

The RIA is calculated from:

$$RIA = \left(\frac{RL \bullet BW}{q_1^* \bullet RE} - TBI \right) \bullet 10^3 \quad (15)$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight (kg)
q_1^*	=	human cancer potency $(mg/kg \bullet day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Because this pathway considers the direct ingestion of sewage sludge, the reference calculation of pollutant in sewage sludge is calculated by dividing the adjusted reference intake of pollutant in humans by the product of a soil ingestion rate and a duration exposure adjustment factor:

$$RSC = \frac{RIA}{I_s \cdot DE} \qquad (16)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
I_s	=	soil ingestion rate (g-soil DW/day)
DE	=	exposure duration adjustment (unitless)

Degradation of organics is not considered in this pathway, because the sludge is not mixed with soil and is subject to little degradation in the environment.

Input Parameters

Adjusted Reference Intake in Humans, RIA. The values used to calculate RIAs are and designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk. The definition and derivation of each of the parameters used to estimate RIA for nonthreshold-acting toxicants are further discussed in the following sections.

Risk Level, RL. Since by definition no "safe" level exists for exposure to nonthreshold agents, specification of a given risk level on which to base regulations is a matter of policy. For this risk assessment, RL was set at 10^{-4}. The RIA will therefore be the concentration that, for lifetime exposure, is calculated to have an upper-bound cancer risk of one case in 10,000 individuals exposed. This risk level refers to excess cancer risk that is over and above the background cancer risk in unexposed individuals.

Body Weight, BW. As with inorganics, the body weight used for toddlers was 19 kg.

Total Background Intake Rate of Pollutant, TBI. No TBI values are available for organic compounds; they were assumed to be negligible.

Human Cancer Potency, q_1*. This variable is described in detail in Agricultural Pathway 1, Section 5.2.1.4.2.2.5. See Table 5.2.1-13, also in Agricultural Pathway 1, for a summary of the q_1*s used in the risk assessment for land application.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should be applied only where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the carcinogens, RE was set equal to 1.

Sewage Sludge Ingestion Rate, I_s. The soil ingestion rate used was 0.2 g-soil DW/day based on the 1989 OSWER directive suggesting this value for children at highest risk (U.S. EPA, 1989d).

Exposure Duration Adjustment, DE. An adjustment to the RIA was required based on the brief duration (2 years) of this exposure. Values of q_1* are usually calculated to represent a lifetime exposure. Duration adjustment of cancer risk estimates is consistent with the method in which potency estimates q_1* are derived, and has been used previously by EPA. The value was derived on the basis of exposure duration divided by assumed lifetime, or 2 years/70 years = 0.029.

Input and Output Values

Tables 5.3.3-5 and 5.3.3-6 present the input and output values for organic pollutants for Nonagricultural Pathway 3, for forest land and soil reclamation sites, and for public contact sites, respectively.

TABLE 5.3.3-5

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY 3, FOREST LAND AND SOIL RECLAMATION SITES

Pollutant	RL	BW	q1*	RE	RIA	Is	DE	RSC
Aldrin/Dieldrin	1.00E-04	19	16	1	0.119	0.2	0.0286	20
Benzo(a)pyrene	1.00E-04	19	7.3	1	0.260	0.2	0.0286	45
Chlordane	1.00E-04	19	1.3	1	1.462	0.2	0.0286	250
DDT	1.00E-04	19	0.34	1	5.588	0.2	0.0286	970
Heptachlor	1.00E-04	19	4.5	1	0.422	0.2	0.0286	73
Hexachlorobenzene	1.00E-04	19	1.6	1	1.188	0.2	0.0286	200
Hexachlorobutadiene	1.00E-04	19	0.078	1	24.359	0.2	0.0286	4200
Lindane	1.00E-04	19	1.33	1	1.429	0.2	0.0286	250
n-Nitrosodimethylamine	1.00E-04	19	51	1	0.037	0.2	0.0286	6.5
PCBs	1.00E-04	19	7.7	1	0.247	0.2	0.0286	43
Toxaphene	1.00E-04	19	1.1	1	1.727	0.2	0.0286	300
Trichloroethylene	1.00E-04	19	0.011	1	172.727	0.2	0.0286	30000

Notes:
Totals may not add due to rounding.
RL = risk level (unitless)
BW = human body weight (kg)
q1* = human cancer potency (mg/kg-day)^(-1)
RE = relative effectiveness of ingestion exposure (unitless)
RIA = adjusted reference intake of pollutant in humans (μg-pollutant/day)
Is = soil ingestion rate (g-soil DW/day)
DE = exposure duration adjustment (unitless)
RSC = reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)

TABLE 5.3.3-6

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY 3, PUBLIC CONTACT SITES

	RL	BW	q1*	RE	RIA	Is	DE	RSC
Aldrin/Dieldrin	1.00E-04	16	16	1	0.100	0.2	0.0714	7.0
Benzo(a)pyrene	1.00E-04	16	7.3	1	0.219	0.2	0.0714	15
Chlordane	1.00E-04	16	1.3	1	1.231	0.2	0.0714	86
DDT	1.00E-04	16	0.34	1	4.706	0.2	0.0714	320
Heptachlor	1.00E-04	16	4.5	1	0.356	0.2	0.0714	24
Hexachlorobenzene	1.00E-04	16	1.6	1	1.000	0.2	0.0714	70
Hexachlorobutadiene	1.00E-04	16	0.078	1	20.513	0.2	0.0714	1400
Lindane	1.00E-04	16	1.33	1	1.203	0.2	0.0714	84
n-Nitrosodimethylamine	1.00E-04	16	51	1	0.031	0.2	0.0714	2.1
PCBs	1.00E-04	16	7.7	1	0.208	0.2	0.0714	14
Toxaphene	1.00E-04	16	1.1	1	1.455	0.2	0.0714	100
Trichloroethylene	1.00E-04	16	0.011	1	145.455	0.2	0.0714	10000

Notes:
Totals may not add due to rounding.
RL = risk level (unitless)
BW = human body weight (kg)
q1* = human cancer potency (mg/kg-day)^(-1)
RE = relative effectiveness of ingestion exposure (unitless)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
Is = soil ingestion rate (g-soil DW/day)
DE = exposure duration adjustment (unitless)
RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

Sample Calculations

The following is a sample calculation for organic pollutants for Nonagricultural Pathway 3, Forest Land and Soil Reclamation Sites. The pollutant used as an example is benzo(a)pyrene.

First, RIA is calculated from:

$$RIA = \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI\right) \cdot 10^3 \qquad (17)$$

$$RIA = \left(\frac{0.0001 \cdot 19}{7.3 \cdot 1} - 0.00\right) \cdot 10^3 \qquad (18)$$

$$RIA = 0.260\ \mu g\text{-benzo(a)pyrene/day} \qquad (19)$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight (kg)
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Then, RSC is calculated from:

$$RSC = \frac{RIA}{I_s \cdot DE} \qquad (20)$$

$$RSC = \frac{0.260}{0.2 \cdot 0.0286} \qquad (21)$$

$$RSC = 45\ \mu g\text{-pollutant/g-sewage sludge DW (rounded down to 2 significant figures)} \qquad (22)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
I_s	=	soil ingestion rate (g-soil DW/day)
DE	=	exposure duration adjustment (unitless)

The following is a sample calculation for organic pollutants for Nonagricultural Pathway 3, Public Contact Sites. The pollutant used as an example is benzo(a)pyrene.

First, RIA is calculated from:

$$RIA = \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI\right) \cdot 10^3 \quad (23)$$

$$RIA = \left(\frac{0.001 \cdot 16}{7.3 \cdot 1} - 0.00\right) \cdot 10^3 \quad (24)$$

$$RIA = 0.219 \ \mu g\text{-benzo(a)pyrene/day} \quad (25)$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight (kg)
q_1^*	=	human cancer potency $(mg/kg \cdot day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Then, RSC is calculated from:

$$RSC = \frac{RIA}{I_s \cdot DE} \quad (26)$$

$$RSC = \frac{0.219}{0.2 \cdot 0.0714} \quad (27)$$

$$RSC = 15\ \mu g\text{-pollutant/g-sewage sludge DW (rounded down to 2 significant figures)} \quad (28)$$

where:

RSC	=	reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)
RIA	=	adjusted reference intake of pollutant in humans (μg-pollutant/day)
I_s	=	soil ingestion rate (g-soil DW/day)
DE	=	exposure duration adjustment (unitless)

5.3.4 Nonagricultural Pathway 4 (Human Toxicity from Plant to Animal Consumption)

5.3.4.1 Description of Pathway

Sludge → Soil → Plant → Animal → Human

Sewage sludge applied to forest lands may contaminate forage plants by uptake or direct adherence. Herbivores (i.e., deer and elk) may forage in sewage sludge-amended areas and later may be taken by hunters. Then humans may ingest the deer and elk. The situation for reclaimed lands is similar to that of forest lands, since large animals might graze there, but it is unlikely that they will be found grazing on public contact sites.

5.3.4.2 Pollutants Evaluated

Table 5.3.4-1 lists the organic and inorganic compounds assessed for this pathway.

5.3.4.3 Highly Exposed Individual

Forest Land

The HEI for amended forest land is a hunter of herbivores who preserves meat for consumption throughout the year. This person also keeps the herbivore's liver and freezes it for several meals throughout the year.

Soil Reclamation Sites

The potential for an HEI to exist near a reclaimed soil area is similar to that for forest land; therefore, the same assumptions are made as for forest land.

TABLE 5.3.4-1

POLLUTANTS EVALUATED FOR NONAGRICULTURAL PATHWAY 4

Inorganics	Organics
Cadmium	Aldrin/Diedrin
Mercury	Chlordane
Selenium	DDT/DDE/DDD
Zinc	Heptachlor
	Hexachlorobenzene
	Lindane
	Polychlorinated biphenyls (PCBs)
	Toxaphene

Public Access Sites

It is likely that public contact sites will be relatively small and will not support large animals. Also it is assumed that hunting will be prohibited, because the public use such sites. Therefore, the assessment of this pathway for public contact sites is not appropriate.

5.3.4.4 Algorithm Development

5.3.4.4.1 Inorganics

Equations

The RIA for inorganics is derived as follows:

$$RIA = \left(\frac{RfD \cdot BW}{RE} - TBI\right) \cdot 10^3 \qquad (1)$$

where:

RIA	=	adjusted reference intake of pollutants in human beings (µg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
10^3	=	conversion factor (µg/mg)

Because this pathway involves the consumption of animal products by humans, the next equation in this analysis is a reference application rate of pollutant, RF (µg-pollutant/g-diet DW):

$$RF = \frac{RIA}{\sum (UA_i \cdot DA_i \cdot FA_i)} \qquad (2)$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in animal tissue food group i (μg-pollutant/g-animal tissue DW)(μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of animal tissue food group i (g-animal tissue DW/day)
FA_i	=	fraction of food group i assumed to be derived from animals which ingest forage grown on sewage sludge-amended soil (unitless)

For inorganics, a cumulative reference application rate of pollutant, RP (kg-pollutant/ha) is calculated:

$$RP_c = \frac{RF}{UC} \qquad (3)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
UC	=	uptake response slope of pollutant in forage crop (μg-pollutant/g forage DW)(kg-pollutant/ha)$^{-1}$

Input Parameters

Adjusted Reference Intake of Pollutants in Human Beings, RIA. The adjusted reference intake of pollutant in humans, RIA (μg-pollutant/day), is a level of daily pollutant intake that is likely to have no appreciable risk of adverse effects during a lifetime of exposure. It is a dose-response function calculated by considering factors such as human body weight, relative effectiveness of ingestion exposure, total background intake rate of pollutant, and reference dose.

Oral Reference Dose, RfD. The same RfDs used in Agricultural Pathway 4 for cadmium, mercury, selenium, and zinc were used for this pathway. Inorganics were assessed as threshold chemicals, and the RfDs were taken from IRIS (U.S. EPA, 1992). The recommended dietary allowance (RDA) was used for zinc instead of the RfD, because the RfD did not meet the RDA, which is necessary to maintain health (see Table 5.3.3-2). (For a more detailed discussion, see Section 5.2.1.4.1.2.2 in Agricultural Pathway 1.)

Human Body Weight, BW. An adult body weight of 70 kg was used, as explained in Section 5.2.1.4.1.2.3.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should be applied only where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the pollutants, RE was set equal to 1.

Total Background Intake Rate of Pollutant from All Other Sources of Exposure, TBI. Humans are exposed to pollutants found in sewage sludge (e.g., cadmium, volatile organic compounds), even if no sewage sludge is applied to agricultural land. These sources include background levels (natural and/or anthropogenic) in drinking water, food, and air. When TBI is subtracted from the weight-adjusted RfD, the remainder defines the increment that can be added from use or disposal of sewage sludge without exceeding the threshold. The TBIs used for adults are presented in Table 5.3.1-4 in Pathway 1.

Uptake Response Slope of Pollutant in Animal Tissue Food Group, UA. It is assumed that elk and deer uptake responses are the same as those for cattle. For a complete description of the methodology used to generate animal uptake slopes, see Section 5.2.4.4.1.2.6 in Agricultural Pathway 4.

Daily Dietary Consumption of Animal Tissue Food Group, DA. It was assumed that total consumption of deer and elk meat and fat constitutes 50 percent of the HEI's consumption of beef, beef liver, pork, lamb, poultry, dairy, and eggs and their fat counterparts, or 62.4 g DW/day. (See Table 5.3.1-10 in Agricultural Pathway 1 for the intake values for these food groups.) Beef liver consumption (Estimated Lifetime Dietary Intake) was assumed to be the same as for the agricultural pathways. The remainder of the diet (61.3 g DW/day) was assumed to be 75 percent meat and 25 percent fat. The analysis is complicated by the assumption that the ratio of elk meat to deer meat is 2 to 1 (since elk weigh twice as much as deer). Therefore, for liver consumption (i.e., 0.90-(213), elk liver is consumed at a rate of 0.60 g DW/day, and deer liver at 0.30 g DW/day. For organics, as discussed in Agricultural Pathway 4, it was necessary to use total liver consumption. Therefore, elk liver (total) is consumed at a rate of 0.76 g DW/day, and deer liver (total) at 0.38 g DW/Day.

If the remainder of the diet (61.3 g DW/day) is divided in a similar fashion, remembering that the meat-to-fat ratio is 3 to 1, elk meat consumption is 30.6 g DW/day [i.e., 61.3•(2/3)•(3/4)]; elk fat consumption is 10.2 g DW/day [i.e., 61.3•(2/3)•(1/4)]; deer meat consumption is 15.3 g DW/day [i.e., 61.3•(1/3)•(3/4)]; and deer fat consumption is 5.1 g DW/day [i.e., 61.3 (1/3)•(1/4)]. These dietary consumption data are summarized in Table 5.3.4-2.

Fraction of Food Group Assumed to be Derived from Animals That Ingest Forage Grown on Sewage Sludge-Amended Soil, FA. It is reasonable to assume that all deer inhabit areas in which sludge has been applied, because deer have been shown to preferentially feed in sewage sludge-amended areas. Therefore, the FA for deer was 100 percent. Elk have a much greater territorial range and do not spend as much time on a sludge-amended site. The PRC (1989) estimated that 50 percent of the elk come from areas to which sewage sludge has been applied, or that an elk spends only 50 percent of the time on sludge-treated areas.

Uptake Response Slope of Pollutants in Forage, UC. The uptake slopes for forage were derived using the same methodology used and described in Agricultural Pathway 1. See Section 5.2.1.4.1.2.6 for a detailed discussion. The geometric mean of the uptake slopes for forage for each inorganic evaluated are: 0.07 for cadmium, 0.043 for mercury, 0.003 for selenium, and 0.048 for zinc.

Input and Output Values

Table 5.3.4-3 presents the input and output values for inorganic compounds for Nonagricultural Pathway 4.

TABLE 5.3.4-2

ASSUMPTIONS FOR PATHWAY 4
DIETARY INTAKE AND FRACTION OF ANIMAL TISSUE FROM ANIMALS LIVING ON SEWAGE SLUDGE-AMENDED SOIL

	Daily Dietary Consumption of Food Group, DA (g-diet DW/day)	**Fraction of Food Group Produced on Sewage Sludge-Amended Soil, FA (percent)**
Deer Muscle	15.3	100
Deer Fat	5.1	100
Deer Liver	0.30	100
Deer Liver (total)	0.38	100
Elk Muscle	30.6	50
Elk Fat	10.2	50
Elk Liver	0.60	50
Elk Liver (total)	0.76	50

TABLE 5.3.4-3

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY 4, FOREST LAND AND SOIL RECLAMATION SITES

Cadmium

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle	0.008	15.3166	1	0.1154
Elk muscle	0.008	30.6332	0.5	0.1154
Deer liver	0.413	0.2994	1	0.1235
Elk liver	0.413	0.5989	0.5	0.1235
		sum UA*DA*FA		0.4778

RfD	0.001
BW	70
RE	1
TBI	0.01614
UC	0.070
RIA	53.86
RF	112.721

RPc	1600

Mercury

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle	0.004	15.3166	1	0.0602
Elk muscle	0.004	30.6332	0.5	0.0602
Deer liver	0.262	0.2994	1	0.0783
Elk liver	0.262	0.5989	0.5	0.0783
		sum UA*DA*FA		0.2771

RfD	0.0003
BW	70
RE	1
TBI	0.0032
UC	0.043
RIA	17.8
RF	64.240

RPc	1500

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.4-3 (cont.)

Selenium

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle	0.151	15.3166	1	2.3100
Elk muscle	0.151	30.6332	0.5	2.3100
Deer liver	1.195	0.2994	1	0.3578
Elk liver	1.195	0.5989	0.5	0.3578
		sum UA*DA*FA		5.3356

RfD	0.005
BW	70
RE	1
TBI	0.115
UC	0.003
RIA	235
RF	44.043

RPc	15000

Zinc

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle	0.006	15.3166	1	0.0854
Elk muscle	0.006	30.6332	0.5	0.0854
Deer liver	0.003	0.2994	1	0.0008
Elk liver	0.003	0.5989	0.5	0.0008
		sum UA*DA*FA		0.1723

RfD	0.21
BW	70
RE	1
TBI	13.42
UC	0.048
RIA	1280
RF	7430.526

RPc	150000

Notes:
Totals may not add due to rounding.
UA = uptake slope of pollutant in animal tissue (µg-pollutant/g-animal tissue DW)/(µg-pollutant/g-diet DW)
DA = daily dietary consumption of animal tissue food group (g-diet DW/day)
FA = fraction of food group assumed to be derived from animals which ingest sewage sludge (unitless)
RfD = oral reference dose (mg/kg-day)
BW = human body weight (kg)
RE = relative effectiveness of ingestion exposure (unitless)
TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
UC = uptake response slope of pollutant in forage (µg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
RF = reference concentration of pollutant in diet (µg-pollutant/g-diet DW)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

Sample Calculations

The following are sample calculations for inorganics for Nonagricultural Pathway 4, Forest Land and Soil Reclamation Sites. The pollutant used as an example is cadmium.

