United States Environmental Protection Agency
Office of Water Regulations and Standards Washington, DC 20460
Water
June, 1985

EPA

Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Lindane

PREFACE

This document is one of a series of preliminary assessments dealing with chemicals of potential concern in municipal sewage sludge. The purpose of these documents is to: (a) summarize the available data for the constituents of potential concern, (b) identify the key environmental pathways for each constituent related to a reuse and disposal option (based on hazard indices), and (c) evaluate the conditions under which such a pollutant may pose a hazard. Each document provides a scientific basis for making an initial determination of whether a pollutant, at levels currently observed in sludges, poses a likely hazard to human health or the environment when sludge is disposed of by any of several methods. These methods include landspreading on food chain or nonfood chain crops, distribution and marketing programs, landfilling, incineration and ocean disposal.

These documents are intended to serve as a rapid screening tool to narrow an initial list of pollutants to those of concern. If a significant hazard is indicated by this preliminary analysis, a more detailed assessment will be undertaken to better quantify the risk from this chemical and to derive criteria if warranted. If a hazard is shown to be unlikely, no further assessment will be conducted at this time; however, a reassessment will be conducted after initial regulations are finalized. In no case, however, will criteria be derived solely on the basis of information presented in this document.

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SECTION 1

INTRODUCTION

This preliminary data profile is one of a series of profiles dealing with chemical pollutants potentially of concern in municipal sewage sludges. Lindane was initially identified as being of potential concern when sludge is landspread (including distribution and marketing), placed in a landfill, incinerated or ocean disposed.* This profile is a compilation of information that may be useful in determining whether lindane poses an actual hazard to human health or the environment when sludge is disposed of by these methods.

The focus of this document is the calculation of "preliminary hazard indices" for selected potential exposure pathways, as shown in Section 3. Each index illustrates the hazard that could result from movement of a pollutant by a given pathway to cause a given effect (e.g., sludge → soil → plant uptake → animal uptake → human toxicity). The values and assumptions employed in these calculations tend to represent a reasonable "worst case"; analysis of error or uncertainty has been conducted to a limited degree. The resulting value in most cases is indexed to unity; i.e., values >1 may indicate a potential hazard, depending upon the assumptions of the calculation.

The data used for index calculation have been selected or estimated based on information presented in the "preliminary data profile", Section 4. Information in the profile is based on a compilation of the recent literature. An attempt has been made to fill out the profile outline to the greatest extent possible. However, since this is a preliminary analysis, the literature has not been exhaustively perused.

The "preliminary conclusions" drawn from each index in Section 3 are summarized in Section 2. The preliminary hazard indices will be used as a screening tool to determine which pollutants and pathways may pose a hazard. Where a potential hazard is indicated by interpretation of these indices, further analysis will include a more detailed examination of potential risks as well as an examination of site-specific factors. These more rigorous evaluations may change the preliminary conclusions presented in Section 2, which are based on a reasonable "worst case" analysis.

The preliminary hazard indices for selected exposure routes pertinent to landspreading and distribution and marketing, landfilling, incineration and ocean disposal practices are included in this profile. The calculation formulae for these indices are shown in the Appendix. The indices are rounded to two significant figures.

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* Listings were determined by a series of expert workshops convened during March-May, 1984 by the Office of Water Regulations and Standards (OWRS) to discuss landspreading, landfilling, incineration, and ocean disposal, respectively, of municipal sewage sludge.

SECTION 2

PRELIMINARY CONCLUSIONS FOR LINDANE IN MUNICIPAL SEWAGE SLUDGE

The following preliminary conclusions have been derived from the calculation of "preliminary hazard indices", which represent conservative or "worst case" analyses of hazard. The indices and their basis and interpretation are explained in Section 3. Their calculation formulae are shown in the Appendix.

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Lindane

No increase in the concentration of lindane in sludge-amended soil is expected to occur from application rates of 5 to 50 mt/ha. A slight increase in lindane concentration in soil is expected to occur when sludge is applied at a cumulative rate of 500 mt/ha (see Index 1).

B. Effect on Soil Biota and Predators of Soil Biota

Landspreading of sludge is not expected to pose a toxic hazard due to lindane for soil biota which inhabit sludge-amended soil (see Index 2). Accordingly, the landspreading of municipal sewage sludge is not expected to pose a toxic hazard to predators of soil biota due to lindane contamination (see Index 3).

C. Effect on Plants and Plant Tissue Concentration

Landspreading of sludge is not expected to result in soil concentrations of lindane which pose a phytotoxic hazard (see Index 4). The tissue concentrations of lindane in plants grown in sludge-amended soil, and the phytotoxic tissue concentrations of lindane for the same plants could not be determined due to lack of data (see Indices 5 and 6).

D. Effect on Herbivorous Animals

The effects of lindane on herbivorous animals consuming plants grown in sludge-amended soil could not be determined due to lack of data (see Index 7). However, the incidental ingestion of sludge-amended soil by herbivorous animals is not expected to result in a toxic hazard due to lindane (see Index 8).

E. Effect on Humans

The potential cancer risk due to lindane for humans who consume plants grown in sludge-amended soil or who consume animal products derived from animals that grazed on plants grown in sludge-amended soils could not be evaluated due to lack of data (see Indices 9 and 10). The landspreading of sludge containing a high concentration of lindane is expected to slightly increase the cancer risk due to lindane for humans who consume animal products derived from animals ingesting sludge-amended soils (see Index 11). The consumption of sludge-amended soils that have received application rates of 5 to 50 mt/ha by toddlers or adults is not expected to increase the risk of human cancer due to lindane above the pre-existing risk attributable to other dietary sources of lindane. There may be an increased risk when soils amended with sludge at a cumulative rate of 500 mt/ha are ingested (see Index 12). The aggregate human cancer risk due to lindane associated with the landspreading of municipal sewage sludge could not be determined due to a lack of data (see Index 13).

II. LANDFILLING

The landfilling disposal of municipal sewage sludge is generally expected to result in slight increases in lindane concentrations in groundwater. However, when the composite worst-case scenario is evaluated, a moderate increase in concentration is anticipated (see Index 1). Accordingly, the landfilling of sludge should not increase the risk of cancer due to the ingestion of lindane above that normally associated with consuming groundwater. But when the worst-case scenario is evaluated, a moderate increase in cancer risk can be expected when contaminated groundwater is ingested (see Index 2).

III. INCINERATION

The incineration of municipal sewage sludge at typical sludge feed rates may moderately increase lindane concentrations in air. At high rates, the resulting concentration may be substantially higher than typical urban levels (see Index 1). Inhalation of emissions from incineration of sludge may slightly increase the human cancer risk due to lindane, above the risk posed by background urban air concentrations of lindane (see Index 2).

IV. OCEAN DISPOSAL

Only slight increases of lindane are expected to occur at the disposal site after sludge dumping and initial mixing (see Index 1). Only slight increases in lindane concentrations are apparent after a 24-hour dumping cycle (see Index 2). Only slight to moderate incremental increases in hazard to aquatic life were determined. No toxic conditions occur via any of the scenarios evaluated (see Index 3). No increase of risk to human health from consumption of seafood is expected to occur due to the ocean disposal of sludge (see Index 4).

SECTION 3

PRELIMINARY HAZARD INDICES FOR LINDANE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Lindane

1. Index of Soil Concentration (Index 1)

a. **Explanation** - Calculates concentrations in µg/g DW of pollutant in sludge-amended soil. Calculated for sludges with typical (median, if available) and worst (95 percentile, if available) pollutant concentrations, respectively, for each of four applications. Loadings (as dry matter) are chosen and explained as follows:

0 mt/ha	No sludge applied. Shown for all indices for purposes of comparison, to distinguish hazard posed by sludge from preexisting hazard posed by background levels or other sources of the pollutant.
5 mt/ha	Sustainable yearly agronomic application; i.e., loading typical of agricultural practice, supplying ~50 kg available nitrogen per hectare.
50 mt/ha	Higher single application as may be used on public lands, reclaimed areas or home gardens.
500 mt/ha	Cumulative loading after 100 years of application at 5 mt/ha/year.

b. **Assumptions/Limitations** - Assumes pollutant is incorporated into the upper 15 cm of soil (i.e., the plow layer), which has an approximate mass (dry matter) of 2×10^3 mt/ha and is then dissipated through first order processes which can be expressed as a soil half-life.

c. **Data Used and Rationale**

i. **Sludge concentration of pollutant (SC)**

Typical	0.11 µg/g DW
Worst	0.22 µg/g DW

In a study of lindane in the municipal sludge of 74 cities in Missouri (Clevenger et al.,

1983) the mean concentration was 0.11 μg/g DW and the maximum concentration was 0.22 μg/g DW. These values were used for the typical and worst concentrations of pollutant in sludge since they were the only data immediately available. (See Section 4, p. 4-1.)

ii. **Background concentration of pollutant in soil (BS) = 0.13 μg/g DW**

This concentration was derived by taking the mean value of the most recent soil data available (Matsumura, 1972a). Although significant commercial use of purified lindane continues (U.S. EPA, 1980), this was the most current information for generating a background concentration value. (See Section 4, p. 4-2.)

iii. **Soil half-life of pollutant ($t_{\frac{1}{2}}$) = 1.04 years**

A soil half-life of 378 days is reported for sandy loam soils and 56 days in clay loam (U.S. EPA, 1984a). The value for sandy loam soils was used because it represents the worst case, namely, longer persistence. (See Section 4, p. 4-10.)

d. **Index 1 Values (μg/g DW)**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.13	0.13	0.13	0.27
Worst	0.13	0.13	0.13	0.27

e. **Value Interpretation** - Value equals the expected concentration in sludge-amended soil.

f. **Preliminary Conclusion** - No increase in the concentration of lindane in sludge-amended soil is expected to occur from application rates of 5 to 50 mt/ha. A slight increase in lindane concentration in soil is expected to occur when sludge is applied at a cumulative rate of 500 mt/ha.

B. **Effect on Soil Biota and Predators of Soil Biota**

1. **Index of Soil Biota Toxicity (Index 2)**

a. **Explanation** - Compares pollutant concentrations in sludge-amended soil with soil concentration shown to be toxic for some soil organism.

b. **Assumptions/Limitations** - Assumes pollutant form in sludge-amended soil is equally bioavailable and toxic as form used in study where toxic effects were demonstrated.

c. **Data Used and Rationale**

i. **Concentration of pollutant in sludge-amended soil (Index 1)**

See Section 3, p. 3-2.

ii. **Soil concentration toxic to soil biota (TB) = >100 µg/g DW**

There is limited data on soil concentrations toxic to soil biota. (See Section 4, p. 4-15.) A range of 12.5 to 100 µg/g was given for experimental soil concentrations for bacteria/fungi (Eno and Everett, 1958). The high value of 100 µg/g was selected so as to represent a conservative worst case. The "greater than" symbol is used to indicate that this concentration did not actually generate toxic effects, although a 35% reduction of fungi did occur.

d. **Index 2 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	<0.0013	<0.0013	<0.0013	<0.0027
Worst	<0.0013	<0.0013	<0.0013	<0.0027

e. **Value Interpretation** - Value equals factor by which expected soil concentration exceeds toxic concentration. Value > 1 indicates a toxic hazard may exist for soil biota.

f. **Preliminary Conclusion** - Landspreading of sludge is not expected to pose a toxic hazard due to lindane for soil biota which inhabit sludge-amended soil.

2. **Index of Soil Biota Predator Toxicity (Index 3)**

a. **Explanation** - Compares pollutant concentrations expected in tissues of organisms inhabiting sludge-amended soil with food concentration shown to be toxic to a predator on soil organisms.

b. **Assumptions/Limitations** - Assumes pollutant form bioconcentrated by soil biota is equivalent in toxicity to form used to demonstrate toxic effects in predator. Effect level in predator may be estimated from that in a different species.

c. **Data Used and Rationale**

i. **Concentration of pollutant in sludge-amended soil (Index 1)**

See Section 3, p. 3-2.

ii. **Uptake factor of pollutant in soil biota (UB) =** 1.05 μg/g tissue DW (μg/g soil DW)$^{-1}$

The only available uptake factor of lindane in soil biota is for the earthworm (Yadav et al., 1976). A range of 0.45 to 1.05 was given, and the high value of 1.05 was used so as to represent a conservative worst case. (See Section 4, p. 4-16.)

iii. **Feed concentration toxic to predator (TR) =** 50 μg/g DW

No data are available for a typical earthworm predator (e.g., a bird) so the value of 50 μg/g in rats was used. This concentration represents the lowest level that produced a toxic effect: hypertrophy of the liver. (See Section 4, p. 4-13.)

d. **Index 3 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.0027	0.0027	0.0027	0.0056
Worst	0.0027	0.0027	0.0028	0.0056

e. **Value Interpretation** - Values equals factor by which expected concentration in soil biota exceeds that which is toxic to predator. Value > 1 indicates a toxic hazard may exist for predators of soil biota.

f. **Preliminary Conclusion** - The landspreading of municipal sewage sludge is not expected to pose a toxic hazard to predators of soil biota due to lindane contamination.

C. Effect on Plants and Plant Tissue Concentration

1. Index of Phytotoxic Soil Concentration (Index 4)

a. **Explanation** - Compares pollutant concentrations in sludge-amended soil with the lowest soil concentration shown to be toxic for some plants.

b. **Assumptions/Limitations** - Assumes pollutant form in sludge-amended soil is equally bioavailable and toxic as form used in study where toxic effects were demonstrated.

c. **Data Used and Rationale**

i. **Concentration of pollutant in sludge-amended soil (Index 1)**

See Section 3, p. 3-2.

ii. **Soil concentration toxic to plants (TP) = 12.5 μg/g DW**

This value represents the lowest soil concentration toxic to plant tops when lindane was applied. At a 12.5 μg/g DW concentration, a 27% reduction in root weight was observed for stringless black valentine beans (Eno and Everett, 1958). BHC values were not considered since they represent data for a blend of the isomeric forms of hexachlorocyclohexane and not just the gamma isomer, lindane. (See Section 4, p. 4-11.)

d. **Index 4 Values**

Sludge Concentration	Sludge Application Rate (mt/ha)			
	0	5	50	500
Typical	0.010	0.010	0.010	0.021
Worst	0.010	0.010	0.010	0.021

e. **Value Interpretation** - Value equals factor by which soil concentration exceeds phytotoxic concentration. Value > 1 indicates a phytotoxic hazard may exist.

f. **Preliminary Conclusion** - Landspreading of sludge is not expected to result in soil concentrations of lindane which pose a phytotoxic hazard.

2. **Index of Plant Concentration Caused by Uptake (Index 5)**

a. **Explanation** - Calculates expected tissue concentrations, in μg/g DW, in plants grown in sludge-amended soil, using uptake data for the most responsive plant species in the following categories: (1) plants included in the U.S. human diet; and (2) plants serving as animal feed. Plants used vary according to availability of data.

b. **Assumptions/Limitations** - Assumes an uptake factor that is constant over all soil concentrations. The uptake factor chosen for the human diet is assumed to be representative of all crops (except fruits) in the human diet. The uptake factor chosen for the animal diet is assumed to be representative of all crops in the animal diet. See also Index 6 for consideration of phytotoxicity.

c. **Data Used and Rationale**

i. **Concentration of pollutant in sludge-amended soil (Index 1)**

See Section 3, p. 3-2.

ii. **Uptake factor of pollutant in plant tissue (UP)** - Data not immediately available.

The uptake factor of the pollutant in plant tissue is derived by comparing the plant tissue concentration with the soil concentration. Due to the lack of tissue concentrations in the available literature (see Section 4, pp. 4-11 to 4-12), a UP value could not be determined.

d. **Index 5 Values** - Values were not calculated due to lack of data.

e. **Value Interpretation** - Value equals the expected concentration in tissues of plants grown in sludge-amended soil. However, any value exceeding the value of Index 6 for the same or a similar plant species may be unrealistically high because it would be precluded by phytotoxicity.

f. **Preliminary Conclusion** - Conclusion was not drawn because index values could not be calculated.

3. **Index of Plant Concentration Permitted by Phytotoxicity (Index 6)**

a. **Explanation** - The index value is the maximum tissue concentration, in μg/g DW, associated with phytotoxicity in the same or similar plant species used in Index 5. The purpose is to determine whether the plant tissue concentrations determined in Index 5 for high applications are realistic, or whether such concentrations would be precluded by phytotoxicity. The maximum concentration should be the highest at which some plant growth still occurs (and thus consumption of tissue by animals is possible) but above which consumption by animals is unlikely.

b. **Assumptions/Limitations** - Assumes that tissue concentration will be a consistent indicator of phytotoxicity.

c. **Data Used and Rationale**

i. **Maximum plant tissue concentration associated with phytotoxicity (PP)** - Data not immediately available.

The tissue concentrations associated with plant phytotoxicity in Table 4-1, pp. 4-11 to 4-12, were not reported. Because of this lack of data, a PP value could not be selected.

d. **Index 6 Values** - Values were not reported due to lack of data.

e. **Value Interpretation** - Value equals the maximum plant tissue concentration which is permitted by phytotoxicity. Value is compared with values for the same or similar plant species given by Index 5. The lowest of the two indices indicates the maximal increase that can occur at any given application rate.

f. **Preliminary Conclusion** - Conclusion was not drawn because index values could not be calculated.

D. **Effect on Herbivorous Animals**

1. **Index of Animal Toxicity Resulting from Plant Consumption (Index 7)**

a. **Explanation** - Compares pollutant concentrations expected in plant tissues grown in sludge-amended soil with feed concentration shown to be toxic to wild or domestic herbivorous animals. Does not consider direct contamination of forage by adhering sludge.

b. **Assumptions/Limitations** - Assumes pollutant form taken up by plants is equivalent in toxicity to form used to demonstrate toxic effects in animal. Uptake or toxicity in specific plants or animals may be estimated from other species.

c. **Data Used and Rationale**

i. **Concentration of pollutant in plant grown in sludge-amended soil (Index 5)** - Values were not calculated due to lack of data.

ii. **Feed concentration toxic to herbivorous animal (TA)** = 50 μg/g DW

Data are reported for an inadvertent poisoning of cows with benzene hexachloride (BHC) which contained 19.1% lindane (McParland et al., 1973). This information was not used because it cannot be determined what part lindane or the other 80.9% hexachlorocyclohexane isomers played in causing the deaths of the animals. The only available chronic data for lindane pertain to rats, which exhibited no effects at 25 μg/g but showed liver hypertrophy after 50 μg/g lindane was consumed in the diet for 2 years (NRC, 1982). (See Section 4, p. 4-13.) This value will be assumed to apply to all herbivorous species.

d. **Index 7 Values** - Values were not calculated due to lack of data.

e. **Value Interpretation** - Value equals factor by which expected plant tissue concentration exceeds that which is toxic to animals. Value > 1 indicates a toxic hazard may exist for herbivorous animals.

f. **Preliminary Conclusion** - Conclusion was not drawn because index values could not be calculated.

2. **Index of Animal Toxicity Resulting from Sludge Ingestion (Index 8)**

a. **Explanation** - Calculates the amount of pollutant in a grazing animal's diet resulting from sludge adhesion to forage or from incidental ingestion of sludge-amended soil and compares this with the dietary toxic threshold concentration for a grazing animal.

b. **Assumptions/Limitations** - Assumes that sludge is applied over and adheres to growing forage, or that sludge constitutes 5 percent of dry matter in the grazing animal's diet, and that pollutant form in sludge is equally bioavailable and toxic as form used to demonstrate toxic effects. Where no sludge is applied (i.e., 0 mt/ha), assumes diet is 5 percent soil as a basis for comparison.

c. **Data Used and Rationale**

i. **Sludge concentration of pollutant (SC)**

Typical 0.11 μg/g DW
Worst 0.22 μg/g DW

See Section 3, p. 3-1.

ii. **Fraction of animal diet assumed to be soil (GS)** = 5%

Studies of sludge adhesion to growing forage following applications of liquid or filter-cake sludge show that when 3 to 6 mt/ha of sludge solids is applied, clipped forage initially consists of up to 30 percent sludge on a dry-weight basis (Chaney and Lloyd, 1979; Boswell, 1975). However, this contamination diminishes gradually with time and growth, and generally is not detected in the following year's growth. For example, where pastures amended at 16 and 32 mt/ha were grazed throughout a growing season (168 days), average sludge content of forage was only 2.14 and 4.75 percent, respectively (Bertrand et al., 1981). It seems reasonable to assume that animals may receive long-term dietary exposure to 5 percent sludge if maintained on a forage to which sludge is regularly applied. This estimate of 5 percent sludge is used regardless of application rate, since the above studies did not show a clear relationship between application rate and initial contamination, and since adhesion is not cumulative yearly because of die-back.