First RIA is calculated to be:

$$RIA = \left(\frac{RfD \bullet BW}{RE} - TBI\right) \bullet 10^3 \tag{4}$$

$$RIA = \left(\frac{0.001 \bullet 70}{1} - 0.01614\right) \bullet 10^3 \tag{5}$$

$$RIA = 53.86\ \mu g\text{-cadmium/day} \tag{6}$$

where:

RIA	=	adjusted reference intake of pollutants in human beings (μg-pollutant/day)
RfD	=	oral reference dose (mg/kg•day)
BW	=	human body weight (kg)
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Then, RF is calculated to be:

$$RF = \frac{RIA}{\sum (UA_i \bullet DA_i \bullet FA_i)} \tag{7}$$

$$RF = \frac{53.86}{0.478} \tag{8}$$

$$RF = 112.722\ \mu g\text{-cadmium/g-dietDW} \tag{9}$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in animal tissue food group i (μg-pollutant/g-animal tissue DW) (μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of animal tissue food group i (g-animal tissue DW/day)
FA_i	=	fraction of food group i assumed to be derived from animals that ingest forage grown on sewage sludge-amended soil (unitless)

Finally, RP_c is calculated to be:

$$RP_c = \frac{RF}{UC} \tag{10}$$

$$RP_c = \frac{112.722}{0.070} \tag{11}$$

$$RP_c = 1{,}600 \text{ kg-cadmium/ha (rounded down to 2 significant figures)} \tag{12}$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
UC	=	uptake response slope of pollutant in forage crop (μg-pollutant/g forage DW) (kg-pollutant/ha)$^{-1}$

5.3.4.4.2 Organics

Equations

The RIA is calculated from:

$$RIA = \left(\frac{RL \cdot BW}{q_1^* \cdot RE} - TBI\right) \cdot 10^3 \tag{13}$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency $(mg/kg \bullet day)^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Because this pathway involves the consumption of animal products by humans, the next equation in this analysis is a reference application rate of pollutant, RF (μg-pollutant/g-diet DW):

$$RF = \frac{RIA}{\sum (UA_i \cdot DA_i \cdot FA_i)} \qquad (14)$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in animal tissue food group i (μg-pollutant/g-animal tissue DW)(μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of animal tissue food group i (g-animal tissue DW/day)
FA_i	=	fraction of food group i assumed to be derived from animals which ingest forage grown on sewage sludge-amended soil (unitless)

For organics, a reference concentration of pollutant in soil is calculated:

$$RLC = \frac{RF}{UC} \qquad (15)$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
UC	=	uptake response slope of pollutant in forage crop (μg-pollutant/g-forage DW)(μg-pollutant/g-soil)$^{-1}$

Finally, soil concentration, RLC, is converted to an annual application rate (RP_a) by considering the mass of soil (MS) and the decay series as shown below:

$$RP_a = RLC \bullet MS \bullet 10^{-9} \bullet [1 + e^{-k} + e^{-2k} + ... + e^{(1-n)k}]^{-1} \quad (16)$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \bullet 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application until equilibrium conditions are reached (yr)

The half-lives of dieldrin and chlordane indicate that these organic pollutants do not degrade. Thus, they are treated slightly differently from the other organics in that a cumulative pollutant application rate, not an annual application rate, is calculated from:

$$RP_c = RLC \bullet MS \bullet 10^{-9} \quad (17)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \bullet 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)

Input Parameters

Adjusted Reference Intake in Humans, RIA. The values used to calculate RIAs are designed to protect the sensitive members of the population. Thus, if the entire population experienced the level of exposure these values represent, only a small portion of the population would be at risk. The definition and derivation of each of the parameters used to estimate RIA for nonthreshold-acting toxicants are further discussed in the following sections.

Risk Level, RL. Since by definition no "safe" level exists for exposure to nonthreshold agents. specification of a given risk level on which to base regulations is a matter of policy. For this risk assessment, RL was set at 10^{-4}. The RIA will therefore be the concentration that, for lifetime exposure, is calculated to have an upper-bound cancer risk of one case in 10,000 individuals exposed. This risk level refers to excess cancer risk that is over and above the background cancer risk in unexposed individuals.

Body Weight, BW. In keeping with U.S. EPA policy, an adult body weight of 70 kg was used, as explained in Section 5.2.1.4.1.2.3.

Human Cancer Potency, q_1*. A complete description of this variable can be found in Agricultural Pathway 1, Section 5.2.1.4.2.2.5. The values used for q_1*s are presented in Table 5.2.1-13 in Agricultural Pathway 1.

Relative Effectiveness of Ingestion Exposure, RE. As stated previously, an RE factor should be applied only where well-documented/referenced information is available on the contaminant's observed relative effectiveness. Since this information was not available for any of the carcinogens, RE was set equal to 1.

Total Background Intake Rate of Pollutant, TBI. No TBI values are available for organic compounds; they were assumed to be negligible.

Reference Concentration of Pollutant in Diet, RF. Animal uptake of a pollutant is in direct proportion to the concentration of pollutant in food. RLC relates the adjusted reference intake in humans (RIA) to animal uptake of pollutants and human dietary consumption of such animals.

Uptake Response Slope of Pollutant in Animal Tissue Food Group, UA. The animal tissue uptake slopes relate the concentration of pollutant in animal tissue to its concentration in animal feed. As for inorganics in this pathway, uptake of pollutants in beef muscle and beef liver were used as surrogates for uptake of pollutants in deer and elk muscle and liver.

Daily Dietary Consumption of the Food Group, DA. Since organics sequester in the fat and liver, the food groups assessed were: deer muscle (fat), elk muscle (fat), deer liver, and elk liver. The daily dietary consumption of these food groups is the same as for inorganics (see Table 5.3.4-2 in this pathway).

Fraction of Food Group Assumed to be Derived from Animals that Ingest Forage Grown on Sewage Sludge-Amended Soil, FA. As for inorganics for this pathway, deer are assumed to spend 100 percent of their time in sewage sludge-amended areas, while elk spend only 50 percent of their time there.

Uptake Response Slope of Pollutants in Forage, UC. Since very little data were available on the uptake of organic compounds by plants, the response slopes could not be calculated and were therefore conservatively set to a default slope of 0.001.

Reference Annual Application Rate of Pollutant, RP_a. The reference annual application rate applies to organic compounds that degrade in the environment. The amount of pollutant in sludge that can be added to a hectare each year takes this degradation into account.

Assumed Mass of Dry Soil in Upper 15 cm, MS. The assumed mass of dry soil in the upper 15 cm is $2 \cdot 10^9$ g-soil DW/ha. (See Section 5.2.1.4.2.2.12 for a complete description of the derivation of this value.)

Decay Rate Constant, k. A complete description of this variable is located in Section 5.2.1.4.2.2.1.3 in Agricultural Pathway 1. The values used for k are presented in Table 5.2.1-14, also in Agricultural Pathway 1.

Input and Output Values

Table 5.3.4-4 presents the input and output values for organic compounds for nonagricultural Pathway 4.

TABLE 5.3.4-4

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS
FOR NONAGRICULTURAL PATHWAY 4
FOR FOREST LAND AND SOIL RECLAMATION SITES

Aldrin/Dieldrin

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle (fat)	2.156	5.1055	1.0000	11.0074
Elk muscle (fat)	2.156	10.2111	0.5000	11.0074
Deer liver	2.873	0.3813	1.0000	1.0952
Elk liver	2.873	0.7625	0.5000	1.0952
		sum UA*DA*FA		24.2053

RL	1.00E-04
BW	70
q1*	16
RE	1
UC	0.001
MS	2E+09
RIA	0.438
RF	0.018
RLC	18.075

RPc	36

Chlordane

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle (fat)	0.071	5.1055	1.0000	0.3610
Elk muscle (fat)	0.071	10.2111	0.5000	0.3610
Deer liver	0.071	0.3813	1.0000	0.0270
Elk liver	0.071	0.7625	0.5000	0.0270
		sum UA*DA*FA		0.7760

RL	1.00E-04
BW	70
q1*	1.3
RE	1
UC	0.001
MS	2E+09
RIA	5.385
RF	6.939
RLC	6939.236

RPc	13000

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.4-4 (cont.)

DDT/DDE/DDD

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle (fat)	2.800	5.1055	1.00	14.2945
Elk muscle (fat)	2.800	10.2111	0.50	14.2945
Deer liver	12.891	0.3813	1.00	4.9150
Elk liver	12.891	0.7625	0.50	4.9150
		sum UA*DA*FA		38.4189

RL	1.00E-04
BW	70
q1*	0.34
RE	1
UC	0.001
MS	2E+09
k	0.04
RIA	20.588
RF	0.536
RLC	535.888

RPa	46

Heptachlor

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle (fat)	3.718	5.1055	1.00	18.9814
Elk muscle (fat)	3.718	10.2111	0.50	18.9814
Deer liver	12.362	0.3813	1.00	4.7132
Elk liver	12.362	0.7625	0.50	4.7132
		sum UA*DA*FA		47.3891

RL	1.00E-04
BW	70
q1*	4.5
RE	1
UC	0.001
MS	2E+09
k	6.024
RIA	1.556
RF	0.033
RLC	32.825

RPa	65

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.4-4 (cont.)

Hexachlorobenzene

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle (fat)	3.482	5.1055	1.00	17.7771
Elk muscle (fat)	3.482	10.2111	0.50	17.7771
Deer liver	6.461	0.3813	1.00	2.4634
Elk liver	6.461	0.7625	0.50	2.4634
		sum UA*DA*FA		40.4809

RL	1.00E-04
BW	70
q1*	1.6
RE	1
UC	0.001
MS	2E+09
k	0.122
RIA	4.375
RF	0.108
RLC	108.076

RPa	25

Lindane

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle (fat)	1.117	5.1055	1.00	5.7043
Elk muscle (fat)	1.117	10.2111	0.50	5.7043
Deer liver	1.117	0.3813	1.00	0.4260
Elk liver	1.117	0.7625	0.50	0.4260
		sum UA*DA*FA		12.2605

RL	1.00E-04
BW	70
q1*	1.33
RE	1
UC	0.001
MS	2E+09
k	1.2
RIA	5.263
RF	0.429
RLC	429.279

RPa	600

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.4-4 (cont.)

PCBs

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle (fat)	4.215	5.1055	1.00	21.5183
Elk muscle (fat)	4.215	10.2111	0.50	21.5183
Deer liver	6.664	0.3813	1.00	2.5407
Elk liver	6.664	0.7625	0.50	2.5407
			sum UA*DA*FA	48.1179

RL	1.00E-04
BW	70
q1*	7.7
RE	1
UC	0.001
MS	2E+09
k	0.063
RIA	0.909
RF	0.019
RLC	18.893

RPa	2.4

Toxaphene

Food Group	UA	DA	FA	UA*DA*FA
Deer muscle (fat)	18.653	5.1055	1.00	95.2339
Elk muscle (fat)	18.653	10.2111	0.50	95.2339
Deer liver	18.653	0.3813	1.00	7.1118
Elk liver	18.653	0.7625	0.50	7.1118
			sum UA*DA*FA	204.6915

RL	1.00E-04
BW	70
q1*	1.1
RE	1
UC	0.001
MS	2E+09
k	1.2
RIA	6.364
RF	0.031
RLC	31.089

RPa	43

Notes:
Totals may not add due to rounding.
UA = uptake slope of pollutant in animal tissue (µg-pollutant/g-animal tissue DW)/(µg-pollutant/g-diet DW)
DA = daily dietary consumption of animal tissue food group (g-diet DW/day)
FA = fraction of food group assumed to be derived from animals which ingest sewage sludge (unitless)
RL = risk level (unitless)
BW = human body weight (kg)
q1* = human cancer potency (mg/kg-day)^(-1)
RE = relative effectiveness of ingestion exposure (unitless)

TABLE 5.3.4-4 (cont.)

UC = uptake response slope of pollutant in forage (µg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
k = loss rate constant (yr)^(-1)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
RF = reference concentration of pollutant in diet (µg-pollutant/g-diet DW)
RLC = reference concentration of pollutant in soil (µg-pollutant/g-soil DW)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)
RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

Sample Calculations

As discussed previously, two approaches are used for organic pollutants. The first, for organics that degrade over time, is shown by the following sample calculations. The pollutant used as an example is heptachlor.

First, RIA is calculated from:

$$RIA = \left(\frac{RL \bullet BW}{q_1^* \bullet RE} - TBI\right) \bullet 10^3 \qquad (18)$$

$$RIA = \left(\frac{0.0001 \bullet 70}{4.5 \bullet 1} - 0.00\right) \bullet 10^3 \qquad (19)$$

$$RIA = 1.556 \ \mu g\text{-heptachlor/day} \qquad (20)$$

where:

RIA	=	adjusted reference intake in humans (μg-pollutant/day)
RL	=	risk level
BW	=	human body weight
q_1^*	=	human cancer potency (mg/kg•day)$^{-1}$
RE	=	relative effectiveness of ingestion exposure (unitless)
TBI	=	total background intake rate of pollutant (mg-pollutant/day)
10^3	=	conversion factor (μg/mg)

Next, RF is calculated to be:

$$RF = \frac{RIA}{\sum (UA_i \bullet DA_i \bullet FA_i)} \qquad (21)$$

$$RF = \frac{1.556}{47.389} \qquad (22)$$

$$RF = 0.0328 \ \mu g\text{-heptachlor/g-dietDW} \qquad (23)$$

where:

RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
RIA	=	adjusted reference intake in humans (μg-pollutant/day)
UA_i	=	uptake response slope of pollutant in animal tissue food group i (μg-pollutant/g-animal tissue DW)(μg-pollutant/g-diet DW)$^{-1}$
DA_i	=	daily dietary consumption of animal tissue food group i (g-animal tissue DW/day)
FA_i	=	fraction of food group i assumed to be derived from animals that ingest forage grown on sewage sludge-amended soil (unitless)

Next, RLC is calculated to be:

$$RLC = \frac{RF}{UC} \tag{24}$$

$$RLC = \frac{0.0328}{0.001} \tag{25}$$

$$RLC = 32.825\ \mu g\text{-heptachlor/g-soilDW} \tag{26}$$

where:

RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
RF	=	reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
UC	=	uptake response slope of pollutant in forage crop (μg-pollutant/g-forage DW)(μg-pollutant/g-soil)$^{-1}$

Finally, RP_a is calculated to be:

$$RP_a = RLC \cdot MS \cdot 10^{-9} \cdot [1 + e^{-k} + e^{-2k} + ... + e^{(1-a)k}]^{-1} \tag{27}$$

$$RP_a = 32.825 \cdot 2 \cdot 10^{9} \cdot 10^{-9} \cdot [1 + e^{-6.023} + e^{-2 \cdot 6.023} + ... + e^{(1-100) \cdot 6.023}]^{-1} \tag{28}$$

$$RP_a = 65\ \text{kg-heptachlor/ha} \cdot \text{yr (rounded down to 2 significant figures)} \tag{29}$$

where:

RP_a	=	reference annual application rate of pollutant (kg-pollutant/ha•yr)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)
e	=	base of natural logarithms, 2.718 (unitless)
k	=	loss rate constant (yr^{-1})
n	=	years of application until equilibrium conditions are reached (yr)

The second approach is for organics that do not degrade over time. The calculations are identical to the first approach for organics until the final calculation. The difference between the two approaches is that the output of the second approach is a reference cumulative application rate of pollutant. The following calculation, using chlordane as an example, shows only the final step in the procedure, where RP_c is calculated to be:

$$RP_c = RLC \cdot MS \cdot 10^{-9} \quad (30)$$

$$RP_c = 6939.236 \cdot 2 \cdot 10^{9} \cdot 10^{-9} \quad (31)$$

$$RP_c = 13{,}000 \text{ kg-chlordane/yr (rounded down to 2 significant figures)} \quad (32)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
RLC	=	reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS	=	$2 \cdot 10^9$ g-soil DW/ha = assumed mass of dry soil in upper 15 cm
10^{-9}	=	conversion factor (kg/μg)

5.3.5 Nonagricultural Pathway 5 (Human Toxicity from Consumption of Livestock)

5.3.5.1 Description of Pathway

Sewage Sludge → Animal → Human

Sewage sludge applied to forest land and reclamation sites may be ingested by domestic animals that graze on grasses growing on forest land or reclaimed land; the animals are then ingested by humans. The pathway continues to individuals that regularly consume these animals' products. It is assumed that the sludge is not mixed into the soil and is therefore ingested in an undiluted form. Exposure on public contact sites is limited, because grazing on these sites is controlled; therefore public contact sites were not assessed.

5.3.5.2 Pollutants Evaluated

As discussed in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results* (EPA, 1985c), all pollutants except for aldrin/dieldrin, cadmium, chlordane, DDT/DDE/DDD, heptachlor, hexachlorobenzene, hexachlorobutadiene, lindane, mercury, PCBs, and toxaphene, were screened out during the initial evaluation. In addition to the pollutants remaining, selenium and zinc were assessed, because the animal uptake data were readily available from Pathway 4. Table 5.3.5-1 lists the organic and inorganic compounds assessed for this pathway.

5.3.5.3 Highly Exposed Individual

Forest Land

This pathway is designed to protect humans that consume domestic animals that graze on the grasses growing on sewage sludge-treated forest land. The pathway is not considered for wild animals in forest land, because deer do not graze on plants close to the ground (they are

TABLE 5.3.5-1

POLLUTANTS EVALUATED FOR NONAGRICULTURAL PATHWAY 5

Inorganics	Organics
Cadmium	Aldrin/Dieldrin
Mercury	Chlordane
Selenium	DDT/DDE/DDD
Zinc	Heptachlor
	Hexachlorobenzene
	Hexochlorobutadiene
	Lindane
	Polychlorinated biphenyls (PCBs)
	Toxaphene

browsers), and other wild-ranging animals have large territories. The HEI is a person who regularly eats the meats of animals that have grazed on sewage sludge-amended forest land. This scenario is similar to an agricultural pastureland scenario. The outputs calculated for Agricultural Pathway 5 will, therefore, be used for forest land.

Soil Reclamation Sites

Soil reclamation sites can also be used for grazing domestic animals. Therefore, the same assumptions used for forest land apply to soil reclamation sites. That is, the outputs calculated for Agricultural Pathway 5 will be used.

Public Contact Sites

Exposure through public contact sites is not considered significant. It is not expected that grazing will be allowed on these sites, nor are the areas assumed to be large enough to support grazing animals.

5.3.5.4 Algorithm Development

See Agricultural Pathway 5 for a complete description of the equations and input values used.

5.3.5.5 Input and Output Values

Tables 5.3.5-2 and 5.3.5-3 list input and output values for inorganics and organics, respectively.

TABLE 5.3.5-2

INPUT AND OUTPUT VALUES FOR INORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY 5

Cadmium

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.008	19.2547	0.10	0.0145
Beef liver	0.413	0.8983	0.10	0.0371
Lamb	0.008	0.2008	0.10	0.0002
Dairy	0.001	28.8679	0.03	0.0010
		sum UA*DA*FA		0.0528

RfD	0.001
BW	70
RE	1
TBI	0.01614
FS	0.015
RIA	53.86
RF	1020.556

RSC	68000

Mercury

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.004	19.2547	0.10	0.0076
Beef liver	0.262	0.8983	0.10	0.0235
Lamb	0.024	0.2008	0.10	0.0005
Dairy	0.020	28.8679	0.03	0.0171
		sum UA*DA*FA		0.0487

RfD	0.0003
BW	70
RE	1
TBI	0.0032
FS	0.015
RIA	17.8
RF	365.714

RSC	24000

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.5-2 (cont.)

Selenium

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.151	19.2547	0.10	0.2904
Beef liver	1.195	0.8983	0.10	0.1074
Lamb	0.901	0.2008	0.10	0.0181
Dairy	0.901	28.8679	0.03	0.7802
		sum UA*DA*FA		1.1960

RfD	0.005
BW	70
RE	1
TBI	0.115
FS	0.015
RIA	235
RF	196.487

RSC	13000

Zinc

Food Group	UA	DA	FA	UA*DA*FA
Beef	0.006	19.2547	0.10	0.0107
Beef liver	0.003	0.8983	0.10	0.0002
Lamb	1.106	0.2008	0.10	0.0222
Dairy	0.005	28.8679	0.03	0.0045
		sum UA*DA*FA		0.0377

RfD	0.21
BW	70
RE	1
TBI	13.42
FS	0.015
RIA	1280
RF	33970.494

RSC	2200000

Notes:
Totals may not add due to rounding.
UA = uptake slope of pollutant in animal tissue (µg-pollutant/g-animal tissue DW)/(µg-pollutant/g-diet DW)
DA = daily dietary consumption of animal tissue food group (g-diet DW/day)
FA = fraction of food group assumed to be derived from animals which ingest sewage sludge (unitless)
RfD = oral reference dose (mg/kg-day)
BW = human body weight (kg)
RE = relative effectiveness of ingestion exposure (unitless)
TBI = total background intake rate of pollutant from all other sources of exposure (mg-pollutant/day)
FS = fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
RF = reference concentration of pollutant in diet (µg-pollutant/g-diet DW)
RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

TABLE 5.3.5-3

INPUT AND OUTPUT VALUES FOR ORGANIC POLLUTANTS FOR NONAGRICULTURAL PATHWAY 5

Aldrin/Dieldrin

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	2.156	15.4977	0.10	3.3413
Beef liver (incl. fat)	2.873	1.1438	0.10	0.3286
Lamb (fat)	1.553	0.2080	0.10	0.0323
Dairy (fat)	12.880	18.1252	0.03	7.0037
		sum UA*DA*FA		10.7058

RL	1.00E-04
BW	70
q1*	16
RE	1
FS	0.015
RIA	0.438
RF	0.041

RSC	2.7

Chlordane

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	0.071	15.4977	0.10	0.1096
Beef liver (incl. fat)	0.071	1.1438	0.10	0.0081
Lamb (fat)	0.071	0.2080	0.10	0.0015
Dairy (fat)	0.060	18.1252	0.03	0.0324
		sum UA*DA*FA		0.1515

RL	1.00E-04
BW	70
q1*	1.3
RE	1
FS	0.015
RIA	5.385
RF	35.538

RSC	2300

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.5-3 (cont.)

DDT/DDE/DDD

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	2.800	15.4977	0.10	4.3390
Beef liver (incl. fat)	12.891	1.1438	0.10	1.4745
Lamb (fat)	2.289	0.2080	0.10	0.0476
Dairy (fat)	5.601	18.1252	0.03	3.0453
		sum UA*DA*FA		8.9065

RL	1.00E-04
BW	70
q1*	0.34
RE	1
FS	0.015
RIA	20.588
RF	2.312

RSC	150

Heptachlor

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	3.718	15.4977	0.10	5.7617
Beef liver (incl. fat)	12.362	1.1438	0.10	1.4139
Lamb (fat)	0.853	0.2080	0.10	0.0177
Dairy (fat)	12.362	18.1252	0.03	6.7218
		sum UA*DA*FA		13.9153

RL	1.00E-04
BW	70
q1*	4.5
RE	1
FS	0.015
RIA	1.556
RF	0.112

RSC	7.4

Hexachlorobenzene

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	3.482	15.4977	0.10	5.3962
Beef liver (incl. fat)	6.461	1.1438	0.10	0.7390
Lamb (fat)	8.353	0.2080	0.10	0.1737
Dairy (fat)	6.461	18.1252	0.03	3.5132
		sum UA*DA*FA		9.8221

RL	1.00E-04
BW	70
q1*	1.6
RE	1
FS	0.015
RIA	4.375
RF	0.445

RSC	29

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.5-3 (cont.)

Hexachlorobutadiene

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	3.482	15.4977	0.10	5.3962
Beef liver (incl. fat)	6.461	1.1438	0.10	0.7390
Lamb (fat)	8.353	0.2080	0.10	0.1737
Dairy (fat)	6.461	18.1252	0.03	3.5132
		sum UA*DA*FA		9.8221

RL	1.00E-04
BW	70
q1*	0.078
RE	1
FS	0.015
RIA	89.744
RF	9.137

RSC	600

Lindane

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	1.117	15.4977	0.10	1.7315
Beef liver (incl. fat)	1.117	1.1438	0.10	0.1278
Lamb (fat)	1.117	0.2080	0.10	0.0232
Dairy (fat)	1.117	18.1252	0.03	0.6075
		sum UA*DA*FA		2.4901

RL	1.00E-04
BW	70
q1*	1.33
RE	1
FS	0.015
RIA	5.263
RF	2.114

RSC	140

PCBs

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	4.215	15.4977	0.10	6.5318
Beef liver (incl. fat)	6.664	1.1438	0.10	0.7622
Lamb (fat)	6.664	0.2080	0.10	0.1386
Dairy (fat)	10.536	18.1252	0.03	5.7289
		sum UA*DA*FA		13.1615

RL	1.00E-04
BW	70
q1*	7.7
RE	1
FS	0.015
RIA	0.909
RF	0.069

RSC	4.6

Note: Totals may not add due to rounding; see end of table for acronym definitions and units.

TABLE 5.3.5-3 (cont.)

Toxaphene

Food Group	UA	DA	FA	UA*DA*FA
Beef (fat)	18.653	15.4977	0.10	28.9079
Beef liver (incl. fat)	18.653	1.1438	0.10	2.1335
Lamb (fat)	18.653	0.2080	0.10	0.3880
Dairy (fat)	18.653	18.1252	0.03	10.1427
		sum UA*DA*FA		41.5722

RL	1.00E-04
BW	70
q1*	1.1
RE	1
FS	0.015
RIA	6.364
RF	0.153

RSC	10

Notes:
Totals may not add due to rounding.
UA = uptake slope of pollutant in animal tissue (µg-pollutant/g-animal tissue DW)/(µg-pollutant/g-diet DW)
DA = daily dietary consumption of animal tissue food group (g-diet DW/day)
FA = fraction of food group assumed to be derived from animals which ingest sewage sludge (unitless)
RL = risk level (unitless)
BW = human body weight (kg)
q1* = human cancer potency (mg/kg-day)^(-1)
RE = relative effectiveness of ingestion exposure (unitless)
FS = fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)
RIA = adjusted reference intake of pollutant in humans (µg-pollutant/day)
RF = reference concentration of pollutant in diet (µg-pollutant/g-diet DW)
RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

5.3.5.6 Sample Calculations

See Section 5.2.5.6 in Agricultural Pathway 5 for sample calculations.

5.3.6 Nonagricultural Pathway 6 (Animal Toxicity from Consumption of Plants)

5.3.6.1 Description of Pathway

Sewage Sludge → Soil → Plant → Animal

This pathway is similar to Pathways 4 and 5, where animals foraging in forests or on reclaimed soil sites ingest sewage sludge-amended soil. The point of concern here, however, is the direct toxicity to the animal from the plants.

5.3.6.2 Pollutants Evaluated

For scenario 1, described below, cadmium has been shown to accumulate in small herbivores. Therefore, only cadmium was evaluated for this scenario.

For scenario 2, also described below, the same pollutants were evaluated as for Agricultural Pathway 6: arsenic, cadmium, chromium, copper, lead, molybdenum, nickel, selenium, and zinc.

5.3.6.3 Highly Exposed Individual

Forest Land

In a forest application site, two Highly Exposed Individuals (HEIs) are possible. In scenario 1, the HEI is a small mammal (herbivore) that lives its entire life in a sewage sludge-amended area feeding on seeds and small plants close to the sludge/soil layer. In scenario 2, the HEI is a domestic animal that grazes on the grasses growing on sewage sludge-amended forest land. To assess which of these two HEIs provides more restrictive limits, both were analyzed. A deer mouse was chosen for the first case. Domestic animals were chosen for the second case, because larger herbivores such as deer probably receive a considerable portion of their diet from areas not amended with sewage sludge, since they have a larger foraging territory. In addition, deer are browsers rather than grazers, and they do not ingest as much sewage sludge as domestic animals such as cattle or sheep. Using cattle makes this pathway identical to Agricultural Pathway 6, so the inputs and outputs from Agricultural Pathway 6 were used.

Soil Reclamation Sites

Soil reclamation sites can also be used as pastureland. Thus, the limits calculated for Agricultural Pathway 6 were used.

Public Contact Sites

The HEI for public contact sites is similar to that for the small mammal described for the forest scenario. Therefore the values for forest land scenario 1 were used for public contact sites.

5.3.6.4 Algorithm Development

5.3.6.4.1 Equations

For this pathway, threshold feed concentrations and forage uptake slopes are used to calculate reference application rates of pollutants. Although many studies have identified increased concentrations of pollutants in kidneys of small herbivores living in sites to which sewage sludge has been applied, none has established threshold feed concentrations. Therefore, a new approach was developed that uses threshold contaminant concentrations in organs and organ uptake slopes.

For a small mammal, the deer mouse, (for forest land scenario 1 and public contact sites), a reference concentration of pollutant is calculated:

$$RP_c = \frac{TO - ABI}{UA} \qquad (1)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
TO	=	threshold concentration of pollutant in animal organ (μg-pollutant/g-organ DW)
ABI	=	background concentration of pollutant in animal organ (μg-pollutant/g-organ DW)
UA	=	uptake response slope of pollutant in animal organ from consumption of plants (μg-pollutant/g-organ DW)(kg-pollutant/ha)$^{-1}$

5.3.6.4.2 Input Parameters

Threshold Concentration of Pollutant in Animal Organ, TO. Threshold organ concentrations have been calculated by Chaney (1991a). Linear response slopes were calculated from kidneys of deer mice from control sites and sites to which sludge had been applied.

Background Concentration of Pollutant in Animal Organ, ABI. The background organ concentrations were calculated from a geometric mean of kidneys from deer mice from a number of control sites in Washington state.

Uptake Response Slope of Pollutant in Animal Organ from Consumption of Plants, UA. Uptake response slopes of pollutant in animal organs from their having consumed plants have been calculated from kidneys of deer mice from control sites and sites to which sewage sludge has been applied.

5.3.6.5 Input and Output Values

The input and output values for the deer mouse are presented in Table 5.3.6-1. Input and output values for domestic animals from Agricultural Pathway 6 are presented in Table 5.3.6-2.

TABLE 5.3.6-1

INPUT AND OUTPUT VALUES FOR NONAGRICULTURAL PATHWAY 6 FOR PUBLIC CONTACT SITES

Pollutant	TO	ABI	UA
Cadmium	696	12.2	0.596

RPc
1100

Notes:
Totals may not add due to rounding.
TO = threshold concentration of pollutant in animal organ ((μg-pollutant/g-organDW)
ABI = background concentration of pollutant in animal organ ((μg-pollutant/g-organDW)
UA = uptake slope of pollutant in animal tissue (μg-pollutant/g-animal tissue DW)/(μg-pollutant/g-diet DW)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

TABLE 5.3.6-2

INPUT AND OUTPUT VALUES FOR NONAGRICULTURAL PATHWAY 6
FOR FOREST LAND AND SOIL RECLAMATION SITES

Pollutant	TPI	BC	RF	UC	RPc
Arsenic	50	0.304	49.696	0.030	1600
Cadmium	10	0.225	9.775	0.070	140
Chromium	3000	**		**	
Copper	50	5.842	44.158	0.012	3700
Lead	30	2.204	27.796	0.002	11000
Molybdenum	10	2.084	7.916337913	0.423	18
Nickel	100	0.696	99.304	0.055	1800
Selenium	2.3	0.055	2.245	0.003	790
Zinc	600	17.372	582.628	0.048	12000

Notes:
** No data
Totals may not add due to rounding.
TPI = threshold pollutant intake level (μg-pollutant/g-diet DW)
BC = background concentration of pollutant in forage (μg-pollutant/g-plant tissue DW)
RF = reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
UC = uptake slope of pollutant in forage (μg-pollutant/g-plant tissue DW)/(kg-pollutant/ha)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

5.3.6.6 Sample Calculations

The following is a sample calculation for Nonagricultural Pathway 6, Forest Land scenario 1 and Public Contact Sites. The pollutant used as an example is cadmium:

$$RP_c = \frac{TO - ABI}{UA} \quad (2)$$

$$RP_c = \frac{696 - 12.2}{0.596} \quad (3)$$

$$RP_c = 1{,}100 \text{ kg-cadmium/ha (rounded down to 2 significant figures)} \quad (4)$$

where:

RP_c	=	reference cumulative application rate of pollutant (kg-pollutant/ha)
TO	=	threshold concentration of pollutant in animal organ (μg-pollutant/g-organ DW)
ABI	=	background concentration of pollutant in animal organ (μg-pollutant/g-organ DW)
UA	=	uptake response slope of pollutant in animal organ from consumption of plants (μg-pollutant/g-organ DW)(kg-pollutant/ha)$^{-1}$

For Forest Land scenario 2 and for Soil Reclamation sites, the limits calculated for Agricultural Pathway 6 are used. Sample calculations for zinc can be found in Agricultural Pathway 6, Section 5.2.6.6.

5.3.7 Nonagricultural Pathway 7 (Animal Toxicity From Consumption of Sewage Sludge)

5.3.7.1 Description of Pathway

Sewage Sludge → Animal

For this pathway, sewage sludge is applied to a forest area or to reclaimed land, and it adheres to plant surfaces, or remains in the thatch layer on the soil surface. Foraging or browsing animals then ingest sewage sludge directly through consuming plants to which sewage sludge and soil adhere.

5.3.7.2 Pollutants Evaluated

As discussed in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results* (EPA, 1985c), all pollutants except copper and iron were screened during the initial evaluation. Since the original screening was completed, further research indicates that iron is not a problem to animals that incidentally eat sludge, and that arsenic, cadmium, chromium, molybdenum, nickel, lead, selenium, and zinc are of concern for animals that incidentally ingest sludge. Table 5.3.7-1 lists the inorganic pollutants assessed for this pathway.

5.3.7.3 Highly Exposed Individual

Forest Land

Forest animals typically browse rather than graze. As in Nonagricultural Pathway 6, grazing on forest land is assumed to be similar to grazing on agricultural pasturelands; therefore the limits calculated for Agricultural Pathway 7 will be used for forest land.

TABLE 5.3.7-1

POLLUTANTS EVALUATED FOR NONAGRICULTURAL PATHWAY 7

Inorganics
Arsenic
Cadmium
Chromium
Lead
Molybdenum
Nickel
Selenium
Zinc

Soil Reclamation Sites

The same assumptions exist for soil reclamation practice as for forest land. Therefore, the limits calculated for agricultural use will be used.

Public Contact Sites

This pathway is not considered significant for public contact sites. It is not expected that grazing will be allowed on these sites, nor is the area large enough to support grazing animals.

5.3.7.4 Algorithm Development

See Agricultural Pathway 7 for a complete description of the equations and input parameters used.

5.3.7.5 Input and Output Values

The input and output values for this pathway are presented in Table 5.3.7-2.

5.3.7.6 Sample Calculations

Sample calculations can be found in Agricultural Pathway 7 in Section 5.2.7.6.