Studies of grazing animals indicate that soil ingestion, ordinarily <10 percent of dry weight of diet, may reach as high as 20 percent for cattle and 30 percent for sheep during winter months when forage is reduced (Thornton and Abrams, 1983). If the soil were sludge-amended, it is conceivable that up to 5 percent sludge may be ingested in this manner as well. Therefore, this value accounts for either of these scenarios, whether forage is harvested or grazed in the field.

iii. **Feed concentration toxic to herbivorous animal (TA)** = 50 μg/g DW

See Section 3, p. 3-8.

d. **Index 8 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.0	0.00011	0.00011	0.00011
Worst	0.0	0.00022	0.00022	0.00022

e. **Value Interpretation** - Value equals factor by which expected dietary concentration exceeds toxic concentration. Value > 1 indicates a toxic hazard may exist for grazing animals.

f. **Preliminary Conclusion** - The incidental ingestion of sludge-amended soil by herbivorous animals is not expected to result in a toxic hazard due to lindane.

E. **Effect on Humans**

1. **Index of Human Cancer Risk Resulting from Plant Consumption (Index 9)**

a. **Explanation** - Calculates dietary intake expected to result from consumption of crops grown on sludge-amended soil. Compares dietary intake with the cancer risk-specific intake (RSI) of the pollutant.

b. **Assumptions/Limitations** - Assumes that all crops are grown on sludge-amended soil and that all those considered to be affected take up the pollutant at the same rate. Divides possible variations in dietary intake into two categories: toddlers (18 months to 3 years) and individuals over 3 years old.

c. **Data Used and Rationale**

i. **Concentration of pollutant in plant grown in sludge-amended soil (Index 5)** - Values were not calculated due to lack of data.

ii. Daily human dietary intake of affected plant tissue (DT)

Toddler	74.5 g/day
Adult	205 g/day

The intake value for adults is based on daily intake of crop foods (excluding fruit) by vegetarians (Ryan et al., 1982); vegetarians were chosen to represent the worst case. The value for toddlers is based on the FDA Revised Total Diet (Pennington, 1983) and food groupings listed by the U.S. EPA (1984b). Dry weights for individual food groups were estimated from composition data given by the U.S. Department of Agriculture (USDA) (1975). These values were composited to estimate dry-weight consumption of all non-fruit crops.

iii. Average daily human dietary intake of pollutant (DI)

Toddler	2.71 µg/day
Adult	8.21 µg/day

The DI value for lindane was determined by calculating the daily pollutant intake through food consumption and adding it to the daily intake of pollutant through ingestion of water. Assumptions made are that the average adult weighs 70 kg, that the average adult consumes 2.0 L of water daily, and that a toddler consumes 33% of an adult intake per day.

The average total relative daily intake of lindane from food over a four-year period from 1975 to 1978 was 0.0030 µg/kg body weight/day (Food and Drug Administration (FDA), 1979). When this value is multiplied by the average adult weight of 70 kg, the daily intake of lindane due to food is 0.21 µg/day.

A data point of 4.0 µg/L was available for drinking water in Streator, Illinois (U.S. EPA, 1980). (See Section 4, p. 4-3.) By multiplying the value of 4.0 µg/L by the consumption rate of 2.0 L of water/day, the daily intake of lindane due to water consumption equals 8.0 µg/day.

By adding together the dietary intake and water intake value, the total daily human dietary intake of lindane during the period 1975 to 1978 is estimated at 8.21 µg/day for an adult.

It is assumed that a toddler consumes 33% of this value or 2.71 μg/day.

iv. **Cancer potency** = 1.33 $(mg/kg/day)^{-1}$

Because of a lack of human data, the value of 1.33 $(mg/kg/day)^{-1}$ was derived from a study of mice in which oral doses of lindane resulted in liver tumors (U.S. EPA, 1980). (See Section 4, p. 4-6.)

v. **Cancer risk-specific intake (RSI)** = 0.053 μg/day

The RSI is the pollutant intake value which results in an increase in cancer risk of 10^{-6} (1 per 1,000,000). The RSI is calculated from the cancer potency using the following formula:

$$RSI = \frac{10^{-6} \times 70 \text{ kg} \times 10^{3} \text{ μg/mg}}{\text{Cancer potency}}$$

d. **Index 9 Values** - Values were not calculated due to lack of data.

e. **Value Interpretation** - Value >1 indicates a potential increase in cancer risk of $>10^{-6}$ (1 per 1,000,000). Comparison with the null index value at 0 mt/ha indicates the degree to which any hazard is due to sludge application, as opposed to pre-existing dietary sources.

f. **Preliminary Conclusion** - Conclusion was not drawn because index values could not be calculated.

2. **Index of Human Cancer Risk Resulting from Consumption of Animal Products Derived from Animals Feeding on Plants (Index 10)**

a. **Explanation** - Calculates human dietary intake expected to result from pollutant uptake by domestic animals given feed grown on sludge-amended soil (crop or pasture land) but not directly contaminated by adhering sludge. Compares expected intake with RSI.

b. **Assumptions/Limitations** - Assumes that all animal products are from animals receiving all their feed from sludge-amended soil. Assumes that all animal products consumed take up the pollutant at the highest rate observed for muscle of any commonly consumed species or at the rate observed for beef liver or dairy products (whichever is higher). Divides possible variations in dietary intake into two categories: toddlers (18 months to 3 years) and individuals over 3 years old.

c. **Data Used and Rationale**

i. **Concentration of pollutant in plant grown in sludge-amended soil (Index 5)** - Values were not calculated due to lack of data.

ii. **Uptake factor of pollutant in animal tissue (UA)** = 0.65 μg/g tissue DW (μg/g feed DW)$^{-1}$

Uptake factors for lindane in beef fat varied from 0.35 to 0.65 μg/g tissue (μg/g diet)$^{-1}$ for feed concentrations of 10 and 100 μg/g (Claborn, 1960, cited in Kenaga, 1980). As a conservative approach, the higher value is used to represent the uptake factor for lindane in all animal fats in the human diet. (See Section 4, p. 4-14.) The uptake factor of pollutant in animal tissue (UA) used is assumed to apply to all animal fats.

iii. **Daily human dietary intake of affected animal tissue (DA)**

Toddler	43.7 g/day
Adult	88.5 g/day

The fat intake values presented, which comprise meat, fish, poultry, eggs and milk products, are derived from the FDA Revised Total Diet (Pennington, 1983), food groupings listed by the U.S. EPA (1984b) and food composition data given by USDA (1975). Adult intake of meats is based on males 25 to 30 years of age and that for milk products on males 14 to 16 years of age, the age-sex groups with the highest daily intake. Toddler intake of milk products is actually based on infants, since infant milk consumption is the highest among that age group (Pennington, 1983).

iv. **Average daily human dietary intake of pollutant (DI)**

Toddler	2.71 μg/day
Adult	8.21 μg/day

See Section 3, p. 3-11.

v. **Cancer risk-specific intake (RSI)** = 0.053 μg/day

See Section 3, p. 3-12.

d. **Index 10 Values** - Values were not calculated due to lack of data.

e. **Value Interpretation** - Same as for Index 9.

f. **Preliminary Conclusion** - Conclusion was not drawn because index values could not be calculated.

3. **Index of Human Cancer Risk Resulting from Consumption of Animal Products Derived from Animals Ingesting Soil (Index 11)**

a. **Explanation** - Calculates human dietary intake expected to result from consumption of animal products derived from grazing animals incidentally ingesting sludge-amended soil. Compares expected intake with RSI.

b. **Assumptions/Limitations** - Assumes that all animal products are from animals grazing sludge-amended soil, and that all animal products consumed take up the pollutant at the highest rate observed for muscle of any commonly consumed species or at the rate observed for beef liver or dairy products (whichever is higher). Divides possible variations in dietary intake into two categories: toddlers (18 months to 3 years) and individuals over 3 years old.

c. **Data Used and Rationale**

i. **Animal tissue** = Beef fat

See Section 3, p. 3-13.

ii. **Sludge concentration of pollutant (SC)**

Typical	0.11 μg/g DW
Worst	0.22 μg/g DW

See Section 3, p. 3-1.

iii. **Background concentration of pollutant in soil (BS)** = 0.13 μg/g DW

See Section 3, p. 3-2.

iv. **Fraction of animal diet assumed to be soil (GS) = 5%**

See Section 3, p. 3-9.

v. **Uptake factor of pollutant in animal tissue (UA)** = 0.65 μg/g tissue DW (μg/g feed DW)$^{-1}$

See Section 3, p. 3-13.

vi. **Daily human dietary intake of affected animal tissue (DA)**

Toddler	39.4 g/day
Adult	82.4 g/day

The affected tissue intake value is assumed to be from the fat component of meat only (beef, pork, lamb, veal) and milk products (Pennington, 1983). This is a slightly more limited choice than for Index 10. Adult intake of meats is based on males 25 to 30 years of age and the intake for milk products on males 14 to 16 years of age, the age-sex groups with the highest daily intake. Toddler intake of milk products is actually based on infants, since infant milk consumption is the highest among that age group (Pennington, 1983).

vii. **Average daily human dietary intake of pollutant (DI)**

Toddler	2.71 μg/day
Adult	8.21 μg/day

See Section 3, p. 3-11.

viii. **Cancer risk-specific intake (RSI) =** 0.053 μg/day

See Section 3, p. 3-12.

d. **Index 11 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	54	54	54	54
	Worst	54	56	56	56
Adult	Typical	160	160	160	160
	Worst	160	170	170	170

e. **Value Interpretation** - Same as for Index 9.

f. **Preliminary Conclusion** - The landspreading of sludge containing a high concentration of lindane is expected to slightly increase the cancer risk due to lindane for humans who consume animal products derived from animals ingesting sludge-amended soils.

4. **Index of Human Cancer Risk from Soil Ingestion (Index 12)**

a. **Explanation** - Calculates the amount of pollutant in the diet of a child who ingests soil (pica child) amended with sludge. Compares this amount with RSI.

b. **Assumptions/Limitations** - Assumes that the pica child consumes an average of 5 g/day of sludge-amended soil. If the RSI specific for a child is not available, this index assumes the RSI for a 10 kg child is the same as that for a 70 kg adult. It is thus assumed that uncertainty factors used in deriving the RSI provide protection for the child, taking into account the smaller body size and any other differences in sensitivity.

c. **Data Used and Rationale**

i. **Concentration of pollutant in sludge-amended soil (Index 1)**

See Section 3, p. 3-2.

ii. **Assumed amount of soil in human diet (DS)**

Pica child	5 g/day
Adult	0.02 g/day

The value of 5 g/day for a pica child is a worst-case estimate employed by U.S. EPA's Exposure Assessment Group (U.S. EPA, 1983a). The value of 0.02 g/day for an adult is an estimate from U.S. EPA, 1984b.

iii. **Average daily human dietary intake of pollutant (DI)**

Toddler	2.71 μg/day
Adult	8.21 μg/day

See Section 3, p. 3-11.

iv. **Cancer risk-specific intake (RSI) = 0.053 μg/day**

See Section 3, p. 3-12.

d. **Index 12 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	63	63	63	76
	Worst	63	63	64	76
Adult	Typical	150	150	150	160
	Worst	150	150	150	160

e. **Value Interpretation** - Same as for Index 9.

f. **Preliminary Conclusion** - The consumption of sludge-amended soils that have received application rates of 5 to 50 mt/ha by toddlers or adults is not expected to increase the risk of human cancer due to lindane above the pre-existing risk attributable to other dietary sources of lindane. There may be an increase of cancer risk for both toddler and adults when soils amended with sludge at a cumulative rate of 500 mt/ha are ingested.

5. **Index of Aggregate Human Cancer Risk (Index 13)**

a. **Explanation** - Calculates the aggregate amount of pollutant in the human diet resulting from pathways described in Indices 9 to 12. Compares this amount with RSI.

b. **Assumptions/Limitations** - As described for Indices 9 to 12.

c. **Data Used and Rationale** - As described for Indices 9 to 12.

d. **Index 13 Values** - Values were not calculated due to lack of data.

e. **Value Interpretation** - Same as for Index 9.

f. **Preliminary Conclusion** - Conclusion was not drawn because index values could not be calculated.

II. LANDFILLING

A. Index of Groundwater Concentration Resulting from Landfilled Sludge (Index 1)

1. **Explanation** - Calculates groundwater contamination which could occur in a potable aquifer in the landfill vicinity. Uses U.S. EPA's Exposure Assessment Group (EAG)

model, "Rapid Assessment of Potential Groundwater Contamination Under Emergency Response Conditions" (U.S. EPA, 1983b). Treats landfill leachate as a pulse input, i.e., the application of a constant source concentration for a short time period relative to the time frame of the analysis. In order to predict pollutant movement in soils and groundwater, parameters regarding transport and fate, and boundary or source conditions are evaluated. Transport parameters include the interstitial pore water velocity and dispersion coefficient. Pollutant fate parameters include the degradation/decay coefficient and retardation factor. Retardation is primarily a function of the adsorption process, which is characterized by a linear, equilibrium partition coefficient representing the ratio of adsorbed and solution pollutant concentrations. This partition coefficient, along with soil bulk density and volumetric water content, are used to calculate the retardation factor. A computer program (in FORTRAN) was developed to facilitate computation of the analytical solution. The program predicts pollutant concentration as a function of time and location in both the unsaturated and saturated zone. Separate computations and parameter estimates are required for each zone. The prediction requires evaluations of four dimensionless input values and subsequent evaluation of the result, through use of the computer program.

2. **Assumptions/Limitations** - Conservatively assumes that the pollutant is 100 percent mobilized in the leachate and that all leachate leaks out of the landfill in a finite period and undiluted by precipitation. Assumes that all soil and aquifer properties are homogeneous and isotropic throughout each zone; steady, uniform flow occurs only in the vertical direction throughout the unsaturated zone, and only in the horizontal (longitudinal) plane in the saturated zone; pollutant movement is considered only in direction of groundwater flow for the saturated zone; all pollutants exist in concentrations that do not significantly affect water movement; for organic chemicals, the background concentration in the soil profile or aquifer prior to release from the source is assumed to be zero; the pollutant source is a pulse input; no dilution of the plume occurs by recharge from outside the source area; the leachate is undiluted by aquifer flow within the saturated zone; concentration in the saturated zone is attenuated only by dispersion.

3. **Data Used and Rationale**

a. **Unsaturated zone**

i. **Soil type and characteristics**

(a) **Soil type**

Typical	Sandy loam
Worst	Sandy

These two soil types were used by Gerritse et al. (1982) to measure partitioning of elements between soil and a sewage sludge solution phase. They are used here since these partitioning measurements (i.e., K_d values) are considered the best available for analysis of metal transport from landfilled sludge. The same soil types are also used for nonmetals for convenience and consistency of analysis.

(b) **Dry bulk density (P_{dry})**

Typical	1.53 g/mL
Worst	1.925 g/mL

Bulk density is the dry mass per unit volume of the medium (soil), i.e., neglecting the mass of the water (CDM, 1984a).

(c) **Volumetric water content (θ)**

Typical	0.195 (unitless)
Worst	0.133 (unitless)

The volumetric water content is the volume of water in a given volume of media, usually expressed as a fraction or percent. It depends on properties of the media and the water flux estimated by infiltration or net recharge. The volumetric water content is used in calculating the water movement through the unsaturated zone (pore water velocity) and the retardation coefficient. Values obtained from CDM, 1984a.

(d) **Fraction of organic carbon (f_{oc})**

Typical	0.005 (unitless)
Worst	0.0001 (unitless)

Organic content of soils is described in terms of percent organic carbon, which is required in the estimation of partition coefficient, K_d.

Values, obtained from R. Griffin (1984) are representative values for subsurface soils.

ii. **Site parameters**

(a) **Landfill leaching time (LT)** = 5 years

Sikora et al. (1982) monitored several sludge entrenchment sites throughout the United States and estimated time of landfill leaching to be 4 or 5 years. Other types of landfills may leach for longer periods of time; however, the use of a value for entrenchment sites is conservative because it results in a higher leachate generation rate.

(b) **Leachate generation rate (Q)**

Typical	0.8 m/year
Worst	1.6 m/year

It is conservatively assumed that sludge leachate enters the unsaturated zone undiluted by precipitation or other recharge, that the total volume of liquid in the sludge leaches out of the landfill, and that leaching is complete in 5 years. Landfilled sludge is assumed to be 20 percent solids by volume, and depth of sludge in the landfill is 5 m in the typical case and 10 m in the worst case. Thus, the initial depth of liquid is 4 and 8 m, and average yearly leachate generation is 0.8 and 1.6 m, respectively.

(c) **Depth to groundwater (h)**

Typical	5 m
Worst	0 m

Eight landfills were monitored throughout the United States and depths to groundwater below them were listed. A typical depth to groundwater of 5 m was observed (U.S. EPA, 1977). For the worst case, a value of 0 m is used to represent the situation where the bottom of the landfill is occasionally or regularly below the water table. The depth to groundwater must be estimated in order to evaluate the likelihood that pollutants moving through the unsaturated soil will reach the groundwater.

(d) Dispersivity coefficient (α)

Typical 0.5 m
Worst Not applicable

The dispersion process is exceedingly complex and difficult to quantify, especially for the unsaturated zone. It is sometimes ignored in the unsaturated zone, with the reasoning that pore water velocities are usually large enough so that pollutant transport by convection, i.e., water movement, is paramount. As a rule of thumb, dispersivity may be set equal to 10 percent of the distance measurement of the analysis (Gelhar and Axness, 1981). Thus, based on depth to groundwater listed above, the value for the typical case is 0.5 and that for the worst case does not apply since leachate moves directly to the unsaturated zone.

iii. Chemical-specific parameters

(a) Sludge concentration of pollutant (SC)

Typical 0.11 mg/kg DW
Worst 0.22 mg/kg DW

See Section 3, p. 3-1.

(b) Soil half-life of pollutant ($t_{1/2}$) = 378 days

See Section 3, p. 3-2.

(c) Degradation rate (μ) = 0.0018 day^{-1}

The unsaturated zone can serve as an effective medium for reducing pollutant concentration through a variety of chemical and biological decay mechanisms which transform or attenuate the pollutant. While these decay processes are usually complex, they are approximated here by a first-order rate constant. The degradation rate is calculated using the following formula:

$$\mu = \frac{0.693}{t_{1/2}}$$

(d) Organic carbon partition coefficient (K_{oc}) = 1080 mL/g

The organic carbon partition coefficient is multiplied by the percent organic carbon content of soil (f_{oc}) to derive a partition coefficient (K_d), which represents the ratio of absorbed pollutant concentration to the dissolved (or solution) concentration. The equation (K_{oc} x f_{oc}) assumes that organic carbon in the soil is the primary means of adsorbing organic compounds onto soils. This concept serves to reduce much of the variation in K_d values for different soil types. The value of K_{oc} is from Hassett et al. (1983).

b. Saturated zone

i. Soil type and characteristics

(a) Soil type

Typical	Silty sand
Worst	Sand

A silty sand having the values of aquifer porosity and hydraulic conductivity defined below represents a typical aquifer material. A more conductive medium such as sand transports the plume more readily and with less dispersion and therefore represents a reasonable worst case.

(b) Aquifer porosity (ϕ)

Typical	0.44 (unitless)
Worst	0.389 (unitless)

Porosity is that portion of the total volume of soil that is made up of voids (air) and water. Values corresponding to the above soil types are from Pettyjohn et al. (1982) as presented in U.S. EPA (1983b).

(c) Hydraulic conductivity of the aquifer (K)

Typical	0.86 m/day
Worst	4.04 m/day

The hydraulic conductivity (or permeability) of the aquifer is needed to estimate flow velocity based on Darcy's Equation. It is a measure of the volume of liquid that can flow through a unit area or media with time; values can range over nine orders of magnitude depending on the nature of the media. Heterogenous conditions produce large spatial variation in hydraulic conductivity, making estimation of a single effective value extremely difficult. Values used are from Freeze and Cherry (1979) as presented in U.S. EPA (1983b).