TABLE 5.3.7-2

INPUT AND OUTPUT VALUES
FOR NONAGRICULTURAL PATHWAY 7

Pollutant	TPI	BS	RF	FS	RSC
Arsenic	50	3	47	0.015	3100
Cadmium	10	0.2	9.8	0.015	650
Chromium	3000	100	2900	0.015	190000
Copper	50	19	31	0.015	2000
Lead	30	11	19	0.015	1200
Molybdenum	10	2	8	0.015	530
Nickel	100	18	82	0.015	5400
Selenium	2.3	0.21	2.09	0.015	130
Zinc	600	54	546	0.015	36000

Notes:
Totals may not add due to rounding.
TPI = threshold pollutant intake level (μg-pollutant/g-diet DW)
BS = background concentration of pollutant in soil (μg-pollutant/g-soil DW)
RF = reference concentration of pollutant in diet (μg-pollutant/g-diet DW)
FS = fraction of animal diet that is sewage sludge (g-sewage sludge DW/g-diet DW)
RSC = reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)

5.3.8 Nonagricultural Pathway 8 (Plant Toxicity)

5.3.8.1 Description of Pathway

Sewage Sludge → Soil → Plant Phytotoxicity

When sewage sludge is added to an existing plant community, plant uptake of sewage sludge constituents can lead to phytotoxicity. When sewage sludge is applied to forest land or to reclaimed land where a crop is planted to stabilize the soil from erosion, surface-level roots of plants are highly exposed and can easily take up sewage sludge constituents from this layer. In public contact sites, plants are chosen for aesthetic appeal rather than for their compatibility with sewage sludge. Therefore, such plants may be highly sensitive to additions of sewage sludge.

5.3.8.2 Pollutants Evaluated

Table 5.3.8-1 lists the organic and inorganic compounds assessed for this pathway.

5.3.8.3 Highly Exposed Individual

Forest Land

Few studies have been conducted to evaluate the sensitivity of wild plant species to trace metals in sewage sludge. Phytotoxicity in forest land is also difficult to evaluate or define. When nutrient-rich sewage sludge is added to an existing plant community, the species that respond most to nutrients will obviously out-compete other species. Some studies have been conducted on plant species that occupy a site following application of sewage sludge. In general, the same plant species exist a number of years after application, but the percentage of each species changes somewhat. However, this change probably does not constitute phytotoxicity.

Because information is lacking on the phytotoxicity of wild plants to the constituents of sewage sludge, this pathway cannot be directly evaluated. A conservative approach would,

TABLE 5.3.8-1

POLLUTANTS EVALUATED FOR NONAGRICULTURAL PATHWAY 8

Inorganics
Chromium
Copper
Nickel
Zinc

therefore, be to use the same limits used for the analogous agricultural pathway, Agricultural Pathway 8.

Soil Reclamation Sites

By definition, crops directly ingested by humans are not grown in soil reclamation sites. Less sensitive vegetation (i.e., species that are quite hardy) will be established to provide long-term ground cover. Thus, use of agricultural phytotoxicity values are conservative, because agricultural plants include more sensitive species of plants than are usually represented by plants that grow on nonagricultural land. Phytotoxicity does not appear to apply for this practice, because plants will be chosen that are compatible with sewage sludge. Therefore, this pathway was not assessed.

Public Contact Sites

In public contact sites, sewage sludge is used for a variety of plant species that are chosen for their aesthetic appeal rather than for their compatibility with sewage sludge. Thus, it is reasonable to use, as the limiting criteria, the phytotoxic values established for agricultural practices for sensitive crops.

5.3.8.4 Algorithm Development

The equations and input parameters used are fully described in Agricultural Pathway 8. Two approaches were used to evaluate this pathway, then the most stringent result was adopted as the allowable reference cumulative application rate of pollutant.

5.3.8.5 Input and Output Values

The limiting values for this pathway are presented in Table 5.3.8-2.

TABLE 5.3.8-2

LIMITING RESULTS FOR NONAGRICULTURAL PATHWAY 8

Pollutant	RPc
Chromium	3000
Copper	1500
Nickel	420
Zinc	2800

Note:
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

5.3.9 Nonagricultural Pathway 9 (Soil Organism Toxicity From Soil)

5.3.9.1 Description of Pathway

Sewage Sludge → Soil → Soil Organisms

This pathway assesses the application of sewage sludge to the land, and the ingestion by soil organisms of sewage sludge incorporated into the soil.

5.3.9.2 Pollutants Evaluated

As discussed in the *Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results* (EPA, 1985c), all pollutants except copper were screened out during the initial evaluation. Since the original screening was completed, no information indicates that this decision should be altered. Therefore, copper was the only pollutant assessed for this pathway.

5.3.9.3 Highly Exposed Individual

The analysis developed for this pathway is designed to assist in setting pollutant loading limits that protect the most exposed/most sensitive soil organisms. There is as yet no field data that indicate the level at which copper in sludge becomes toxic to soil organisms. However, Hartenstein et al. (1980c) routinely produced earthworms in soil containing sewage sludge, thereby providing a limited source of data. There is no evidence that earthworms are the most sensitive species; however, because of the lack of data for other species, the criteria for this pathway have been set using data for earthworms. As will be evident later, the criteria are based on a No Observed Adverse Effect Level (NOAEL) for the earthworm, *Eisenia foetida*.

5.3.9.4 Algorithm Development

Although there can be differences between populations of soil organisms in agricultural and in nonagricultural soils, a lack of data leads to the assumption that the analysis for agricultural land is pertinent to that for nonagricultural land. A complete discussion of the equations and input parameters used can be found in Agricultural Pathway 9.

5.3.9.5 Input and Output Values

The input and output values are summarized in Table 5.3.9-1.

TABLE 5.3.9-1

INPUT AND OUTPUT VALUES FOR NONAGRICULTURAL PATHWAY 9

Pollutant	RLC	BS	MS
Copper	1500	19.0	2E+09

RPc
2900

Notes:
Totals may not add due to rounding.
RLC = reference concentration of pollutant in soil (μg-pollutant/g-soil DW)
BS = background concentration of pollutant in soil (μg-pollutant/g-soil DW)
MS = assumed mass of dry soil in upper 15 cm (g-soil DW/ha)
RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

5.3.10 Nonagricultural Pathway 10 (Toxicity to Predators of Soil Organisms from Consuming Soil Organisms)

5.3.10.1 Description of Pathway

Sewage Sludge → Soil Organisms → Predators of Soil Organisms

Toxicity to predators of soil organisms is a concern for small mammals that feed on soil organisms and live on sewage sludge-amended soils. As discussed in Pathway 9, the exposure of soil organisms, can extend to predators of soil organisms through the food chain. The scenario applies to forest lands, as well as to public contact sites and reclaimed lands.

5.3.10.2 Pollutants Evaluated

Earthworms are a main food of shrews. Earthworms either slightly accumulate essential elements such as zinc, or they do not accumulate them at all. Earthworms do not accumulate chromium, while they somewhat accumulate lead (Chaney, 1991a). Mammals known to ingest earthworms also have efficient homeostatic mechanisms that preclude metal toxicity unless aerosol deposition contaminates forages. Three pollutants were evaluated for this pathway: cadmium, lead, and polychlorinated biphenyls (PCBs).

5.3.10.3 Highly Exposed Individual

In all nonagricultural practices, the Highly Exposed Individual (HEI), is a shrew, a small mammal that lives its entire life in a sewage sludge-amended area feeding on soil organisms. Mammals known to ingest earthworms have efficient homeostatic mechanisms that preclude metal toxicity unless aerosol deposition contaminates forages. However, worms highly accumulate cadmium; therefore this pathway limits the analysis to cadmium. Data are not available on threshold feed concentration of shrews, especially from sludge research. However, studies have indicated that high levels of cadmium accumulate in shrews living on sites to which sludge has been applied (Hegstrom, 1986). In particular, shrews accumulated the highest levels of cadmium in kidneys. No predator of soil organisms has been singled out as being particularly sensitive to cadmium and lead. Rather, the literature indicates that the insectivorous small mammals (shrews) are the best sentinels for both inorganic and organic contaminants, and are thus assumed to be the most exposed. This is not the case for PCBs, where there is clear evidence that chickens are the most sensitive species.

5.3.10.4 Algorithm Development

The values from Agricultural Pathway 10 were used, because the HEI and the approach are identical. A complete discussion of the equations, input parameters used, results, and sample calculations, can be found in Agricultural Pathway 10.

5.3.11 Nonagricultural Pathway 11 (Tractor Operator Pathway)

As discussed in Section 5.1, this pathway was not assessed, because it is not an appropriate pathway for the nonagricultural setting.

5.3.12 Nonagricultural Pathway 12 (Surface Water Pathway)

The values for this pathway were taken directly from Agricultural Pathway 12. See Agricultural Pathway 12 for a complete discussion of this pathway.

5.3.13 Nonagricultural Pathway 13 (Air Pathway)

The values for this pathway were taken directly from Agricultural Pathway 13. See Agricultural Pathway 13 for a complete discussion of this pathway.

5.3.14 Nonagricultural Pathway 14 (Ground Water Pathway)

The values for this pathway were taken directly from Agricultural Pathway 14. See Agricultural Pathway 14 for a complete discussion of this pathway.

5.4 AGRICULTURAL AND NONAGRICULTURAL RESULTS

This section presents 10 tables summarizing the results from Section Five.

The first four tables (Tables 5.4-1 through 5.4-4) present output data for inorganic pollutants from the four scenarios: agricultural; nonagricultural forest land; nonagricultural soil reclamation sites; and nonagricultural public contact sites. Table 5.4-5 presents the limiting number for each pathway for each pollutant. The limiting number is the lowest number generated from the four scenarios for each pollutant/pathway combination.

The following five tables (Tables 5.4-6 through 5.4-10) present the results for organic pollutants in the same manner. That is, four tables present all the results, and the final table presents the limiting numbers.

TABLE 5.4-1

AGRICULTURAL RESULTS FOR INORGANIC POLLUTANTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pollutant	**RPc**	**RPc**	**RSC**	**RPc**	**RSC**	**RPc**	**RSC**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**
Arsenic	6700	930	41			1600	3100				400	66000		1200
Cadmium	610	120	39	6400	68000	140	650			53	8000	63000		unlimited
Chromium			79000				190000	3000			5000	unlimited		12000
Copper			10000			3700	2000	1500	2900			unlimited		unlimited
Lead			300			11000	1200			5000	10000	unlimited		unlimited
Mercury	180	370	17	4000	24000						10000	1100		unlimited
Molybdenum			400			18	530							
Nickel	63000	10000	820			1800	5400	420			3000	unlimited		13000
Selenium	14000	1200	100	15000	13000	790	130							
Zinc	16000	3600	16000	530000	2200000	12000	36000	2800						

Note: All results rounded down to two significant figures

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

TABLE 5.4-2

NONAGRICULTURAL RESULTS FOR INORGANIC POLLUTANTS FOR FOREST LAND

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pollutant	RPc	RPc	RSC	RPc	RSC	RPc	RSC	RPc	RPc	RPc	RPc	RPc	RPc	RPc
Arsenic	47000		53			1600	3100					66000		1200
Cadmium	1800		54	1600	68000	140	650			53		63000		unlimited
Chromium			94000				190000	3000				unlimited		12000
Copper			10000			3700	2000	1500	2900			unlimited		unlimited
Lead			300			11000	1200			5000		unlimited		unlimited
Mercury	6000		22	1500	24000							1100		unlimited
Molybdenum			470			18	530							
Nickel	570000		1100			1800	5400	420				unlimited		13000
Selenium	35000		170	15000	13000	790	130							
Zinc	85000		16000	150000	2200000	12000	36000	2800						

Note: All results rounded down to two significant figures

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

TABLE 5.4-3

NONAGRICULTURAL RESULTS FOR INORGANIC POLLUTANTS FOR SOIL RECLAMATION SITES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pollutant	RPc	RPc	RSC	RPc	RSC	RPc	RSC	RPc	RPc	RPc	RPc	RPc	RPc	RPc
Arsenic	47000		53			1600	3100					66000		1200
Cadmium	1800		54	1600	68000	140	650			53		63000		unlimited
Chromium			94000				190000					unlimited		12000
Copper			10000			3700	2000		2900			unlimited		unlimited
Lead			300			11000	1200			5000		unlimited		unlimited
Mercury	6000		22	1500	24000							1100		unlimited
Molybdenum			470			18	530							
Nickel	570000		1100			1800	5400					unlimited		13000
Selenium	35000		170	15000	13000	790	130							
Zinc	85000		16000	150000	2200000	12000	36000							

Note: All results rounded down to two significant figures

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)

TABLE 5.4-4

NONAGRICULTURAL RESULTS FOR INORGANIC POLLUTANTS FOR PUBLIC CONTACT SITES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pollutant	RPc	RPc	RSC	RPc	RSC	RPc	RSC	RPc	RPc	RPc	RPc	RPc	RPc	RPc
Arsenic	47000		41									66000		1200
Cadmium	1800		39			1100				53		63000		unlimited
Chromium			79000					3000				unlimited		12000
Copper			10000					1500	2900			unlimited		unlimited
Lead			300							5000		unlimited		unlimited
Mercury	6000		17									1100		unlimited
Molybdenum			400											
Nickel	570000		820					420				unlimited		13000
Selenium	35000		100											
Zinc	85000		16000					2800						

Note: All results rounded down to two significant figures

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (μg-pollutant/g-sewage sludge DW)

TABLE 5.4-5

LIMITING RESULTS FOR EACH PATHWAY FOR INORGANIC POLLUTANTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pollutant	RPc	RPc	RSC	RPc	RSC	RPc	RSC	RPc	RPc	RPc	RPc	RPc	RPc	RPc
Arsenic	6700	930	41			1600	3100				400	66000		1200
Cadmium	610	120	39	1600	68000	140	650			53	8000	63000		unlimited
Chromium			79000				190000	3000			5000	unlimited		12000
Copper			10000			3700	2000	1500	2900			unlimited		unlimited
Lead			300			11000	1200			5000	10000	unlimited		unlimited
Mercury	180	370	17	1500	24000						10000	1100		unlimited
Molybdenum			400			18	530							
Nickel	63000	10000	820			1800	5400	420			3000	unlimited		13000
Selenium	14000	1200	100	15000	13000	790	130							
Zinc	1280	1280	16000	150000	2200000	12000	36000	2800						

Note: All results rounded down to two significant figures

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

TABLE 5.4-6

AGRICULTURAL RESULTS FOR ORGANIC POLLUTANTS

	1		2		3	4		5	6	7	8	9	10	11	12	13	14
Pollutant	RPa	RPc	RPa	RPc	RSC	RPa	RPc	RSC					RPa	RPc	RPa	RPa	RPa
Aldrin/Dieldrin		280		64	7.0		17	2.7						30000			
Benzo(a)pyrene	230		54		15										1.3	3500	unlimited
Chlordane		3400		790	86		36000	2300							5.3	3.9	unlimited
DDT	560		130		320	48		150						100000	1.2	45	unlimited
Heptachlor	990		220		24	110		7.4									
Hexachlorobenzene	320		75		70	48		29									
Hexachlorobutadiene	43000		10000		1400			600									
Lindane	2300		540		84	1500		140							2100	110	unlimited
n-Nitrosodimethylamine	87		20		2.1										29000	22	0.056
PCBs	37		8.5		14	4.3		4.6					0.50	200	0.34	1.4	unlimited
Toxaphene	2800		650		100	120		10							5.0	120	unlimited
Trichloroethylene	220000		51000		10000										unlimited	420	unlimited

Note: All results rounded down to two significant figures

RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

TABLE 5.4-7

NONAGRICULTURAL RESULTS FOR ORGANIC POLLUTANTS FOR FOREST LAND

	1		2		3	4		5	6	7	8	9	10	11	12	13	14
Pollutant	RPa	RPc	RPa	RPc	RSC	RPa	RPc	RSC					RPa	RPc	RPa	RPa	RPa
Aldrin/Dieldrin		1000			20		36	2.7									
Benzo(a)pyrene	910				45										1.3	3500	unlimited
Chlordane		13000			250		13000	2300							5.3	3.9	unlimited
DDT	2200				970	46		150							1.2	45	unlimited
Heptachlor	3800				73	65		7.4									
Hexachlorobenzene	1200				200	25		29									
Hexachlorobutadiene	160000				4200			600									
Lindane	9200				250	600		140							2100	110	unlimited
n-Nitrosodimethylamine	340				6.5										29000	22	0.056
PCBs	140				43	2.4		4.6					0.50		0.34	1.4	unlimited
Toxaphene	11000				300	43		10							5.0	120	unlimited
Trichloroethylene	860000				30000										unlimited	420	unlimited

Note: All results rounded down to two significant figures

RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

TABLE 5.4-8

NONAGRICULTURAL RESULTS FOR ORGANIC POLLUTANTS FOR SOIL RECLAMATION SITES

	1		2		3	4		5	6	7	8	9	10	11	12	13	14
Pollutant	RPa	RPc	RPa	RPc	RSC	RPa	RPc	RSC					RPa	RPc	RPa	RPa	RPa
Aldrin/Dieldrin		1300			20		36	2.7									
Benzo(a)pyrene	1100				45										1.3	3500	unlimited
Chlordane		16000			250		13000	2300							5.3	3.9	unlimited
DDT	2700				970	46		150							1.2	45	unlimited
Heptachlor	4700				73	65		7.4									
Hexachlorobenzene	1500				200	25		29									
Hexachlorobutadiene	200000				4200			600									
Lindane	11000				250	600		140							2100	110	unlimited
n-Nitrosodimethylamine	420				6.5										29000	22	0.056
PCBs	170				43	2.4		4.6					0.50		0.34	1.4	unlimited
Toxaphene	13000				300	43		10							5.0	120	unlimited
Trichloroethylene	1000000				30000										unlimited	420	unlimited

Note: All results rounded down to two significant figures

RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

TABLE 5.4-9

NONAGRICULTURAL RESULTS FOR ORGANIC POLLUTANTS FOR PUBLIC CONTACT SITES

	1		2		3	4		5	6	7	8	9	10	11	12	13	14
Pollutant	RPa	RPc	RPa	RPc	RSC	RPa	RPc	RSC					RPa	RPc	RPa	RPa	RPa
Aldrin/Dieldrin		1300			7.0												
Benzo(a)pyrene	1100				15										1.3	3500	unlimited
Chlordane		16000			86										5.3	3.9	unlimited
DDT	2700				320										1.2	45	unlimited
Heptachlor	4700				24												
Hexachlorobenzene	1500				70												
Hexachlorobutadiene	200000				1400												
Lindane	11000				84										2100	110	unlimited
n-Nitrosodimethylamine	420				2.1										29000	22	0.056
PCBs	170				14								0.50		0.34	1.4	unlimited
Toxaphene	13000				100										5.0	120	unlimited
Trichloroethylene	1000000				10000										unlimited	420	unlimited

Note: All results rounded down to two significant figures

RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

TABLE 5.4-10

LIMITING RESULTS FOR EACH PATHWAY FOR ORGANIC POLLUTANTS

	1		2		3	4		5	6	7	8	9	10	11	12	13	14
Pollutant	RPa	RPc	RPa	RPc	RSC	RPa	RPc	RSC					RPa	RPc	RPa	RPa	RPa
Aldrin/Dieldrin		280		64	7.0		17	2.7						30000			
Benzo(a)pyrene	230		54		15										1.3	3500	unlimited
Chlordane		3400		790	86		13000	2300							5.3	3.9	unlimited
DDT	560		130		320	46		150						100000	1.2	45	unlimited
Heptachlor	990		220		24	65		7.4									
Hexachlorobenzene	320		75		70	25		29									
Hexachlorobutadiene	43000		10000		1400			600									
Lindane	2300		540		84	600		140							2100	110	unlimited
n-Nitrosodimethylamine	87		20		2.1										29000	22	0.056
PCBs	37		8.5		14	2.4		4.6					0.50	200	0.34	1.4	unlimited
Toxaphene	2800		650		100	43		10							5.0	120	unlimited
Trichloroethylene	220000		51000		10000										unlimited	420	unlimited

Note: All results rounded down to two significant figures

RPa = reference annual application rate of pollutant (kg-pollutant/ha-yr)

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

SECTION SIX

POLLUTANT LIMITS

This section first describes how the pollutant limits calculated in the risk assessment in Section Five relate to the pollutant limits in the regulation. The regulatory limits are then presented and described. Section 6.1 describes the deletion of organic pollutants from the final rule, and Section 6.2 presents the limiting concentrations by pathway. The development of regulatory limits is described in Section 6.3 and the implementation of these regulatory limits is summarized in Section 6.4.