(d) **Fraction of organic carbon (f_{oc}) = 0.0 (unitless)**

Organic carbon content, and therefore adsorption, is assumed to be 0 in the saturated zone.

ii. **Site parameters**

(a) **Average hydraulic gradient between landfill and well (i)**

Typical	0.001 (unitless)
Worst	0.02 (unitless)

The hydraulic gradient is the slope of the water table in an unconfined aquifer, or the piezometric surface for a confined aquifer. The hydraulic gradient must be known to determine the magnitude and direction of groundwater flow. As gradient increases, dispersion is reduced. Estimates of typical and high gradient values were provided by Donigian (1985).

(b) **Distance from well to landfill ($\Delta \ell$)**

Typical	100 m
Worst	50 m

This distance is the distance between a landfill and any functioning public or private water supply or livestock water supply.

(c) **Dispersivity coefficient (α)**

Typical	10 m
Worst	5 m

These values are 10 percent of the distance from well to landfill ($\Delta \ell$), which is 100 and 50 m, respectively, for typical and worst conditions.

(d) **Minimum thickness of saturated zone (B) = 2 m**

The minimum aquifer thickness represents the assumed thickness due to preexisting flow; i.e., in the absence of leachate. It is termed the minimum thickness because in the vicinity of the site it may be increased by leachate infiltration from the site. A value of 2 m represents a worst case assumption that preexisting flow is very limited and therefore dilution of the plume entering the saturated zone is negligible.

(e) **Width of landfill (W) = 112.8 m**

The landfill is arbitrarily assumed to be circular with an area of 10,000 m^2.

iii. **Chemical-specific parameters**

(a) **Degradation rate (μ) = 0 day^{-1}**

Degradation is assumed not to occur in the saturated zone.

(b) **Background concentration of pollutant in groundwater (BC) = 0 μg/L**

It is assumed that no pollutant exists in the soil profile or aquifer prior to release from the source.

4. **Index Values** - See Table 3-1.

5. **Value Interpretation** - Value equals the maximum expected groundwater concentration of pollutant, in μg/L, at the well.

6. **Preliminary Conclusion** - The landfill disposal of municipal sewage sludge is generally expected to result in slight increases in lindane concentrations in groundwater. When the composite worst-case scenario is evaluated, a moderate increase in concentration is anticipated.

B. **Index of Human Cancer Risk Resulting from Groundwater Contamination (Index 2)**

1. **Explanation** - Calculates human exposure which could result from groundwater contamination. Compares exposure with cancer risk-specific intake (RSI) of pollutant.

2. **Assumptions/Limitations** - Assumes long-term exposure to maximum concentration at well at a rate of 2 L/day.

3. **Data Used and Rationale**

a. **Index of groundwater concentration resulting from landfilled sludge (Index 1)**

See Section 3, p. 3-26.

b. **Average human consumption of drinking water (AC) = 2 L/day**

The value of 2 L/day is a standard value used by U.S. EPA in most risk assessment studies.

c. **Average daily human dietary intake of pollutant (DI) = 8.21 μg/day**

See Section 3, p. 3-11.

d. **Cancer risk-specific intake (RSI) = 0.053 μg/day**

See Section 3, p. 3-12.

4. **Index 2 Values** - See Table 3-1.

5. **Value Interpretation** - Value >1 indicates a potential increase in cancer risk of 10^{-6} (1 in 1,000,000). The null index value should be used as a basis for comparison to indicate the degree to which any risk is due to landfill disposal, as opposed to preexisting dietary sources.

6. **Preliminary Conclusion** - Generally, the landfill disposal of municipal sewage sludge should not increase the risk of cancer due to the ingestion of lindane above that normally associated with consuming groundwater. When the worst-case scenario is evaluated, a moderate increase in cancer risk can be expected when contaminated groundwater is ingested.

III. INCINERATION

A. Index of Air Concentration Increment Resulting from Incinerator Emissions (Index 1)

1. **Explanation** - Shows the degree of elevation of the pollutant concentration in the air due to the incineration of sludge. An input sludge with thermal properties defined by the energy parameter (EP) was analyzed using the BURN model (CDM, 1984a). This model uses the thermodynamic and mass balance relationships appropriate for multiple hearth incinerators to relate the input sludge characteristics to the stack gas parameters. Dilution and dispersion of these stack gas releases were described by the U.S. EPA's Industrial Source Complex Long-Term (ISCLT) dispersion model from which normalized annual ground level concentrations were predicted (U.S. EPA, 1979). The predicted pollutant concentration can then be compared to a ground level concentration used to assess risk.

TABLE 3-1. INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.0014	0.0028	0.0018	0.0030	0.0075	0.057	1.3	0
Index 2 Value	160	160	160	160	160	160	200	160

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

2. **Assumptions/Limitations** - The fluidized bed incinerator was not chosen due to a paucity of available data. Gradual plume rise, stack tip downwash, and building wake effects are appropriate for describing plume behavior. Maximum hourly impact values can be translated into annual average values.

3. **Data Used and Rationale**

a. **Coefficient to correct for mass and time units (C)** = 2.78×10^{-7} hr/sec x g/mg

b. **Sludge feed rate (DS)**

i. **Typical** = 2660 kg/hr (dry solids input)

A feed rate of 2660 kg/hr DW represents an average dewatered sludge feed rate into the furnace. This feed rate would serve a community of approximately 400,000 people. This rate was incorporated into the U.S. EPA-ISCLT model based on the following input data:

EP = 360 lb H_2O/mm BTU
Combustion zone temperature - 1400°F
Solids content - 28%
Stack height - 20 m
Exit gas velocity - 20 m/s
Exit gas temperature - 356.9°K (183°F)
Stack diameter - 0.60 m

ii. **Worst** = 10,000 kg/hr (dry solids input)

A feed rate of 10,000 kg/hr DW represents a higher feed rate and would serve a major U.S. city. This rate was incorporated into the U.S. EPA-ISCLT model based on the following input data:

EP = 392 lb H_2O/mm BTU
Combustion zone temperature - 1400°F
Solids content - 26.6%
Stack height - 10 m
Exit gas velocity - 10 m/s
Exit gas temperature - 313.8°K (105°F)
Stack diameter - 0.80 m

c. **Sludge concentration of pollutant (SC)**

Typical	0.11 mg/kg DW
Worst	0.22 mg/kg DW

See Section 3, p. 3-1.

d. **Fraction of pollutant emitted through stack (FM)**

Typical 0.05 (unitless)
Worst 0.20 (unitless)

These values were chosen as best approximations of the fraction of pollutant emitted through stacks (Farrell, 1984). No data was available to validate these values; however, U.S. EPA is currently testing incinerators for organic emissions.

e. **Dispersion parameter for estimating maximum annual ground level concentration (DP)**

Typical 3.4 μg/m^3
Worst 16.0 μg/m^3

The dispersion parameter is derived from the U.S. EPA-ISCLT short-stack model.

f. **Background concentration of pollutant in urban air (BA) = 0.00005 μg/m^3**

Since lindane was only infrequently detected in air samples from 9 U.S. cities (Stanley et al., 1971), a value of one-half the detection limit of 0.1 ng/m^3, or 0.00005 μg/m^3, will be used to represent a typical urban background concentration. (See Section 4, p. 4-3.)

4. **Index 1 Values**

Fraction of Pollutant Emitted Through Stack	Sludge Concentration	Sludge Feed Rate (kg/hr DW)[a] 0	2660	10,000
Typical	Typical	1.0	1.3	5.9
	Worst	1.0	1.6	11
Worst	Typical	1.0	2.1	20
	Worst	1.0	3.2	40

[a] The typical (3.4 μg/m^3) and worst (16.0 μg/m^3) dispersion parameters will always correspond, respectively, to the typical (2660 kg/hr DW) and worst (10,000 kg/hr DW) sludge feed rates.

5. **Value Interpretation** - Value equals factor by which expected air concentration exceeds background levels due to incinerator emissions.

6. **Preliminary Conclusion** - The incineration of municipal sewage sludge at typical sludge feed rates may moderately increase lindane concentrations in air. At high feed rates, the resulting concentration may be substantially higher than typical urban levels.

B. **Index of Human Cancer Risk Resulting from Inhalation of Incinerator Emissions (Index 2)**

1. **Explanation** - Shows the increase in human intake expected to result from the incineration of sludge. Ground level concentrations for carcinogens typically were developed based upon assessments published by the U.S. EPA Carcinogen Assessment Group (CAG). These ambient concentrations reflect a dose level which, for a lifetime exposure, increases the risk of cancer by 10^{-6}.

2. **Assumptions/Limitations** - The exposed population is assumed to reside within the impacted area for 24 hours/day. A respiratory volume of 20 m^3/day is assumed over a 70-year lifetime.

3. **Data Used and Rationale**

a. **Index of air concentration increment resulting from incinerator emissions (Index 1)**

See Section 3, p. 3-28.

b. **Background concentration of pollutant in urban air (BA)** = 0.00005 $\mu g/m^3$

See Section 3, p. 3-28.

c. **Cancer potency** = 1.33 $(mg/kg/day)^{-1}$

This potency estimate has been derived from that for ingestion, assuming 100% absorption for both ingestion and inhalation routes (see Section 3, p. 3-12).

d. **Exposure criterion (EC)** = 0.00263 $\mu g/m^3$

A lifetime exposure level which would result in a 10^{-6} cancer risk was selected as ground level concentration against which incinerator emissions are compared. The risk estimates developed by CAG are defined as the lifetime incremental cancer risk in a hypothetical population exposed continuously throughout their lifetime to the stated concentration of the carcinogenic agent. The exposure criterion is calculated using the following formula:

$$EC = \frac{10^{-6} \times 10^{3}\ \mu g/mg \times 70\ kg}{\text{Cancer potency} \times 20\ m^{3}/day}$$

4. **Index 2 Values**

Fraction of Pollutant Emitted Through Stack	Sludge Concentration	Sludge Feed Rate (kg/hr DW)[a]		
		0	2660	10,000
Typical	Typical	0.019	0.024	0.11
	Worst	0.019	0.030	0.20
Worst	Typical	0.019	0.040	0.39
	Worst	0.019	0.061	0.76

[a] The typical (3.4 $\mu g/m^3$) and worst (16.0 $\mu g/m^3$) dispersion parameters will always correspond, respectively, to the typical (2660 kg/hr DW) and worst (10,000 kg/hr DW) sludge feed rates.

5. **Value Interpretation** - Value > 1 indicates a potential increase in cancer risk of > 10^{-6} (1 per 1,000,000). Comparison with the null index value at 0 kg/hr DW indicates the degree to which any hazard is due to sludge incineration, as opposed to background urban air concentration.

6. **Preliminary Conclusion** - Inhalation of emissions from incineration of sludge may slightly increase the human cancer risk due to lindane, above the risk posed by background urban air concentrations of lindane.

IV. OCEAN DISPOSAL

For the purpose of evaluating pollutant effects upon and/or subsequent uptake by marine life as a result of sludge disposal, two types of mixing were modeled. The initial mixing or dilution shortly after dumping of a single load of sludge represents a high, pulse concentration to which organisms may be exposed for short time periods but which could be repeated frequently; i.e., every time a recently dumped plume is encountered. A subsequent additional degree of mixing can be expressed by a further dilution. This is defined as the average dilution occurring when a day's worth of sludge is dispersed by 24 hours of current movement and represents the time-weighted average exposure concentration for organisms in the disposal area. This dilution accounts for 8 to 12 hours of the high pulse concentration encountered by the organisms during daylight disposal operations and 12 to 16 hours of recovery (ambient water concentration) during the night when disposal operations are suspended.

A. Index of Seawater Concentration Resulting from Initial Mixing of Sludge (Index 1)

1. **Explanation** - Calculates increased concentrations in μg/L of pollutant in seawater around an ocean disposal site assuming initial mixing.

2. **Assumptions/Limitations** - Assumes that the background seawater concentration of pollutant is unknown or zero. The index also assumes that disposal is by tanker and that the daily amount of sludge disposed is uniformly distributed along a path transversing the site and perpendicular to the current vector. The initial dilution volume is assumed to be determined by path length, depth to the pycnocline (a layer separating surface and deeper water masses), and an initial plume width defined as the width of the plume four hours after dumping. The seasonal disappearance of the pycnocline is not considered.

3. **Data Used and Rationale**

   a. **Disposal conditions**

	Sludge Disposal Rate (SS)	Sludge Mass Dumped by a Single Tanker (ST)	Length of Tanker Path (L)
Typical	825 mt DW/day	1600 mt WW	8000 m
Worst	1650 mt DW/day	3400 mt WW	4000 m

The typical value for the sludge disposal rate assumes that 7.5 x 10^6 mt WW/year are available for dumping from a metropolitan coastal area. The conversion to dry weight assumes 4 percent solids by weight. The worst-case value is an arbitrary doubling of the typical value to allow for potential future increase.

The assumed disposal practice to be followed at the model site representative of the typical case is a modification of that proposed for sludge disposal at the formally designated 12-mile site in the New York Bight Apex (City of New York, 1983). Sludge barges with capacities of 3400 mt WW would be required to discharge a load in no less than 53 minutes traveling at a minimum speed of 5 nautical miles (9260 m) per hour. Under these conditions, the barge would enter the site, discharge the sludge over 8180 m and exit the site. Sludge barges with capacities of 1600 mt WW would be required to discharge a load in no less than 32 minutes traveling at a minimum speed of 8 nautical miles (14,816 m) per hour. Under these conditions, the barge would enter the site, discharge the sludge over 7902 m and exit the site. The mean path length for the large and small tankers is 8041 m or approximately 8000 m. Path length is assumed to lie perpendicular to the direction of prevailing current flow. For the typical disposal rate (SS) of 825 mt DW/day, it is assumed that this would be accomplished by a mixture of four 3400 mt WW and four 1600 mt WW capacity barges. The overall daily disposal operation would last from 8 to 12 hours. For the worst-case disposal rate (SS) of 1650 mt DW/day, eight 3400 mt WW and eight 1600 mt WW capacity barges would be utilized. The overall daily disposal operation would last from 8 to 12 hours. For both disposal rate scenarios, there would be a 12 to 16 hour period at night in which no sludge would be dumped. It is assumed that under the above des-ribed disposal operation, sludge dumping would occur every day of the year.

The assumed disposal practice at the model site representative of the worst case is as stated for the typical site, except that barges would dump half their load along a track, then turn around and dispose of the balance along the same track in order to prevent a barge from dumping outside of the site. This practice would effectively halve the path length compared to the typical site.

b. Sludge concentration of pollutant (SC)

Typical	0.11 mg/kg DW
Worst	0.22 mg/kg DW

See Section 3, p. 3-1.

c. Disposal site characteristics

	Depth to pycnocline (D)	Average current velocity at site (V)
Typical	20 m	9500 m/day
Worst	5 m	4320 m/day

Typical site values are representative of a large, deep-water site with an area of about 1500 km^2 located beyond the continental shelf in the New York Bight. The pycnocline value of 20 m chosen is the average of the 10 to 30 m pycnocline depth range occurring in the summer and fall; the winter and spring disappearance of the pycnocline is not considered and so represents a conservative approach in evaluating annual or long-term impact. The current velocity of 11 cm/sec (9500 m/day) chosen is based on the average current velocity in this area (CDM, 1984b).

Worst-case values are representative of a near-shore New York Bight site with an area of about 20 km^2. The pycnocline value of 5 m chosen is the minimum value of the 5 to 23 m depth range of the surface mixed layer and is therefore a worst-case value. Current velocities in this area vary from 0 to 30 cm/sec. A value of 5 cm/sec (4320 m/day) is arbitrarily chosen to represent a worst-case value (CDM, 1984c).

4. Factors Considered in Initial Mixing

When a load of sludge is dumped from a moving tanker, an immediate mixing occurs in the turbulent wake of the vessel, followed by more gradual spreading of the plume. The entire plume, which initially constitutes a narrow band the length of the tanker path, moves more-or-less as a unit with the prevailing surface current and, under calm conditions, is not further dispersed by the current itself. However, the current acts to separate successive tanker loads, moving each out of the immediate disposal path before the next load is dumped.

Immediate mixing volume after barge disposal is approximately equal to the length of the dumping track with a cross-sectional area about four times that defined by the draft and width of the discharging vessel (Csanady, 1981, as cited in NOAA, 1983). The resulting plume is initially 10 m deep by 40 m wide (O'Connor and Park, 1982, as cited in NOAA, 1983). Subsequent spreading of plume band width occurs at an average rate of approximately 1 cm/sec (Csanady et al., 1979, as cited in NOAA, 1983). Vertical mixing is limited by the depth of the pycnocline or ocean floor, whichever is shallower. Four hours after disposal, therefore, average plume width (W) may be computed as follows:

$$W = 40 \text{ m} + 1 \text{ cm/sec} \times 4 \text{ hours} \times 3600 \text{ sec/hour} \times 0.01 \text{ m/cm} = 184 \text{ m} = \text{approximately } 200 \text{ m}$$

Thus the volume of initial mixing is defined by the tanker path, a 200 m width, and a depth appropriate to the site. For the typical (deep water) site, this depth is chosen as the pycnocline value of 20 m. For the worst (shallow water) site, a value of 10 m was chosen. At times the pycnocline may be as shallow as 5 m, but since the barge wake causes initial mixing to at least 10 m, the greater value was used.

5. **Index 1 Values (μg/L)**

Disposal Conditions and Site Characteristics	Sludge Concentration	Sludge Disposal Rate (mt DW/day)		
		0	825	1650
Typical	Typical	0.0	0.00022	0.00022
	Worst	0.0	0.00044	0.00044
Worst	Typical	0.0	0.0019	0.0019
	Worst	0.0	0.0037	0.0037

6. **Value Interpretation** - Value equals the expected increase in lindane concentration in seawater around a disposal site as a result of sludge disposal after initial mixing.

7. **Preliminary Conclusion** - Only slight increases of lindane occur at the disposal site after sludge dumping and initial mixing.

B. **Index of Seawater Concentration Representing a 24-Hour Dumping Cycle (Index 2)**

1. **Explanation** - Calculates increased effective concentrations in μg/L of pollutant in seawater around an ocean disposal site utilizing a time weighted average (TWA) concentration. The TWA concentration is that which would be experienced by an organism remaining stationary (with respect to the ocean floor) or moving randomly within the disposal vicinity. The dilution volume is determined by the tanker path length and depth to pycnocline or, for the shallow water site, the 10 m effective mixing depth, as before, but the effective width is now determined by current movement perpendicular to the tanker path over 24 hours.

2. **Assumptions/Limitations** - Incorporates all of the assumptions used to calculate Index 1. In addition, it is assumed that organisms would experience high-pulsed sludge concentrations for 8 to 12 hours per day and then experience recovery (no exposure to sludge) for 12 to 16 hours per day. This situation can be expressed by the use of a TWA concentration of sludge constituent.

3. **Data Used and Rationale**

   See Section 3, pp. 3-31 to 3-33.

4. **Factors Considered in Determining Subsequent Additional Degree of Mixing (Determination of TWA Concentrations)**

   See Section 3, p. 3-34.

5. **Index 2 Values (μg/L)**

Disposal Conditions and Site Characteristics	Sludge Concentration	Sludge Disposal Rate (mt DW/day) 0	825	1650
Typical	Typical	0.0	0.000059	0.00012
	Worst	0.0	0.00012	0.00024
Worst	Typical	0.0	0.00052	0.0010
	Worst	0.0	0.0010	0.0021

6. **Value Interpretation** - Value equals the effective increase in lindane concentration expressed as a TWA concentration in seawater around a disposal site experienced by an organism over a 24-hour period.

7. **Preliminary Conclusion** - Only slight increases in lindane concentrations are apparent after 24-hour dumping cycle.

C. **Index of Toxicity to Aquatic Life (Index 3)**

1. **Explanation** - Compares the effective increased concentration of pollutant in seawater around the disposal site resulting from the initial mixing of sludge (Index 1) with the marine ambient water quality criterion of the pollutant, or with another value judged protective of marine aquatic life. For lindane, this value is the criterion that will protect marine aquatic organisms from both acute and chronic toxic effects.