6.1 DELETION OF ORGANIC POLLUTANTS FROM THE FINAL RULE

During the public comment period for *Technical Standards for Use and Disposal of Sewage Sludge; Proposed Rule* (40 CFR Parts 257 and 503, 1989), several commenters recommended deleting some of the organic pollutants found in sewage sludge from the final rule. The main reason for this recommendation was that most of these pollutants are currently either banned or restricted for use in the United States. Because of these comments, the Agency re-evaluated all of the organic pollutants regulated in the proposed Part 503 rule for land application. As a result of this evaluation, all of the organic pollutants were deleted from the final rule for land application. A detailed explanation of the evaluation is presented in Appendix B.

6.2 LIMITING CONCENTRATIONS FOR INORGANIC POLLUTANTS

Separate risk assessments were performed for two types of land: agricultural land, which includes land on which sewage sludge sold or given away in a bag or other container is applied, and nonagricultural land (i.e., forest, public contact sites, and reclamation sites). Fourteen pathways were evaluated for agricultural land and 12 pathways were evaluated for nonagricultural land.

The Agency compared the pollutant limits generated under the agricultural and nonagricultural land application scenarios and used the lower of the two to create pollutant limits for all land-applied sewage sludge, regardless of end use. EPA concluded that having only one limit to comply with instead of two, would make compliance simpler for preparers and appliers of sewage sludge. Table 6-1 shows the most stringent pollutant limits calculated for each pollutant for each pathway. It should be noted that these numbers are rounded down to two significant digits. This decision was made to prevent upward rounding, which would result in pollutant limits less stringent than the risk-based numbers.

As shown in Table 6-1, most risk assessment outputs are reference cumulative application rates (RP_c), whereas outputs for Pathways 3, 5, and 7 are concentrations of pollutants in sewage sludge (RSC). To enable comparison between pathways, all the results were converted to the same units, RP_c using the following equation:

$$RP_c = RSC \cdot AWSAR \cdot 0.001 \cdot SL \qquad (1)$$

where:

RP_c	=	cumulative reference application rate of pollutant in sewage sludge (kg-pollutant/ha)
RSC	=	reference concentration of pollutant in sewage sludge (mg-pollutant/kg-sewage sludge DW)
AWSAR	=	annual whole sludge application rate (mt-sewage sludge DW/ha•yr) (see Section 6.5.3)
0.001	=	conversion factor
SL	=	number of years of site life

The annual whole sludge application rate (AWSAR) is the maximum amount of sewage sludge that is applied to a hectare in a year (40 CFR Part 503). An AWSAR of 10 mt-sewage sludge DW/ha•yr, which is somewhat higher than the typical application rate of 7 mt, and a site life of 100 years, a reasonable maximum site life, were used. Therefore:

$$RP_c = RSC \cdot 0.001 \cdot 10 \cdot 100 \qquad (2)$$

TABLE 6-1

LIMITING RESULTS FOR EACH PATHWAY FOR INORGANIC POLLUTANTS

Pollutant	1 RPc	2 RPc	3 RSC	4 RPc	5 RSC	6 RPc	7 RSC	8 RPc	9 RPc	10 RPc	11 RPc	12 RPc	13 RPc	14 RPc
Arsenic	6700	930	41			1600	3100					66000		1200
Cadmium	610	120	39	1600	68000	140	650			53		63000		unlimited
Chromium			79000				190000	3000				unlimited		12000
Copper			10000			3700	2000	1500	2900			unlimited		unlimited
Lead			300			11000	1200			5000		unlimited		unlimited
Mercury	180	370	17	1500	24000							1100		unlimited
Molybdenum			400			18	530							
Nickel	63000	10000	820			1800	5400	420				unlimited		13000
Selenium	14000	1200	100	15000	13000	790	130							
Zinc	16000	3600	16000	150000	2200000	12000	36000	2800						

Note: All results rounded down to two significant figures

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

RSC = reference concentration of pollutant in sewage sludge (µg-pollutant/g-sewage sludge DW)

Because of the factors used, the RP_cs for Pathways 3, 5, and 7 are the same numbers as the analogous RSCs, but the units differ. The RP_cs are shown in Table 6-2.

For each pollutant, the lowest RP_c of all the pathways is the risk-based limit for land application. Table 6-3 summarizes this limiting number and also shows from which pathway this number was derived.

6.3 DEVELOPMENT OF REGULATORY LIMITS

Part 503 includes two different types of pollutant limits: pollutant concentrations and pollutant loading rates. Pollutant loading rates, which include cumulative pollutant loading rates (CPLRs) and annual pollutant loading rates (APLRs), are described in Section 6.3.1. The pollutant concentration limits, which include both pollutant concentrations and ceiling concentrations, are described in Section 6.3.2. A separate pollutant limit for domestic septage applied to land is specified as an annual application rate. This limit is discussed in Section 6.4.3.

6.3.1 Pollutant Loading Rates

Two types of pollutant loading rates were developed: annual pollutant loading rates, which apply only to the application of sewage sludge sold or given away in a bag or other container, and cumulative pollutant loading rates, which apply to bulk sewage sludge appliers to the land.

6.3.1.1 Development of Cumulative Pollutant Loading Rates (CPLRs)

A cumulative pollutant loading rate (CPLR), measured in kilograms of pollutant per hectare of land (kg-pollutant/ha), is the maximum amount of an inorganic pollutant that can be

TABLE 6-2

LIMITING RESULTS FOR EACH PATHWAY FOR INORGANIC POLLUTANTS, REPORTED AS REFERENCE CUMULATIVE APPLICATION RATE OF POLLUTANT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pollutant	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**	**RPc**
Arsenic	6700	930	41			1600	3100					66000		1200
Cadmium	610	120	39	1600	68000	140	650			53		63000		unlimited
Chromium			79000				190000	3000				unlimited		12000
Copper			10000			3700	2000	1500	2900			unlimited		unlimited
Lead			300			11000	1200			5000		unlimited		unlimited
Mercury	180	370	17	1500	24000							1100		unlimited
Molybdenum			400			18	530							
Nickel	63000	10000	820			1800	5400	420				unlimited		13000
Selenium	14000	1200	100	15000	13000	790	130							
Zinc	16000	3600	16000	150000	2200000	12000	36000	2800						

Note: All results rounded down to two significant figures

RPc = reference cumulative application rate of pollutant (kg-pollutant/ha)

TABLE 6-3

RISK-BASED POLLUTANT LIMITS AND LIMITING PATHWAYS

Pollutant	Cumulative Reference Application Rate of Pollutant RP_c (kg-pollutant/ha)	Limiting Pathway
Arsenic	41	3
Cadmium	39	3
Chromium	3,000	8
Copper	1,500	8
Lead	300	3
Mercury	17	3
Molybdenum	18	6
Nickel	420	8
Selenium	100	3
Zinc	2,800	8

applied to a hectare (40 CFR Part 503). The CPLRs, presented in Table 6-4, are equivalent to the RP_cs.

The values for the CPLRs in the final Part 503 rule differ from those in the proposed rule. The reason for this difference is that the input parameters for the models used to develop the loading rates in the pathway risk assessment were updated on the basis of information received during the public comment period for the proposal. They also incorporate Agency policy decisions made subsequent to the proposal (see Section Five).

6.3.1.2 Development of Annual Pollutant Loading Rates

For sewage sludge sold or given away in a bag or other container for application to the land, an annual pollutant loading rate was calculated. An annual pollutant loading rate (APLR), measured in kilograms of pollutant per hectare of land (kg-pollutant/ha•yr), is the maximum amount of a pollutant that can be applied to an area of land in any 1 year (40 CFR Part 503). The APLRs in Table 6-5 were calculated by dividing the CPLRs in Table 6-4 by an assumed site life of 20 years. The Agency concluded that 20 years is a conservative assumption, because sewage sludge sold or given away in a bag or other container will probably be applied to a lawn, home garden, or a public contact site, and will, therefore, probably not be applied longer than 20 years, particularly 20 consecutive years.

6.3.2 Pollutant Concentration Limits

6.3.2.1 Development of Pollutant Concentrations

A pollutant concentration in sewage sludge is measured in milligrams of pollutant per kilogram of sewage sludge dry weight (DW) (mg-pollutant/kg-sewage sludge DW). The Agency "capped" the risk assessment-derived pollutant concentrations by using the lower of the National Sewage Sludge Survey (NSSS) 99th percentile concentrations (presented in Table 6-6) and the

TABLE 6-4

CUMULATIVE POLLUTANT LOADING RATES

Pollutant	Cumulative Pollutant Loading Rate (kg -pollutant/ha DW)
Arsenic	41
Cadmium	39
Chromium	3,000
Copper	1,500
Lead	300
Mercury	17
Molybdenum	18
Nickel	420
Selenium	100
Zinc	2,800

TABLE 6-5

ANNUAL POLLUTANT LOADING RATES

Pollutant	Annual Pollutant Loading Rate (kilogram per hectare per 365-day period DW)
Arsenic	2.0
Cadmium	2.0
Chromium	150
Copper	75
Lead	15
Mercury	0.85
Molybdenum	0.90
Nickel	21
Selenium	5.0
Zinc	140

TABLE 6-6

NSSS 99TH PERCENTILE VALUES

Pollutant	99th Percentile Value (mg-pollutant/ kg-sewage sludge DW)
Arsenic	75
Cadmium	85
Chromium	1,200
Copper	4,300
Lead	840
Mercury	57
Molybdenum	75
Nickel	420
Selenium	36
Zinc	7,500

risk-based pollutant concentrations. This procedure was used because the Agency concluded that the quality of sewage sludge (based on concentration of pollutants) should be equal to or better than the current quality, which is characterized by the NSSS. This decision is particularly important since general requirements and management practices do not apply if the sewage sludge meets the pollutant concentrations, the Class A pathogen requirements, and one of the appropriate vector attraction reduction requirements (see Sections Ten and Eleven).

The pollutant concentrations in Part 503, therefore, are the more stringent of either the risk-based pollutant concentrations or the 99th percentile concentrations of the NSSS. The risk-based pollutant concentrations are the same number as the CPLRs, but the units differ.

The formula used to convert a CPLR (kg/ha) to a risk-based pollutant concentration (mg/kg) is:

$$PC = \frac{CPLR}{SL \bullet AWSAR \bullet 0.001} \tag{3}$$

where:

PC	=	concentration of pollutant in sewage sludge (mg-pollutant/kg-sewage sludge DW)
CPLR	=	cumulative pollutant loading rate (kg-pollutant/ha)
SL	=	number of years of site life
AWSAR	=	annual whole sludge application rate (mt-sewage sludge DW/ha•yr)
0.001	=	a conversion factor (unitless)

The pollutant concentration was calculated using the CPLRs, an assumed 100-year site life, and an assumed AWSAR of 10 metric tons per year (see Section 6.4.2.1). Therefore:

$$PC = \frac{CPLR}{10 \bullet 100 \bullet 0.001} \tag{4}$$

The risk-based pollutant concentrations, which are monthly averages, the NSSS 99th percentiles, and the lesser of these two numbers, the pollutant concentrations, are shown in Table 6-7.

TABLE 6-7

NUMBERS USED TO DERIVE POLLUTANT CONCENTRATIONS

Pollutant	Risk-based Pollutant Concentration (mg-pollutant/kg-sewage sludge DW)	NSSS 99th Percentile (mg-pollutant/kg-sewage sludge DW)	Part 503 Pollutant Concentration, Monthly Average (mg-pollutant/kg sewage sludge DW)
Arsenic	41	75	41
Cadmium	39	85	39
Chromium	3,000	1,200	1,200
Copper	1,500	4,300	1,500
Lead	300	840	300
Mercury	17	57	17
Molybdenum	18	75	18
Nickel	420	420	420
Selenium	100	36	36
Zinc	2,800	7,500	2,800

6.3.2.2 Development of Ceiling Concentrations

A ceiling concentration in sewage sludge is measured in milligrams of pollutant per kilogram of sewage sludge dry weight (DW) (mg-pollutant/kg-sewage sludge DW). For each pollutant, the ceiling concentration is the higher of either the risk-based pollutant concentration (calculated as an intermediate number in Section 6.3.2.1), or the 99th percentile concentration of the NSSS. These ceilings were developed to prevent the application to land of sewage sludge containing high concentrations of pollutants. The risk-based pollutant concentrations, the NSSS 99th percentiles, and the greater of these two numbers, which are the ceiling concentrations, are shown in Table 6-8.

6.4 IMPLEMENTATION OF REGULATORY LIMITS

The pollutant limits for sewage sludge applied to land, specified in Section 503.13 of Subpart B, include those for bulk sewage sludge, sewage sludge sold or given away in a bag or other container, and domestic septage. A discussion of how these pollutant limits apply to bulk sewage sludge is included in Section 6.4.1, and a discussion of how they apply to sewage sludge sold or given away in a bag or other container is included in Section 6.4.2. A discussion of the pollutant limit for domestic septage is included in Section 6.4.3.

6.4.1 Pollutant Limits for Bulk Sewage Sludge Applied to the Land

Bulk sewage sludge applied to agricultural land, forests, public contact sites, or reclamation sites must meet either the ceiling concentrations in Table 6-9 and the CPLRs shown in Table 6-4; or the ceiling concentrations in Table 6-9 and the pollutant concentrations in Table 6-10. Bulk sewage sludge applied to a lawn or home garden must meet both the ceiling concentrations and pollutant concentrations.

TABLE 6-8

NUMBERS USED TO DERIVE CEILING CONCENTRATIONS

Pollutant	Risk-based Pollutant Concentration (mg-pollutant/kg-sewage sludge DW)	NSSS 99th Percentile (mg-pollutant/kg-sewage sludge DW)	Part 503 Ceiling Concentrations (mg-pollutant/kg-sewage sludge DW)
Arsenic	41	75	75
Cadmium	39	85	85
Chromium	3,000	1,200	3,000
Copper	1,500	4,300	4,300
Lead	300	840	840
Mercury	17	57	57
Molybdenum	18	75	75
Nickel	420	420	420
Selenium	100	36	100
Zinc	2,800	7,500	7,500

TABLE 6-9

CEILING CONCENTRATIONS

Pollutant	Concentration (mg-pollutant/kg-sewage sludge DW)
Arsenic	75
Cadmium	85
Chromium	3,000
Copper	4,300
Lead	840
Mercury	57
Molybdenum	75
Nickel	420
Selenium	100
Zinc	7,500

TABLE 6-10

POLLUTANT CONCENTRATIONS

Pollutant	Concentration, Monthly Average (mg-pollutant/kg-sewage sludge DW)
Arsenic	41
Cadmium	39
Chromium	1,200
Copper	1,500
Lead	300
Mercury	17
Molybdenum	18
Nickel	420
Selenium	36
Zinc	2,800

6.4.1.1 Ceiling Concentrations

Ceiling concentrations must be met when sewage sludge is applied to land. If any of the ceiling concentrations in Table 6-9 are exceeded, the sewage sludge cannot be applied to the land. Bulk sewage sludge that meets all of the ceiling concentrations in Table 6-9 must also meet either the CPLRs in Table 6-4 or the pollutant concentrations in Table 6-10.

6.4.1.2 Cumulative Pollutant Loading Rates

The CPLR for each pollutant listed in Table 6-4 must not be exceeded when bulk sewage sludge is applied to agricultural land, forests, public contact sites, or reclamation sites. Once the CPLR for any one pollutant has been reached, either in the first year or over a number of years, no additional bulk sewage sludge can be applied to that site. This provision reflects the fact that metals persist in the soil and accumulate over time. The concentration of a pollutant in sewage sludge and the rate at which sewage sludge is applied contribute to how quickly the limit of pollutant per hectare is reached. To comply with this requirement, records that include the amount of each inorganic pollutant in sewage sludge applied to each site must be kept (see Section Ten).

6.4.1.3 Pollutant Concentrations

As discussed in Section 6.4.1, bulk sewage sludge applied to agricultural land, forests, public contact sites, or reclamation sites, may meet the ceiling concentrations in Table 6-9 and the CPLRs in Table 6-4 or the ceiling concentrations in Table 6-9 and the pollutant concentrations in Table 6-10.

Bulk sewage sludge applied to a lawn or home garden must meet the ceiling concentrations in Table 6-9 and the concentrations in Table 6-10. The concentration of each pollutant in the sewage sludge must be equal to or less than the concentration indicated for that pollutant in Table 6-10.

6.4.2 Pollutant Limits for Sewage Sludge Sold or Given Away in a Bag or Other Container for Application to the Land

Sewage sludge sold or given away in a bag or other container for application to the land must meet the ceiling concentrations in Table 6-9 and the APLRs listed in Table 6-5 and explained in Section 6.4.2.1 below; or it must meet the ceiling concentrations in Table 6-9 and the pollutant concentrations in Table 6-10.

6.4.2.1 Annual Pollutant Loading Rates

APLRs are used for sewage sludge sold or given away in bags or other containers, rather than CPLRs, because the number of sewage sludge applications made to a site over a period of years cannot be controlled when sewage sludge is sold or given away in a bag or other container for application to the land.

APLRs must be met for each pollutant listed in Table 6-5 when sewage sludge is sold or given away in a bag or other container for application to the land. To meet these loading rates, the product of the concentration of each regulated pollutant in the sewage sludge and the AWSAR for the sewage sludge must not cause the applicable APLR in Table 6-5 to be exceeded.

The AWSAR is determined as shown in the following equation:

$$\mathrm{AWSAR} = \frac{\mathrm{APLR}}{\mathrm{C} \cdot 0.001} \qquad (5)$$

where:

AWSAR	=	annual whole sludge application rate (mt-sewage sludge DW/ha•yr)
APLR	=	annual pollutant loading rate (in Table 6-5) (kg-pollutant/ha•yr)
C	=	pollutant concentration (mg-pollutant/kg-sewage sludge DW)
0.001	=	a conversion factor (unitless)

The AWSAR is calculated separately for each pollutant. The allowable AWSAR for sewage sludge is the lowest AWSAR calculated for any pollutant. The procedure to determine the AWSAR for a sewage sludge is discussed further in Appendix A of the regulation.

6.4.3 Pollutant Limit for Domestic Septage

The regulation contains a separate pollutant limit for domestic septage applied to agricultural land, forests, or reclamation sites. This requirement is an annual application rate. The annual application rate for domestic septage depends on the nitrogen requirement of the crop or vegetation grown on the land where the domestic septage is applied and is expressed as an hydraulic loading rate in gallons per acre per year. The annual application rate for domestic septage is determined using the following equation:

$$AAR = \frac{N}{0.0026} \qquad (6)$$

where:

AAR	=	Annual application rate in gallons per acre per 365-day period
N	=	Amount of nitrogen in pounds per acre per 365-day period needed by the crop or vegetation grown on the land (nitrogen amounts based on crop yield are published by various government agencies, such as the Agriculture Extension Service).

EPA chose only to allow the annual application rate to be used when domestic septage is applied to agricultural land, forests, or reclamation sites, because certain site restrictions are imposed on sites where domestic septage is applied. EPA's determination is based on the assumption that the applier has control over the application site. Because of the difficulty of imposing site restrictions on a public site, a lawn, or a home garden, EPA is prohibiting the application of domestic septage to a public contact site, a lawn, or a home garden at an annual application rate. If domestic septage is applied to other types of land (e.g., a public contact site), the requirements in the land application subpart for sewage sludge have to be met.

EPA chose to limit the annual application rate to domestic septage for two reasons. First, available data indicate that domestic septage has pollutant concentrations that are lower than the pollutant concentrations in commercial septage (e.g., grease from a grease trap at a restaurant) and industrial septage (e.g., liquid or solid material removed from a septic tank or similar treatment works that receives industrial wastewater). Second, the Agency determined that the pollutant concentrations in commercial and industrial septage vary greatly. The higher pollutant concentrations and the variability of those concentrations requires that samples of commercial and industrial septage be analyzed periodically to determine the quality of the commercial and industrial septage prior to being used or disposed. For these reasons, the annual application rate limit for domestic septage is not appropriate for commercial or industrial septage. Because the characteristics of domestic septage and commercial and industrial septage are different, the Part 503 requirements for domestic septage do not apply to commercial or industrial septage.

The justification for the annual application rate for domestic septage can be found in Appendix K.

SECTION SEVEN

POLICY DECISIONS FOR THE PART 503 REGULATION

This section presents the policy determinations EPA made in the course of developing the Part 503 Regulations. These decisions include how pollutant limits were set, the basis for EPA's decision to prohibit the development of site-specific information, and the reasoning behind the definition of the term "other container."

7.1 ANNUAL WHOLE SLUDGE APPLICATION RATE (AWSAR)

The Agency used annual whole sludge application rates of 7, 26, 18, and 74 mt DW/hectare•yr for agricultural land, forests, public contact sites, and reclamation sites, respectively. These rates were obtained from data in the National Sewage Sludge Survey (U.S. EPA, 1990e).

7.2 POLLUTANT LIMITS

The pollutant concentrations limits in Table 6-10 protect human health and the environment from reasonably anticipated adverse effects from pollutants in sewage sludge, because they are derived from the cumulative pollutant loading rates (Table 6-4) that provide the same protection. Also, if sewage sludge meeting pollutant concentration limits is applied to the land at the AWSARs discussed in Section 7.1 above, the CPLRs in Table 6-4 will not be exceeded for agricultural land until approximately 100 years have passed; for forests, 55 years; for public contact sites, 32 years; or for reclamation sites, 13 years. The Agency concluded that sewage sludge will probably not be applied to these types of land each year throughout these periods of time.

The annual pollutant loading rates given in Table 6-5, which apply to sewage sludge sold or given away in a bag or other container for application to the land, are based on a 20-year site life. The Agency concluded that 20 years is a conservative assumption, because sewage sludge sold or given away in a bag or other container will most likely be applied to lawns, home gardens, or public contact sites. Sewage sludge will probably not be applied to these types of land for longer than 20 years, particularly 20 consecutive years. The most recent census information, collected in 1990, showed that in 1990, 44 percent of Americans lived in a different house than they had in 1985 (U.S. Department of Commerce News, 1992). Although no statistics are available on the number of U.S. citizens that live in the same house for 20 years, the Agency concluded that they constitute a very small percentage of the general population.

The annual pollutant loading rates in Table 6-5 are based on 1/20 of the cumulative pollutant loading rates and provide equal protection to public health and the environment, as it is unlikely that home gardeners will apply sewage sludge yearly for 20 consecutive years.

7.3 SITE-SPECIFIC FACTORS

Although the Agency considered allowing publicly owned treatment works (POTWs) to develop site-specific cumulative pollutant loading rates, it decided against such rates for several reasons. First, to develop site-specific cumulative pollutant loading rates, a site-specific pathway risk assessment has to be conducted. For many of the pathways, the terms in the algorithm used to calculate the allowable loading rate are based on Agency decisions (e.g., the RfD for a pollutant, the soil ingestion rate). EPA concluded that values for such terms should not be allowed to change in a site-specific assessment. Consequently, if the limiting cumulative pollutant loading rate for a pollutant is based on a pathway for which the algorithm only contains terms based on Agency decisions, a site-specific cumulative pollutant loading rate could not be calculated for that pollutant. This decision rules out site-specific cumulative pollutant loading rates for 4 of the 10 inorganic pollutants regulated under Subpart B, because the factors in their limiting pathways are based on immutable EPA decisions. Thus, only six of the inorganic pollutants would have been eligible for site-specific cumulative pollutant loading rates.

In addition, the information that has to be developed to conduct a site-specific pathway risk assessment is comprehensive and includes, among other things, site-specific information on pollutant uptake slopes for each food group grown on each site, the uptake of pollutants by grazing animals, and variables for the ground water pathway (e.g., depth to ground water). Much of this information is difficult and expensive to obtain, particularly for every land application site. Furthermore, the permitting authority would have to have the necessary expertise to evaluate the quality of the model inputs.

A third reason the Agency decided not to allow site-specific cumulative pollutant loading rates is that they have to be developed for individual land application sites. A POTW could not simply develop one set of site-specific cumulative pollutant loading rates and use them for all application sites. Instead, a site-specific cumulative pollutant loading rate has to be developed for each site. Considering the information that has to be developed to conduct site-specific pathway risk assessment and the cost to obtain that information, the Agency concluded that it is not feasible or cost-effective to conduct such an assessment for each application site.

7.4 OTHER CONTAINER

An other container is defined as either an open or closed container. This includes, but is not limited to, a bucket, a box, a carton, or a vehicle or trailer that has a load capacity of 1 metric ton or less. The vehicle load capacity of 1 metric ton was chosen as the cut-off for an other container because of the assumptions the Agency used to develop the standards for sewage sludge sold or given away in a bag or other container for application to the land. EPA assumed that this sewage sludge would be applied to the land in small amounts. The Agency considers 1 metric ton of sewage sludge to be a small amount, particularly for the types of land on which these types of products will be used (i.e., lawns, home gardens, or public contact sites). In addition, EPA determined that a vehicle with a load capacity of 1 metric ton or less will not be used to haul the amount of sewage sludge needed on agricultural land, and that such a vehicle will not be used to make several trips to the same site.

SECTION EIGHT

APPLICABILITY

Part 503.10 of Subpart B indicates to whom and to what the land application requirements apply and exemptions from these requirements. The applicability of the land application requirement is discussed in Sections 8.1 and 8.2 below.

8.1 APPLICABILITY OF SUBPART B REQUIREMENTS

Subpart B requirements apply to:

- Any person who prepares sewage sludge that is applied to the land.
- Any person who applies sewage sludge to the land.
- Sewage sludge that is applied to the land.
- The land on which sewage sludge is applied.

8.2 EXEMPTIONS

As mentioned previously, the Part 503 use or disposal standards consist of general requirements, pollutant limits, management practices, and operational standards. For land application of sewage sludge, there are three cases in which not all requirements must be met to comply with the standards. Both bulk sewage sludge applied to the land and sewage sludge sold or given away in a bag or other container for application to the land may be included in one of these three cases.

In the first case, bulk sewage sludge is exempted from the general requirements (see Section Ten) and the management practices (see Section Eleven) when certain requirements are met. These requirements are the pollutant concentration limits in 503.13(b)(3) (see Table 6-10);

the Class A pathogen requirements (503.32(a)); and one of the vector attraction reduction requirements in 503.33(b)(1) through 503.33(b)(8) (see Section Twelve for a description of vector attraction reduction requirements). In these cases, the frequency of monitoring requirements (see Section Thirteen), the recordkeeping requirements (see Section Fourteen), and the reporting requirements (see Section Fifteen) must be met from reasonably observed effects of pollutants in sewage sludge.

In the second case, when sewage sludge that does not meet the quality requirements described above is used to derive a bulk material (e.g., a combination of sewage sludge and wood chips), and the derived material meets the requirements described above, the general requirements and management practices of Subpart B do not apply when the derived material is applied to the land.

In the third case, when sewage sludge meeting the three quality requirements is used to derive a material, none of the Part 503 requirements apply when the derived material is applied to land. The rationale for the exemption of bulk sewage sludge and sewage sludge sold or given away in a bag or other container for application to the land from the general requirements and management practices in the case where pollutant concentration limits, Class A pathogen requirements, and one of the vector attraction reduction requirements specified above are met, is that the sewage sludge that meets these three quality requirements is a valuable commercial product. Because of this, the sewage sludge most likely will not be applied to the land inappropriately (i.e., "wasted"). In addition, the Agency concluded that over-application of the sewage sludge will not occur because over-application reduces crop yield; increasing yield is the main reason to apply sewage sludge to the land. The Agency concluded that, if the sewage sludge meets the three quality requirements, it is a fertilizer material and should be treated in a manner similar to other fertilizers. For these reasons, the sewage sludge is exempted from the general requirements and management practices in the land application subpart.

The three cases are similar for sewage sludge sold or given away in a bag or other container. There is one major difference, however, between the exemptions for bulk sewage sludge, and for sewage sludge sold or given away in a bag or other container. For bulk sewage sludge corresponding to the first two cases, the Regional Administrator or the State Director (in states with an EPA-approved sewage sludge management program) may apply any or all of the general requirements and the management practices to the sewage sludge on a case-by-case basis after determining that these requirements are necessary to protect public health and the environment. This is not the case for a material derived from sewage sludge that meets the three quality requirements, because this material is exempted from Part 503. Records on who receives that sewage sludge or what happens to the sewage sludge after the three quality requirements are met are not required. There is no way to know when a material is derived from the sewage sludge.

Additionally, the provision concerning imposing the general requirements and management practices after a sewage sludge or material derived from sewage sludge meets the three quality requirements does not apply to sewage sludge sold or given away in a bag or other container for application to the land. As mentioned above, this provision allows control to be re-established over the site where the sewage sludge is applied, among other things. The underlying assumption for the requirements for sewage sludge sold or given away in a bag or other container is that it is impossible to exert direct control over the user of the sewage sludge. If there is no control over the user of the sewage sludge initially, there is no way to re-establish that control through the imposition of general requirements or management practices. For this reason, the provision concerning re-imposing certain requirements is not applicable in this case.

SECTION NINE

DEFINITIONS

Section 503.9, General Definitions of Subpart A, defines words, phrases, and acronyms specific to Part 503. Section 503.11, Special Definitions of Subpart B, defines words, phrases, and acronyms specific to land application of sewage sludge. Section 503.31, Special Definitions of Subpart D, defines words, phrases, and acronyms specific to pathogen and vector attraction reduction. These definitions are included in Appendix A. (Most of these definitions are also included in the Glossary at the beginning of this document.) Many of these definitions are self-explanatory; others are discussed further in the preamble to 40 CFR Part 503 as published in the *Federal Register*.

9.1 GENERAL DEFINITIONS

The following words, phrases, and acronyms are defined in Section 503.9 of Subpart A:

Apply sewage sludge or sewage sludge applied to the land
Base flood
Class I sludge management facility
Cover crop
CWA
Domestic septage
Domestic sewage
Dry weight basis
EPA
Feed crops
Fiber crops
Food crops
Ground water
Industrial wastewater
Municipality
Permitting authority
Person
Person who prepares sewage sludge
Place sewage sludge or sewage sludge placed
Pollutant

Pollutant limit
Runoff
Sewage sludge
State
Store or storage of sewage sludge
Threatened or endangered species
Treat or treatment of sewage sludge
Treatment works
Wetlands

9.2 SPECIAL DEFINITIONS FOR LAND APPLICATION OF SEWAGE SLUDGE

The following words, phrases, and acronyms are defined in Section 503.11 of Subpart B:

Agricultural land
Agronomic rate
Annual pollutant loading rate
Annual whole sludge application rate
Bulk sewage sludge
Cumulative pollutant loading rate
Forest
Land application
Monthly average
Other container
Pasture
Public contact site
Range land
Reclamation land

9.3 SPECIAL DEFINITIONS FOR PATHOGEN AND VECTOR ATTRACTION REDUCTION

The following words, phrases, and acronyms are defined in section 503.31 of Subpart D:

Aerobic digestion
Anaerobic digestion
Density of microorganisms
Land with a high potential for public exposure

Land with a low potential for public exposure
Pathogenic organisms
pH
Specific oxygen uptake rate (SOUR)
Total solids
Unstabilized solids
Vector attraction
Volatile solids

SECTION TEN

GENERAL REQUIREMENTS

Section 503.12 of the regulation specifies general requirements for the land application of sewage sludge. These requirements are specified for both the preparer and the applier of sewage sludge and are described in Sections 10.1 and 10.2. A discussion of sewage sludge or material derived from sewage sludge that is exempted from general requirements is included in Section 10.3.

10.1 GENERAL REQUIREMENTS FOR THE PERSON WHO PREPARES SEWAGE SLUDGE FOR APPLICATION TO THE LAND

General requirements for the person who prepares sewage sludge that is applied to the land include providing notice and information to users of sewage sludge and to the permitting authority.

The person who prepares bulk sewage sludge (excluding bulk sewage sludge and derived bulk material exempted from general requirements—see Section 10.3) that is applied to agricultural land, forests, public contact sites, or reclamation sites must provide the person who applies the bulk sewage sludge written notification of the concentration of total nitrogen (as N on a dry-weight basis) in the bulk sewage sludge. The purpose of this general requirement is to ensure that the person who applies the bulk sewage sludge is aware of its nitrogen concentration and can therefore determine the proper agronomic rate (see Section 11.4) for the crop.

The person who prepares sewage sludge that is applied to the land must provide notice and information necessary to comply with the requirements of Subpart B to the person who applies sewage sludge and to the person who further prepares the sewage sludge (e.g., the person who derives a bulk material from the sewage sludge) or who prepares sewage sludge that is sold or given away in a bag or other container.

The last general requirement for any person who prepares bulk sewage sludge that is applied to the land addresses a notice that must be provided when bulk sewage sludge (excluding bulk sewage sludge exempted from general requirements—see Section 10.3) is transported across state lines for land application in another state. When bulk sewage sludge is generated in one state (the generating state) and transferred to another state (the receiving state), the person who prepares the bulk sewage sludge must notify the permitting authority in the receiving state in which the bulk sewage sludge will be applied. The notification must be provided to the permitting authority prior to the application of the bulk sewage sludge and must include:

- The location, by either street address or latitude and longitude, of each land application site.
- The approximate period of time bulk sewage sludge will be applied to the site.
- The name, address, telephone number, and National Pollutant Discharge Elimination System permit number for the person who prepares the bulk sewage sludge.
- The name, address, telephone number, and National Pollutant Discharge Elimination System permit number for the person who will apply the bulk sewage sludge.

The permitting authority may request additional information or a full permit application if necessary. This notice requirement provides the permitting authority the flexibility to impose additional requirements, if needed, and to ensure compliance with Part 503.

10.2 GENERAL REQUIREMENTS FOR THE PERSON WHO APPLIES SEWAGE SLUDGE TO THE LAND

General requirements for the person who applies sewage sludge include restrictions for applying sewage sludge to the land and requirements for providing notice and information to users of sewage sludge, to the owner/leaseholder of the land, and to the permitting authority.

No person shall apply sewage sludge to the land except in accordance with the requirements in Subpart B. In addition, no person shall apply bulk sewage sludge subject to the pollutant ceiling concentrations in Table 6-9 and the cumulative pollutant loading rates in Table 6-4 to agricultural land, forests, public contact sites, or reclamation sites if any of the cumulative pollutant loading rates have been reached at these sites; or apply domestic septage to agricultural land, forests, or reclamation sites during a 365-day period if the annual application rate (see Section 6.4) has been reached during that period.

The applier of sewage sludge to the land must obtain the information necessary to comply with the requirements of Subpart B. This information must be provided by the applier to the owner or lease holder of the land on which bulk sewage sludge is applied.