   Wherever a short-term, "pulse" exposure may occur as it would from initial mixing, it is usually evaluated using the "maximum" criteria values of EPA's ambient water quality criteria methodology. However, under this scenario, because the pulse is repeated several times daily on a long-term basis, potentially resulting in an accumulation of injury, it seems more appropriate to use values designed to be protective against chronic toxicity. Therefore, to evaluate the potential for adverse effects on marine life resulting from initial mixing concentrations, as quantified by Index 1, the chronically derived criteria values are used.

2. **Assumptions/Limitations** - In addition to the assumptions stated for Indices 1 and 2, assumes that all of the released pollutant is available in the water column to move through predicted pathways (i.e., sludge to seawater to aquatic organism to man). The possibility of effects arising from accumulation in the sediments is neglected since the U.S. EPA presently lacks a satisfactory method for deriving sediment criteria.

3. **Data Used and Rationale**

a. **Concentration of pollutant in seawater around a disposal site (Index 1)**

See Section 3, p. 3-34.

b. **Ambient water quality criterion (AWQC)** = 0.16 μg/L

Water quality criteria for the toxic pollutants listed under Section 307(a)(1) of the Clean Water Act of 1977 were developed by the U.S. EPA under Section 304(a)(1) of the Act. These criteria were derived by utilization of data reflecting the resultant environmental impacts and human health effects of these pollutants if present in any body of water. The criteria values presented in this assessment are excerpted from the ambient water quality criteria document for hexachlorocyclohexane.

The 0.16 μg/L value chosen as the criterion to protect saltwater organisms is based on acute toxicity data for marine fish and invertebrate species exposed to lindane. No data for the chronic effects of lindane on marine organisms are presently available (U.S. EPA, 1980). (See Section 4, p. 4-9.)

4. **Index 3 Values**

Disposal Conditions and Site Characteristics	Sludge Concentration	Sludge Disposal Rate (mt DW/day)		
		0	825	1650
Typical	Typical	0.0	0.0014	0.0014
	Worst	0.0	0.0028	0.0028
Worst	Typical	0.0	0.012	0.012
	Worst	0.0	0.023	0.023

5. **Value Interpretation** - Value equals the factor by which the expected seawater concentration increase in lindane exceeds the protective value. A value >1 indicates that acute or chronic toxic conditions may exist for organisms at the site.

6. **Preliminary Conclusion** - Only slight to moderate incremental increases in hazard to aquatic life were determined via this assessment. No toxic conditions occur via any of the scenarios evaluated.

D. **Index of Human Cancer Risk Resulting from Seafood Consumption (Index 4)**

1. **Explanation** - Estimates the expected increase in human pollutant intake associated with the consumption of seafood, a fraction of which originates from the disposal site vicinity, and compares the total expected pollutant intake with the cancer risk-specific intake (RSI) of the pollutant.

2. **Assumptions/Limitations** - In addition to the assumptions listed for Indices 1 and 2, assumes that the seafood tissue concentration increase can be estimated from the increased water concentration by a bioconcentration factor. It also assumes that, over the long term, the seafood catch from the disposal site vicinity will be diluted to some extent by the catch from uncontaminated areas.

3. **Data Used and Rationale**

   a. **Concentration of pollutant in seawater around a disposal site (Index 2)**

      See Section 3, p. 3-35.

      Since bioconcentration is a dynamic and reversible process, it is expected that uptake of sludge pollutants by marine organisms at the disposal site will reflect TWA concentrations, as quantified by Index 2, rather than pulse concentrations.

   b. **Dietary consumption of seafood (QF)**

Typical	14.3 g WW/day
Worst	41.7 g WW/day

      Typical and worst-case values are the mean and the 95th percentile, respectively, for all seafood consumption in the United States (Stanford Research Institute (SRI) International, 1980).

   c. **Fraction of consumed seafood originating from the disposal site (FS)**

      For a typical harvesting scenario, it was assumed that the total catch over a wide region is mixed by harvesting, marketing and consumption practices, and that exposure is thereby diluted. Coastal areas have been divided by the National Marine Fishery Service (NMFS) into reporting areas for reporting on data on seafood landings. Therefore it was convenient to express the total area affected by sludge disposal as a fraction of an NMFS reporting area.

The area used to represent the disposal impact area should be an approximation of the total ocean area over which the average concentration defined by Index 2 is roughly applicable. The average rate of plume spreading of 1 cm/sec referred to earlier amounts to approximately 0.9 km/day. Therefore, the combined plume of all sludge dumped during one working day will gradually spread, both parallel to and perpendicular to current direction, as it proceeds down-current. Since the concentration has been averaged over the direction of current flow, spreading in this dimension will not further reduce average concentration; only spreading in the perpendicular dimension will reduce the average. If stable conditions are assumed over a period of days, at least 9 days would be required to reduce the average concentration by one-half. At that time, the original plume length of approximately 8 km (8000 m) will have doubled to approximately 16 km due to spreading.

It is probably unnecessary to follow the plume further since storms, which would result in much more rapid dispersion of pollutants to background concentrations are expected on at least a 10-day frequency (NOAA, 1983). Therefore, the area impacted by sludge disposal (AI, in km^2) at each disposal site will be considered to be defined by the tanker path length (L) times the distance of current movement (V) during 10 days, and is computed as follows:

$$AI = 10 \times L \times V \times 10^{-6}\ km^2/m^2 \qquad (1)$$

To be consistent with a conservative approach, plume dilution due to spreading in the perpendicular direction to current flow is disregarded. More likely, organisms exposed to the plume in the area defined by equation 1 would experience a TWA concentration lower than the concentration expressed by Index 2.

Next, the value of AI must be expressed as a fraction of an NMFS reporting area. In the New York Bight, which includes NMFS areas 612-616 and 621-623, deep-water area 623 has an area of approximately 7200 km^2 and constitutes approximately 0.02 percent of the total seafood landings for the Bight (CDM, 1984b). Near-shore area 612 has an area of approximately 4300 km^2 and constitutes approximately 24 percent of the total seafood landings (CDM, 1984c). Therefore the fraction of all seafood landings (FS_t) from the Bight which could originate from the area of impact of either the typical (deep-water) or worst (near-shore) site can be calculated for this typical harvesting scenario as follows:

For the typical (deep water) site:

$$FS_t = \frac{AI \times 0.02\%}{7200\ km^2} = \quad (2)$$

$$\frac{[10 \times 8000\ m \times 9500\ m \times 10^{-6}\ km^2/m^2] \times 0.0002}{7200\ km^2} = 2.1 \times 10^{-5}$$

For the worst (near shore) site:

$$FS_t = \frac{AI \times 24\%}{4300\ km^2} = \quad (3)$$

$$\frac{[10 \times 4000\ m \times 4320\ m \times 10^{-6}\ km^2/m^2] \times 0.24}{4300\ km^2} = 9.6 \times 10^{-3}$$

To construct a worst-case harvesting scenario, it was assumed that the total seafood consumption for an individual could originate from an area more limited than the entire New York Bight. For example, a particular fisherman providing the entire seafood diet for himself or others could fish habitually within a single NMFS reporting area. Or, an individual could have a preference for a particular species which is taken only over a more limited area, here assumed arbitrarily to equal an NMFS reporting area. The fraction of consumed seafood (FS_w) that could originate from the area of impact under this worst-case scenario is calculated as follows:

For the typical (deep water) site:

$$FS_w = \frac{AI}{7200\ km^2} = 0.11 \quad (4)$$

For the worst (near shore) site:

$$FS_w = \frac{AI}{4300\ km^2} = 0.040 \quad (5)$$

d. Bioconcentration factor of pollutant (BCF) = 130 L/kg

The value chosen is the weighted average BCF of technical grade BHC (39% lindane) for the edible portion of all freshwater and estuarine aquatic organisms consumed by U.S. citizens (U.S. EPA, 1980). No lindane-specific BCF is presently available. The weighted average BCF is derived as part of the water quality criteria developed by the U.S. EPA to protect human health from the potential carcinogenic effects of lindane induced by ingestion of contaminated water and aquatic organisms. Although no measured steady-state BCF is available for lindane or any of its isomers, the BCF of lindane for aquatic organisms containing about 7.6 percent lipids can be estimated from the octanol-water partition coefficient. The weighted average BCF is derived by application of an adjustment factor to correct for the 3 percent lipids content of consumed fish and shellfish (U.S. EPA, 1980). It should be noted that lipids of marine species differ in both structure and quantity from those of freshwater species. Although a BCF value calculated entirely from marine data would be more appropriate for this assessment, no such data are presently available.

e. **Average daily human dietary intake of pollutant (DI) = 8.21 μg/day**

See Section 3, p. 3-11.

f. **Cancer risk-specific intake (RSI) = 0.053 μg/day**

See Section 3, p. 3-12.

4. **Index 4 Values**

Disposal Conditions and Site Characteristics	Sludge Concentration[a]	Seafood Intake[a,b]	Sludge Disposal Rate (mt DW/day) 0	825	1650
Typical	Typical	Typical	150	150	150
	Worst	Worst	150	150	150
Worst	Typical	Typical	150	150	150
	Worst	Worst	150	150	150

[a] All possible combinations of these values are not presented. Additional combinations may be calculated using the formulae in the Appendix.

[b] Refers to both the dietary consumption of seafood (QF) and the fraction of consumed seafood originating from the disposal site (FS). "Typical" indicates the use of the typical-case values for both of these parameters; "worst" indicates the use of the worst-case values for both.

5. **Value Interpretation** - Value equals factor by which the expected intake exceeds the RSI. A value >1 indicates a possible human health threat. Comparison with the null index value at 0 mt/day indicates the degree to which any hazard is due to sludge disposal, as opposed to preexisting dietary sources.

6. **Preliminary Conclusion** - No increase of risk to human health from consumption of seafood is expected to occur due to the ocean disposal of sludge.

SECTION 4

PRELIMINARY DATA PROFILE FOR LINDANE IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

Hexachlorocyclohexane is a broad spectrum insecticide of the group of cyclic chlorinated hydrocarbons called organochlorine insecticides. Lindane is the common name approved by the International Standards Organization for the γ-isomers of 1,2,3,4,5,6-hexachlorocyclohexane. BHC is the common name for the mixed configurational isomers of 1,2,3,4,5,6-hexachlorocyclohexane, although the terms BHC and benzene hexachloride are misnomers for this aliphatic compound and should not be confused with aromatic compounds of similar structure, such as the aromatic compound hexachlorobenzene. — U.S. EPA, 1980 (p. A-1, A-2)

A. Sludge

1. Frequency of Detection

In samples from 40 waste treatment plants, lindane occurred in influent and effluent but not in sludges (438 samples) — U.S. EPA, 1982 (p. 36, 39, 41)

2. Concentration

Lindane not found in Denver-metro sludge
Alpha-BHC occurred at 20 ng/g (WW) in waste-activated sludge — Baxter et al., 1983a (p. 315)

<500 μg/L in Chicago sludge — Jones and Lee, 1977 (p. 52)

Summary of lindane in sludge of 74 cities in Missouri (μg/g DW) — Clevenger et al., 1983 (p. 1471)

Min.	Max.	Mean	Median
0.05	0.22	0.11	0.11

B. Soil - Unpolluted

1. Frequency of Detection

0.9% positive detection in Florida soils, 1969 — Mattraw, 1975 (p. 109)

Not detected in cropland soil from 37 states, 1973 1 detection out of 1,483 samples for benzene hexachloride	Carey et al., 1979 (p. 212)

2. **Concentration**

Concentration of gamma-BHC (lindane) in various soils (data 1971 or earlier)	Edwards, 1973 (p. 417)

	Mean (µg/g)	Maximum (µg/g)
Orchard	0.05	0.06
Horticultural	0.001	0.05
Agricultural	0.26	0.60
Pasture	0.04	1.40
Noncropland	-	-
Desert	0.20	0.30

Trace to 0.26 µg/g lindane in U.S. soils	Matsumura, 1972a (p. 47)
Lindane was not detected in soil samples from Everglades National Park and adjacent areas	Requejo et al., 1979, (p. 934)

C. **Water - Unpolluted**

1. **Frequency of Detection**

Data not immediately available.

2. **Concentration**

a. **Freshwater**

Trace to 0.7 µg/L lindane in U.S. waters (data 1965-1971)	Edwards, 1973 (p. 441)
Detectable but not quantifiable amounts of lindane were found in the Great Lakes.	Glooschenko et al., 1976 (p. 63)
Trace to 0.28 µg/L gamma-BHC in U.S. water systems (1965-67 data)	Matsumura 1972a (p. 42)

b. **Seawater**

Data not available for seawater concentrations

c. **Drinking Water**

0.01 μg/L highest level observed in finished water	NAS, 1977 (p. 794)
4.0 μg/L criteria for domestic water supply (health)	U.S. EPA, 1976 (p. 157)
56 μg/L permissible criteria for lindane in public water supplies	Edwards, 1973 (p. 449)
Finished water in Streator, IL found to contain 4 μg/L of lindane	U.S. EPA, 1980 (p. C-5)

D. Air

1. Frequency of Detection

Not detected in air of 6 agriculutral, 1 city, and 1 suburban sites	Edwards, 1971 (p. 18)
Lindane occurrence in 9 U.S. cities (detection limit = 0.1 ng/m^3): 4 of 123 samples, Baltimore, MD 0 of 57 samples, Buffalo, NY 0 of 90 samples, Dothan, AL 0 of 120 samples, Fresno, CA 1 of 94 samples, Iowa City, IA 0 of 99 samples, Orlando, FL 0 of 94 samples, Riverside, CA 24 of 100 samples, Salt Lake City, UT 0 of 98 samples, Stoneville, MS	Stanley et al., 1971 (p. 435)

2. Concentration

a. **Urban**

Maximum pesticide levels in 3 U.S. cities: 2.6 ng/m^3, Baltimore 0.1 ng/m^3, Iowa City 7.0 ng/m^3, Salt Lake City	Stanley et al., 1971 (p. 435)

b. **Rural**

alpha-BHC 0.25 ng/m^3 mean, 0.075 to 0.57 ng/m^3 at Enewetak Atoll gamma-BHC 0.015 ng/m^3 mean, 0.006 to 0.021 ng/m^3 range at Enewetak Atoll	Atlas and Giam, 1980 (p.163)

E. Food

1. Total Average Intake

10 ug/kg body weight/day acceptable FAO/WHO intake — FDA, 1979

Total relative daily intake ug/kg body weight/day — FDA, 1979

FY75	FY76	FY77	FY78
0.0031	0.0026	0.0038	0.0024

2. Frequency of Detection and Concentration

Frequency and range of lindane in food groups (number of occurrence out of 20 composites) — FDA, 1979

Food Group	Occurrence
Dairy	1
Meat/fish	3
Grain & cereals	1
Potatoes	-
Leafy vegetables	-
Legumes	-
Root vegetables	-
Garden fruit	5
Fruit	-
Oils/fats	-
Sugars	-
Range	T*-0.005 µg/g

* T = Trace

Lindane residues in milk and milk products (1,169 samples) in Illinois 1971-1976: — Wedberg et al., 1978 (p. 164)

Number of positive: 857
% positive: 73
Mean: 0.01 µg/g
Range: 0.00 to <0.20 µg/g

Out of 360 composite market basket samples (1972-3), 39 contained lindane. Thirteen contained trace levels and 26 contained levels ranging from 0.0003 to 0.006 µg/g. Occurrences by food class were as follows: — Johnson and Manske, 1976 (p. 160-166)

	No. Positive Samples	Range (μg/g)
Dairy products	7 out of 30	T-0.0006
Meat, fish, & poultry	16 out of 30	T-0.003
Garden fruits	1 out of 30	0.006
Sugars and adjuncts	11 out of 30	T-0.002
Potatoes	1 out of 30	0.001

Lindane residues (μg/g) in four market basket samples: — Johnson and Manske, 1976 (p. 168-9)

Ice cream	0.001
Cheese	0.001
Roast beef	0.004
Ground beef	0.004
Fish	0.027
Lunch meat	T-0.002
Frankfurters	0.003
Ham	T
Lamb	T

Out of 420 composite market basket samples (1971-2), 17 contained lindane. Eleven contained trace levels and 6 contained levels ranging from 0.001 to 0.005 μg/g. Occurrences by food class were as follows: — Manske and Johnson, 1975

	No. Positive Samples	Range (μg/g)
Meat, fish, & poultry	5 out of 35	T-0.001
Grain & cereal	3 out of 35	T-0.002
Root vegetables	1 out of 35	T
Garden fruits	1 out of 35	T
Sugars & adjuncts	6 out of 35	T-0.007

II. HUMAN EFFECTS

A. Ingestion

1. Carcinogenicity

a. Qualitative Assessment

No epidemiological studies of cancer in humans associated with exposure to lindane have been reported.	U.S. EPA, 1984a (p. 16)
However, liver tumors have been observed in mice given oral doses of 52 mg/kg/day. In order to report the most conservative case, lindane has been assumed to be a possible carcinogen to humans.	U.S. EPA, 1980 (p. C-62)

b. Potency

Cancer potency = 1.33 $(mg/kg/day)^{-1}$	U.S. EPA, 1980 (p. C-62)
Derived from mice research in which oral doses of lindane resulted in liver tumors.	

2. Chronic Toxicity

The recommended long-term ADI is equal to 0.023 mg/day. This value is based on a NOAEL of 4 ppm dietary lindane given to rats for 84 consecutive days.	U.S. EPA, 1985 (p. I-4)

3. Absorption Factor

~95% absorption in rats	U.S. EPA, 1984a (p. 3)

4. Existing Regulations

Water quality criteria for human health have been developed.	U.S. EPA, 1980

B. Inhalation

1. Carcinogenicity

a. Qualitative Assessment

Based on mice studies where carcinogenic effects were observed, lindane has been assumed to be a possible human carcinogen so as to project a conservative case.	From data presented in U.S. EPA, 1980 (p. C-62)

b. Potency

Cancer potency = 1.33 $(mg/kg/day)^{-1}$ This potency estimate has been derived from that for ingestion, assuming 100% absorption for both ingestion and inhalation routes.	Values derived from data presented in U.S. EPA, 1980 (p. C-62)

c. Effects

Data not immediately available.

2. Chronic Toxicity

Data not evaluated since assessment based on carcinogenicity.

3. Absorption Factor

Pertinent data regarding absorption of lindane following inhalation exposure could not be located in the available literature.	U.S. EPA, 1984a (p. 3)

4. Existing Regulations

American Conference of Governmental and Industrial Hygienists have set a time weighted average - threshold limit value at 0.5 mg/m^3, and a short-term exposure limit of 1.5 mg/m^3.	U.S. EPA, 1984a (p. 23)

III. PLANT EFFECTS

A. Phytotoxicity

See Table 4-1.

B. Uptake

0.6 μg/g lindane in maize, 3 crop periods following 2.8 kg/ha application to soil	Finlayson and MacCarthy, 1973 (p. 63)

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. Toxicity

See Table 4-2.

B. Uptake

See Table 4-3.

Uptake data for pure lindane were not found in the available literature.

Concentration of lindane in fatty tissue of cows overwintered two seasons on sludge-amended plots:	Hansen et al., 1981 (p. 1015)

Sludge Application Rate	Fat Concentration (μg/g WW)
Control	3 ± 2
126 t/ha	2 ± 1
252 t/ha	<1
504 t/ha	<1

0.010 μg/g (WW) alpha-BHC in fat of cattle feeding on sludge-amended plots with 0.020 μg/g alpha-BHC in sludge 0.030 μg/kg alpha-BHC in control cattle	Baxter et al., 1983b (p. 318)

V. AQUATIC LIFE EFFECTS

A. Toxicity

1. Freshwater

a. Acute

Acute toxicity has been observed over a range of 2 μg/L to 141 μg/L for brown trout and goldfish, respectively.	U.S. EPA, 1980 (p. B-2)

b. Chronic

Freshwater invertebrates displayed a range of chronic toxicity of of 3.3 μg/L to 14.5 μg/L.	U.S. EPA, 1980 (p. B-4)
A freshwater vertebrate (fathead minnow) had a chronic value of 14.6 μg/L.	U.S. EPA, 1980 (p. B-5)

2. Saltwater

a. Acute

Ambient saltwater quality criteria for lindane is 0.16 μg/L	U.S. EPA, 1980 (p. vi)
Saltwater invertebrates display a range of acute toxicity from 0.17 μg/L to 3,680 μg/L.	U.S. EPA, 1980 (p. B-3)
LC_{50} value for pinfish and sheephead minnows are 30.6 μg/L and 103.9 μg/L, respectively.	U.S. EPA, 1980 (p. B-4)

b. Chronic

Data not immediately available.