When bulk sewage sludge subject to the pollutant ceiling concentrations in Table 6-9 and the cumulative pollutant loading rates in Table 6-4 is applied to the land, either to land in the same state where the bulk sewage sludge is generated or to land in a state different from the state in which the bulk sewage sludge is generated, the person who applies the bulk sewage sludge must notify the permitting authority for the state in which the bulk sewage sludge will be applied. This notice is a one-time notice for a land application site for each applier. It must be provided to the permitting authority prior to the initial application of bulk sewage sludge to a site and must include:

- The location, by either street address or latitude and longitude, of the land application site.
- The name, address, telephone number, and National Pollutant Discharge Elimination System permit number, if appropriate, of the person who will apply the bulk sewage sludge.

The purpose of this general requirement is to ensure that a record is kept that indicates that bulk sewage sludge subject to pollutant ceiling concentrations and cumulative pollutant loading rates has been applied to a site. Without that information, a person who intends to apply bulk sewage sludge subject to these requirements cannot determine whether bulk sewage sludge has been applied to a site. Without this information, the cumulative pollutant loading rates cannot be enforced.

If bulk sewage sludge subject to pollutant ceiling concentrations and cumulative pollutant loading rates has not been applied to the site 120 days after the effective date of Part 503, the cumulative amount for each pollutant in Table 6-4 can be applied to the site. The applier must keep a record of the amount of each pollutant in the bulk sewage sludge applied to the site by the applier.

If bulk sewage sludge subject to pollutant ceiling concentrations and cumulative pollutant loading rates has been applied to the site within 120 days after the effective date of Part 503, the applier must look for the records that indicate the amount of each pollutant in bulk sewage sludge applied to the site since the effective date. When those records are available, the applier must use that information to determine the additional amount of each pollutant that can be applied to the site in accordance with Tables 6-9 and 6-4. In this case, the applier must keep the records of the amount of each pollutant applied previously by other appliers and must also keep a record of the amount of each pollutant in the bulk sewage sludge applied to the site by the applier.

If bulk sewage sludge subject to pollutant ceiling concentrations and cumulative pollutant loading rates has been applied to the site within 120 days after the effective date of Part 503, and records indicating the cumulative amount of each pollutant in the bulk sewage sludge applied to the site since the effective date cannot be found, an additional amount of each pollutant cannot be applied to the site.

10.3 EXEMPTIONS FROM GENERAL REQUIREMENTS

When bulk sewage sludge, a derived bulk material, or sewage sludge for sale or give away in a bag or other container meets the pollutant concentration limits in Table 6-10, Class A pathogen requirements (see Section Twelve), and one of the vector attraction reduction requirements other than injection or incorporation of sewage sludge into the soil [503.33(b)(1) through 503.33(b)(8)—see Section Twelve], the general requirements and management practice requirements do not apply. This exemption, specified in 503.10 (Applicability—see Section Eight), can be revoked if the Regional Administrator or State Director determines on a case-by-case basis that for bulk sewage sludge these requirements are necessary to protect public health and the environment.

SECTION ELEVEN

MANAGEMENT PRACTICES

Management practices specified in Section 503.14 of the regulation and described in Sections 11.1 through 11.5 below are required when bulk sewage sludge is applied to agricultural land, forests, public contact sites, or reclamation sites, unless the sewage sludge is exempted from these requirements. A discussion of sewage sludge that is exempted from management practice requirements is included in Section 11.6.

11.1 PROTECTION OF THREATENED OR ENDANGERED SPECIES

The federal government has a mandate to protect threatened or endangered species. The final regulation [Section 503.14(a)] prohibits the application of bulk sewage sludge to the land if it will adversely affect a threatened or endangered species (listed under Section 4 of the Endangered Species Act), or its designated critical habitat. Because pollutant limits in Subpart B are not designed to protect threatened or endangered species (because those species are not considered "reasonable worst-case" species), or to protect against the destruction or adverse modification of a critical habitat, this management practice was needed.

11.2 RESTRICTION ON THE APPLICATION TO FLOODED, FROZEN, OR SNOW-COVERED LAND

Bulk sewage sludge cannot be applied to flooded, frozen, or snow-covered agricultural land, forests, public contact sites, or reclamation sites in such a way that the bulk sewage sludge enters a wetland or other waters of the United States, as defined in 40 CFR Part 122.2[1], except

[1] Waters of the United States, as defined in 40 CFR Part 122.2, means: (a) All waters which are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide; (b) All interstate waters, including interstate "wetlands;" (c) All other waters such as intrastate lakes,
(continued...)

as provided in a permit issued pursuant to Section 402 or 404 of the CWA, as amended. This management practice allows the application of bulk sewage sludge to flooded, frozen, or snow-covered land when the bulk sewage sludge does not enter United States waters or wetlands.

Because the worst-case scenario of application of sewage sludge to flooded, frozen, or snow-covered lands was not modeled in the risk assessment, the pollutant limits in the regulation are not designed to protect wetlands and waters from application of sewage sludge to flooded, frozen, or snow-covered land. When bulk sewage sludge is applied to the land under these conditions, it can easily be transported into nearby waters unless carefully handled or unless wetlands or other water bodies are not located near the site. Therefore, the Agency determined that this management practice was necessary to protect U.S. waters and wetlands.

11.3 TEN-METER BUFFER FOR U.S. WATERS

Bulk sewage sludge cannot be applied to agricultural land, forests, or reclamation sites that are 10 meters or less from U.S. waters, unless otherwise specified by the permitting authority. This management practice reduces the likelihood that sewage sludge applied to the land can reach U.S. waters through runoff resulting from precipitation. It is included in the final regulation because pollutant limits in Subpart B are not designed to protect U.S. waters when sewage sludge is applied to land that is 10 meters or less from those waters. This management practice does not apply to a public contact site, because these sites are typically small areas where the application of sewage sludge is in small quantities and is easily controlled.

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[1](...continued)
rivers, streams (including intermittent streams), mudflats, sandflats, "wetlands," sloughs, prairie, potholes, wet meadows, playa lakes, or natural ponds the use, degradation, or destruction of which would affect or could affect interstate of foreign commerce including any such waters: (1) Which are or could be used by interstate of foreign travelers for recreational or other purposes; (2) From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or (3) Which are used or could be used for industrial purposes by industries in interstate commerce; (d) All impoundments of waters otherwise defined as waters of the United States under this definition; (e) Tributaries of waters identified in parts (a) through (d) of this definition; (f) The territorial sea; and (g) "Wetlands" adjacent to waters (other than waters that are themselves wetlands) identified in parts (a) through (f) of this definition.

11.4 AMOUNT APPLIED LIMITED BY AGRONOMIC RATE

Bulk sewage sludge must be applied to agricultural land, forests, or public contact sites at a rate that is equal to or less than the agronomic rate. The agronomic rate is the whole sludge application rate designed to: (1) provide the amount of nitrogen needed by the crop or vegetation grown on the land, and (2) minimize the amount of nitrogen in the sewage sludge that passes to the ground water below the root zone of the crop or vegetation grown on the land (40 CFR Part 503). This management practice also applies to reclamation sites, unless otherwise specified by the permitting authority. The permitting authority may allow larger amounts of sewage sludge to be applied to reclamation sites. In such cases, the permitting authority may impose other requirements on the reclamation site (e.g., only apply larger amounts in one application).

Several factors must be considered in deriving the agronomic application rate for a crop site. These include, but are not limited to: the amount of nitrogen needed by the crop or vegetation grown on the land; the amount of nitrogen remaining from previous application of nitrogen-containing materials; the amount of organic nitrogen that becomes available each year from previous application of nitrogen-containing materials; the type of soil at the site; and the geologic conditions of the site. Although the agronomic rate is designed to minimize the amount of nitrogen that passes to the ground water below the root zone of the crop or vegetation grown on the land, some of the nitrogen in the sewage sludge may reach the ground water. However, the Agency determined that by designing the rate to minimize that amount, long-term contamination of the ground water probably will not occur, because most of the nitrogen will be taken up by the crop or vegetation grown on the land.

Application is not limited by the agronomic rate if bulk sewage sludge is applied to a lawn or home garden or when sewage sludge is sold or given away in a bag or other container for application to the land. It is unlikely that large amounts of sewage sludge will be applied to such land in those cases. For this reason, the Agency has determined that the whole sludge application rate for sewage sludge applied to a lawn or home garden or sold or given away should not be limited by the amount of nitrogen needed.

11.5 LABELING REQUIREMENTS

The final management practice requires that a label be affixed to the bag or other container in which sewage sludge is sold or given away for application to the land, or that an information sheet be provided to the person who receives such sewage sludge sold or given away in a bag or other container. The label or information sheet must contain the following information: the name and address of the person who prepared the sewage sludge for sale or give away in a bag or other container; a statement that prohibits application of the sewage sludge to the land except in accordance with the instructions on the label or information sheet; and the annual whole sludge application rate for the sewage sludge that does not cause the annual pollutant loading rates in Table 6-5 to be exceeded. These label information requirements are minimum requirements, and the person who prepares the label may include additional information on the label, such as information required by a state or local government.

11.6 EXEMPTIONS FROM MANAGEMENT PRACTICES

Bulk sewage sludge that meets the pollutant concentration limits in Table 6-10, the Class A pathogen requirements (see Section Twelve), and one of the vector attraction reduction requirements other than injection and incorporation of sewage sludge into the soil [vector attraction reduction methods in 503.33(b)(1) through 503.33(b)(8) — see Section Twelve] is exempted from management practice requirements. This exemption, specified in 503.10 (Applicability—see Section Eight), can be revoked if the Regional Administrator or State Director determines on a case-by-case basis that for bulk sewage sludge these requirements are necessary to protect public health and the environment.

Management practice requirements do not apply if bulk sewage sludge is applied to a lawn or home garden, because large amounts of bulk sewage sludge most likely will not be applied to a lawn or a home garden multiple times.

SECTION TWELVE

PATHOGEN AND VECTOR ATTRACTION REDUCTION REQUIREMENTS

Section 503.15 of Subpart B specifies operational standards for pathogen and vector attraction reduction in sewage sludge that is applied to the land. These operational standards refer to specific requirements in Sections 503.32 and 503.33 in Subpart D, Pathogen and Vector Attraction Reduction. These pathogen and vector attraction reduction requirements are described in the *Technical Support Document for Reduction of Pathogens and Vector Attraction in Sewage Sludge* (U.S. EPA, 1992a). Pathogen and vector attraction reduction requirements as they apply to land application are discussed in Sections 12.1 and 12.2 below.

12.1 SEWAGE SLUDGE

12.1.1 Pathogen Requirements

Bulk sewage sludge applied to agricultural land, forests, public contact sites, or reclamation sites must meet either Class A pathogen requirements or Class B pathogen requirements and site restrictions (restrictions for harvesting of crops and turf, grazing of animals, and public access). The EPA has determined that public health and the environment are protected against the reasonably anticipated adverse effects of pathogens in sewage sludge in both cases.

Bulk sewage sludge applied to a lawn or home garden and sewage sludge sold or given away in a bag or other container for application to the land must meet Class A pathogen requirements. The reason for this requirement is that is not feasible to impose site restrictions (required for a sewage sludge that meets Class B pathogen requirements) on a lawn or home garden on which bulk sewage sludge is applied and it is impossible to impose the site restrictions for sewage sludge sold or given away in a bag or other container for application to the land.

12.1.1.1 Class A Pathogen Requirements

Class A pathogen requirements are the more stringent of the pathogen requirements. To meet Class A pathogen requirements, one of six pathogen reduction requirements in 503.32(a) has to be met. Consequently, when sewage sludge meeting Class A pathogen requirements is applied to the land, site restrictions (restrictions for harvesting of crops and turf, grazing of animals, and public access), which must be met when sewage sludge meeting Class B pathogen requirements is applied to the land, are not required.

12.1.1.2 Class B Pathogen Requirements

To meet Class B pathogen requirements, a treatment works must meet one of the three alternatives for pathogen reduction in sewage sludge described in 503.32(b). These alternatives include testing for fecal coliform by collecting seven samples of sewage sludge at the time the sewage sludge is used or disposed, treating the sewage sludge using a process to significantly reduce pathogens (PSRP), or treating the sewage sludge using a process determined by the permitting authority to be equivalent to a PSRP.

Whenever sewage sludge meeting Class B pathogen requirements is applied to the land, the harvesting of crops and turf, the grazing of animals, and public access is restricted for a certain period of time. These site restrictions are described in 503.32(b)(5).

12.1.2 Vector Attraction Reduction Requirements

Bulk sewage sludge applied to agricultural land, forests, public contact sites, or reclamation sites also must meet 1 of the 10 vector attraction reduction requirements in 503.33(b)(1) through 503.33(b)(10). These requirements are designed to reduce the characteristics of the sewage sludge that attract vectors such as mosquitos and flies. The EPA concluded that each of the 10 alternative vector attraction reduction requirements protects public health and the environment from the reasonably anticipated adverse effects of the characteristics in sewage sludge that attract vectors.

Bulk sewage sludge applied to a lawn or home garden and sewage sludge sold or given away in a bag or other container for application to the land must meet one of the eight vector attraction reduction requirements in 503.33(b)(1) through 503.33(b)(8). The two vector attraction reduction requirements that cannot be met when sewage sludge is applied to a lawn or a home garden are injection of the bulk sewage sludge below the land surface and incorporation of sewage sludge into the soil. Implementation of these requirements for bulk sewage sludge applied to a lawn or home garden is difficult, if not impossible; and is not feasible for sewage sludge sold or given away in a bag or other container for application to the land.

12.2 DOMESTIC SEPTAGE

12.2.1 Pathogen Requirements

When domestic septage is applied to agricultural land, forests, or reclamation sites, one of two pathogen requirements must be met. Site restrictions concerning harvesting crops and turf, grazing animals, and permitting public access must be met (see Section 12.1.1.2), or the pH of the domestic septage must be adjusted and the site restrictions concerning harvesting crops must be met. Restrictions on harvesting crops are included in the latter requirement, because the Agency concluded that pathogen reduction achieved by pH adjustment is inadequate to allow crops to be harvested immediately after the application of domestic septage.

12.2.2 Vector Attraction Reduction Requirements

For domestic septage applied to agricultural land, forests, or reclamation sites, one of the following vector attraction reduction methods must be applied:

- Raise the pH of the domestic septage to 12 or higher using alkali addition and, without the addition of more alkali, keep the domestic septage at 12 or higher for 30 minutes.

- Inject the domestic septage below the surface of the land. No significant amount of domestic septage can be present on the land surface within 1 hour after it is injected.

- Incorporate the domestic septage into the soil within 6 hours after application to the land.

SECTION THIRTEEN

FREQUENCY OF MONITORING

Land-applied sewage sludge must be monitored for pollutant concentrations, pathogens, and vector attraction reduction. Domestic septage must be monitored for pH when pH adjustment is used to meet either the pathogen requirement and vector attraction reduction requirement. The frequency of monitoring is specified in Section 503.16 of Subpart B, and discussed in Sections 13.1 and 13.2.

13.1 SEWAGE SLUDGE

To ensure compliance with Part 503, sewage sludge must be monitored for:

- Arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc.
- The pathogen density requirements in 503.32(a) through 503.32(b)(4) (Class A and B pathogen requirements—see Section Twelve).
- The selected vector attraction reduction requirements, except the vector attraction reduction requirements in 503.33(b)(9) and 503.33(b)(10), which apply to injection or incorporation of sewage sludge into the soil and, therefore, do not contain any monitoring requirements.

The frequency of monitoring for pollutant concentrations, pathogens, and vector attraction reduction, as presented in Table 13-1, is 1, 4, 6, or 12 times per year, depending on the number of metric tons (mt) (dry-weight basis) of sewage sludge used or disposed annually. The basis for the frequency of monitoring requirements is discussed in Appendix L.

After the sewage sludge is monitored for 2 years at the frequency in Table 13-1, the permitting authority can reduce the frequency of monitoring for pollutant concentrations and the pathogen density requirements in 503.32(a)(5)(ii) and 503.32(a)(5)(iii) (requires the analysis of

TABLE 13-1

FREQUENCY OF MONITORING—LAND APPLICATION

Amounts of Sewage Sludge[a] (metric tons per 365-day period)	Frequency
Greater than zero, but less than 290	Once per year
Equal to or greater than 290, but less than 1,500	Once per quarter (4 times per year)
Equal to or greater than 1,500, but less than 15,000	Once per 60 days (6 times per year)
Equal to or greater than 15,000	Once per month (12 times per year)

[a]Either the amount of bulk sewage sludge applied to the land or the amount of sewage sludge received by a person who prepares the sewage sludge that is sold or given away in a bag or other container for application to the land (dry weight basis).

Note: Appendix L describes how to calculate the amounts of sewage sludge used or disposed in order to determine the required frequency of monitoring.

sewage sludge for enteric viruses and viable helminth ova prior to pathogen treatment—see Section Twelve). However, in no case can the frequency of monitoring be less than once per year when sewage sludge is applied to the land.

In deciding whether to reduce the frequency of monitoring pollutant concentrations, the permitting authority considers the variability and the magnitude of the pollutant concentrations. The Agency has determined that data collected over a 2-year period are adequate to calculate the variability of pollutant concentrations and to determine the magnitude of the pollutant concentrations when deciding whether to change the frequency of monitoring.

The pathogen density requirements in 503.32(a)(5)(ii) and 503.32(a)(5)(iii) specify that sewage sludge be analyzed for enteric viruses and viable helminth ova every time the sewage sludge is monitored. After these two organisms are found in the influent to the pathogen reduction process and after the required reduction for these organisms is demonstrated through the pathogen reduction process, the sewage sludge does not have to be monitored for enteric viruses and viable helminth ova if values for the process operating parameters are consistent with the documented values for those parameters. Because of the costs and complexity of the analytical methods for enteric viruses and viable helminth ova, the Agency decided to allow the permitting authority to determine whether to reduce the monitoring frequency after monitoring at the frequency in Table 13-1 for 2 years. In deciding whether to reduce the monitoring frequency, the permitting authority considers the frequency of detection of enteric viruses and viable helminth ova in the sewage sludge. The Agency has concluded that 2 years of monitoring should provide enough information to make that judgement. The frequency of monitoring cannot be reduced for the other pathogen density requirements.