B. Uptake

The bioconcentration factor for freshwater species ranges from 35 to 486.	U.S. EPA, 1980 (p. B-22)
The weighted average bioconcentration factor for the edible portion of all freshwater and estuarine aquatic organisms consumed by U.S. citizens was generated using technical grade BHC which contained 39.0% lindane. The resulting value is 130.	U.S. EPA, 1980 (p. C-6, C-7)

VI. SOIL BIOTA EFFECTS

A. Toxicity

See Table 4-4.

B. Uptake

See Table 4-5.

VII. PHYSIOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

Chemical name: gamma-1, 2, 3, 4, 5, 6, - hexachlorocyclohexane	
Vapor pressure of lindane (gamma-BHC) at 20°C (mm Hg): 9.4×10^{-6} lindane described as volatile	Edwards, 1973 (p. 433)
Water solubility of lindane at 20 to 30°C: 10 mg/L	Edwards, 1973 (p. 447)
Lindane is immobile to slightly mobile in soils (R_f = 0.09 to 0.00)	Lawless et al., 1975 (p. 57)
36-month persistence in soils	Lawless et al., 1975 (p. 52)
Half-life in soil: 56 days in clay loam, 378 days in sandy loam	U.S. EPA, 1984a (p.1)
General persistence of lindane in soils: 95% disappearance = 6.5 years 75-100% disappearance = 3 years	Matsumura, 1972a (p. 39)
Melting point = 65°C Molecular weight = 290.0	U.S. EPA, 1980 (p. A-1)
Gamma-BHC (lindane) is the actual insecticidal principle of BHC. Aside from gamma-BHC, perhaps the most important terminal residue arising from the use of BHC is beta-BHC. This isomer appears to be the most stable one, among others, and is the factor causing the eventual increase of beta-BHC in the environment, in comparison to other sources.	Matsumura, 1972b (p. 527)
In a micro agro ecosystem study, lindane was applied to the soil (65.4 mg) and after 11 days, 51.2 mg (78.3%) had volatilized and 8.51 mg (13%) remained on the soil surface.	Nash, 1983 (p. 214)
Organic carbon partition coefficient (K_{oc}): 1,080 mL/g	Hassett et al., 1983

TABLE 4-1. PHYTOTOXICITY OF LINDANE

Plant/Tissue	Chemical Form Applied	Soil Type	Control Tissue Concentration (µg/g DW)	Soil Concentration (µg/g DW)	Application Rate (kg/ha)	Experimental Tissue Concentration (µg/g DW)	Effects	References
Stringless black valentine beans/ seed	Lindane	loamy sand	NR[a]	12.5-100	NR	NR	No significant effect on germination	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean/ root	Lindane	loamy sand	NR	12.5	NR	NR	27% reduced weight	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean/ root	Lindane	loamy sand	NR	50	NR	NR	47% reduced weight	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean/ root	Lindane	loamy sand	NR	100	NR	NR	72% reduced weight	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean/ top	Lindane	loamy sand	NR	12.5	NR	NR	No effect	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean/ top	Lindane	loamy sand	NR	50	NR	NR	13% reduced weight	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean top	Lindane	loamy sand	NR	100	NR	NR	37% reduced weight	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean/ root	BHC[b]	loamy sand	NR	12.5	NR	NR	46% reduced weight	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean/ root	BHC	loamy sand	NR	50	NR	NR	68% reduced weight	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean/ root	BHC	loamy sand	NR	100	NR	NR	84% reduced weight	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean/ top	BHC	loamy sand	NR	12.5	NR	NR	11% reduced weight	Eno and Everett, 1958 (p. 236)

TABLE 4-1. (continued)

Plant/Tissue	Chemical Form Applied	Soil Type	Control Tissue Concentration (µg/g DW)	Soil Concentration (µg/g DW)	Application Rate (kg/ha)	Experimental Tissue Concentration (µg/g DW)	Effects	References
Stringless black valentine bean/ top	BHC	loamy sand	NR	50	NR	NR	57% reduced weight	Eno and Everett, 1958 (p. 236)
Stringless black valentine bean/ top	BHC	loamy sand	NR	100	NR	NR	70% reduced weight	Eno and Everett, 1958 (p. 236)
Sugarcane roots	BHC	NR	NR	10	NR	NR	No effect	NAS, 1968 (p. 19)
Sugarcane roots	BHC	NR	NR	11-400	NR	NR	Increasingly shorter and fewer roots	NAS, 1968 (p. 19)

[a] NR = Not reported
[b] BHC = Benzene hexachloride, a trade name for the insecticide, hexachlorocyclohexane.

TABLE 4-2. TOXICITY OF LINDANE TO DOMESTIC ANIMALS AND WILDLIFE

Species (N)[a]	Chemical Form Fed	Feed Concentration (µg/g DW)	Water Concentration (mg/L)	Daily Intake (mg/kg)	Duration of Study	Effects	References
Mallard	BHC-25% g.i.[b]	NR	NR[c]	>2,000	NR	LD_{50}	Tucker and Crabtree, 1970 (p. 76)
Dog	Lindane	15	NR	0.3	NR	No effect	U.S. EPA, 1976 (p. 157)
Rat	Lindane	100	NR	NR	2 yr	Liver change	NAS, 1977 (p. 587)
Rat	Lindane	<50	NR	NR	2 yr	No effect	NAS, 1977 (p. 587)
Cow	Lindane	NR	NR	200	1 day	Lethal	McParland et al., 1973 (p. 370)
Cow	BHC[d] - gamma	NR	NR	140-225	1 day	Fatal dose	McParland et al., 1973 (p. 370)
Mice	Lindane	NR	NR	86	NR	LD_{50}	NRC, 1982 (p. 30)
Rats	Lindane	NR	NR	125-230	NR	LD_{50}	NRC, 1982 (p. 30)
Guinea pigs	Lindane	NR	NR	100-127	NR	LD_{50}	NRC, 1982 (p. 30)
Rabbits	Lindane	NR	NR	60-200	NR	LD_{50}	NRC, 1982 (p. 30)
Rats (50)	Lindane	25	NR	NR	2 yr	No effect	NRC, 1982 (p. 30)
Rats (50)	Lindane	50	NR	NR	2 yr	Hypertrophy of liver	NRC, 1982 (p. 30)
Rats (50)	Lindane	100	NR	NR	2 yr	Hypertrophy of liver and fatty tissue degeneration	NRC, 1982 (p. 30)

[a] N = Number of experimental animals.
[b] g.i. = gamma isomer.
[c] NR = Not reported.
[d] BHC = Benzenehexachloride, a trade name for the insecticide hexachlorocyclohexane.

TABLE 4-3. UPTAKE OF LINDANE BY DOMESTIC ANIMALS AND WILDLIFE

Species	Chemical Form Fed	Feed Concentrations (μg/g)	Tissue Analyzed	Tissue Concentration (μg/g)	Uptake Factor[a]	References
Cow	Lindane	10	Fat	3.5	0.35	Claborn et al., 1960 in Kenaga, 1980 (p. 554)
		100		65	0.65	
Rat	Lindane	NR[b]	Fat	NR	0.4	Jacobs et al., 1974 in Geyer et al., 1980 (p. 282)
Rat	Lindane	NR	Fat	NR	1.4	Baron et al., 1975 in Geyer et al., 1980 (p. 282)

[a] Uptake factor = y/x: y = tissue concentration; x = feed concentration.
[b] NR = Not reported.

TABLE 4-4. TOXICITY OF LINDANE TO SOIL BIOTA

Species	Chemical Form Applied	Soil Type	Control Tissue Concentration (µg/g DW)	Soil Concentration (µg/g DW)	Application Rate (kg/ha)	Experimental Tissue Concentration (µg/g DW)	Effects	References
Bacteria/fungi	Lindane	fine sand	NR[a]	12.5-100	NR	NR	No effect on numbers of bacteria and fungi	Eno and Everett, 1958 (p. 235)
Bacteria/fungi	BHC[b]	fine sand	NR	12.5-100	NR	NR	12% reduction of fungi at 50.0 µg/g 35% reduction of fungi at 100 µg/g	Eno and Everett, 1958 (p. 235)
Soil microbes	BHC (gamma)	silty loam	NR	NR	0.28-22.4	NR	Molds: no significant or consistent effect but some depression of numbers Bacteria: no significant effect except for a 50% reduction in streptomycetes at 22.4 kg/ha	Bollen et al., 1954 (p. 303)
Red worms	BHC-3% g.i.[c]	sandy loam	NR	NR	35.8	NR	No mortality	Hopkins et al., 1957
Red worms	BHC-3% g.i.	sandy loam	NR	NR	71.7	NR	60% mortality	
Red worms	BHC-3% g.i.	sandy loam	NR	NR	143.4	NR	100% mortality	
Soil microbes	Lindane	sandy loam	NR	NR	1.12	NR	No significant effect	Martin et al., 1959 (p. 337)

[a] NR = Not reported.
[b] BHC = Benzenehexachloride, a trade name for the insecticide hexachlorocyclohexane.
[c] g.i. = gamma isomer.

TABLE 4-5. UPTAKE OF LINDANE BY SOIL BIOTA

Species	Chemical Form Applied	Soil Type	Soil Concentration (μg/g)	Range of Tissue Concentration (μg/g)	Uptake Factor	References
Earthworms	Lindane	NR[a]	1	0.45-1.05	0.45-1.05	Yadav et al., 1976 (p. 542)

[a] NR = Not reported.

SECTION 5

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APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR LINDANE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Lindane

1. Index of Soil Concentration (Index 1)

a. Formula

$$CS_s = \frac{(SC \times AR) + (BS \times MS)}{AR + MS}$$

$$CS_r = CS_s \left[1 + 0.5^{(1/t_{\frac{1}{2}})} + 0.5^{(2/t_{\frac{1}{2}})} + \ldots + 0.5^{(n/t_{\frac{1}{2}})}\right]$$

where:

CS_s = Soil concentration of pollutant after a single year's application of sludge (µg/g DW)
CS_r = Soil concentration of pollutant after the yearly application of sludge has been repeated for n + 1 years (µg/g DW)
SC = Sludge concentration of pollutant (µg/g DW)
AR = Sludge application rate (mt/ha)
MS = 2000 mt ha/DW = assumed mass of soil in upper 15 cm
BS = Background concentration of pollutant in soil (µg/g DW)
$t_{\frac{1}{2}}$ = Soil half-life of pollutant (years)
n = 99 years

b. Sample calculation

CS_s is calculated for AR = 0, 5, and 50 mt/ha only

$$0.129950 \text{ µg/g DW} = \frac{(0.11 \text{ µg/g DW} \times 5 \text{ mt/ha}) + (0.13 \text{ µg/g DW} \times 2000 \text{ mt/ha})}{(5 \text{ mt/ha DW} + 2000 \text{ mt/ha DW})}$$

CS_r is calculated for AR = 5 mt/ha applied for 100 years

$$0.267117 \text{ µg/g DW} = 0.129950 \text{ µg/g DW} \left[1 + 0.5^{(1/1.04)} + 0.5^{(2/1.04)} + \ldots + 0.5^{(99/1.04)}\right]$$

B. Effect on Soil Biota and Predators of Soil Biota

1. Index of Soil Biota Toxicity (Index 2)

a. Formula

$$\text{Index 2} = \frac{I_1}{TB}$$

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (μg/g DW)
TB = Soil concentration toxic to soil biota (μg/g DW)

b. Sample calculation

$$< 0.00129950 = \frac{0.129950\ \mu g/g\ DW}{>100\ \mu g/g\ DW}$$

2. Index of Soil Biota Predator Toxicity (Index 3)

a. Formula

$$\text{Index 3} = \frac{I_1 \times UB}{TR}$$

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (μg/g DW)
UB = Uptake factor of pollutant in soil biota (μg/g tissue DW [μg/g soil DW]$^{-1}$)
TR = Feed concentration toxic to predator (μg/g DW)

b. Sample calculation

$$0.002728 = \frac{0.129950\ \mu g/g\ DW \times 1.05\ \mu g/g\ tissue\ DW\ (\mu g/g\ soil\ DW)^{-1}}{50\ \mu g/g\ DW}$$

C. Effect on Plants and Plant Tissue Concentration

1. Index of Phytotoxic Soil Concentration (Index 4)

a. Formula

$$\text{Index 4} = \frac{I_1}{TP}$$

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (μg/g DW)
TP = Soil concentration toxic to plants (μg/g DW)

b. Sample calculation

$$0.010396 = \frac{0.129950\ \mu g/g\ DW}{12.5\ \mu g/g\ DW}$$

2. Index of Plant Concentration Caused by Uptake (Index 5)

a. Formula

$$\text{Index } 5 = I_1 \times UP$$

where:

I_1 = Index 1 = Concentration of pollutant in sludge - amended soil (μg/g DW)
UP = Uptake factor of pollutant in plant tissue (μg/g tissue DW [μg/g soil DW]$^{-1}$)

b. Sample Calculation - Index values were not calculated due to lack of data.

3. Index of Plant Concentration Increment Permitted by Phytotoxicity (Index 6)

a. Formula

$$\text{Index } 6 = PP$$

where:

PP = Maximum plant tissue concentration associated with phytotoxicity (μg/g DW)

b. Sample calculation - Index values were not calculated due to lack of data.

D. Effect on Herbivorous Animals

1. Index of Animal Toxicity Resulting from Plant Consumption (Index 7)

a. Formula

$$\text{Index } 7 = \frac{I_5}{TA}$$

where:

I_5 = Index 5 = Concentration of pollutant in plant grown in sludge-amended soil (μg/g DW)
TA = Feed concentration toxic to herbivorous animal (μg/g DW)

b. **Sample calculation** - Values were not calculated due to lack of data.

2. **Index of Animal Toxicity Resulting from Sludge Ingestion (Index 8)**

a. **Formula**

If AR = 0; Index 8 = 0

$$\text{If AR} \neq 0;\ \text{Index 8} = \frac{SC \times GS}{TA}$$

where:

AR = Sludge application rate (mt DW/ha)
SC = Sludge concentration of pollutant (μg/g DW)
GS = Fraction of animal diet assumed to be soil
TA = Feed concentration toxic to herbivorous animal (μg/g DW)

b. **Sample calculation**

If AR = 0; Index 8 = 0

$$\text{If AR} \neq 0;\ 0.00011 = \frac{0.11\ \mu g/g\ DW \times 0.05}{50\ \mu g/g\ DW}$$

E. **Effect on Humans**

1. **Index of Human Cancer Risk Resulting from Plant Consumption (Index 9)**

a. **Formula**

$$\text{Index 9} = \frac{(I_5 \times DT)\ + DI}{RSI}$$

where:

I_5 = Index 5 = Concentration of pollutant in plant grown in sludge-amended soil (μg/g DW)
DT = Daily human dietary intake of affected plant tissue (g/day DW)

DI = Average daily human dietary intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

b. **Sample calculation (toddler)** - Values were not calculated due to lack of data.

2. **Index of Human Cancer Risk Resulting from Consumption of Animal Products Derived from Animals Feeding on Plants (Index 10)**

a. **Formula**

$$\text{Index } 10 = \frac{(I_5 \times UA \times DA) + DI}{RSI}$$

where:

I_5 = Index 5 = Concentration of pollutant in plant grown in sludge-amended soil (μg/g DW)
UA = Uptake factor of pollutant in animal tissue (μg/g tissue DW [μg/g feed DW]$^{-1}$)
DA = Daily human dietary intake of affected animal tissue (g/day DW) (milk products and meat, poultry, eggs, fish)
DI = Average daily human dietary intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

b. **Sample calculation (toddler)** - Values were not calculated due to lack of data.

3. **Index of Human Cancer Risk Resulting from Consumption of Animal Products Derived from Animals Ingesting Soil (Index 11)**

a. **Formula**

$$\text{If } AR = 0; \text{ Index } 11 = \frac{(BS \times GS \times UA \times DA) + DI}{RSI}$$

$$\text{If } AR \neq 0; \text{ Index } 11 = \frac{(SC \times GS \times UA \times DA) + DI}{RSI}$$

where:

AR = Sludge application rate (mt DW/ha)
BS = Background concentration of pollutant in soil (μg/g DW)
SC = Sludge concentration of pollutant (μg/g DW)
GS = Fraction of animal diet assumed to be soil
UA = Uptake factor of pollutant in animal tissue (μg/g tissue DW [μg/g feed DW]$^{-1}$)
DA = Daily human dietary intake of affected animal tissue (g/day DW) (milk products and meat only)

DI = Average daily human dietary intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

b. Sample calculation (toddler)

$$53.78971 = [(0.11 \ \mu g/g \ DW \times 0.05 \times 0.65 \ \mu g/g \ tissue \ DW \ [\mu g/g \ feed \ DW]^{-1} \times 39.4 \ g/day \ DW) + 2.71 \ \mu g/day] \div 0.053 \ \mu g/day$$

4. Index of Human Cancer Risk Resulting from Soil Ingestion (Index 12)

a. Formula

$$\text{Index 12} = \frac{(I_1 \times DS) + DI}{RSI}$$

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (μg/g DW)
DS = Assumed amount of soil in human diet (g/day)
DI = Average daily human dietary intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

b. Sample calculation (toddler)

$$63.39152 = \frac{(0.129950 \ \mu g/g \ DW \times 5 \ g/day) + 2.71 \ \mu g \ day}{0.053 \ \mu g/day}$$

5. Index of Aggregate Human Cancer Risk (Index 13)

a. Formula

$$\text{Index 13} = I_9 + I_{10} + I_{11} + I_{12} - (\frac{3DI}{RSI})$$

where:

I_9 = Index 9 = Index of human cancer risk resulting from plant consumption (unitless)
I_{10} = Index 10 = Index of human cancer risk resulting from consumption of animal products derived from animals feeding on plants (unitless)
I_{11} = Index 11 = Index of human cancer risk resulting from consumption of animal products derived from animals ingesting soil (unitless)

I_{12} = Index 12 = Index of human cancer risk resulting from soil ingestion (unitless)
DI = Average daily human dietary intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

b. Sample calculation (toddler) - Values were not calculated due to lack of data.

II. LANDFILLING

A. Procedure

Using Equation 1, several values of C/C_0 for the unsaturated zone are calculated corresponding to increasing values of t until equilibrium is reached. Assuming a 5-year pulse input from the landfill, Equation 3 is employed to estimate the concentration vs. time data at the water table. The concentration vs. time curve is then transformed into a square pulse having a constant concentration equal to the peak concentration, C_u, from the unsaturated zone, and a duration, t_0, chosen so that the total areas under the curve and the pulse are equal, as illustrated in Equation 3. This square pulse is then used as the input to the linkage assessment, Equation 2, which estimates initial dilution in the aquifer to give the initial concentration, C_0, for the saturated zone assessment. (Conditions for B, minimum thickness of unsaturated zone, have been set such that dilution is actually negligible.) The saturated zone assessment procedure is nearly identical to that for the unsaturated zone except for the definition of certain parameters and choice of parameter values. The maximum concentration at the well, C_{max}, is used to calculate the index values given in Equations 4 and 5.

B. Equation 1: Transport Assessment

$$\frac{C(\chi,t)}{C_0} = \frac{1}{2}\left[\exp(A_1)\ \mathrm{erfc}(A_2) + \exp(B_1)\ \mathrm{erfc}(B_2)\right] = P(\chi,t)$$

Requires evaluations of four dimensionless input values and subsequent evaluation of the result. $\mathrm{Exp}(A_1)$ denotes the exponential of A_1, e^{A_1}, where $\mathrm{erfc}(A_2)$ denotes the complimentary error function of A_2. $\mathrm{Erfc}(A_2)$ produces values between 0.0 and 2.0 (Abramowitz and Stegun, 1972).

where:

$$A_1 = \frac{\chi}{2D^*}\left[V^* - (V^{*2} + 4D^* \times \mu^*)^{\frac{1}{2}}\right]$$

$$A_2 = \frac{\chi - t\ (V^{*2} + 4D^* \times \mu^*)^{\frac{1}{2}}}{(4D^* \times t)^{\frac{1}{2}}}$$

$$B_1 = \frac{X}{2D^*} [V^* + (V^{*2} + 4D^* \times \mu^*)^{\frac{1}{2}}]$$

$$B_2 = \frac{X + t\ (V^{*2} + 4D^* \times \mu^*)^{\frac{1}{2}}}{(4D^* \times t)^{\frac{1}{2}}}$$

and where for the unsaturated zone:

C_o = SC x CF = Initial leachate concentration (μg/L)
SC = Sludge concentration of pollutant (mg/kg DW)
CF = 250 kg sludge solids/m^3 leachate =

$$\frac{PS \times 10^3}{1 - PS}$$

PS = Percent solids (by weight) of landfilled sludge = 20%
t = Time (years)
X = h = Depth to groundwater (m)
D^* = $\alpha \times V^*$ (m^2/year)
α = Dispersivity coefficient (m)

$V^* = \frac{Q}{\theta \times R}$ (m/year)
Q = Leachate generation rate (m/year)
θ = Volumetric water content (unitless)

$R = 1 + \frac{P_{dry}}{\theta} \times K_d$ = Retardation factor (unitless)
P_{dry} = Dry bulk density (g/mL)
$K_d = f_{oc} \times K_{oc}$ (mL/g)
f_{oc} = Fraction of organic carbon (unitless)
K_{oc} = Organic carbon partition coefficient (mL/g)

$\mu^* = \frac{365 \times \mu}{R}$ $(\text{years})^{-1}$
μ = Degradation rate (day^{-1})

and where for the saturated zone:

C_o = Initial concentration of pollutant in aquifer as determined by Equation 2 (μg/L)
t = Time (years)
X = $\Delta\ell$ = Distance from well to landfill (m)
D^* = $\alpha \times V^*$ (m^2/year)
α = Dispersivity coefficient (m)

$V^* = \frac{K \times i}{\phi \times R}$ (m/year)
K = Hydraulic conductivity of the aquifer (m/day)
i = Average hydraulic gradient between landfill and well (unitless)
ϕ = Aquifer porosity (unitless)

$R = 1 + \frac{P_{dry}}{\phi} \times K_d$ = Retardation factor = 1 (unitless)
since $K_d = f_{oc} \times K_{oc}$ and f_{oc} is assumed to be zero for the saturated zone.

C. **Equation 2. Linkage Assessment**

$$C_o = C_u \times \frac{Q \times W}{365\ [(K \times i) + \emptyset] \times B}$$

where:

C_o = Initial concentration of pollutant in the saturated zone as determined by Equation 1 (µg/L)
C_u = Maximum pulse concentration from the unsaturated zone (µg/L)
Q = Leachate generation rate (m/year)
W = Width of landfill (m)
K = Hydraulic conductivity of the aquifer (m/day)
i = Average hydraulic gradient between landfill and well (unitless)
$\emptyset$ = Aquifer porosity (unitless)
B = Thickness of saturated zone (m) where:

$$B \geq \frac{Q \times W \times \emptyset}{K \times i \times 365} \text{ and } B \geq 2$$

D. **Equation 3. Pulse Assessment**

$$\frac{C(\chi,t)}{C_o} = P(\chi,t) \text{ for } 0 \leq t \leq t_o$$

$$\frac{C(\chi,t)}{C_o} = P(\chi,t) - P(\chi,t - t_o) \text{ for } t > t_o$$

where:

t_o (for unsaturated zone) = LT = Landfill leaching time (years)

t_o (for saturated zone) = Pulse duration at the water table (χ = h) as determined by the following equation:

$$t_o = [\ {}_0\int^{\infty} C\ dt] \div C_u$$

$P(\chi,t) = \frac{C(\chi,t)}{C_o}$ as determined by Equation 1

E. **Equation 4. Index of Groundwater Concentration Resulting from Landfilled Sludge (Index 1)**

1. **Formula**

Index 1 = C_{max}

where:

C_{max} = Maximum concentration of pollutant at well = maximum of $C(\Delta\ell,t)$ calculated in Equation 1 (µg/L)

2. **Sample Calculation**

0.00142 μg/L = 0.00142 μg/L

F. **Equation 5. Index of Human Cancer Risk Resulting from Groundwater Contamination (Index 2)**

1. **Formula**

$$\text{Index 2} = \frac{(I_1 \times AC) + DI}{RSI}$$

where:

I_1 = Index 1 = Index of groundwater concentration resulting from landfilled sludge (μg/L)
AC = Average human consumption of drinking water (L/day)
DI = Average daily human dietary intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

2. **Sample Calculation**

$$154.959 = \frac{(0.00142\ \mu g/L \times 2\ L/day) + 8.21\ \mu g/day}{0.053\ \mu g/day}$$

III. INCINERATION

A. **Index of Air Concentration Increment Resulting from Incinerator Emissions (Index 1)**

1. **Formula**

$$\text{Index 1} = \frac{(C \times DS \times SC \times FM \times DP) + BA}{BA}$$

where:

C = Coefficient to correct for mass and time units (hr/sec x g/mg)
DS = Sludge feed rate (kg/hr DW)
SC = Sludge concentration of pollutant (mg/kg DW)
FM = Fraction of pollutant emitted through stack (unitless)
DP = Dispersion parameter for estimating maximum annual ground level concentration ($\mu g/m^3$)
BA = Background concentration of pollutant in urban air ($\mu g/m^3$)

2. **Sample Calculation**

$$1.276565 = [(2.78 \times 10^{-7} \text{ hr/sec} \times \text{g/mg} \times 2660 \text{ kg/hr DW} \times 0.11 \text{ mg/kg DW} \times 0.05 \times 3.4 \ \mu\text{g/m}^3) + 0.00005 \mu\text{g/m}^3] \div 0.00005 \mu\text{g/m}^3$$

B. **Index of Human Cancer Risk Resulting from Inhalation of Incinerator Emissions (Index 2)**

1. **Formula**

$$\text{Index 2} = \frac{[(I_1 - 1) \times BA] + BA}{EC}$$

where:

I_1 = Index 1 = Index of air concentration increment resulting from incinerator emissions (unitless)
BA = Background concentration of pollutant in urban air ($\mu g/m^3$)
EC = Exposure criterion ($\mu g/m^3$)

2. **Sample Calculation**

$$0.024269 = \frac{[(1.276565 - 1) \times 0.00005 \ \mu g/m^3] + 0.00005 \ \mu g/m^3}{0.00263 \ \mu g/m^3}$$

IV. **OCEAN DISPOSAL**

A. **Index of Seawater Concentration Resulting from Initial Mixing of Sludge (Index 1)**

1. **Formula**

$$\text{Index 1} = \frac{SC \times ST \times PS}{W \times D \times L}$$

where:

SC = Sludge concentration of pollutant (mg/kg DW)
ST = Sludge mass dumped by a single tanker (kg WW)
PS = Percent solids in sludge (kg DW/kg WW)
W = Width of initial plume dilution (m)
D = Depth to pycnocline or effective depth of mixing for shallow water site (m)
L = Length of tanker path (m)

2. **Sample Calculation**

$$0.00022 \ \mu g/L = \frac{0.11 \text{ mg/kg DW} \times 1600000 \text{ kg WW} \times 0.04 \text{ kg DW/kg WW} \times 10^3 \ \mu g/mg}{200 \text{ m} \times 20 \text{ m} \times 8000 \text{ m} \times 10^3 \text{ L/m}^3}$$

B. **Index of Seawater Concentration Representing a 24-Hour Dumping Cycle (Index 2)**

1. **Formula**

$$\text{Index 2} = \frac{SS \times SC}{V \times D \times L}$$

where:

SS = Daily sludge disposal rate (kg DW/day)
SC = Sludge concentration of pollutant (mg/kg DW)
V = Average current velocity at site (m/day)
D = Depth to pycnocline or effective depth of mixing for shallow water site (m)
L = Length of tanker path (m)

2. **Sample Calculation**

$$0.000059\ \mu g/L = \frac{825000\ \text{kg DW/day} \times 0.11\ \text{mg/kg DW} \times 10^3\ \mu g/mg}{9500\ \text{m/day} \times 20\ \text{m} \times 8000\ \text{m} \times 10^3\ L/m^3}$$

C. **Index of Toxicity to Aquatic Life (Index 3)**

1. **Formula**

$$\text{Index 3} = \frac{I_1}{AWQC}$$

where:

I_1 = Index 1 = Index of seawater concentration resulting from initial mixing after sludge disposal (μg/L)
AWQC = Criterion or other value expressed as an average concentration to protect marine organisms from acute and chronic toxic effects (μg/L)

2. **Sample Calculation**

$$0.0014 = \frac{0.00022\ \mu g/L}{0.16\ \mu g/L}$$

D. **Index of Human Cancer Risk Resulting from Seafood Consumption (Index 4)**

1. **Formula**

$$\text{Index 4} = \frac{(I_2 \times BCF \times 10^{-3}\ \text{kg/g} \times FS \times QF) + DI}{RSI}$$

where:

I_2 = Index 2 = Index of seawater concentration representing a 24-hour dumping cycle (μg/L)
QF = Dietary consumption of seafood (g WW/day)
FS = Fraction of consumed seafood originating from the disposal site (unitless)
BCF = Bioconcentration factor of pollutant (L/kg)
DI = Average daily human dietary intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

2. **Sample Calculation**

$$150 = \frac{(0.000059\ \mu g/L \times 130\ L/kg \times 10^{-3}\ kg/g \times 0.000021 \times 14.3\ g\ WW/day) + 8.21\ \mu g/day}{0.053\ \mu g/day}$$

TABLE A-1. INPUT DATA VARYING IN LANDFILL ANALYSIS AND RESULT FOR EACH CONDITION

Input Data	Condition of Analysis							
	1	2	3	4	5	6	7	8
Sludge concentration of pollutant, SC (μg/g DW)	0.11	0.22	0.11	0.11	0.11	0.11	0.22	N[a]
Unsaturated zone								
Soil type and characteristics								
Dry bulk density, P_{dry} (g/mL)	1.53	1.53	1.925	NA[b]	1.53	1.53	NA	N
Volumetric water content, θ (unitless)	0.195	0.195	0.133	NA	0.195	0.195	NA	N
Fraction of organic carbon, f_{oc} (unitless)	0.005	0.005	0.0001	NA	0.005	0.005	NA	N
Site parameters								
Leachate generation rate, Q (m/year)	0.8	0.8	0.8	1.6	0.8	0.8	1.6	N
Depth to groundwater, h (m)	5	5	5	0	5	5	0	N
Dispersivity coefficient, α (m)	0.5	0.5	0.5	NA	0.5	0.5	NA	N
Saturated zone								
Soil type and characteristics								
Aquifer porosity, ϕ (unitless)	0.44	0.44	0.44	0.44	0.389	0.44	0.389	N
Hydraulic conductivity of the aquifer, K (m/day)	0.86	0.86	0.86	0.86	4.04	0.86	4.04	N
Site parameters								
Hydraulic gradient, i (unitless)	0.001	0.001	0.001	0.001	0.001	0.02	0.02	N
Distance from well to landfill, Δℓ (m)	100	100	100	100	100	50	50	N
Dispersivity coefficient, α (m)	10	10	10	10	10	5	5	N

TABLE A-1. (continued)

Results	Condition of Analysis							
	1	2	3	4	5	6	7	8
Unsaturated zone assessment (Equations 1 and 3)								
Initial leachate concentration, C_o (μg/L)	27.5	55.0	27.5	27.5	27.5	27.5	55.0	N
Peak concentration, C_u (μg/L)	1.64	3.27	16.3	27.5	1.64	1.64	55.0	N
Pulse duration, t_o (years)	39.9	39.9	5.02	5.00	39.9	39.9	5.00	N
Linkage assessment (Equation 2)								
Aquifer thickness, B (m)	126	126	126	253	23.8	6.32	2.38	N
Initial concentration in saturated zone, C_o (μg/L)	1.64	3.27	16.3	27.5	1.64	1.64	55.0	N
Saturated zone assessment (Equations 1 and 3)								
Maximum well concentration, C_{max} (μg/L)	0.00142	0.00284	0.00178	0.00299	0.00754	0.0569	1.27	N
Index of groundwater concentration resulting from landfilled sludge, Index 1 (μg/L) (Equation 4)	0.00142	0.00284	0.00178	0.00299	0.00754	0.0569	1.27	0
Index of human cancer risk resulting from groundwater contamination, Index 2 (unitless) (Equation 5)	155	155	155	155	155	157	203	155

[a]N = Null condition, where no landfill exists; no value is used.
[b]NA = Not applicable for this condition.

LINDANE

p. 3-2 Index 1 Values should read:
typical at 500 mt/ha = 0.13; worst at 500 mt/na - 0.13

Preliminary Conclusion - should read:
No increase in the concentration of lindane in sludge-amended soil is expected to occur at any application rate.

p. 3-3 Index 2 Values should read:
typical at 500 mt/ha = <.0013; worst at 500 mt/ha <.0013

p. 3-4 Index 3 Values should read:
typical at 500 mt/ha = 0.0027; worst at 500 mt/ha - 0.0027

p. 3-5 Index 4 Values should read:
typical at 500 mt/ha = 0.01; worst at 500 mt/ha = 0.01

p. 3-17 Index 12 Values should read:
adult-typical at 500 mt/ha = 150; worst at 500 mt/ha = 150
toddler-typical at 500 mt/ha = 63; worst at 500 mt/ha = 63

Preliminary Conclusion - should read:
The consumption of sludge-amended soils by toddlers or adults not expected to increase the risk of human cancer due to lindane above the pre-existing risk attributable to other dietary source of lindane

APPENDIX D:

HAZARD INDEX METHODOLOGIES

APPENDIX D: SUMMARY OF EPA'S METHODOLOGY FOR PRELIMINARY ASSESSMENT OF CHEMICAL HAZARDS RESULTING FROM VARIOUS SLUDGE DISPOSAL PRACTICES

This appendix contains a short synopsis of the draft "Methodology for Preliminary Assessment of Chemical Hazards Resulting from Various Sewage Sludge Disposal Practices" developed by EPA's Environmental Criteria and Assessment Office (ECAO-Cincinnati). This methodology was developed to conduct preliminary assessments of chemical hazards resulting from the utilization or disposal of municipal sewage sludges. The methodology enables the Agency to rapidly screen a list of chemicals so that those most likely to pose a hazard to human health or the environment can be identified for further assessment and possible regulatory control. Four different sludge utilization or disposal practices were considered: land application (including distribution and marketing), landfilling, incineration and ocean disposal.

The goal of this methodology is to approximate the degree of contamination that could occur as a result of each disposal practice, and then to compare the potential exposures that could result from such contamination with the maximum levels considered safe, or with those levels expected to cause adverse effects to humans or other organisms. The methodology has been kept as simple as possible to enable rapid preliminary screening of the chemicals. Estimating potential exposures is extremely complex, and often requires the use of assumptions. Unfortunately, modifying the assumptions used may cause the results to vary substantially. Therefore, the assumptions used tend to be conservative to prevent falsely negative determinations of hazard. This is of critical importance in a screening exercise.

However, to preserve the utility of the method, an effort has been made to ensure that the conservative assumptions are nevertheless realistic, or have a reasonable probability of occurring under unregulated or uncontrolled conditions.

The simplicity and conservatism that make this methodology appropriate for screening of chemicals make it inappropriate for estimating regulatory criteria or standards. The latter require more detailed analysis so that the resulting levels are adequately protective, yet no more stringent than necessary based on the best available scientific information and risk assessment procedures.

IDENTIFICATION OF EXPOSURE PATHWAYS

Each disposal practice may result in the release of sludge-borne contaminants by several different environmental pathways, which vary in their potential for causing exposures that may lead to adverse effects. For each practice, this methodology attempts to identify and assess only the most overriding pathway(s). If a chemical does not pose a hazard in the overriding pathway(s), it is unlikely to do so by a minor pathway.

CALCULATION OF CONTAMINANT TRANSPORT

Methods for estimating contaminant transport have been kept as simple as possible, so that the screening procedure could be carried out rapidly. Thus, in some cases, a simple volumetric dilution of the sludge by an environmental medium (e.g., soil, seawater) is assumed, followed by the use of simple biological uptake relationships. Computerized models were used to estimate groundwater transport, incinerator operation and aerial dispersion.

The identification of parameter values used as inputs to the equations was a task of major importance. Parameters can be divided into two types: those having values that are independent of the identity of the chemical being assessed (such as rate of sludge application to land, depth of the water table, or amount of seafood consumed per day) and those specific to the chemical (such as its rate of uptake by plants, adsorption to soil or toxicity).

In an attempt to show the variability of possible exposures, two values were ordinarily chosen for chemical-independent parameters; these are identified as "typical" and "worst-case." The typical value represents the situation most frequently encountered; if known, a median or mean value has been used. The worst-case value represents the "reasonable worst-case;" if known, a 95th percentile value has been used.

For chemical-specific parameters, a single value was ordinarily chosen because of the effort required to make two determinations for each chemical, and because of the paucity of information available. In each case, the value that gave the more conservative result was chosen.

An exception to the single value was the selection of typical and worst-case values for contaminant concentrations in sludge. Sludge concentration may be viewed as the starting point for each method. A valid estimate of the level of contamination is essential to determine if a hazard exists. Without it, none of the indices can be calculated. For a given chemical, the majority of Publicly Owned Treatment Works (POTWs) have relatively low sludge concentration levels, but a few have much higher concentrations. Because of the importance of contaminant concentrations in sludge for each of the indices, a typical and worst-case value have been chosen for this parameter.

Data on sludge contaminant concentrations were derived from an EPA report, "Fate of Priority Pollutants in Publicly Owned Treatment Works" (U.S. EPA, 1982), frequently referred to as the "40-City Study". Wherever the 40-City Study provided insufficient information, data from another report prepared for the U.S. EPA, "A Comparison of Studies of Toxic Substances in POTW Sludges" was used (Camp, Dresser & McKee, 1984).

CALCULATION OF HAZARD INDICES

After contaminant transport has been estimated, a series of "hazard indices" are calculated for each chemical. Each hazard index is a ratio that is interpreted according to whether it is greater or less than one, as further explained below. The purpose for calculating these indices is to reduce a large and complex body of data to terms that facilitate evaluation and decision-making. Careful interpretation of these indices indicates whether a more detailed analysis of a chemical should be undertaken or whether the chemical can be "screened out" at this stage. The hazard indices may be separated into two types, one type showing the expected increase of contaminant concentration in an environmental medium ("incremental index") and the other showing whether adverse effects could result ("effect index").

Incremental Indices and Their Interpretation

Incremental indices show the expected degree of increase of contaminant concentration in water, soil, air or food resulting from sludge disposal. The incremental index does not by itself indicate hazard, since contamination alone does not necessarily mean that adverse effects will occur. However, the incremental index aids in both the calculation and interpretation of the subsequent effect indices. For inorganic chemicals, the incremental index (I_1) is calculated as follows:

$$I_1 = \frac{A + B}{B}$$

where A is the expected concentration of the chemical that is due to sludge disposal, from the transport estimation method, and B is the background concentration in the medium. The index is thus a simple, dimensionless ratio of expected total concentration to background concentration. Its interpretation is equally simple. A value of 2.0 would indicate that sludge application doubles the background concentration; a value of 1.0 would indicate that the concentration is unchanged.* In addition, for the null case, where no sludge is applied, A = 0 and therefore $I_1 = 1.0$.

Consideration of background levels is important since concentration increase resulting from sludge may be quite small relative to the background. In some instances, sludge use could even result in a decrease of contaminant concentration.† Failure to recognize this fact may cause a loss of perspective on the importance of a particular concentration level. On the other hand, this calculation fails to distinguish between the chemical form or availability of the contaminant present as background and that added by sludge disposal.