13.2 DOMESTIC SEPTAGE

As discussed in Section Twelve, one of two pathogen requirements and one of three vector attraction reduction requirements must be met for domestic septage applied to the land. The pathogen requirements specify either that the pH of domestic septage be raised to a minimum of 12 for at least 30 minutes and the land on which domestic septage is applied be subject to crop harvesting restrictions; or no pH adjustment is performed, but the harvesting of crops and turf, the grazing of animals, and public access must be restricted on the land where domestic septage is applied. The vector attraction reduction requirements specify the same pH method or either injection or incorporation of the domestic septage into the soil. If the pH method is used for pathogen and/or vector attraction reduction, each container (e.g., each tank truck load) of domestic septage applied to agricultural land, forests, or reclamation sites must be monitored for compliance with the pH testing requirements. Every container must be monitored, because there is no way to ensure that the domestic septage in each container meets the pH requirement by monitoring domestic septage in only a certain number of containers.

SECTION FOURTEEN

RECORDKEEPING

The regulation requires that certain information be recorded and retained when sewage sludge is applied to the land. Recordkeeping requirements vary depending on whether sewage sludge is in bulk form or placed in a bag or other container for application to the land. They also vary depending on which pollutant limits are met, whether Class A or Class B pathogen requirements are met, and which vector attraction reduction requirements are met. Recordkeeping requirements are specified in Section 503.17, described in Sections 14.1 through 14.3 below, and summarized in Table 14-1.

14.1 SEWAGE SLUDGE MEETING POLLUTANT CONCENTRATION LIMITS, CLASS A PATHOGEN REQUIREMENTS, AND ONE OF THE VECTOR ATTRACTION REDUCTION REQUIREMENTS IN 503.33(b)(1) THROUGH 503.33(b)(8)

Bulk sewage sludge and sewage sludge for sale or give away in a bag or other container meeting the pollutant concentration limits in Table 6-10, the Class A pathogen requirements, and one of the vector attraction reduction requirements other than injection and incorporation of sewage sludge into the soil [vector attraction reduction requirements in 503.33(b)(1) through 503.33(b)(8)] is associated with minimum recordkeeping requirements when the sewage sludge is applied to the land. These requirements, which must be met by the **person who prepares** such sewage sludge include collecting, recording, and retaining for 5 years the following information:

- The concentration of each regulated pollutant in the sewage sludge.
- The certification statement in 503.17(a)(1)(ii) that certifies that the Class A pathogen requirements and one of the vector attraction reduction requirements other than injection or incorporation of sewage sludge into the soil have been met.

  Many of recordkeeping requirements specify statements certifying that certain Subpart B requirements are met. A general certification statement is used with

TABLE 14-1

RECORDKEEPING RESPONSIBILITIES BY TYPE OF SEWAGE SLUDGE AND PERSON RESPONSIBLE

Type of Record	Type of Sewage Sludge					
	Bulk Sewage Sludge Subject to Cumulative Limits		Sewage Sludge Meeting Pollutant Concentration Limits		Material Derived from Bulk Sewage Sludge/Material Meets Pollutant Concentration Limits (Bulk or Bags)	Bagged Sewage Sludge Not Meeting Pollutant Concentration Limits
	Class A Pathogen Reduction	Class B Pathogen Reduction	Class A Pathogen Reduction (Bulk or Bags)	Class B Pathogen Reduction (Bulk or Bags)		
Pollutant Concentrations	Preparer	Preparer	Preparer	Preparer	Preparer	Preparer
Management Practice Certification and Description	Applier	Applier	None-if not injected or incorporated Applier-if injected or incorporated (bulk only)	Applier	None	Preparer (certification only)
Site Restriction Certification and Description	None	Applier	None	Applier	None	None
Vector Attraction Reduction Certification and Description[a]	Preparer or Applier	Preparer or Applier	Preparer or Applier	Preparer or Applier	Preparer	Preparer
Pathogen Reduction Certification and Description	Preparer	Preparer	Preparer	Preparer	Preparer	Preparer

TABLE 14-1 (cont.)

	Type of Sewage Sludge					
	Bulk Sewage Sludge Subject to Cumulative Limits		Sewage Sludge Meeting Pollutant Concentration Limits			
Type of Record	Class A Pathogen Reduction	Class B Pathogen Reduction	Class A Pathogen Reduction (Bulk or Bags)	Class B Pathogen Reduction (Bulk or Bags)	Material Derived from Bulk Sewage Sludge/Material Meets Pollutant Concentration Limits (Bulk or Bags)	Bagged Sewage Sludge Not Meeting Pollutant Concentration Limits
Other Information	Applier: Site Location, No. of Hectares, Date & Time of Application, Cumulative Amount of Pollutant Applied, including previous amounts; Amount of sewage sludge applied; certification and description of information gathering[b]	Applier: Site Location, No. of Hectares, Date & Time of Application, Cumulative Amount of Pollutant Applied, including previous amounts; Amount of sewage sludge applied; certification and description of information gathering[b]	None	None	None	Preparer: Appropriate AWSAR

[a]The preparer certifies and describes vector attraction reduction methods other than injection and incorporation into the soil. If vector attraction reduction using injection or incorporation, the applier is responsible for certification and description of method. If the sewage sludge is to meet the three high-quality requirements, it cannot be injected or incorporated to meet the vector attraction reduction requirement, thus only the preparer can certify and describe the procedure used.

[b]Information gathering includes obtaining information from the permitting authority regarding the existing cumulative pollutant load at the site from previous sewage sludge applications.

Source: ERG, based on 40 CFR Part 503 Regulation.

the appropriate requirements included. This general certification statement is as follows:

"I certify under penalty of law, that the ... have been met. This determination has been made under my direction and supervision in accordance with the system designed to assure that qualified personnel properly gather and evaluate the information used to determine that the requirements have been met. I am aware that there are significant penalties for false certification including the possibility of fine and imprisonment."

- A description of how the Class A pathogen requirements and one of the vector attraction reduction requirements other than injection or incorporation of sewage sludge into the soil are met.

14.2 MATERIAL DERIVED FROM BULK SEWAGE SLUDGE THAT MEETS POLLUTANT CONCENTRATION LIMITS, CLASS A PATHOGEN REQUIREMENTS, AND ONE OF THE VECTOR ATTRACTION REDUCTION REQUIREMENTS IN 503.33 (b)(1) THROUGH 503.33(b)(8)

As discussed in Sections Six and Eight, when sewage sludge meeting the pollutant concentration limits in Table 6-10, the Class A pathogen requirements, and one of the vector attraction reduction requirements other than injection or incorporation of sewage sludge into the soil [vector attraction reduction requirements in 503.33(b)(1) through 503.33(b)(8)] is used to derive a bulk material (e.g., a combination of sewage sludge and wood chips), the derived material is exempted from coverage by Subpart B (specified in 503.10). However, when sewage sludge not meeting the quality requirements described above is used to produce a derived material that does meet the quality requirements described above, there are minimum recordkeeping requirements when the derived material is applied to the land whether in bulk form or for sale or give away in a bag or other container. The person who derives the material must collect, record, and retain for 5 years the same information listed in 14.1.1 above.

14.3 BULK SEWAGE SLUDGE MEETING POLLUTANT CONCENTRATION LIMITS, CLASS A PATHOGEN REQUIREMENTS, AND ONE OF THE VECTOR ATTRACTION REDUCTION REQUIREMENTS IN 503.33(b)(9) OR 503.33(b)(10)

Bulk sewage sludge meeting pollutant concentration limits, Class A pathogen requirements, and one of the vector attraction reduction requirements in either 503.33(b)(9) or 503.33(b)(10) (injection or incorporation of sewage sludge into the soil) applied to agricultural land, forests, public contact sites, or reclamation sites is also associated with minimum recordkeeping requirements. These requirements are specified separately for the applier and the preparer of the bulk sewage sludge. The **person who applies** the bulk sewage sludge must collect, record, and retain for 5 years the following information:

- The certification statement in 503.17(a)(3)(ii)(A) that certifies that the management practices in 503.14 and the selected vector attraction reduction requirement of either injection or incorporation of sewage sludge into the soil are met.
- A description of how the management practices and the selected vector attraction reduction requirements are met for each site on which bulk sewage sludge is applied.

The **person who prepares** the bulk sewage sludge must collect, record, and retain for 5 years the following information:

- The concentration of each regulated pollutant in the bulk sewage sludge.
- The certification statement in 503.17(a)(3)(i)(B) that certifies that the Class A pathogen requirements have been met.
- A description of how the Class A pathogen requirements are met.

14.4 BULK SEWAGE SLUDGE MEETING POLLUTANT CEILING CONCENTRATIONS AND CUMULATIVE POLLUTANT LOADING RATES

Bulk sewage sludge meeting the pollutant ceiling concentrations in Table 6-9 and the cumulative pollutant loading rates in Table 6-4 applied to agricultural land, forests, public contact sites, or reclamation sites is associated with the most comprehensive recordkeeping requirements. These requirements are specified separately for the applier and the preparer of bulk sewage sludge. The **person who applies** such bulk sewage sludge must collect, record, and retain **indefinitely** the following information:

- The location, either by street address or latitude and longitude, of each site on which bulk sewage sludge is applied.
- The number of hectares in each site on which bulk sewage sludge is applied.
- The date and time bulk sewage sludge is applied to each site.
- The cumulative amount of each regulated pollutant (i.e., kilograms) in the bulk sewage sludge applied to each site.
- The amount of sewage sludge (metric tons) applied to each site.
- The certification statement in 503.17(5)(ii)(F) that certifies that the requirements to obtain information as required in 503.12(e)(2) are met. A description of how these requirements are met is also required. [Part 503.12(e)(2) specifies that the permitting authority be contacted to determine whether bulk sewage sludge has been applied to the site since 120 days from the effective date of Part 503—see Section Ten.]

The **person who applies** bulk sewage sludge meeting pollutant ceiling concentrations and cumulative pollutant loading rates must also collect, record, and retain for 5 years the following information:

- The certification statement in 503.17(5)(ii)(H) that certifies that management practices in 503.14 have been met for each site on which the bulk sewage sludge is applied.
- A description of how the management practices are met for each site on which bulk sewage sludge is applied.
- When the bulk sewage sludge meets the Class B pathogen requirements, the certification statement in 503.17(5)(ii)(J) is required. This statement certifies that the site restrictions for harvesting of crops, grazing of animals, and public access (see Section Twelve) are met for each site on which the Class B bulk sewage sludge is applied.

- A description of how these site restrictions are met.

- If either injection or incorporation of sewage sludge into the soil is used to achieve vector attraction reduction, the certification statement in 503.17(5)(ii)(L) that certifies that these are met and a description of how these are met is required.

The person who **prepares** the bulk sewage sludge meeting pollutant ceiling concentrations and cumulative pollutant loading rates must collect, record, and retain for 5 years the following information:

- The concentration of each regulated pollutant in the bulk sewage sludge.

- The certification statement in 503.17(a)(5)(i)(B) that certifies that the Class A or B pathogen requirements and 1 of the vector attraction reduction requirements other than injection or incorporation of sewage sludge into the soil are met.

- A description of how the pathogen and vector attraction reduction requirements discussed above are met.

14.5 BULK SEWAGE SLUDGE MEETING POLLUTANT CONCENTRATION LIMITS AND CLASS B PATHOGEN REQUIREMENTS

Bulk sewage sludge meeting the pollutant concentration limits in Table 6-10 and Class B pathogen requirements is also associated with minimum recordkeeping requirements when it is applied to agricultural land, forests, public contact sites, or reclamation sites. Recordkeeping requirements are specified separately for the applier and the preparer of the sewage sludge. The **person who applies** such bulk sewage sludge must collect, record, and retain for 5 years the following information:

- The certification statement in 503.17(a)(4)(ii)(A) that certifies that the management practices; the site restrictions for harvesting of crops and turf, grazing of animals, and public access; and one of the vector attraction reduction requirements of either injection or incorporation of sewage sludge into the soil (if it is met) are met for each site on which bulk sewage sludge is applied. A description of how these are met is also required.

The **person who prepares** the bulk sewage sludge meeting pollutant concentration limits and Class B pathogen requirements must collect, record, and retain for 5 years the following information:

- The concentration of each regulated pollutant in the bulk sewage sludge.
- The certification statement in 503.17(a)(4)(i)(B) that certifies that Class B pathogen requirements and one of the vector attraction reduction requirements other than injection and incorporation of sewage sludge into the soil are met (if one of these vector attraction reduction requirements is met). A description of how these are met is also required.

14.6 SEWAGE SLUDGE SOLD OR GIVEN AWAY IN A BAG OR OTHER CONTAINER FOR APPLICATION TO THE LAND THAT MEETS THE ANNUAL POLLUTANT LOADING RATES

Sewage sludge for sale or give away, in a bag or other container for application to the land that meets the annual pollutant loading rates in Table 6-5 is associated with a small number of recordkeeping requirements. These requirements are specified for the **person who prepares** such sewage sludge, which includes collecting, recording, and retaining for 5 years the following information:

- The annual whole sludge application rate for the sewage sludge that does not cause the annual pollutant loading rates in Table 6-5 to be exceeded.
- The concentration of each regulated pollutant in the sewage sludge.
- The certification statement in 503.17(a)(6)(iii) that certifies that the management practices, Class A pathogen requirements, and one of the vector attraction reduction requirements other than injection or incorporation of sewage sludge into the soil are met.
- A description of how the Class A pathogen requirements and one of the selected vector attraction reduction requirements are met.

14.7 DOMESTIC SEPTAGE

Recordkeeping requirements for the **applier** of domestic septage to agricultural land, forests, or reclamation sites include, collecting, recording, and retaining for 5 years the following information:

- The location, either by street address or latitude and longitude, of the site on which domestic septage is applied.
- The number of acres in the application site.
- The date and time domestic septage is applied to each site.
- The nitrogen requirement of the crop or vegetation grown on each site during the 365-day period.
- The rate, in gallons per year, at which domestic septage is applied to the site.
- The certification statement in 503.17(b)(6) that certifies that the pathogen and vector attraction reduction requirements for domestic septage have been met.
- A description of how these pathogen and vector attraction reduction requirements for domestic septage are met.

SECTION FIFTEEN

REPORTING

Section 503.18 of the regulation specifies reporting requirements for Class I sewage sludge management facilities, POTWs with a design flow rate equal to or greater than 1 MGD, and POTWs that serve 10,000 people or more to report information to the permitting authority.

Class I sewage sludge management facilities are either a POTW required to have a pretreatment program or a treatment works treating domestic sewage (TWTDS) that has the potential to affect public health and the environment adversely because of the TWTDS's sewage sludge use or disposal practice.

POTWs required to pretreat, industry wastewater and, thus, are more likely to generate sewage sludge that contains the pollutants controlled in Part 503. For this reason, the Agency has determined that those POTWs should report the information on sewage sludge use or disposal to the permitting authority. The reporting requirement also applies to other Class I sludge management facilities, the TWTDS, whose sewage sludge use or disposal practice has the potential to adversely affect public health and the environment.

The reporting requirement also applies to POTWs that are not a Class I facility and either have a design flow rate equal to or greater than 1 MGD, or serve 10,000 people or more. These facilities are included because of the potential for industrial wastewater to be part of the influent. Sewage sludge generated at such POTWs is more likely to contain the pollutants controlled in Part 503. For this reason, the Agency concluded that those POTWs should report the information in the recordkeeping section to the permitting authority.

Each POTW that is a Class I sewage sludge management facility with a design flow rate equal to or greater than 1 MGD that serves a population of 10,000 or greater, is required to submit most of the information required in the recordkeeping section to the permitting authority each year (on the month and day that Part 503 is published). There is some information that does *not* have to be submitted:

- The information in 503.17(b), which must be recorded when domestic septage is applied to the agricultural land, forests, or reclamation sites, does not have to be submitted to the permitting authority.

- The information in 503.17(a)(3)(ii), which must be recorded when sewage sludge meeting pollutant concentration limits, Class A pathogen requirements, and the vector attraction reduction requirements of either injection or incorporation of sewage sludge into the soil is applied to agricultural land, forests, public contact sites or reclamation sites, does not have to be submitted to the permitting authority. This includes the following information regarding each site to which bulk sewage sludge is applied: a description of how the management practice requirements and the vector attraction reduction requirements of either injection or incorporation of sewage sludge into the soil are met and a certification statement that these are met.

- The information in 503.17(a)(4)(ii), which must be recorded when sewage sludge meeting pollutant concentration limits and Class B pathogen requirements is applied to agricultural land, forests, public contact sites, or reclamation sites, does not have to be submitted to the permitting authority. This includes the following information regarding each site to which bulk sewage sludge is applied: a description of how the management practices, site restrictions, and vector attraction reduction requirements of injection or incorporation of sewage sludge into the soil (if either of these vector attraction reduction requirements are met), and a certification statement that these are met (see Section 14.1.4).

- The information in 503.17(a)(5)(ii), which must be recorded when bulk sewage sludge meeting pollutant ceiling concentrations and cumulative pollutant loading rates is applied to agricultural land, forests, public contact sites, or reclamation sites does not have to be submitted to the permitting authority. This includes information regarding each site to which bulk sewage sludge is applied, such as the location, the number of hectares of land, the date and time bulk sewage sludge is applied, the cumulative amount of each pollutant in the bulk sewage sludge, and the amount of sewage sludge in metric tons.

However, when 90 percent or more of any of the cumulative pollutant loading rates is reached at a site, the information in 503.17(a)(5)(ii)(A) through 503.17(a)(5)(ii)(G), must be submitted to the permitting authority each year (on the month and day that Part 503 is published). This includes the following information regarding each site to which bulk sewage sludge is applied: the location, the number of hectares of land, the date and time bulk sewage sludge is applied, the cumulative amount of each pollutant in the bulk sewage sludge, the amount of sewage sludge in metric tons, a statement certifying that the requirements to obtain information in 503.12(e)(2) (information regarding the cumulative amount of pollutants applied to a site—see Section Ten) have been met, and a description of how this information was obtained (see Section 14.1.5).

SECTION 16

REFERENCES

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40 CFR Part 124. 1989. (relates to state permits or domestic septage).

40 CFR Part 501. 1989. State Sludge Management Program Regulations. May 2.

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