The above equation assumes that the background concentration in the medium of concern is known and is not zero, as is usually the case for inorganic chemicals. For organic chemicals, this assumption often does not hold. Since in these cases it is impossible to express the increase as a ratio, the index then becomes the following:

$$I_1 = A$$

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*In most cases, A will be finite and positive, and thus $I>1$. However, since the index values are not carried to more than two significant figures, if B is far greater than A, then I will be given as 1.0.

†For example, if soil is amended with sludge having a contaminant concentration lower than the soil background, then $I<1.0$.

Therefore, when the background concentration for organic chemicals is unknown, or assumed to be zero, the incremental indices show the absolute increase, in units of concentration. Note that these do not fit the form of the other indices and that for the null case, $I_1 = 0$ for organic chemicals.

Effect Indices and Their Interpretation

Effect indices show whether a given increase in contaminant level could be expected to result in a given adverse impact on health of humans or other organisms. For both inorganic and organic chemicals, the effect index (I_e) is calculated as follows:

$$I_e = \frac{C + D}{E}$$

where C is the increase in exposure that is due to sludge disposal, usually calculated from I_1; D is the background exposure; and E is the exposure value used to evaluate the potential for adverse effects, such as a toxicity threshold. Units of all exposures are the same (i.e., they are expressed either as concentration or as daily intake), and therefore the index value is dimensionless.

The interpretation of I_e varies according to whether E refers to a threshold or nonthreshold effect. Threshold effects are those for which a safe level of contaminant exposure can be defined. EPA considers all non-carcinogenic effects to have thresholds. For effects on nonhuman organisms, the value chosen for E is usually the lowest level showing some adverse effect in long-term exposures, and thus is slightly above the chronic-response threshold. For humans, the value chosen is generally an established Acceptable Daily Intake (ADI), which usually is designed to be below the threshold for chronic toxicity. In either case, if $I_e < 1$ the adverse effect is considered unlikely to occur, whereas if $I_e > 1$ the effect cannot be ruled out. Values of I_e close to 1 may be somewhat ambiguous and require careful interpretation.

EPA considers carcinogenic effects to be nonthreshold; that is, any level of exposure to a carcinogenic contaminant is regarded as posing some risk. Since no threshold can be identified, a "benchmark" level of risk was chosen against which to evaluate carcinogen exposures. The Carcinogen Assessment Group of the U.S. EPA has estimated the carcinogenic potency (i.e., the slope of risk versus exposure) for humans exposed to low dose levels of carcinogens. These potency values indicate the upper 95% confidence limit estimate of excess cancer risk for individuals experiencing a given exposure over a 70-year lifetime. They can also be used to derive the exposure level expected to correspond to a given level of excess risk. A risk level of 10^{-6}, or one in one million, has been chosen as an arbitrary benchmark. Therefore, for nonthreshold effects, if $I_e > 1$ then the cancer risk resulting from the disposal practice may exceed 10^{-6}. Effect indices based on nonthreshold effects must be clearly differentiated from those based on threshold effects, since their interpretation is fundamentally different. Subthreshold exposures are normally considered acceptable, whereas the acceptability of a given low level of risk is less clear.

LIMITATIONS OF THE APPROACH

The approach summarized in this appendix involves many assumptions and has many limitations that must be recognized, a few of which are discussed here.

In the null case, where no sludge is applied, the increase in exposure from sludge disposal (C) is zero. Therefore, the effect index, I_e, reduces to the background exposure level divided by the level associated with adverse effects, or D/E. If E refers to a threshold effect, then it should be the case that $I_e < 1$. If instead $I_e > 1$ then one of the following must be true. Either a background condition is causing adverse effects (an unlikely situation); D or E has been incorrectly chosen; or D and E each may have been correctly chosen per se, but are based on two different forms of the contaminant.

For example, perhaps a pure form of the contaminant caused toxicity to a bird species at a dietary concentration (E) of 100 µg/g, but the background concentration (D) measured in earthworms, which the bird consumes, is 200 µg/g. The value for the null case of Land Application Index 3, the Index of Soil Biota Predator Toxicity, would then be 200/100 or $I_e = 2$. Such an index value is clearly unrealistic, since earthworms are not ordinarily toxic to birds. It may be impossible to correct the value within the limited scope of this analysis; that is, without detailed study of the speciation or complexation of the contaminant in soil and earthworm tissues. Therefore, proper interpretation of the index may require comparison of all values to the null value rather than to 1.0. For example, if the null value of I_e is 2.0 and the value under the worst sludge disposal scenario is 2.1, the best interpretation is that there is little cause for concern. If on the other hand the worst scenario resulted in a value of 10, there probably is cause for concern. In situations intermediate to these two cases, judgment should be used following careful examination of the data on which C, D and E are based.

If E refers to a nonthreshold effect, i.e., carcinogenesis, a null-case value of $I_e > 1$ is still more difficult to interpret. If D and E are chosen correctly, the straightforward interpretation is that current background exposure levels are associated with an upper-bound lifetime cancer risk of $>10^{-6}$. This risk estimate may be accurate in some instances since there is a background risk of cancer in the U.S. population, some of which may be attributable to pollutant exposures. However, the interpretation is probably impossible to verify because the model used to estimate the cancer potency has extrapolated from observable incidences in the high-dose range to low doses where incidences are not observable.

In addition to uncertainties about the accuracy of the low-dose extrapolation the same issues of chemical form discussed earlier arise here as well. The chemical forms assessed in cancer bioassays or epidemiology studies may be significantly different toxicologically than either background forms or forms released due to sludge disposal practices.

Although the hazard indices presented below are geared toward rapid and simplified decision-making (i.e., screening), they cannot be interpreted blindly. Their interpretation requires a familiarity with the fundamental principles underlying the generation and selection of the data on which they are based, and the exercise of careful judgment on a case-by-case basis.

As stated earlier, the preceding has been summarized from the draft document entitled "Methodology for Preliminary Assessment of Chemical Hazards Resulting from Various Sewage Sludge Disposal Practices". The latter document has undergone peer review within the Agency and by outside scientists. Comments effecting revision of the methodology are appropriately reflected in this summary. The final document will soon be available in final form.

HAZARD INDICES

The following outline illustrates how each hazard index was derived, including the types of data needed and the calculation formulae employed. However, the guidelines and assumptions that were used in selecting the numerical values for each parameter are not included in this brief summary. For more information, the reader is referred to the draft report, "Methodology for Preliminary Assessment of Chemical Hazards Resulting from Various Sewage Sludge Disposal Practices (ECAO-CIN-452)," which will be available in final form from ECAO-Cincinnati.

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration

1. Index of Soil Concentration Increment (Index 1)

a. For Inorganic Chemicals

$$\text{Index 1} = \frac{(SC \times AR) + (BS \times MS)}{BS\ (AR + MS)}$$

where:

SC = Sludge concentration of pollutant (μg/g DW)
AR = Sludge application rate (mt DW/ha)
BS = Background concentration of pollutant in soil (μg/g DW)
MS = 2000 mt DW/ha = Assumed mass of soil in upper 15 cm

b. For Organic Chemicals

$$\text{Index 1} = CS_s = \frac{(SC \times AR) + (BS \times MS)}{AR + MS}$$

or

$$\text{Index 1} = CS_r =$$

$$(CS_s - BS)\ [1 + 0.5^{(1/t_{1/2})} + 0.5^{(2/t_{1/2})} + \ldots + 0.5^{(n/t_{1/2})}] + BS$$

(CS_s is calculated for AR = 0, 5 and 50 mt/ha only; CS_r is calculated for AR = 500 mt/ha, based on 5 mt/ha applied annually for 100 years)

where:

CS_s = Soil concentration of pollutant after a single year's application of sludge (μg/g DW)
CS_r = Soil concentration of pollutant after the yearly application of sludge has been repeated for n + 1 years (μg/g DW)
SC = Sludge concentration of pollutant (μg/g DW)
AR = Sludge application rate (mt/ha)
MS = 2000 mt DW/ha = assumed mass of soil in upper 15 cm
BS = Background concentration of pollutant in soil (μg/g DW)
$t_{1/2}$ = Soil half-life of pollutant (years)
n = 99 years

B. Effect on Soil Biota and Predators of Soil Biota

1. Index of Soil Biota Toxicity (Index 2)

a. For Inorganic Chemicals

$$\text{Index 2} = \frac{I_1 \times BS}{TB}$$

where:

I_1 = Index 1 = Index of soil concentration increment (unitless)
BS = Background concentration of pollutant in soil (μg/g DW)
TB = Soil concentration toxic to soil biota (μg/g DW)

b. For Organic Chemicals

$$\text{Index 2} = \frac{I_1}{TB}$$

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (μg/g DW)
TB = Soil concentration toxic to soil biota (μg/g DW)

2. Index of Soil Biota Predator Toxicity (Index 3)

a. For Inorganic Chemicals

$$\text{Index 3} = \frac{(I_1 - 1)(BS \times UB) + BB}{TR}$$

where:

- I_1 = Index 1 = Index of soil concentration increment (unitless)
- BS = Background concentration of pollutant in soil (μg/g DW)
- UB = Uptake slope of pollutant in soil biota (μg/g tissue DW [μg/g soil DW]$^{-1}$)
- BB = Background concentration in soil biota (μg/g DW)
- TR = Feed concentration toxic to predator (μg/g DW)

b. For Organic Chemicals

$$\text{Index 3} = \frac{I_1 \times UB}{TR}$$

where:

- I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (μg/g DW)
- UB = Uptake factor of pollutant in soil biota (μg/g tissue DW [μg/g soil DW]$^{-1}$)
- TR = Feed concentration toxic to predator (μg/g DW)

C. Effect on Plants and Plant Tissue Concentration

1. Index of Phytotoxicity (Index 4)

a. For Inorganic Chemicals

$$\text{Index 4} = \frac{I_1 \times BS}{TP}$$

where:

- I_1 = Index 1 = Index of soil concentration increment (unitless)
- BS = Background concentration of pollutant in soil (μg/g DW)
- TP = Soil concentration toxic to plants (μg/g DW)

b. For Organic Chemicals

$$\text{Index 4} = \frac{I_1}{TP}$$

where:

- I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (μg/g DW)
- TP = Soil concentration toxic to plants (μg/g DW)

2. Index of Plant Concentration Increment Caused by Uptake (Index 5)

a. For Inorganic Chemicals

$$\text{Index 5} = \frac{(I_1 - 1) \times BS}{BP} \times CO \times UP + 1$$

where:

I_1 = Index 1 = Index of soil concentration increment (unitless)
BS = Background concentration of pollutant in soil (µg/g DW)
CO = 2 kg/ha $(\mu g/g)^{-1}$ = Conversion factor between soil concentration and application rate
UP = Uptake slope of pollutant in plant tissue (µg/g tissue DW $[kg/ha]^{-1}$)
BP = Background concentration in plant tissue (µg/g DW)

b. For Organic Chemicals

$$\text{Index 5} = I_1 \times UP$$

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (µg/g DW)
UP = Uptake factor of pollutant in plant tissue (µg/g tissue DW $[\mu g/g \text{ soil DW}]^{-1}$)

3. Index of Plant Concentration Increment Permitted by Phytotoxicity (Index 6)

a. For Inorganic Chemicals

$$\text{Index 6} = \frac{PP}{BP}$$

where:

PP = Maximum plant tissue concentration associated with phytotoxicity (µg/g DW)
BP = Background concentration in plant tissue (µg/g DW)

b. For Organic Chemicals

Index 6 = PP

where:

PP = Maximum plant tissue concentration associated with phytotoxicity (µg/g DW)

C. Effect on Herbivorous Animals

1. Index of Animal Toxicity Resulting from Plant Consumption (Index 7)

a. For Inorganic Chemicals

$$\text{Index 7} = \frac{I_5 \times BP}{TA}$$

where:

I_5 = Index 5 = Index of plant concentration increment caused by uptake (unitless)
BP = Background concentration in plant tissue (μg/g DW)
TA = Feed concentration toxic to herbivorous animal (μg/g DW)

b. For Organic Chemicals

$$\text{Index 7} = \frac{I_5}{TA}$$

where:

I_5 = Index 5 = Concentration of pollutant in plant grown in sludge-amended soil (μg/g DW)
TA = Feed concentration toxic to herbivorous animal (μg/g DW)

2. Index of Animal Toxicity Resulting from Sludge Ingestion (Index 8)

a. For Inorganic Chemicals

If AR = 0, $$I_8 = \frac{BS \times GS}{TA}$$

If AR ≠ 0, $$I_8 = \frac{SC \times GS}{TA}$$

where:

AR = Sludge application rate (mt DW/ha)
SC = Sludge concentration of pollutant (μg/g DW)
BS = Background concentration of pollutant in soil (μg/g DW)
GS = Fraction of animal diet assumed to be soil (unitless)
TA = Feed concentration toxic to herbivorous animal (μg/g DW)

b. For Organic Chemicals

If AR = 0, Index 8 = 0

If AR ≠ 0, $I_8 = \frac{SC \times GS}{TA}$

where:

AR = Sludge application rate (mt DW/ha)
SC = Sludge concentration of pollutant (μg/g DW)
GS = Fraction of animal diet assumed to be soil
TA = Feed concentration toxic to herbivorous animal (μg/g DW)

E. Effect on Humans

1. Index of Human Toxicity/Cancer Risk Resulting from Plant Consumption (Index 9)

a. For Inorganic Chemicals

$$\text{Index 9} = \frac{[(I_5 - 1)\ BP \times DT] + DI}{\text{ADI or RSI}}$$

where:

I_5 = Index 5 = Index of plant concentration increment caused by uptake (unitless)
BP = Background concentration in plant tissue (μg/g DW)
DT = Daily human dietary intake of affected plant tissue (g/day DW)
DI = Average daily human dietary intake of pollutant (μg/day)
ADI = Acceptable daily intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

b. For Organic Chemicals

$$\text{Index 9} = \frac{[(I_5 - BS \times UP) \times DT] + DI}{\text{ADI or RSI}}$$

where:

I_5 = Index 5 = Concentration of pollutant in plant grown in sludge-amended soil (μg/g DW)
DT = Daily human dietary intake of affected plant tissue (g/day DW)
DI = Average daily human dietary intake of pollutant (μg/day)
ADI = Acceptable daily intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

2. Index of Human Toxicity/Cancer Risk Resulting from Consumption of Animal Products Derived from Animals Feeding on Plants (Index 10)

a. For Inorganic Chemicals

$$\text{Index 10} = \frac{[(I_5 - 1)\ BP \times UA \times DA] + DI}{ADI \text{ or } RSI}$$

where:

I_5 = Index 5 = Index of plant concentration increment caused by uptake (unitless)
BP = Background concentration in plant tissue (µg/g DW)
UA = Uptake slope of pollutant in animal tissue (µg/g tissue DW [µg/g feed DW]$^{-1}$)
DA = Daily human dietary intake of affected animal tissue (g/day DW)
DI = Average daily human dietary intake of pollutant (µg/day)
ADI = Acceptable daily intake of pollutant (µg/day)
RSI = Cancer risk-specific intake (µg/day)

b. For Organic Chemicals

$$\text{Index 10} = \frac{[(I_5 - BS \times UP) \times UA \times DA] + DI}{ADI \text{ or } RSI}$$

where:

I_5 = Index 5 = Concentration of pollutant in plant grown in sludge-amended soil (µg/g DW)
UA = Uptake factor of pollutant in animal tissue (µg/g tissue DW [µg/g feed DW]$^{-1}$)
DA = Daily human dietary intake of affected animal tissue (g/day DW)
DI = Average daily human dietary intake of pollutant (µg/day)
ADI = Acceptable daily intake of pollutant (µg/day)
RSI = Cancer risk-specific intake (µg/day)

3. Index of Human Toxicity/Cancer Risk Resulting from Consumption of Animal Products Derived from Animals Ingesting Soil (Index 11)

a. For Inorganic and Organic Chemicals

If AR = 0, $$\text{Index 11} = \frac{(BS \times GS \times UA \times DA) + DI}{ADI \text{ or } RSI}$$

If AR ≠ 0, $$\text{Index 11} = \frac{(SC \times GS \times UA \times DA) + DI}{ADI \text{ or } RSI}$$

where:

- AR = Sludge application rate (mt DW/ha)
- BS = Background concentration of pollutant in soil (μg/g DW)
- SC = Sludge concentration of pollutant (μg/g DW)
- GS = Fraction of animal diet assumed to be soil (unitless)
- UA = Uptake slope (inorganics) or uptake factor (organics) of pollutant in animal tissue (μg/g tissue DW [μg/g feed DW^{-1}])
- DA = Average daily human dietary intake of affected animal tissue (g/day DW)
- DI = Average daily human dietary intake of pollutant (μg/day)
- ADI = Acceptable daily intake of pollutant (μg/day)
- RSI = Cancer risk-specific intake (μg/day)

4. Index of Human Toxicity/Cancer Risk Resulting from Soil Ingestion (Index 12)

a. For Inorganic Chemicals

$$\text{Index 12} = \frac{(I_1 \times BS \times DS) + DI}{ADI \text{ or } RSI}$$

Pure sludge ingestion: $$\text{Index 12} = \frac{(SC \times DS) + DI}{ADI \text{ or } RSI}$$

where:

- I_1 = Index 1 = Index of soil concentration increment (unitless)
- SC = Sludge concentration of pollutant (μg/g DW)
- BS = Background concentration of pollutant in soil (μg/g DW)
- DS = Assumed amount of soil in human diet (g/day)
- DI = Average daily dietary intake of pollutant (μg/day)
- ADI = Acceptable daily intake of pollutant (μg/day)
- RSI = Cancer risk-specific intake (μg/day)

b. For Organic Chemicals

$$\text{Index 12} = \frac{(I_1 \times DS) + DI}{ADI \text{ or } RSI}$$

Pure sludge ingestion: $$\text{Index 12} = \frac{(SC \times DS) + DI}{ADI \text{ or } RSI}$$

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (μg/g DW)
SC = Sludge concentration of pollutant (μg/g DW)
DS = Assumed amount of soil in human diet (g/day)
DI = Average daily human dietary intake of pollutant (μg/day)
ADI = Acceptable daily intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

5. Index of Aggregate Human Toxicity/Cancer Risk (Index 13)

a. For Inorganic and Organic Chemicals

$$\text{Index 13} = I_9 + I_{10} + I_{11} + I_{12} - \frac{3DI}{ADI \text{ or } RSI}$$

where:

I_9 = Index 9 = Index of human toxicity/cancer risk resulting from plant consumption (unitless)
I_{10} = Index 10 = Index of human toxicity/cancer risk resulting from consumption of animal products derived from animals feeding on plants (unitless)
I_{11} = Index 11 = Index of human toxicity/cancer risk resulting from consumption of animal products derived from animals ingesting soil (unitless)
I_{12} = Index 12 = Index of human toxicity/cancer risk resulting from soil ingestion (unitless)
DI = Average daily dietary intake of pollutant (μg/day)
ADI = Acceptable daily intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

II. LANDFILLING

A. Procedure

Using Equation 1, several values of C/C_0 for the unsaturated zone are calculated corresponding to increasing values of t until equilibrium is reached. Assuming a 5-year pulse input from the landfill, Equation 3 is employed to estimate the concentration vs. time data at the water table. The concentration vs. time curve is then transformed into a square pulse having a constant concentration equal to the peak concentration, C_u, from the unsaturated zone, and a duration, t_o, chosen so that the total areas under the curve and the pulse are equal, as illustrated in Equation 3. This square pulse is then used as the input to the linkage assessment, Equation 2, which estimates initial dilution in the aquifer to give the initial concentration, C_o, for the saturated zone assessment. (Conditions for B, thickness of unsaturated zone, have been set such that dilution is actually negligible.) The saturated zone assessment procedure is nearly identical to that for the unsaturated zone except for the definition of certain parameters and choice of parameters values. The maximum concentration at the well, C_{max}, is used to calculate the index values given in Equations 4 and 5.

B. Equation 1: Transport Assessment

$$\frac{C(x,t)}{C_o} = 1/2\ [\exp(A_1)\ \mathrm{erfc}(A_2) + \exp(B_1)\ \mathrm{erfc}(B_2)] = P(x,t)$$

Requires evaluations of four dimensionless input values and subsequent evaluation of the result. $\mathrm{Exp}(A_1)$ denotes the exponential of A_1, e^{A_1}, and $\mathrm{erfc}(A_2)$ denotes the complimentary error function of A_2. $\mathrm{Erfc}(A_2)$ produces values between 0.0 and 2.0 (Abramowitz and Stegun, 1972).

where:

$$A_1 = \frac{x}{2D^*}\ [V^* - (V^{*2} + 4D^* \times \mu^*)^{1/2}]$$

$$A_2 = \frac{x - t\ (V^{*2} + 4D^* \times \mu^*)^{1/2}}{(4D^* \times t)^{1/2}}$$

$$B_1 = \frac{x}{2D^*}\ [V^* + (V^{*2} + 4D^* \times \mu^*)^{1/2}]$$

$$B_2 = \frac{x + t\ (V^{*2} + 4D^* \times \mu^*)^{1/2}}{(4D^* \times t)^{1/2}}$$

D. Equation 3. Pulse Assessment

$$\frac{C(x,t)}{C_0} = P(x,t) \text{ for } 0 \leq t \leq t_0$$

$$\frac{C(x,t)}{C_0} = P(x,t) - P(x,t - t_0) \text{ for } t > t_0$$

where:

t_0 (for unsaturated zone) = LT = Landfill leaching time (years)

t_0 (for saturated zone) = Pulse duration at the water table ($x = h$) as determined by the following equation:

$$t_0 = [{}_0\int^{\infty} C\,dt] \div C_u$$

$P(x,t) = \frac{C(x,t)}{C_0}$ as determined by Equation 1

E. Equation 4. Index of Groundwater Concentration Increment Resulting from Landfilled Sludge (Index 1)

1. For Inorganic Chemicals

$$\text{Index 1} = \frac{C_{max} + BC}{BC}$$

where:

C_{max} = Maximum concentration of pollutant at well = Maximum of $C(\Delta \ell, t)$ calculated in Equation 1 ($\mu g/\ell$)

BC = Background concentration of pollutant in groundwater ($\mu g/\ell$)

2. For Organic Chemicals

Index 1 = C_{max}

where:

C_{max} = Maximum concentration of pollutant at well = Maximum of $C(\Delta \ell, t)$ calculated in Equation 1 ($\mu g/\ell$)

F. Equation 5. Index of Human Toxicity/Cancer Risk Resulting from Groundwater Contamination (Index 2)

1. For Inorganic Chemicals

$$\text{Index 2} = \frac{[(I_1 - 1)\ BC \times AC] + DI}{ADI \text{ or } RSI}$$

where:

I_1 = Index 1 = Index of groundwater concentration increment resulting from landfilled sludge
BC = Background concentration of pollutant in groundwater (μg/ℓ)
AC = Average human consumption of drinking water (ℓ/day)
DI = Average daily human dietary intake of pollutant (μg/day)
ADI = Acceptable daily intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

2. For Organic Chemicals

$$\text{Index 2} = \frac{(I_1 \times AC) + DI}{ADI \text{ or } RSI}$$

where:

I_1 = Index 1 = Groundwater concentration resulting from landfilled sludge
AC = Average human consumption of drinking water (ℓ/day)
DI = Average daily human dietary intake of pollutant (μg/day)
ADI = Acceptable daily intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

III. INCINERATION

A. Index of Air Concentration Increment Resulting from Incinerator Emissions (Index 1)

1. For Inorganic and Organic Chemicals

$$\text{Index 1} = \frac{(C \times DS \times SC \times FM \times DP) + BA}{BA}$$

where:

C = Coefficient to correct for mass and time units (hr/sec x g/mg)
DS = Sludge feed rate (kg/hr DW)
SC = Sludge concentration of pollutant (mg/kg DW)
FM = Fraction of pollutant emitted through stack (unitless)
DP = Dispersion parameter for estimating maximum annual ground level concentration ($\mu g/m^3$ $[g/sec]^{-1}$)
BA = Background concentration of pollutant in urban air ($\mu g/m^3$)

B. Index of Human Toxicity/Cancer Risk Resulting from Inhalation of Incinerator Emissions (Index 2)

1. For Inorganic and Organic Chemicals

$$\text{Index 2} = \frac{[(I_1 - 1) \times BA] + BA}{EC}$$

where:

I_1 = Index 1 = Index of air concentration increment resulting from incinerator emissions (unitless)
BA = Background concentration of pollutant in urban air ($\mu g/m^3$)
EC = Exposure cirterion ($\mu g/m^3$)

IV. OCEAN DISPOSAL

A. Index of Seawater Concentration Resulting from Initial Mixing of Sludge (Index 1)

1. For Inorganic Chemicals

$$\text{Index 1} = \frac{SC \times ST \times PS}{W \times D \times L \times CA} + 1$$

where:

SC = Sludge concentration of pollutant (mg/kg DW)
ST = Sludge mass dumped by a single tanker (kg WW)
PS = Percent solids in sludge (kg DW/kg WW)
W = Width of initial plume dilution (m)
D = Depth to pycnocline or effective depth of mixing for shallow water site (m)
L = Length of tanker path (m)
CA = Ambient water concentration of pollutant (μg/ℓ)

2. For Organic Chemicals

$$\text{Index 1} = \frac{SC \times ST \times PS}{W \times D \times L}$$

where:

SC = Sludge concentration of pollutant (mg/kg DW)
ST = Sludge mass dumped by a single tanker (kg WW)
PS = Percent solids in sludge (kg DW/kg WW)
W = Width of initial plume dilution (m)
D = Depth to pycnocline or effective depth of mixing for shallow water site (m)
L = Length of tanker path (m)

B. Index of Seawater Concentration Representing a 24-Hour Dumping Cycle (Index 2)

1. For Inorganic Chemicals

$$\text{Index 2} = \frac{SS \times SC}{V \times D \times L \times CA}$$

where:

SS = Daily sludge disposal rate (kg DW/day)
SC = Sludge concentration of pollutant (mg/kg DW)
V = Average current velocity at site (m/day)
D = Depth to pycnocline or effective depth of mixing for shallow water site (m)
L = Length of tanker path (m)
CA = Ambient water concentration of pollutant (μg/ℓ)

2. For Organic Chemicals

$$\text{Index 2} = \frac{SS \times SC}{V \times D \times L}$$

where:

SS = Daily sludge disposal rate (kg DW/day)
SC = Sludge concentration of pollutant (mg/kg DW)
V = Average current velocity at site (m/day)
D = Depth to pycnocline or effective depth of mixing for shallow water site (m)
L = Length of tanker path (m)

C. Index of Toxicity to Aquatic Life (Index 3)

1. For Inorganic Chemicals

$$\text{Index 3} = \frac{I_1 \text{ or } I_2 \times CA}{AWQC}$$

where:

I_1 = Index 1 = Index of seawater concentration resulting from initial mixing after sludge disposal

AWQC = Criterion or other value expressed as an average concentration to protect marine organisms from acute and chronic toxic effects (μg/ℓ)

I_2 = Index 2 = Index of seawater concentration representing a 24-hour dumping cycle

AWQC = Criterion expressed as an average concentration to protect the marketability of edible marine organisms (AWQC)

CA = Ambient water concentration of pollutant (μg/ℓ)

2. For Organic Chemicals

$$\text{Index 3} = \frac{I_1 \text{ or } I_2}{AWQC}$$

where:

I_1 = Index 1 = Index of seawater concentration resulting from initial mixing after sludge disposal (μg/ℓ)

AWQC = Criterion or other value expressed as an average concentration to protect marine organisms from acute and chronic toxic effects (μg/ℓ)

I_2 = Index 2 = Index of seawater concentration representing a 24-hour dumping cycle (μg/ℓ)

AWQC = Criterion expressed as an average concentration to protect the marketability of edible marine organisms

D. Index of Human Toxicity/Cancer Risk Resulting from Seafood Consumption (Index 4)

1. For Inorganic Chemicals

$$\text{Index 4} = \frac{[(I_2 - 1) \times CF \times FS \times QF] + DI}{RSI \text{ or } ADI}$$

where:

I_2 = Index 2 = Index of seawater concentration representing a 24-hour dumping cycle
QF = Dietary consumption of seafood (g WW/day)
FS = Fraction of consumed seafood originating from the disposal site (unitless)
CF = Background concentration of pollutant in seafood (μg/g)
DI = Average daily human dietary intake of pollutant (μg/day)
ADI = Acceptable daily intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

2. For Organic Chemicals

$$\text{Index 4} = \frac{(I_2 \times BCF \times 10^{-3} \text{ kg/g} \times FS \times QF) + DI}{RSI \text{ or } ADI}$$

where:

I_2 = Index 2 = Index of seawater concentration representing a 24-hour dumping cycle (μg/ℓ)
QF = Dietary consumption of seafood (g WW/day)
FS = Fraction of consumed seafood originating from the disposal site (unitless)
BCF = Bioconcentration factor of pollutant (ℓ/kg)
DI = Average daily human dietary intake of pollutant (μg/day)
ADI = Acceptable daily intake of pollutant (μg/day)
RSI = Cancer risk-specific intake (μg/day)

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APPENDIX E:

HAZARD INDEX VALUES FOR ALL CONDITIONS OF ANALYSIS RELATED TO LANDFILLING

ARSENIC

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	1.1	1.6	1.1	1.1	1.7	6.0	120	0
Index 2 Value	53	240	53	53	280	2100	51000	0

[a] T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b] Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c] See Table A-1 in Appendix for parameter values used.

[d] Dry bulk density (P_{dry}) and volumetric water content (θ).

[e] Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f] Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g] Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

BENZENE

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	2.6×10^{-4}	5.3×10^{-3}	6.7×10^{-4}	8.9×10^{-3}	1.4×10^{-3}	1.0×10^{-2}	38	0
Index 2 Value	210	210	210	210	210	210	260	210

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.
[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.
[c]See Table A-1 in Appendix for parameter values used.
[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).
[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).
[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).
[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

BENZO(A)PYRENE

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	1.3×10^{-4}	1.8×10^{-3}	3.3×10^{-4}	3.9×10^{-3}	4.3×10^{-4}	4.6×10^{-4}	11	0
Index 2 Value	150	150	150	150	150	150	3800	150

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

BIS(2-ETHYL HEXL)PHTHALATE

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	2.6	12	2.6	2.6	14	100	2700	0
Index 2 Value	1.0	5.0	1.0	1.0	5.5	40	1100	0

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity (ϕ) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta\ell$), and dispersivity coefficient (α).

CADMIUM

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	1.2	3.4	1.2	1.2	2.1	3.8	510	0
Index 2 Value	0.54	0.61	0.54	0.54	0.57	0.62	16.5	0.54

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}) and volumetric water content (θ).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

CHLORDANE
INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND
INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.044	0.17	0.055	0.087	0.20	0.33	69	0
Index 2 Value	3.8	9.4	4.3	5.8	11	17	3200	1.8

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

CHROMIUM

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	2.0	7.3	2.0	2.0	6.1	37	1300	0
Index 2 Value	0.00070	0.0013	0.00070	0.00070	0.0012	0.0048	0.157	0.00058

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}) and volumetric water content (θ).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

COBALT

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
<u>Unsaturated Zone</u>								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
<u>Saturated Zone</u>								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	12	40	12	12	60	280	8300	0.0
Index 2 Value	Values were not calculated due to lack of data.							

[a] T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.
[b] Index values for combinations other than those shown may be calculated using the formulae in the Appendix.
[c] See Table A-1 in Appendix for parameter values used.
[d] Dry bulk density (P_{dry}) and volumetric water content (θ).
[e] Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).
[f] Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).
[g] Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

COPPER

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	2.1	4.9	2.1	2.1	6.9	40	830	0
Index 2 Value	0.0086	0.030	0.0086	0.0086	0.045	0.30	6.4	0

[a] T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b] Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c] See Table A-1 in Appendix for parameter values used.

[d] Dry bulk density (P_{dry}) and volumetric water content (θ).

[e] Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f] Aquifer porosity (∅) and hydraulic conductivity of the aquifer (K).

[g] Hydraulic gradient (i), distance from well to landfill (Δℓ), and dispersivity coefficient (α).

CYANIDE

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	13	73	13	13	69	520	16000	0
Index 2 Value	3.4×10^{-3}	1.9×10^{-2}	3.4×10^{-3}	3.4×10^{-3}	1.8×10^{-2}	0.14	4.1	0

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.
[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.
[c]See Table A-1 in Appendix for parameter values used.
[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).
[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).
[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).
[g]Hydraulic gradient (i), distance from well to landfill ($\Delta\ell$), and dispersivity coefficient (α).

2,4-D

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.0186	0.0287	0.0321	0.1261	0.0987	0.7435	41.43	0
Index 2 Value	3.3×10^{-4}	3.3×10^{-4}	3.3×10^{-4}	3.5×10^{-4}	3.4×10^{-4}	4.9×10^{-4}	9.8×10^{-3}	3.2×10^{-4}

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta\ell$), and dispersivity coefficient (α).

DDT/DDD/DDE

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND
INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.0038	0.0053	0.018	0.018	0.0038	0.0038	5.4	0.0
Index 2 Value	19	19	19	19	19	19	71	19

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity (Ø) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

DIMETHYL NITROSAMINE

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
<u>Unsaturated Zone</u>								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
<u>Saturated Zone</u>								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	9.0×10^{-4}	9.0×10^{-4}	2.8×10^{-3}	6.9×10^{-2}	4.8×10^{-3}	3.6×10^{-2}	14.8	0
Index 2 Value	740	740	740	790	740	770	12000	740

[a] T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.
[b] Index values for combinations other than those shown may be calculated using the formulae in the Appendix.
[c] See Table A-1 in Appendix for parameter values used.
[d] Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).
[e] Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).
[f] Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).
[g] Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

LEAD

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	2.3	6.8	2.4	2.4	7.4	13	1200	0
Index 2 Value	0.17	0.28	0.17	0.17	0.29	0.42	29	0.14

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (ρ_{dry}) and volumetric water content (θ).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity (ϕ) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

LINDANE

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
<u>Unsaturated Zone</u>								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
<u>Saturated Zone</u>								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.0014	0.0028	0.0018	0.0030	0.0075	0.057	1.3	0
Index 2 Value	160	160	160	160	160	160	200	160

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

MALATHION

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	$2.8x10^{-7}$	$3.9x10^{-6}$	$2.0x10^{-6}$	$1.2x10^{-3}$	$1.5x10^{-6}$	$1.1x10^{-5}$	3.6	0.0
Index 2 Value	$6.3x10^{-3}$	$6.3x10^{-3}$	$6.3x10^{-3}$	$6.3x10^{-3}$	$6.3x10^{-3}$	$6.3x10^{-3}$	$1.1x10^{-2}$	$6.3x10^{-3}$

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta\ell$), and dispersivity coefficient (α).

MERCURY

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	1.4	2.6	1.4	1.4	2.9	4.0	340	0
Index 2 Value	0.25	0.27	0.25	0.25	0.27	0.28	3.6	0.25

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}) and volumetric water content (θ).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta\ell$), and dispersivity coefficient (α).

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.043	0.52	0.043	0.043	0.23	1.7	110	0
Index 2 Value	NC[h]	NC	NC	NC	NC	NC	NC	NC

[a] T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.
[b] Index values for combinations other than those shown may be calculated using the formulae in the Appendix.
[c] See Table A-1 in Appendix for parameter values used.
[d] Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).
[e] Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).
[f] Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).
[g] Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).
[h] Not calculated due to lack of data.

MOLYBDENUM

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	1.0	1.1	1.0	1.0	1.1	2.0	24	0
Index 2 Value	0.090	0.091	0.090	0.090	0.091	0.096	0.22	0.090

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}) and volumetric water content (θ).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

NICKEL

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	1.3	4.8	1.3	1.3	2.3	11	800	0
Index 2 Value	0.11	0.12	0.11	0.11	0.12	0.14	2.3	0.11

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}) and volumetric water content (θ).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta\ell$), and dispersivity coefficient (α).

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.101	0.563	0.101	0.101	0.532	3.29	120.0	0
Index 2 Value	NC[h]	NC	NC	NC	NC	NC	NC	NC

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

[h]NC = Not calculated due to lack of data.

PCB

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.092	0.53	0.099	0.11	0.30	0.33	130	0
Index 2 Value	59	110	59	61	85	88	17000	47

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g][redacted]ulic gradient (i), distance from well to land[redacted]l ($\Delta \ell$), and dispersivity coefficient (α).

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	1.0×10^{-16}	1.8×10^{-15}	9.5×10^{-14}	0.13	5.6×10^{-16}	4.2×10^{-15}	480	0
Index 2 Value	3.0×10^{-20}	5.0×10^{-19}	2.7×10^{-17}	3.8×10^{-5}	1.6×10^{-19}	1.2×10^{-18}	0.14	0

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

SELENIUM

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c] 1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	1.0	1.0	1.0	1.0	1.0	1.2	4.5	0
Index 2 Value	0.24	0.24	0.24	0.24	0.24	0.25	0.37	0.24

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}) and volumetric water content (θ).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta\ell$), and dispersivity coefficient (α).

TOXAPHENE

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
<u>Unsaturated Zone</u>								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
<u>Saturated Zone</u>								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.20	0.27	0.20	0.21	1.1	8.0	62	0.0
Index 2 Value	61	64	62	62	89	310	2100	55

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

TRICHLOROETHYLENE

INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND
INDEX OF HUMAN CANCER RISK RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	0.013	0.49	0.013	0.013	0.066	0.50	100	0
Index 2 Value	0.0068	0.26	0.0068	0.0068	0.036	0.27	56	0

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

ZINC

INDEX OF GROUNDWATER CONCENTRATION INCREMENT RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

	Condition of Analysis[a,b,c]							
Site Characteristics	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value	2.8	13	2.8	2.8	8.7	12	2700	0
Index 2 Value	0.36	0.36	0.36	0.36	0.36	0.36	1.4	0.36

[a]T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.

[b]Index values for combinations other than those shown may be calculated using the formulae in the Appendix.

[c]See Table A-1 in Appendix for parameter values used.

[d]Dry bulk density (P_{dry}) and volumetric water content (θ).

[e]Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).

[f]Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).

[g]Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

APPENDIX F: SLUDGE CONCENTRATION DATA USED IN ENVIRONMENTAL PROFILES AND HAZARD INDICES

Typical and Worst Sludge Pollutant Concentrations in Environmental Profiles

Pollutant	Typical	Worst
Aldrin/Dieldrin	0.07	0.81
Arsenic	4.6	20.77
Benzene	0.326	6.58
Benzidine		12.7
Benzo(a)anthracene	0.68	4.8
Benzo(a)pyrene	0.14	1.94
Beryllium	0.313	1.168
Bis(2-ethylhexyl)phthalate	94.28	459.25
Cadmium	8.15	88.13
Carbon Tetrachloride	0.048	8.006
Chlordane	3.2	12
Chloroform	0.049	1.177
Chromium	230.1	1499.7
Cobalt	11.6	40
Copper	409.6	1427
Cyanide	476.2	2686.6
DDT/DDE/DDD	0.28	0.93
3,3-Dichlorobenzidine	1.64	2.29
Dichloromethane	1.6	19
2,4-Dichlorophenoxyacetic Acid	4.64	7.16
Dimethyl Nitrosamine		2.55
Endrin	0.14	0.17
Fluoride	86.4	738.7
Heptachlor	0.07	0.09
Hexachlorobenzine	0.38	2.18
Hexachlorobutadiene	0.3	8
Iron	28000	78700
Lead	248.2	1070.8
Lindane	0.11	0.22
MOCA	18	86
Malathion	0.045	0.63
Mercury	1.49	5.84
Methyl Ethyl Ketone	Data not	available
Molybdenum	9.8	40
Nickel	44.7	662.7
PCB's	0.99	2.9
Pentachlorophenol	0.0865	30.434
Phenanthrene	3.71	20.69
Phenol	4.884	82.06
Selenium	1.11	4.848
TCDD	Data not	available
TCDF	Data not	available
Tetrachloroethylene	0.181	13.707
Toxaphene	7.88	10.79
Trichloroethylene	0.46	17.85
2,4,6-Trichlorophenol	2.3	4.6
Tricresyl Phosphate	6.85	1650
Vinyl Chloride	0.43	311.942
Zinc	677.6	4580

*U.S. GOVERNMENT PRINTING OFFICE : 1985 0-528-652/30789